Energy and Related Factors in Sustaining Mobile Telecommunications in Disaster Contexts

by

Watcharachai Kongsiriwattana

Thesis
Submitted to Flinders University
for the degree of

Doctor of Philosophy

College of Science and Engineering
October 2019

DECLARATION

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university. To the best of my knowledge and belief, this thesis does not contain any material previously published or written by another person except where due references are made within the thesis.

Adelaide, 31th August 2019

Watcharachai Kongsiriwattana

TABLE OF CONTENTS

ACKNOWLEDGMENTS

I greatly and sincerely appreciate my supervisor Dr. Paul Gardner-Stephen for guidance and supports throughout my PhD journey. His enthusiasm and encouragement are inspirational. I would like to thank The Serval Project Team to support me with valuable discussion, advice and assistance. Also, I would like to thank Dr. Anna Shillabeer, my co supervisor, and Romana Challans for their assistance in giving such invaluable and insightful feedbacks to my thesis during the year 2016/2017.

I am particularly grateful to the Government of Thailand for awarding me the Royal Thai Government Scholarship, which gave me the opportunity to pursue my PhD degree and obtain knowledge for my country.

Finally, I would like to thank my family, Kongsiriwattana, for their encouragement and support. Most importantly, my beloved wife Mrs Aungsumalin Kongsiriwattana. With her great support, I have been happy while living in Australia.

PUBLICATIONS

1. Kongsiriwattana, W., & Gardner-Stephen, P. (2016, October). Smart-phone battery-life short-fall in disaster response: Quantifying the gap. In Global Humanitarian Technology Conference (GHTC), 2016 (pp. 220-225). IEEE.

This paper presents the results of a survey of emergency responders so as to understand how long a battery life of a smartphone should last to avoid the problem occurring during disaster situation. It further explores the potential for bridging the gap of mobile phone battery life. This paper is cited in Chapter 4 of this thesis.

2. Kongsiriwattana, W., & Gardner-Stephen, P. (2016, October). The exploration of alternative phone charging strategies for disaster or emergency situations. In Global Humanitarian Technology Conference (GHTC), 2016 (pp. 233-240). IEEE.

This paper presents a simple methodology and the results for a sample mobile phone charging products and techniques to allow meaningful comparison and assessment and the limitation of sample of solutions to those readily purchasable with realistic and directly actionable outcome for disaster response practitioners. This paper is fully covered in Chapter 5 in this thesis.

3. Kongsiriwattana, W., & Gardner-Stephen, P. Historical distribution of duration of unplanned power outages in Queensland: Insights for sustaining telecommunications during disasters, In Global Humanitarian Technology Conference (GHTC), 2017 (pp 1-8). IEEE.

This paper presents a simple mobile phone battery life prediction model to anticipate the number of mobile phones that would be flat on an hour-by-hour basis over the eleven years of Queensland, Australia during 2005 – 2015. This paper is referred to in Chapter 6 in this thesis.

4. Kongsiriwattana, W., & Gardner-Stephen, P. Eliminating the high stand-by energy consumption of ad-hoc Wi-Fi, In Global Humanitarian Technology Conference (GHTC), 2017(pp 1-7) IEEE.

This paper presents a proof-of-concept hardware, demonstrating that it is possible to provide a device with ad-hoc Wi-Fi communications capabilities with zero impact on stand-by-energy consumption. This paper is fully covered in Chapter 7 of this thesis.

ABSTRACT

Currently, a mobile phone or a smartphone is a device or gadget used for voice, text, video, and data communication. Due to its versatility, the modern mobile phone consumes much more energy or battery life while operating, particularly when turning on Wi-Fi or mobile data. To find out and answer whether a mobile phone battery life can be enhanced to operate for a longer period of time, particularly in disaster or emergency situations, this thesis, thus, investigates the energy and related factors on a mobile phone in disaster contexts by dividing into four major aspects as follows:

First, mobile phones are useful in disaster response. However, they have limited battery life, and during disaster situations there may be fewer opportunities to recharge them. A survey of emergency responders and other private citizens shows that there is a clear short-fall in the battery life of mobile phones, which typically operate for only around one day before requiring a recharge, being only approximately half, or 15 hours too short, of the endurance required, depending on the measure applied.

Second, the battery life of most mobile phones is insufficient to enable their effective use throughout a disaster or emergency situation without requiring a recharge. Therefore, this thesis surveys and classifies a number of strategies that can be used for disaster response or for people living beyond the reach of ubiquitous reliable main electricity supply. This thesis presents simple methodology and results for a sample of mobile telephone charging products and techniques to compare and assess our sample of solutions to those currently available, with the intention of making our findings realistic and directly actionable for disaster response practitioners.

Third, through the analysis of eleven years of fine-grained data from the Queensland electricity network from the years 2005 to 2016, it becomes apparent that widespread and long-lasting blackouts are not uncommon in this region. In this thesis, a simple mobile phone battery life prediction model is employed to anticipate the number of mobile phones that would be flat on an hour-by-hour basis over the eleven years. This data clearly demonstrates that it is not feasible to extend mobile phone battery life so as to prevent battery depletion in such events, and that the policy focus should therefore be on ensuring that alternative means of recharging are easily available.

Fourth, in this thesis, it draws on innovations in passive radio sensing, and combine these with a simple Contiki-inspired protocol that can be used with existing Wi-Fi hardware to allow use of ad-hoc Wi-Fi with zero energy consumption when idle, yet allow communications to be established in milliseconds. Feasibility is demonstrated through proof-of-concept hardware, demonstrating that it is possible to provide devices with ad-hoc Wi-Fi communications capabilities with zero impact on stand-by energy consumption. This simple innovation reactivates the possibility of true peer-to-peer high-bandwidth, low-latency direct phone-to-phone communications, without any supporting equipment, such as a Serval Mesh Extender, increasing the opportunities for resilient and decentralized mobile communications during a disaster.

The contributions of this research are that a mobile phone in disaster contexts should concern about battery life mostly depleted due to human behaviour and Wi-Fi function on a mobile phone. Therefore, the best way to increase a battery life is recharging a mobile phone as soon as power supply is available using normal or alternative phone recharging strategies. Also, this thesis shows the relationship between mobile phone battery life and people living without electricity during disaster situation, and how this make it practically certain that during disasters that many people will not be able to maintain sufficient charge in their mobile telephones which can cause a flat mobile phone as discussed in chapter 6. A further recommendation for this research is to determine how to improve energy efficiency techniques on disaster communication based on mobile phone ad hoc network by considering valuable information based on proposed technique in this thesis.

TABLE OF FIGURES

TABLE OF TABLES

CHAPTER 1: INTRODUCTION

This introductory chapter provides the context and the definition of this thesis. The following sections present: 1) the motivation for this thesis; 2) the scope of this thesis; 3) the objectives of this thesis; 4) the contribution of this thesis, and finally 5) the structure of this thesis.

1.1 Motivation

Mobile phones have been devices that people primarily use for communication among each other in daily life. Mobile phones were developed from land-line telephones in order to overcome the issue of limited portability. The main aim of a mobile phone is to enable people to converse anywhere within a mobile phone base station coverage. Mobile phone functionality has been expanded to include other communication forms such as the Short Message Service, SMS; Voice Mail; and mobile phone Internet access. These services have become basic communication options for mobile phone users. It is affordable for everyone.

In recent years, human beings unexpectedly encounter unpleasant situations from natural disaster or catastrophe such as bushfire, tsunami, earthquake, flooding, cyclone, and so on (Road, 2017a) (Road, 2015) (Road, 2017c) (Road, 2017d) (Road, 2017b) (Suppasri et al., 2017) (Tingsanchali, 2012). During and following these situations, all basic communication infrastructure system including traditional land-line telephone systems, mobile phone systems, Internet networks, and also electrical power systems frequently break down or malfunction. This is a situation leading to the lack of communication system and power outage. Besides, there might be a coincident surge in attempted use from people trying to access telecommunication system or the Internet as they respond to the situation, which can further cause communication breakdown. Hence, people living in disaster zones cannot conveniently communicate to anyone in or outside the area. This is a tremendous issue to address this restriction of mobile phone in inevitable contexts so that basic communication system is still able to operate continuously.

Many researchers have attempted to study how to create simple communication system with acceptable functioning in a disaster situation anywhere anytime. Mobile wireless ad hoc network (M. Rubinstein, I. Moraes, M. Campista, L. K. Costa, & O. B. Duarte, 2006) is an alternative communication system based on IEEE 802.11 standard or

Wi-Fi (Jones, Sivalingam, Agrawal, & Chen, 2001). This technology can overcome the lack of communication system in emergency operation, disaster situation, as well as military activities. Wireless network technology has specific characteristics to operate in the aforementioned situations thanks to the ease of setup, dynamic self-organisation, and temporary topology to form infrastructure (M. Rubinstein et al., 2006). There has also been many researches focusing on how to implement a software which operates based on the wireless ad hoc technology such as Freedom Box (Moglen, 2015), Village Telco (Adeyeye & Gardner-Stephen, 2011) (Telco, 2011) and The Serval Project (P. Gardner-Stephen, R. Challans, et al., 2013) (Gardner-Stephen, 2013b). These projects aim at developing a simple communication software that functions on a modern mobile phone, known as a smartphone, or a specific hardware which is produced to create simple communication without the existing mobile phone communication system.

The entire thesis is based on The Serval Project since their major objective is to develop the platform for a resilient communication in disaster and crisis that can be practically used and still has been continuously developed so far. The Serval Project has offered a possibility to communicate relying on Wi-Fi ad hoc network called mesh or disaster communication platform via their implemented software which will be installed on a smartphone or related device. Some notable features consist of store and forward distribution for sharing data, text and voice messaging, map application, and voice communication (P. Gardner-Stephen, R. Challans, et al., 2013). Nevertheless, the main problem of this project is the energy consumption which is higher than normal mobile phone usage arising from Wi-Fi radio factor. The challenge for this thesis is to seek the energy efficiency improvements and figure out strategies to reduce battery consumption on disaster communications platform to promote sustaining mobile telecommunications in disaster contexts.

An important consideration affecting energy consumption on mobile phone is human behaviours, yet these factors have been overlooked by many researchers. I strongly believe that the mobile phone application usage behaviour affects battery life on mobile phone, and this thesis will gather evidence in support of this hypothesis. This research aims to study mobile phone application usage and recharging behavior either in normal situations or disaster contexts. A normal situation means a situation where a mobile phone can be used in daily life. The disaster situation refers to the circumstance where a mobile phone is used in the serious disruption or destructive event and aftermath. Hence, if the data of usage behaviour are properly applied and analysed based on statistical knowledge discussed in this thesis, it is feasible to suggest or educate people to extend battery runtime or reduce energy consumption by changing phone usage behaviour in an appropriate way. Moreover, there will be an exploration of mobile phone battery runtime from people satisfaction and from mobile phone manufacturer survey. These data will be invaluable to estimate mobile phone battery runtime either in general or disaster situations more accurately. Also, this information can estimate amount of minimum battery runtime in disaster communication in practice.

Supplementary energy is an alternative phone charging strategy to supply power to a mobile phone particularly in disaster situation or off-grid area (Maher, Smith, & Williams, 2003) (Wyche & Murphy, 2012). Not much research has been conducted in the field. The objective of this study is to survey the possibilities to charge the backup mobile phone to enhance sustaining mobile telecommunication in specific situation. Also, which alternative mobile phone charging is reasonable for people to afford or use in a disaster situation. In addition, data sources regarding typical length of loss of power and communications or power outages in a disaster are surveyed or acquired from trustworthy and referenceable sources. This data will help researchers to understand and estimate the distribution of power outages and its impact on mobile phone battery life in disaster situation.

The author has been unable to discover any existing research focusing on energy consumption measurement on particular disaster communication. As a result, energy consumption experiment on nominated disaster communication device from The Serval Project is a crucial aspect to estimate how much disaster communication device consume energy. This experiment will result in fundamental data to develop and propose a new mechanism to reduce battery consumption for improving energy efficiency on disaster communication.

However, energy efficiency in disaster communication is rather sensitive to energy consumption matter and development of methods to extend battery runtime which is not practically implemented. To improve disaster communications and potentially save lives, the work presented in this study will explore the issues of energy limitations and related factors on a mobile phone and disaster communication and provide a feasible solution for extending battery runtime for mobile phones (smartphones) in disaster contexts.

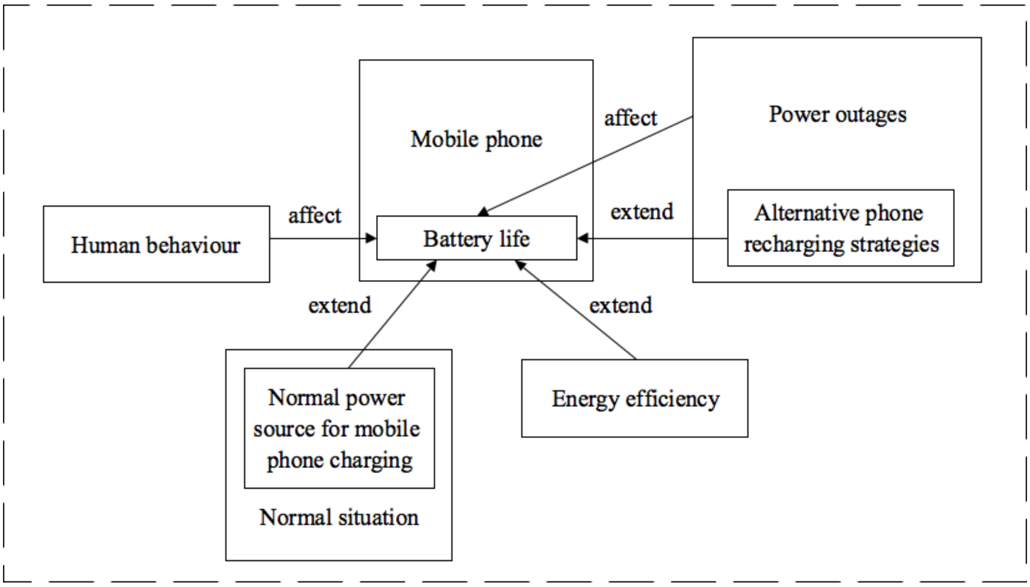


Figure 1.1: Interrelated diagram of mobile phone and related factors

A normal mobile phone is mainly powered by one single source known as a battery. In general situation a mobile phone is recharged via power source such as an adapter or a wall charger. In the meantime, human behaviour can affect battery runtime of phone, depending on their usage behaviour. In terms of disaster contexts, power outages or blackout may occur during short or long periods of time subject to situations. Therefore, alternative phone charging strategies are the ways to extend a mobile phone battery life replacing regular phone charging. Also, energy efficiency technique on a mobile phone is another solution to save or prolong battery life. Figure 1 shows diagram of mobile phone and related factors which this study will explore and address.

1.2 Scope of this thesis

This research pursues a goal to study energy and related factors to extend battery runtime for mobile phone (smartphone) as much as possible to support sustain disaster communication.

Throughout this thesis, a disaster communication platform or disaster communication means refers to a smartphone or particular device that is installed with the software of The Serval Project functioning as a meshing mobile phone or Serval Mesh device, which operates on wireless ad hoc network technology. To clearly elaborate the meaning of a mobile phone in this thesis, it will be assumed that a mobile phone means, “A wireless telephone or cellphone which is able to call voice and text message via cellular system or base stations. Combination of handheld computer and cell phone operating in various advanced functions beyond text and voice, which includes music and movie player, e-mail and Web, GPS, camera, voice and video recorder, and so on, is called smartphone. On the contrary, a general or regular mobile phone is called a feature phone, which functions like cellphone and may offer web browsing and email.” (Technopedia, 2015) (Phone_Scoop, 2015a) (Phone_Scoop, 2015b) (Encyclopedia, 2017b) (Encyclopedia, 2017a) (Encyclopedia, 2017c).

To clarify the scope of this thesis and how it will successfully extend a battery runtime on the disaster communication or mesh communication developed in The Serval Project, it will be demonstrated in Figure 1.2 – 1.4. Figure 1.2 shows how to find out battery runtime on meshing mobile phone or normal mobile phone, where the X variable represents amount of existing battery runtime on meshing mobile phone or mobile phone (hours), the Y variable represents the amount of required battery runtime on meshing mobile phone or mobile phone for the use under disaster circumstances (hours), and Y-X variable presents the gap between needs from people and existing battery runtime on meshing mobile phone or mobile phone (hours). The X and Y variables are to be derived from experiment and survey. When the X and Y variables are identified, it is possible to estimate the shortfall in battery runtime.

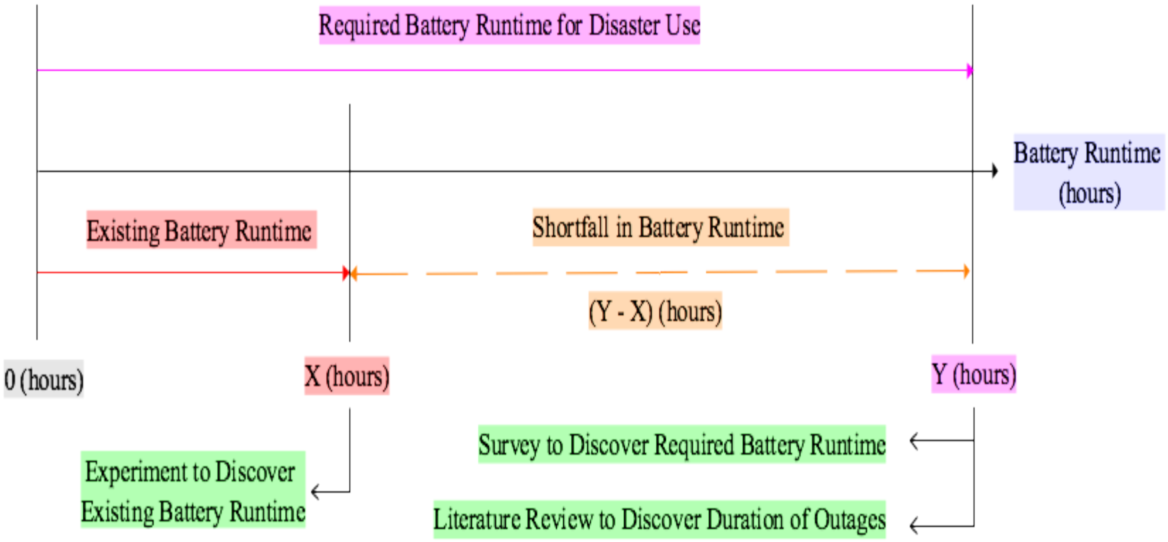


Figure 1.2: A solution to find out battery runtime on meshing mobile phone

The main issue of this research is to develop an approach to extend battery runtime. In this thesis, feasible approaches offer the way to reduce energy consumption and extend battery runtime on mesh communication, which is depicted via the conceptual framework in Figure 1.3, assuming that A, B, C, D, and E are proposed strategies to achieve the way to extend battery runtime. The aim of these approaches is to overcome gap between needed and existing battery runtime on meshing mobile phone. Therefore, A + B + C + D + E + … approaches should be able to extend battery runtime greater than or equal to Y-X variable to reach and fulfill required battery runtime for disaster use.

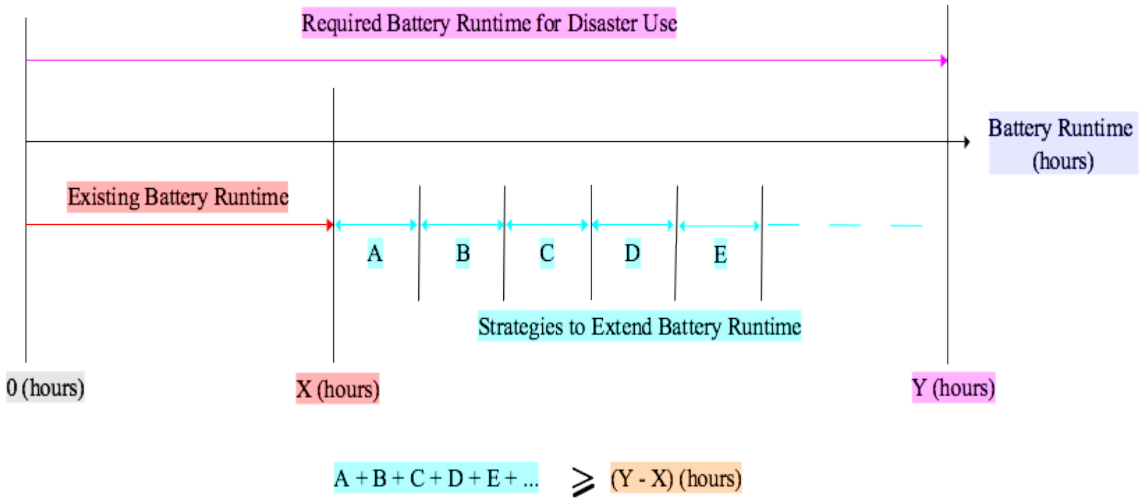


Figure 1.3: A conceptual framework of proposed feasible strategies to extend battery runtime on meshing mobile phone

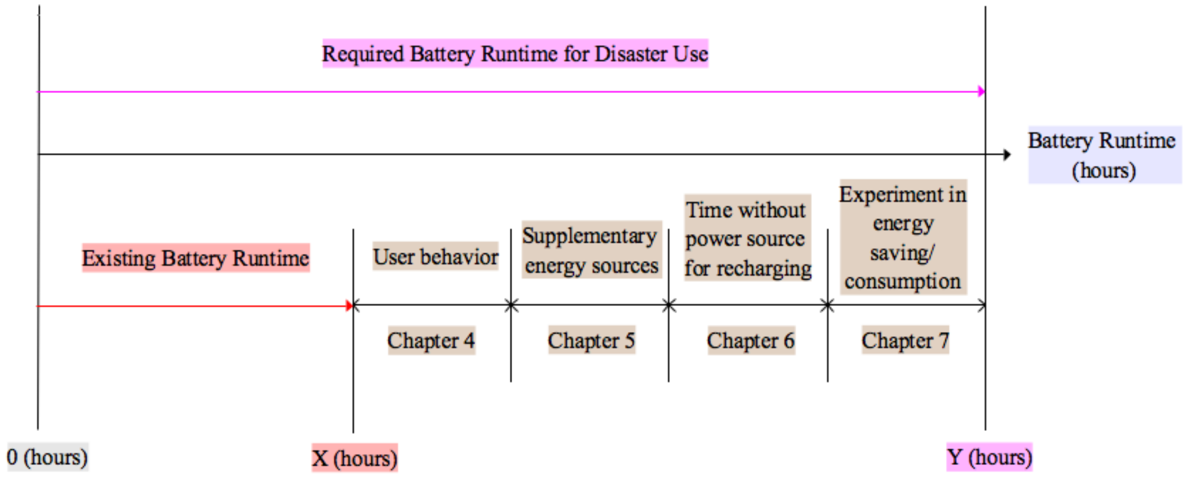


Figure 1.4: Classification of four major chapters in energy and related factors and how to extend battery runtime on meshing mobile phone

This study is classified into four main chapters regarding energy and related factors and how to extend the amount of battery runtime on meshing mobile phone which is depicted in figure 1.4.

The average of a mobile phone's battery life depends on hardware specification (Carroll & Heiser, 2010) and usage behaviour of each user (Oliver, 2010). Sometimes, battery life does last longer more than one day. However, battery life on a modern mobile phone or smartphone does not usually last longer than over 24 to 30 hours, depending on usage and battery capacity (Spoonauer, 2015) (Byrne, 2014). Many manufacturers attempt to develop a mobile phone by increasing battery size to extend battery runtime (Edwards, 2015). This is not the right direction to tackle this issue because battery is mostly drained from other factors (Banerjee, 2017). One of many reasons of battery depletion is caused by human factors (Oliver, 2010). There are many human factors related on mobile phone usage behaviour issues. This thesis focuses on two major categories: recharging behaviour and application usage behaviour. The survey in this thesis was conducted to investigate these issues from sampling group who are likely to either have experienced, worked in or volunteered in an emergency/disaster environment or not. The survey results gave valuable information to propose alternative ways to reduce battery consumption and extend battery runtime on mobile phone and mesh communication (See chapter 4).

Currently, there have been various supplementary power sources supporting a mobile phone in terms of energy backup (Flipsy.com, 2015). Nevertheless, there has not been any research to explore, classify, and compare each method of energy back up for mobile phones in terms of cost per recharge and number of devices that can be charged per day. This research focuses on the investigation of alternative power sources from literature which will investigate the alternative charging methods, especially when used in off-grid area and disaster situation. It is useful and helpful to prove that supplementary energy for mobile phone becomes an important part to increase the time before recharging battery through traditional means on mobile phone and mesh communication unavoidably (See chapter 5).

This research concentrates on the exploration of distribution of duration of power outages and its impact on a mobile phone in disaster situation. The time without power sources for a mobile phone recharging and the time without cellular communication are another major factor to examine energy in mobile telecommunications in disaster contexts. Due to disaster situations, it is impossible to determine when power sources and cellular communication will be recovered. A power blackout and failure of communication may occur all day or more than one day. The question is that what appropriate battery runtime for mobile phone or mesh communication to sustain in that undefined and unpredictable situation is. Therefore, the results from power outages data analysis related to power analysis model merges with minimum operation time of mobile phone obtained from participants in our survey is essential to determine or estimate phone battery life versus flat phone in disaster environment (See chapter 6).

Another major goal of this thesis is to suggest approaches to increase the battery endurance of meshing mobile phones. A meshing mobile phone is practical Wi-Fi ad hoc communication on normal smartphone which is easy to use during a cellular system breakdown. A necessary first step is to measure and experiment the endurance of mobile phones, or some representative device, so that the impact of proposed improvements can be accurately measured. Given the intrinsic difficulty of meshing existing mobile phone handsets, this study will use GL-AR150 (GL_Innovations, 2017) battery-powered wireless router running OpenWRT Linux (OpenWrt, 2015) as such a representative device. This experiment shows the feasibility of implementation with proposed technique in reducing power consumption on the future mobile phone (See chapter 7).

There are several reasons for using the GL-AR150. First using the GL-AR150 allows the impact of the cellular radio and other peripherals from confounding the energy consumption measurements. Second, The Serval Project has gained substantial familiarity with the GL-AR150 through their use of it in the Serval Mesh Extender prototype (Gardner-Stephen, 2013a). Third, the Wi-Fi radio in the GL-AR150 is capable of ad hoc Wi-Fi operation, making it a truly representative test and avoiding the inaccurate use of infrastructure Wi-Fi modes as a proxy for actual mesh communications. Similarly, the GL-AR150 is capable of easily running the Serval Mesh software, so the CPU activity of operating as a true mesh device can also be included. Finally, the GL-AR150 is cheap enough to fit within the budget constraints of the research.

In summary, the hypotheses of this study are presented as follows:

- Human behaviour and mobile phone usage are related to a mobile phone battery life.

- A battery backup or supplement energy are related to a mobile phone battery life.
- The duration of power outages during disasters necessitates increasing or augmenting the battery runtime of mobile phones.
- Energy consumption on a mobile phone relates to the battery runtime of a mobile phone.

From the above hypotheses, this study can be divided into four major research questions:

- How does human behaviour affect battery life on a mobile phone?
- What is the supplementary energy required to a mobile phone and disaster communication?
- What is minimum battery runtime required to sustain communications during the acute phase of a typical disaster?
- How can a battery runtime be prolonged on a disaster communication platform?

These altogether will be used to answer the question: "Can mobile phones be made to operate without reliance on the cellular infrastructure, for the duration of a typical disaster/adverse event?"

1.3 Objectives of this research

The main purpose of this research is to study how to sustain mobile telecommunications in disaster contexts in terms of energy usage and other related factors. To meet the aims of the research, several objectives are addressed.

1. To study whether human behaviour factors can affect battery life on a mobile phone. This human behaviour factors can be divided into two categories including the recharging behaviour and the application usage behaviour on a mobile phone.
2. To survey alternative charging strategies for a mobile phone and cost analysis for phone charging.
3. To explore what minimum endurance is required for battery runtime on mobile phone for people to accept the service and what the minimum battery runtime is required to sustain disaster communications during the acute phase of a typical disaster.

4. To propose the prototype of minimising energy consumption and maximising the battery life during disaster communication.

1.4 Contributions of this research

A mobile phone has become an essential device for users to perform every day communication. Its functionalities are more versatile than making a phone call such as browsing the internet, sharing a location on map, surfing a social network with friends, and so on. In general situation, there is no obstacle to reach a main plug to recharge a phone while it is going to be flat. The issue on an energy consumption on a mobile phone (Tawalbeh & Eardley, 2016) is negligible in daily life. Hence, in disaster or emergency situations, the power outage may occur for long periods of time. Moreover, there might be a lack of power supply to recharge a mobile phone. This should be concerned about how to enable a mobile phone to last longer in a limited and restricted situation.

Therefore, this research attempts to contribute feasible approaches to figure out how to reduce energy usage and increase time and battery life of a mobile phone during disaster occurrence or aftermath.

First, human factors relating to a mobile phone usage shows that a battery recharging behaviour and an application usage behaviour affect battery life on a mobile phone (Kongsiriwattana & Gardner-Stephen, 2016b). This can help establish the understanding concerning application usage and recharging adaptation which help to extend battery runtime on a mobile phone.

Second, this research contributes to the understanding of a category of supplementary energy and methods of battery recharging implemented on a mobile phone, particularly applied in disaster situation. This could assist people to figure out how to recharge their mobile phone while power sources are unable to be supplied in disaster situation. Also, people can wisely choose a mobile phone charging method from cost per recharge analysis (Kongsiriwattana & Gardner-Stephen, 2016a).

Third, this research will find out the minimum required battery runtime for a mobile phone that is practical for people and the minimum battery runtime required to sustain communications platform during the acute phase of a typical disaster. This could give assistance to people in finding the way to improve battery runtime on mesh communication for The Serval Project in order to match the expected battery runtime discussed in the survey.

Additionally, this research represents the first time of detailed data on the statistical distribution of blackout durations, the first time that their effect on loss of personal mobile telecommunications has been modeled, and the first evaluation of the loss of lives due to mobile telephones having flat batteries during prolonged blackouts.

Fourth, the measurement of energy consumption on disaster communication platform in the experiment is another contribution. This could help achieve the practical effective approach to extend battery runtime and meet requirement of people to use it in disaster situations.

Moreover, this research proposes the technique to implement in a mobile phone. It has presented the current technical feasibility of incorporating high-bandwidth low-latency peer-to-peer communications between smart-phones with zero to negligible standby power consumption. This facilitates the fulfillment of compelling use-cases that are currently not possible. Also, it has demonstrated that such peer-to-peer functionality can be incorporated at negligible cost in terms of additional hardware and software. Finally, through initial experiments it has demonstrated that these innovations are not merely theoretical curiosities but are, in fact, practical to implement.

1.5 Structure of this thesis

This section outlines of the content of this thesis.

Chapter 2 is the literature review which clearly elaborates definition, backgrounds, and related factors in this entire thesis as follows:

- Evolution of mobile phone technology
- Categories and aspects of a mobile phone
- Battery runtime of each mobile phone manufacturers on the current market
- Factors causing depletion of battery life on mobile phone
- Definition of current battery recharging and untraditional recharging on a mobile phone
- Definitions, means, and examples of an emergency/disaster context
- Background of disaster communication

- Background of The Serval Project and their service
- Background of wireless ad hoc network technology
- Energy efficiency techniques on wireless ad hoc network

Chapter 3 explains research methodology in details. This chapter explains what the aim of the survey is, who the target group of the survey is, how to setup and implement experimental framework for mesh communication, and how to attain research objectives and answer research questions.

Chapter 4 presents recharging behaviour and application usage behaviour on a mobile phone in an emergency/disaster context which has an impact on battery runtime of a mobile phone. Data from this survey is analysed to determine alternative approaches to reduce energy usage and extend a mobile phone battery life caused by human factors. Moreover, this alternative approach also leads to the guideline to extend battery runtime on mesh communication.

Chapter 5 describes characteristics and categories of supplementary/recharging energy sources supporting a mobile phone which is non-traditional recharging or alternative recharging, finds out what supplementary/recharging energy can be employed in an emergency/disaster situation, and assesses the criteria about cost per recharge and number of devices that can be recharged per day. Also, this chapter shows the tendency of alternative source power to increase the time before they need to recharge their mobile phone at the present which is analysed from our survey.

Chapter 6 represents survey results of typical length of loss of power and communication failure in an emergency/disaster from literatures and provides information from electricity network. Also, the minimum battery runtime on a mobile phone that the participants expect when using the communication service and the minimum battery runtime required to sustain communications during a typical disaster were analysed in terms of relationship of duration time without power outages and cellular communications. This helps find out the relationship between a battery runtime and a flat mobile phone while there is no power to recharge a mobile phone.

Chapter 7 represents energy experiment on mesh communication in The Serval Project known as Mesh Extender device (The_Serval_Project_Team, 2017b). The GL-AR150 was selected as nominated device in the experiment. This research proposes alternative approaches to eliminate energy consumption on Wi-Fi ad hoc network. The experiment demonstrates reduced energy consumption and quantifying what that reduction in energy consumption is. Therefore, this chapter reactivates and proposes the possibility of true peer-to-peer high-bandwidth, low-latency direct phone-to-phone communication. From the experiment, it reveals the possibility of development of a smart-phone-based proof-of-concept for the near future.

Chapter 8 describes general discussion and results to figure out the following issues:

- Do human factors have an impact on battery performance? If so, how can it be managed?
- What can be done to address any shortfall?
- Is the mesh communication ready for mainstream use?

The conclusion provides the main finding of the research and suggestions for future study identified throughout the entire thesis.

CHAPTER 2: LITERATURE REVIEW

This chapter provides background information on the underlying sources and technology that are relevant to this dissertation. This literature review begins with the background of mobile phone technology. Next, the chapter presents categories of a mobile phone in the present day, battery runtime of a mobile phone, categories of alternative mobile phone recharging and battery backup, factors depleting mobile phone battery life, the definition of mobile phone recharging, and energy efficiency on current mobile phone.

This chapter then reviews the background of definition, means, and examples of an emergency and disaster situation, The Serval Project and services, wireless ad hoc network technology, energy efficient techniques on wireless ad hoc network and a mobile phone related to The Serval Project. Finally, the last section outlines factors depleting battery life of disaster communication devices.

2.1 Evolution of mobile phone technology

In the early 1980s, the handheld mobile phone system emerged as a modes of communication via cellular system known as analogue technology or 1st generation (1G) (Bhalla & Bhalla, 2010). It was invented for the sole purpose: a voice communication. One advantageous aspect was that people were able to communicate each other via their mobile device anywhere in coverage base station area. In 1990s, digital mobile phone technology known as 2nd generation (2G) had an influence on new variant communication system development. It proposed text communication or short message service (SMS) other than voice communication (Miki, Ohya, Yoshino, & Umeda, 2005). During 2G to 3rd generation (3G) evolution, there were low data rate Internet system known as General Packet Radio Service (GPRS) and Enhanced Data Rates for GSM Evolution (EDGE) was implemented for supporting low data access internet service (Halonen, Romero, & Melero, 2004). During the early 2000s, 2G mobile phone technologies were replaced by mobile broadband data called Universal Mobile Telecommunication System (UMTS: 3G) and High-speed Packet Access (HSPA) or 3.5G technologies (Hillebrand, 2002). These technologies made people able to access to high-speed Internet via their mobile phone (Patil, Karhe, & Aher, 2012). At the present, Native IP networks or 4th generation (4G) has principal objectives which are to improve high-speed performance of Internet data access as well as increase network capacity (Khan, Qadeer, Ansari, & Waheed, 2009). As a result, this technology is named as Long-Term Evolution (LTE) standard (Khan et al., 2009). It is expected that data access rate must be faster than 3G and 3.5G via mobile telecommunication infrastructure (Cox, 2014). In the near future, it will proceed to 5th generation (5G), focusing on the energy efficient communications, cognitive radio network, and visible light communications (Wang et al., 2014).

Implemented on a modern mobile phone (Smartphone), Wi-Fi or IEEE 802.11 standard based on the industrial, scientific and medical (ISM) radio bands. Normally, it operates on frequency 2.4 GHz and 5 GHz bands (Tanenbaum & Wetherall, 2011). This technology brings users to communicate each other via wireless local area network (WLAN) in limited area relying on power transceiver on each device. In the meantime, it is able to access the Internet via Access Point (AP) device connected with Internet Service Provider (ISP) (Henry & Luo, 2002).

Normally, a mobile phone powered by a battery cannot operate for a long period of time until it goes flat. It always relies on battery capacity (Perrucci, Fitzek, & Widmer, 2011) (Perrucci, Fitzek, Sasso, Kellerer, & Widmer, 2009). As a result, many manufacturers such as Samsung, Asus, Huawei, and Motorola solve this problem by increasing battery capacity size (Wordtheque, 2016) (Villas-Boas, 2015) (La, 2017). It seems that this idea of expanding the battery life is currently the trustworthy concept in normal behavior when using only voice communication (Eason, 2010). However, nowadays people’s usage behavior shifts from using a mobile phone via voice communication to using Internet data access instead. This trend has been known as “Mobile broadband communication” (Correia & Prasad, 1997), people can connect to the Internet via their mobile phone anywhere anytime with coverage cellular stations. Consequently, a mobile phone usage starts to rely primarily on the high-speed internet data access. It is unavoidable that battery consumption rate will be higher in a short period of time since the internet data access technology consumes much energy (Gupta, Jha, Koc, & Vannithamby, 2013). As for Wi-Fi technology, the important shortcoming of Wi-Fi communication on smartphones is that it also consumes much energy while turning Wi-Fi on compared to when it is off (Kalic, Bojic, & Kusek, 2012). The more time is spent on accessing the Internet via a mobile phone (via mobile internet technology or Wi-Fi), the faster the phone battery will drain (Kalic et al., 2012) (Balasubramanian, Balasubramanian, & Venkataramani, 2009). In addition, entertainment features on a smartphone including games, audio and video player and streaming mostly use Wi-Fi or Internet as basic service channel provided to users (Falaki et al., 2010). Unavoidably, a mobile phone battery life is drained from these features (Fowdur, Hurbungs, & Beeharry, 2016). Therefore, it is a huge obstacle and question to develop a mobile phone in terms of energy saving for normal use. This reason leads many researchers (Oliver, 2010) (Mikko V. J. Heikkinen, Nurminen, Smura, & Hämmäinen, 2012) (Bolla, Khan, Parra, & Repetto, 2014) (Zhuang, Kim, & Singh, 2010) (Soumya Kanti Datta, Christian Bonnet, & Navid Nikaein, 2012a) to study how to reduce energy consumption on a mobile phone.

A mobile phone rapidly becomes a major device people use in daily life. There are many features either to communicate or to entertain users. In disaster situation, a mobile phone must be prepared to endure unpredictable events and used as aid tool (AlonsoEmail, Schuck-Paim, & Asrar, 2014). Because its capability as off line and online application can help mitigate difficulties for people during post disaster (Silva, 2018). The categories of a mobile phone would be discussed in the next section.

2.2 Categories of a mobile phone at present

A mobile phone in the marketplace can be generally classified into two types:

2.2.1 Feature phone

A feature phone is normally intended to operate in voice communication service, covering in 1st and 2nd generation of a mobile phone. This phone provides limited features such as camera, games, MP3 player, voice communication, SMS, or even Internet access. A feature phone was originally introduced circa 1993 until its popularity dramatically declined around 2013 (Celkon, 2015) (Miyashita, 2012). It was then replaced by a modern mobile phone or a smartphone. In the past, some manufacturers such as Nokia, Ericsson, Motorola, and Siemens dominated phone market share. Each feature phone has its own operating system (Miyashita, 2012). One of the prominent advantages of a feature phone is its long battery life and its affordable price. However, in February 2017, Nokia just launched and resurrected Nokia 3310 feature phone model which people can afford, and its battery life lasts longer than a normal smartphone (Kelion, 2017).

A feature phone can last many days, it is claimed (Kelly, 2017) that its standby time can be up to 31 days which is probably sufficient in disaster or emergency situations.

However, most people nowadays tend to use a modern mobile phone or a smartphone instead.

2.2.2 Smartphone or modern mobile phone

Authors (Zheng & Ni, 2006) defined the meaning of a smartphone as “a small, networked computer in the form of a cell phone”. It is equipped with powerful CPU or processors, liquid-crystal display: LCD touch screen, large storage. It supports wireless technologies and smart sensor including Bluetooth, Infrared, Wi-Fi, GPS, light sensor, gyroscope sensor, barometer and so on. Moreover, it includes built-in camera, audio/video playback and recording, games, instant messaging, and e-mail.

This study will mention only three current major manufacturers producing a variety of smartphones, categorised by the following operating systems:

- Android operating system is manufactured by Google company (Google_Inc, 2017), known as android mobile phone. In the market, there are many android phones form various manufacturers in the market because it is an open source for the development. Therefore, there have been many manufacturers producing android mobile phone such as Samsung, Motorola, LG, and so on. Android operating system was first launched in September 2008 from version 1.0 until latest version 8.0 with its code name as Oreo (Android, 2017).
- IOS or iPhone operating system is manufactured by Apple company (Apple_Inc, 2017a). This mobile phone is known as iPhone, first launched in October 2007 until current year. The current version is IOS 10 (Apple_Inc, 2017b).
- Windows operating system for a mobile phone is manufactured by Microsoft company (Microsoft_Inc, 2017). Microsoft and Nokia on Lumia Brand originally produced a phone called a Windows phone. It was first launched in October 2010 up until now. The current version of this operating system is version10.

For a smartphone, there are a variety of features to satisfy user’s needs. From the recent review (Spendelow, 2019), The maximum length of time that a battery can last is averagely 28.50 hours. In normal situation, it is sufficient for one day and the users can be worry-free about the battery life. Nevertheless, in disaster or emergency situation, it should be concerned about how long mobile phone battery can last before it goes flat. The next section will discuss about battery capacity and battery runtime.

2.3 Battery runtime and battery capacity of a mobile phone on the current market

In this thesis, it is difficult to classify a mobile phone model from each manufacturer in the market. Because there has been mobile phone models emerging in the market every week. Most new mobile phones operate on android operating system, accounting for over 81.7 percent out of 100 percent in 2017 (Vincent, 2017). To clarify battery runtime thoroughly, a mobile phone survey was categorised by talk time, web browsing time, and video playback time of the 25 well-known brands from longest to shortest battery duration as opposed to battery capacity on February 2017 (GSMArena, 2017a). Also, there is a table showing five latest models of phones with their battery life when using Wi-Fi access. Please refer to appendix A.

According to the survey in appendix A, the highest talk time of a mobile phone was 34.49 hours while its capacity was 5,100 mAh. In terms of the maximum web browsing time, a battery life last 20.22 hours and the battery capacity was 5,000 mAh. While using a video play back, the longest duration was 23.11 mAh on capacity size 5,100 mAh. The longest lasting mobile phone battery life determined by Wi-Fi time was 12.79 hours with the battery capacity of 3,600 mAh.

It should be noted that there is no relationship between battery capacity and battery life. Some mobile phone offers high battery capacity size, but its battery life last shorter than that of other products because there are other factors causing battery drainage which will later discuss in the next section. Moreover, the results of relationship between battery life and battery capacity will be discussed in chapter 4.

2.4 Factors causing depletion of battery life on a mobile phone

In a mobile phone, two main components that drain battery life include hardware and application usage. Both components consume energy or battery, depending on the usage of each component. The following subsection will explain how these components consume energy of a mobile phone.

2.4.1 Hardware usage factors

A mobile phone or a modern mobile phone has many main components including CPU, display, camera, GPS, cellular units, and wireless device units (Wi-Fi and Bluetooth). All of these components are related to the power consumption as summarised in the following literature discussion:

(Carroll & Heiser, 2010) analysed smartphone power consumption based on android mobile phones which are HTC Dream and Google Nexus One. Most power consumption occurs from cellular radio (GSM), display including LCD panel, backlight, touch-screen and graphics accelerator and CPU. From their analysis, it was found that 40% of energy could be saved by dimming the backlight during their call. The authors (Murmuria, Medsger, Stavrou, & Voas, 2012) proposed that power usage measurement of a hardware on the android smartphone, which are Nexus, consists of CPU, display, graphics, GPS, audio, microphone and Wi-Fi. The results showed that the quick battery discharge rate depended on high CPU frequency. On the contrary, Wi-Fi consumes energy proportional to data packet sent or received data rate. In terms of display, pixel strength and duration of uptime of screen affected the battery life. In addition, (Vallina-Rodriguez, Hui, Crowcroft, & Rice, 2010) measured android mobile phone G1 power consumption in four states: a standby state in Airplane mode consumes 19.9 mW, a screen on state in Airplane mode consumes 341.6 mW, a standby state in Cell phone mode consumes 32.2 mW, and a screen on state in Cell phone mode consumes 373.9 mW. These data reflected that turning the screen on is the crucial factor in stimulating energy consumption.

Another experiment (X. Chen, Chen, Ma, & Fernandes, 2013) described the relationship between a mobile phone display and application that specified the battery level on the display and how the applications like a streaming video player, video game, and camera recorder affected the phone battery life. Chen, et al reported that when a camera recording is on, the power consumption occurred at a higher rate than when video player and game. Another energy consumption experiment (M. V. J. Heikkinen & Nurminen, 2010) on a smartphone, Nokia N95, showed that in Wi-Fi (infrastructure mode) the power consumption was 868 mW. Conversely, in Wi-Fi (ad hoc mode) the power consumption rate was 1,629 mW while transmitting at 700 kbps. These data revealed that using Wi-Fi on a smartphone consumed a lot of energy. CPU usage at 2 % consumes 55 mW, at 50% consumes 462 mW and 612 mW at 100%. This means CPU consumption depends on the working load. Power consumption on

GPS was compared in (Paek, Kim, & Govindan, 2010). The results showed that GPS is an important factor in consuming more energy and caused quick battery life depletion. Another experiment on GPS and Wi-Fi based on localization (Constandache, Gaonkar, Sayler, Choudhury, & Cox, 2009) (Gaonkar, Li, Choudhury, Cox, & Schmidt, 2008) illustrated that there was a relationship between energy and localization accuracy while browsing, sharing, and querying information affect the battery life.

The authors (Friedman, Kogan, & Krivolapov, 2013) experimented with sending and receiving file to test throughput performance by using Wi-Fi technology. The results showed that Wi-Fi running in ad hoc mode consumes more energy than in infrastructure mode or access point mode. Another experiment (Kalic et al., 2012) reported that there was measurement of energy consumption of Wi-Fi, Bluetooth, and 3G communication technologies while transferring data uploaded and downloaded via android mobile phone. 3G-communication technology consumed energy more than Wi-Fi and Bluetooth respectively. Metri, el al (Metri, Agrawal, Peri, & Weisong, 2012) experimented on iPhone and Android phones to measure power consumption on Wi-Fi and 3G. It concluded that packet size and interval between sending and receiving packet affect the battery life. This tells us that network transfer activities on broad range applications consume a lot of energy. Also, authors (Perrucci et al., 2011) survey of energy consumption on smartphone including Wi-Fi, 2G/3G, Bluetooth, SMS, display, music player, video calls, file transfer and so on. The results showed that major power consumption emerged from wireless communications.

To sum up, energy consumption of hardware can be comprehensively categorised by GPS, screen display, processors (CPU baseband processor and Application processor: Audio, Video and Touch screen), Cellular network including GSM, 3G, 4G and Wireless network (Wi-Fi and Bluetooth) (Xiangyu, Xiao, Kongyang, & Shengzhong, 2014). It is important to inform users how to use a mobile phone in effective way to save mobile phone battery life (Stokes, 2016). In this thesis, the author pays attention to Wi-Fi consumption on a mobile phone, operating on ad hoc Wi-Fi communication. It is studied and discussed in chapter 7.

2.4.2 Application usage factors

The author (Oliver, 2010) studied usage behavior based on energy consumption, data traffic, spending time on a mobile phone and application. Application usage explored the number of applications, application popularity and application session. The results showed that application, user interaction, and device platform caused energy depletion of the mobile phone battery. (Mikko V. J. Heikkinen et al., 2012) investigated application usage by their participants. It was found that the time users spent running on application depended on battery level, especially on the highest battery level. This study did not specifically examine the energy consumption or the frequency of application usage. (Rahmati & Zhong, 2013) studied participants' usage on social media and location tracking applications on the phone over four months. Application usage was classified into three categories: recreation, Internet and communication, and work/education. The interesting point of this investigation was that participants spent more time on non-voice communication than voice communication. The results interpreted non-voice usage in three measures; average length of usage sessions, average usage time per hour, and average number of sessions per hour. The authors concluded that people always changed their usage behavior over time. (Verkasalo, 2010) proposed the MobilTrack framework that includes behavioral measurements, contextual surveys and web surveys. The author analyzed the data from three points of view including adoption analysis, stickiness analysis and user's satisfaction. Each analysis was shown in proportion to application usage or particular insight in order to provide user experience statistics to device vendors, and application developers. The authors (Böhmer, Hecht, Schöning, Krüger, & Bauer, 2011) examined application usage information based on time of day and location by using AppSensor embedded on the background service of an android mobile phone. The data showed how users spent their time depending on application type. On average, communication application (text & voice) was mostly used more than other applications. On the other hand, people were inclined to use their multimedia application while they were travelling.

Overall, application usage significantly affects a mobile phone battery life since applications must operate upon a mobile phone. Hence, the more frequently a mobile phone is used, the more energy it unavoidably consumes from hardware.

The hardware on a mobile phone cannot be adapted or changed, depending on a model or brand of manufacturers. However, it is possible to change behaviour of a mobile phone usage to preserve its battery life during disaster or emergency situation.

2.5 Definition of mobile phone recharging

Nowadays, lithium ion (Li-ion) cells battery technology is used in mobile phones or smartphones as a source or supply to keep them operate (Yoshio, Brodd, & Kozawa). However, it is necessary to recharge them to the maximum percentage or fully charge in each day as frequently as possible (Takeno, Ichimura, Takano, & Yamaki, 2005). This study defines definition of a mobile phone recharging as follows:

- Traditional recharging means a normal phone recharged via a cable by using a wall charge, USB laptop, and battery backup or power bank. The cost of power bank is dependent on its size and capacity.
- Untraditional recharging means it is the way to recharge a mobile phone via solar, wind, kinetic, fuel, water, heat or thermoelectric converter, radio, and dynamo. The cost of each alternative source for recharging battery relies on each technology to implement for phone recharging

During disaster or emergency circumstances, The loss of communication and long power outages may prevail (Haraguchi & Kim, 2016). Untraditional recharging strategies is potential to use for a mobile phone recharging (Brown, 2019). The question is what solutions can assist to appropriately and valuably recharge a mobile phone. Mobile phone recharging strategies are discussed in details in chapter 5.

2.6 Energy efficiency on current mobile phone

Currently, a battery is a source or supply to a mobile phone or smartphone. Most mobile phones provide various features to users including communication and entertainment feature. Energy consumption is taken into account in the aspect of how to extend battery life and increase time of mobile phone operation. This section describes the concept of Android power management techniques adopted with the current mobile phones and the methods to control mobile phone features.

2.6.1 Android power management

Power management on Android mobile phone (Motlhabi, 2008) is designed based on CPU usage and wakelocks technique. Wake locks is a software mechanism to guarantee that an Android mobile phone is not in deep sleep mode and always ready to operate in the background (S. K. Datta, C. Bonnet, & N. Nikaein, 2012) (K, 2014) (Ashish, 2017). If there is no applications or services running on that period, CPU should not consume energy during that time. Android operating system requests resources with wakelocks through the application framework and native Linux libraries. If there is no wakelocks active by applications or services, CPU is turned off. Therefore, Android mobile phones can save energy while there is no applications or services running. The example of the latest Android power management application implemented by using CPU wakeslocks technique is described (Technologies, 2017).

2.6.2 Control smartphone or mobile phone features and connectivity

This is an easy solution for users to save battery on a mobile phone. It will switch off features, connectivity, and hardware components when not being used. In disaster situations, these solutions do not directly tackle the problem of battery drain on a mobile phone. However, it can prolong a mobile phone battery life in particular situations. The following guidelines to increase battery life have been shown (S. K. Datta et al., 2012) (Martin, 2016) (ZDNet, 2013).

- Turn Wi-Fi, Bluetooth, GPS, 3G, 4G, and mobile data off, when you do not use them.
- Turn down brightness level on display
- Adjust screen timeout
- Turn off phone vibration
- Turn on power saving mode
- Turn off notification application
- Set Wi-Fi timeout.
- Set dark home screen wallpaper.

The best way to prolong a mobile phone battery life during disaster or emergency situation is to turn off a mobile phone. However, it is not the recommended way providing that there are announcements or warnings from a city or government reporting the latest situation. Turning a mobile phone on is still required in this kind of situation. The said solutions are reasonable to save the phone battery runtime. However, the consequence of a disaster causes the lack of communication service. What is a proper communication system that should be provided for people? The disaster communication system will be discussed further in section 2.7.

2.7 Definition, means and examples of an emergency and disaster situation

In this study, the definition of an emergency is a situation that goes out of control and requires an immediate attention (UK_Government, 2004). Examples of an emergency include a car accident, a child who is unwell and needs to be taken to a doctor/hospital, and a house fire. All of these examples mainly show the loss of life, health damage and property damage, or environmental damage (SafeWorkAustralia, 2009).

A disaster refers to a serious disruption to community life causing damage to property which is beyond the day-to-day capacity of the authorities and requires outside help and resources (Mayner, 2013). The authors (Rutherford & de Boer, 1983) cited the definition of a disaster from the international working party that “A disaster is a destructive event which, relative to the resources available, causes many casualties, usually occurring within a short period of time”. Also, International Federation of Red Cross and Red Crescent Societies (IFRC.org, 2017) defined disaster as “a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community’s or society’s ability to cope using its own resources”.

Types of disasters can be classified by natural disasters, natural hazards induced by human activities, and man-made disasters (Jhsph.edu, 2008). Therefore, it can be a natural disaster including powerful and sudden climatic and meteorological assaults, more drawn-out episode. Also, avalanches, earthquakes, landslides, tsunamis, volcanic eruption, biological catastrophes are natural disasters (Baum, 1983). Floods, bush fires, blizzards, hurricanes, tornadoes, windstorms and heatwave are also counted as natural disasters (Bankoff, Frerks, & Hilhorst, 2004). It also includes any situation caused by human activity or man-made and technological hazards including stampedes, fires, war, unrest, oil chemical spills, transport or traffic accidents, industrial accidents, nuclear radiation/explosions, collapse building, poisonous gas, fire, panic, and civil disturbance (de Boer, 1990).

An emergency is a lesser event and can be attended to locally while a disaster overwhelms the community resources and requires outside help (Mayner, 2013).

Examples of major disaster or emergency events in the past over the world can be presented as follows:

- Black Saturday Bushfires in 2009, Victoria, Australia (Peter A Cameron, 2009). Aftermath of this events destroyed properties, residents and vehicles of people. There was evidence (Ross, 2009) showing the lack of a mobile phone coverage during critical event, TV and radio report also cannot be accessed at that time. Also, there were no warning message or announcement to people at that time (Cowan, 2009).
- Haiti earthquake in 2010 (CNN_Library, 2016a) caused loss of power and cellular communication network after the earthquake devastated in Haiti (Bengtsson, Lu, Thorson, Garfield, & von Schreeb, 2011). It took a week or two to restore some communication system (Pallardy, 2010). This earthquake hit the southwestern part of the Haitian Capital with a magnitude of 7.0.
- An earthquake and Tsunami at Fukushima Japan (Zaré & Afrouz, 2012). This earthquake occurred at the east coast of Japan in 2011. This event caused Fukushima nuclear power plant shutdown and then Tsunami stuck the coast after the earthquake about 50 minutes later. The nuclear reactors exploded and emitted radiation to outside area (Atherton, 2016). There were no communication or power source supplied in such disaster area.
- Hurricane Sandy occurred in South Western Caribbean Sea, Central and North America East Coast in 2012 (Diakakis, Deligiannakis, Katsetsiadou, & Lekkas, 2015). The aftermath of Hurricane Sandy led to such disaster as flood, widespread power outage during a storm, and damages to a household and road (CNN_Library, 2016b). Also, there was a report indicating that a wireless communication was out of service, and the wireline central office was affected (Alexis Kwasinski, 2012).

In Australia, there have been many natural disasters occurring all the time. In the past Australia mostly encountered disasters from bushfires, floods, severe storms, droughts, earthquakes and landslides (Australia_Goverment, 2015). It was unfortunate and unexpected events causing hardship and loss of life to people and community. In the aftermath of disasters, there must be many huge destructions of electricity system, power outages, blackout, or even caused the lack of communication system. This study mainly focuses on the duration of power, energy or communication network failure after the occurrence of disasters. The data regarding power outage acquired from electricity network operators or companies and example of natural disasters in Queensland were presented and analysed in chapter 6.

2.8 Background of disaster communication over the time

The disaster or emergency communication means the communication during or after a disaster situation. This communication should be accessible and reliable for responders in disaster crisis. Therefore, this communication should be resilient enough to operate and respond all over period of disaster time and aftermath.

2.8.1 Characteristic of disaster communications

This section discusses the aspects of disaster communication that (Patricelli, Beakley, Carnevale, Tarabochia, & Von Lubitz, 2009) (Ei Sun, 2003) will be considered within the work presented in this thesis.

- Timeliness and speed delivery mean that when an emergency or disaster takes place, the communication should be rapidly established to mitigate those events as fast as it can.
- Ease of use to facilitate effective use of functionality and user interface on provided communication technologies.
- Affordability means the cost of procuring, maintaining and installing of emergency communication system which should be affordable at any time.
- The provided instructions on how to respond to disaster or emergency must be clear and actionable.
- Multiple communication path and redundancy means that disaster communication should provide multiple channels of communications such as SMS, telephone, email, social media, or even ad hoc wireless network. Users can use these communications depending on a situation.
- Interoperability means that disaster communication system should be able to communicate and connect with related systems.

2.8.2 Broadcast technologies

Broadcast technologies refer to the communication via point-to-point that may require infrastructure. It is classified by two main technology frameworks as follows:

2.8.2.1 Infrastructure-independent (Shankar, 2008)

Communication technologies are not dependent on man-made infrastructure to communicate during emergency or disaster situation such as short-wave radio, two-way radio, weather radio, and the internet-based communication.

2.8.2.2 Infrastructure-dependent (Eurapean_Telecommunications_Standards_Institue, 2010)

Communication technologies are dependent on man-made infrastructure to communicate during disaster or emergency situation such as audio public address systems, LED electronic sign, audio/visual public address devices, digital signage, and voice system.

2.8.3 Communication devices and services

In an unexpected disaster or emergency situation, people mostly need some communication system to enable them to contact other people, inform about the current situation, and immediately respond to request for assistance. Hence, communication devices in disaster contexts are very crucial in such situation.

This section reviews important communication devices and services frequently used in disaster or emergency situation. These devices and services include mobile phone or smartphone, SMS messaging, social media, electronic mail, and alternative communication system based on wireless ad hoc network such as mesh mobile phone from The Serval Project.

2.8.3.1 Mobile phone or smartphone

A mobile phone or a smartphone is a communication device being able to efficiently reach and share information between members of the public when disaster strikes. A mobile phone is considered a private communication device, depending on the operator or provider. Without a cellular network or base station, a communication service on mobile phone is normally broken down because there is no available wireless signal to connect between mobile phones. However, it becomes key device of modern communication to help in emergency communication.

2.8.3.2 SMS (Short message service)

The capability of communication to reach one person (point to point) or one to many (point to group) at a time is facilitated through SMS (Fitzgerald, Spriggs, & Keosothea, 2010). In emergency or disaster situation, SMS messaging is easy to use, highly reliable, and fast. SMS text was employed to report the missing people after Haiti earthquake (Patrick & Munro, 2010). This is a powerful basic service provided in every mobile phone.

2.8.3.3 Social media

There are many social media applications available, yet most people tend to use twitter and Facebook more than other applications (Hughes, Rowe, Batey, & Lee, 2012) (Ju, Jeong, & Chyi, 2014). For example, these papers (Gao, Barbier, & Goolsby, 2011) (Haddow & Haddow, 2014b) (Peary, Shaw, & Takeuchi, 2012) represented advantages of using Facebook, Twitter, or YouTube for users who want to share their experiences during disaster through social media.

- Twitter (Twitter, 2017) is online social networking, functioning similar to SMS messaging but it is required to post in limited number of text messages (140 characters) into an individual blog containing share link or short information to friends in twitter community.
- Facebook (Facebook, 2017) is a kind of private and public board to share, post own information in type of audio, video, and text to others. It is a real-time communication which is useful for disaster communication to update situation or events in real time.
- YouTube (YouTube, 2017) is a video sharing website allowing users to upload, download, view, and share contents to public.

2.8.3.4 Electronic mail

Email is an optional media to assist people in disaster or emergency situation. It can send to a specific email address or simultaneously to multiple people. People can receive similar content in their individual email.

2.8.3.5 Practical disaster communications based on wireless ad hoc network

The conceptual idea of communication an telecommunication without base stations or cellular towers is usually known as infrastructure dependent or self-organised network. Wireless ad hoc network (Frodigh, Johansson, & Larsson, 2000) is intended to form the network instantly and rapidly. Currently, one of many researchers proposed practical disaster communication via wireless ad hoc technology (P. Gardner-Stephen, R. Challans, et al., 2013), which is The Serval project. This project intended to assist people to be able to communicate in disaster situation via Wi-Fi ad hoc communication. In order to understand background and overview of this project, please continue to the next section.

2.9 Background of The Serval Project and its services

The founder Dr. Paul Gardner-Stephen and his colleagues at Flinders University, South Australia, established this project in 2011 until present. This project aimed to develop communications which can be operated anywhere and anytime without ordinary communication infrastructure or infrastructure-independence.

2.9.1 The Serval Project objective

The Serval project mainly focuses on developing disaster telecommunication which uses a regular mobile phone (smartphone) or mesh device at least two devices running Serval software or mesh software to communicate without using an ordinary phone tower or base station (Gardner-Stephen, 2013b) (P. Gardner-Stephen, R. Challans, et al., 2013).

2.9.2 Current service on The Serval Project

Currently, the project provides many services including Serval Mesh, Serval Chat, MeshMS, Seval Map, Serval Mesh Extender which will be discussed in the following subsections.

2.9.2.1 Serval Mesh (The_Serval_Project_Team, 2015b) (P. Gardner-Stephen, R. Challans, et al., 2013)

Serval Mesh is a free and open-source application for an Android mobile phone. It allows people to establish voice calls, text message, and file sharing with other Serval Mesh without the requirement of cell phone base stations, satellite communication, SIM, radio repeater, and the Internet. Therefore, users must install Serval Mesh application into their mobile phone to communicate with others.

Serval Mesh makes connection between mobile phones via Wi-Fi capabilities and communications within range of the Wi-Fi. Serval Mesh can function Wi-Fi ad hoc mode to directly communicate with other devices within range. Serval Mesh implements upon on single hop and multiple hops aspect in communication. Android mobile phone Root permission is required to Android mobile phone to allow functions and capabilities in operation.

2.9.2.2 Serval Chat (The_Serval_Project_Team, 2017a)

Serval Chat is still under development; it has not been released at the moment. It was developed on Apple IOS. The characteristics of Serval Chat are listed as follows:

- Peer to peer wireless communication with nearby devices
- Secure private text messaging
- Contact management: allow user to easily manage and monitor online status, offline messaging for contact
- Secure identity cards allow users to reveal their information for other users
- Shared discussion threads between users and participants by using anonymous group

2.9.2.3 MeshMS (The_Serval_Project_Team, 2015a)

MeshMS is a secure text message one-to-one service, similar to chat message or SMS. It is implemented in Serval Mesh application, which operates on Android mobile phones.

2.9.2.4 Serval Maps (The_Serval_Project_Team, 2013)

Serval Maps is an application supported for collaborative mapping activities in ad hoc mesh network. It is a software based on Android mobile phones.

2.9.2.5 Serval Mesh Extender (The_Serval_Project_Team, 2017b)

The Serval Mesh Extender is a low-cost infrastructure-independent communications relay device. The objective aims to increase Wi-Fi range to form peer-to-peer communication up to a hundred meters beyond normal Wi-Fi range. Serval Mesh can connect via this device to communicate with each other. Serval Mesh Extender is still under the development.

2.9.3 Barrier of The Serval Project implemented on mobile phone or related device

There have been some limitations in developing features or services in the Serval Project. This study shows concerns and barriers of the service as follows:

2.9.3.1 Limited on mobile phone

Serval Mesh needs to operate on Android mobile phones which requires “root permission”. Some Android mobile phone cannot operate with Serval Mesh, seen in this reference (The_Serval_Project_Team, 2014b).

2.9.3.2 Energy issue

Serval Mesh and Serval Mesh Extender is implemented on Wi-Fi capability to build peer-to-peer or mesh communication. Major problem of Wi-Fi communication is high energy or power consumption. To tackle this energy problem, the study proposes how to eliminate energy consumption on Wi-Fi ad hoc communication which will be discussed in chapter 7

2.10 Background of wireless ad hoc network technology

This section describes an overview of wireless LAN IEEE 802.11, mode of operation, and details of wireless ad-hoc network.

2.10.1 Wireless LAN IEEE 802.11

In 1997, Wireless LAN (wireless local area network) or WLAN (LaMaire, Krishna, Bhagwat, & Panian, 1996) was released by IEEE (the Institute of Electrical and Electronics Engineers) committee as connection of LAN (Local Area Network) (Law et al., 2013) through wireless (radio) communication, which was IEEE 802.11. WLAN known as Wi-Fi technologies operates on frequency 5GHz or 2.4 GHz ISM band (Industrial, Science, and Medical radio band). The varieties of Wi-Fi standards emerged as wireless technology have been developed. It can currently be divided into six standards as follows:

- IEEE 802.11 was the original standard of wireless LAN.
- IEEE 802.11b was an extension of the original IEEE 802.11 standard, released in 1999.
- IEEE 802.11a was a second extension of the original IEEE 802.11 standard, released in 1999.
- IEEE 802.11g was a creation of combination of IEEE 802.11a and b to maximise and increase range, published in 2002 and 2003.
- IEEE 802.11n was developed from IEEE 802.11g in the amount of bandwidth and used multiple wireless signal and antenna called as MIMO. It is also known as Wireless N, published in 2009.
- IEEE 802.11ac is new generation from wireless standard series which supports simultaneous connection between 2.4 GHz and 5 GHz band, called as dual-bands technology.

Table 2.1: Overview of IEEE 802.11 standard (IEEE_802.11ac, 2012) (Paul & Ogunfrunmiri, 2008) (LaMaire et al., 1996)

Standard	**Frequency**	**Bandwidth**	**Range of communication (approximately)**	
			Indoor	**Outdoor**
IEEE 802.11	2.4 GHz	2 Mbps	20 meters	100 meters
IEEE 802.11b	2.4 GHz	11 Mbps	35 meters	140 metes
IEEE 802.11a	5 GHz	54 Mbps	35 meters	120 meters
IEEE 802.11g	2.4 GHz	54 Mbps	38 meters	140 meters
IEEE 802.11n	2.4/5 GHz	300 Mbps	70 meters	250 meters
IEEE 802.11ac	2.4/5 GHz	450/1300 Mbps	35 metes	-

Each different IEEE 802.11 standard has different specification. Hence, table 2.1 describes the overview of each IEEE 802.11 specification standard

2.10.2 Mode of operation in IEEE 802.11 standard

There are two major modes in wireless LAN including infrastructure and ad hoc mode.

- Infrastructure mode normally acts as a base station, connected with existing LAN or wired network by using access point (AP) as nominated device. Access point operates as central node waiting for client nodes to connect and communicate with other nodes or the Internet.
- Ad-hoc mode can formulate a network without requiring a base station or access point. This mode aims to provide decentralised network to users. This network is sometime called self-organisation because the node in the network can communicate or connect with each other directly and without central node. Therefore, the node or user is independent to move to anywhere anytime. This capability is technically called as mobility. Similarly, peer to peer communication (Gonen, Hua, & Joshi, 2005) and mesh network communication (Portmann & Pirzada, 2008) are ad-hoc communication networks depending on topology and usage.

2.10.3 Wireless ad hoc network

From previous section mentioning about ad hoc network mode of wireless LAN, this thesis substantially takes this mode into account. In disaster or emergency situation, there might be the interruption or disruption of basic communication such as cellular base station, telephone line, the Internet, and so on. In order to temporarily replace the interruption of common communication system, back up, or alternative; the communication system needs to form independent network quickly, easily, and effectively. Wireless ad hoc network is a promising communication channel to deal with and assist people in disaster situations. The benefits and uses of this network are explained in the following subsection.

2.10.3.1 Definition of wireless ad hoc network

Wireless ad hoc network is the deployment of wireless network without relying on local infrastructure. This system is known as a decentralised wireless network or infrastructure-less networking (M. G. Rubinstein, I. M. Moraes, M. E. M. Campista, L. H. M. K. Costa, & O. C. M. B. Duarte, 2006). Wireless nodes can be dynamically self-organised and form temporary network or topology in a short period of time. Each node functions as a router sending and receiving traffic through other nodes. The node that is an intermediate node will only forward the traffic to targeted node which acts as a median for other nodes that come to connect with it and sends the data to the destination. From this characteristic, it is well appropriate for emergency and disaster operation, military services, and large and small scale of networks (M. G. Rubinstein et al., 2006). The communication of wireless ad hoc network established to each node in their network is known as multi hop or single hop network (Abdel Hamid, Hassanein, & Takahara, 2013). The single hop network refers the communication between one-to-one nodes. On the other hand, multi hop network refers to the communication between one-to-many nodes.

2.10.3.2 Categories of wireless ad hoc network

Wireless ad hoc network can be divided into three major types (Abdel Hamid et al., 2013), including wireless mesh network, mobile ad hoc network, and wireless sensor network depicted in figure 2.1.

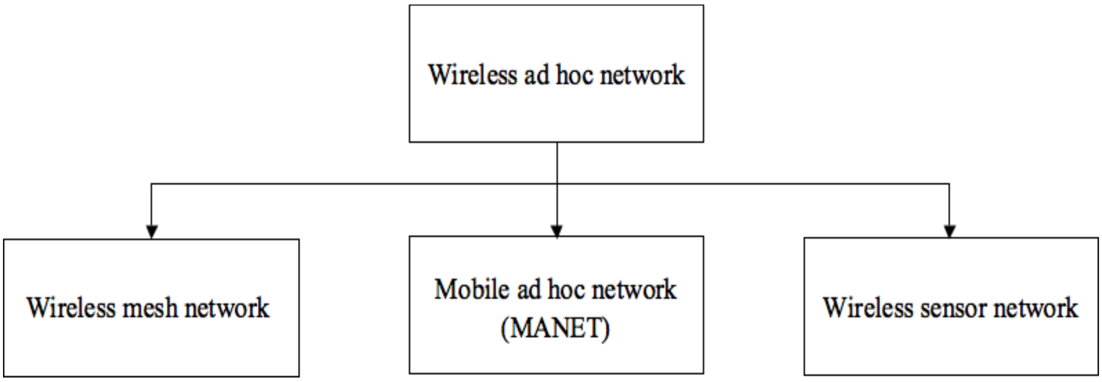


Figure 2.1: Categories of wireless ad hoc network

- Wireless mesh network (WMN) (Akyildiz & Xudong, 2005) is dynamically self-configured and self- organised. It consists of mesh routers with gateways and mesh clients. Mesh routers perform routing and configuring, connected between groups of mesh routers acting as wireless mesh backbone which can be connected to the Internet. A mesh client can be a mobile or a stationary communicating between clients and routers. Mesh clients act like conventional ad hoc network. Consequently, they can also perform routing and self-configuring. One advantage of wireless mesh network is that it can be integrated and implemented with other platform such as cellular system, wireless sensor network (IEEE 802.15), WiMax technology (IEEE 802.16), and wireless LAN (IEEE 801.11). Another advantage of the mesh network is its reliability ad redundancy of network.
- The mobile ad hoc network (MANET) (Jadhav, Kulkarni, & Menon, 2014) operates via mobile computers or nodes which nodes forward packets or traffics through each other. Topology of MANET can vary spontaneously and rapidly over the time, depending on a connected number of nodes. This is sort of self-configuring and decentralised network similar to wireless mesh network or wireless ad hoc network. Each mobile node acts as a router. Routing protocol is then implemented into each node to communicate each other for discovering path and other nodes. The size and range of nodes vary on a number of mobile nodes which can have either large or small network. MANET can operate in any place without relying on any infrastructure. One of the shortcomings of MANET communication is its low speed rate.
- Wireless sensor network (WSN) (Yick, Mukherjee, & Ghosal, 2008) is well suitable with monitoring and tracking manner. Normally, sensor nodes have been implemented with mechanical, biological, thermal, chemical, magnetic, and optical sensors to measure, sense, monitor, and track the environment or particular manner. Sensor node consumes low energy or power while communicates between each other. However, energy is concerned about the constraint of WSN because a battery is the main power source. There are two types of WSN: unstructured and structured. An unstructured WSN monitors and reports information which will be formed in ad hoc network manner. It is called as uncovered regions since the topology always varies over the time. Also, it is difficult to manage and maintain connectivity of each node due to the dense of many nodes (few tens to thousands). A structured WSN has sparse

or fewer nodes to function while communicating between nodes. Generally, it is implemented at specific locations or coverage area. WSN is applied in military activities, disaster monitoring and tracking, health monitoring, environment exploration, earthquake sensing, and so on.

2.10.3.3 Routing protocol in wireless ad hoc network

The routing protocol is important to communication employing ther wired or wireless network. Wireless ad hoc network requires appropriate route to transfer packet from source to destination. In order to comprehend conceptual routing protocol in wireless ad hoc network. This study can be divided into three conventional routing protocols as follows:

- Reactive routing (on demand): the route or path is created by requesting source nodes to immediately communicate with the destination. Route discovery technique is implemented by flooding a packet with route request across a network. As soon as a route is formed from source to destination, the route discovery finally completes at this stage. Such route is maintained for a period of time, depending on a need of source. The reactive routing protocol is a dynamic source routing (DSR) (D. B. Johnson, Maltz, & Broch, 2001) and ad hoc on-demand distance vector (AODV) (C. E. Perkins & Royer, 1999).
- Proactive routing (table driven): routing information is required and stored in a routing table. A routing table contains routes of each node in the network. Every time a node requires sending packet to destination, it will then find route from routing table. Routing table is updated by route update propagated through the network as possible as it can over the time. This technique is not suitable for highly dynamic wireless ad hoc networks because of the lack of consistency and the need for constant updating for the each node in routing table over time. Well-known routing protocol in this scheme is destination-sequenced distance-vector (DSDV) (Charles E. Perkins & Bhagwat, 1994), optimised link state routing (OLSR) (Jacquet et al., 2001), and better approach to mobile ad hoc networking (B.A.T.M.A.N) (D. Johnson, Ntlatlapa, & Aichele, 2008).

- Hybrid routing (reactive and proactive): this routing protocol is the combination between reactive and proactive approach. In high mobility or connection, the reactive approach is implemented to form the network. In small or slow mobility, the proactive or table-driven approach is well suitable to create network. Therefore, it can achieve a high performance in communication manners. The popular routing protocol is a zone routing protocol (ZRP) (Samar, Pearlman, & Haas, 2004).

All in all, wireless ad hoc network is widespread in implementing resilient communication or disaster communication because of its capabilities to form network by itself, its self-organised ability and the decentralisation, which is appropriate to use in disaster or emergency situation. For example, this research (Gunaratna, Jayarathna, Sandamini, & Silva, 2015) established temporary communication service to assist existing network in a post disaster. Users can connect via node services by a mobile phone with specific application. It was able to transmit message by using peer-to-peer as well as file transferring.

2.11 Energy efficient technique for wireless ad hoc network

In order to address the method to reduce energy consumption on disaster communication platform. Literature surveys regarding energy efficient technique for wireless ad hoc were reviewed in the section below:

Currently, a wireless ad hoc network communication system has become an essential equivalent to a wired network. In addition, it is also very significant for the modern world where it is implemented with various platforms especially in mobile devices. As a result, everyone is able to access and communicate to each other anywhere anytime via mobile network, local area network, ad hoc network and the Internet which is convenient for people in their modern lifestyles. One of the major drawbacks of wireless ad hoc network is high energy or power consumption as well as limited power source. Therefore, power or energy efficiency techniques are proposed to deal with this problem. There are several solutions to improve energy efficiency on wireless ad hoc network as follows:

2.11.1 Energy efficiency in network layer

The network layer is mainly responsible for data routing. The goal of energy efficiency in this layer is to minimize or reduce the energy or power consumption at end-to-end or source-to-destination of packet transmission. The node with residual energy is avoided to transfer packet. Also, it attempts to reduce unsuccessful transmission in the network. Geographic adaptive fidelity (GAF) and SPAN are well-known examples described below:

SPAN (B. Chen, Jamieson, Balakrishnan, & Morris, 2002) offers distributed algorithm technique regarding coordination of power saving with routing in multi-hop ad hoc wireless networks. Nodes are selected from a connected dominating set called “coordinators”. SPAN elects coordinators from all nodes in the network by using network topology information and periodic rotation nodes in different time. SPAN coordinators are continually in the idle state while non-coordinator nodes are regularly in the sleep state and will wake up periodically and became a coordinator to exchange traffic with the other coordinator nodes. The advantage of SPAN is its adaptation of idle state to sleep state which can help reduce energy consumption effectively.

Geographic adaptive fidelity (GAF) (Xu, Heidemann, & Estrin, 2001) uses fixed geographic grid size so that all nodes in each grid are equivalent with respect to adjacent grid square regardless of node density. In discovery state, nodes will listen and send an exchange discover message with other nodes by announcing its grid id (location, grid size) and residual energy status. Node will transition from active state to sleep state after node hears a “higher ranking” announcement. This ranking function is used to control energy consumption among nodes. A node in the sleep state transitions back to a discover state after the sleep interval expires.

2.11.2 Energy efficiency in data link layer

In data link layer, energy conservation in MAC layer sub layer is the key issues. It attempts to maximise energy and reduce power consumption at each node in the network. Conventional IEEE 802.11 power saving mode (PSM) and power aware multi-access (PAMAS) protocol is described below:

Power saving mode (PSM) (Eun-Sun & Vaidya, 2002) in an IEEE 802.11 for ad hoc mode is divided into two constant intervals. The beacon interval uses beacon frame for synchronization according to a Timing Synchronization Function (TFS). Ad hoc Traffic Indication Message (ATIM) window is located at first piece of beacon interval where every node will stay awake. PSM presents technique of fixing size of ATIM window that affects the amount of energy saving and throughput. Each node is fully connected and uses global synchronization. Every node will wake up for a short period of time in ATIM window if they have pending packet data transmission. However, if there is no pending packet data transmission, it changes into doze state in the rest of time of beacon interval.

The power aware multi-access (PAMAS) protocol (Singh & Raghavendra, 1998) proposes the technique to save power by turning off the radio while no transmitting or receiving a packet. It is a combination between original MAC protocol and the use of a separate channel for a busy tone signal. Using the busy tone signal, nodes are able to determine how long and when they should turn off their radio interfaces.

2.11.3 Energy efficiency in physical layer

In physical later, network communication concerns about nodes sending and receiving messages from signal, radio, and bit at a period of time. Topology control technique (Cardei, Wu, & Yang, 2006) is one of many approaches in physical layer. It has been proposed to reduce energy or power consumption and improve network capacity while keeping network connectivity. The concept of topology control, nodes in wireless ad hoc network can adjust power transmission instead of transmitting with maximum power. Therefore, energy consumption in transmission mode is reduced. Also, the network topology is formed and becomes the new topology depending on power of transmission.

The said energy efficiency techniques on wireless ad hoc in section 2.11 were only experimented on simulation software. This study, in turn, will explore and conduct the experiment to prove that it is feasible to reduce energy consumption on wireless network in practice. This can help answer whether the enhanced energy efficiency on disaster communication is possible to be implemented on current mobile phones in the future or not.

2.12 Chapter review

This chapter has reviewed the evolution of mobile phone technology contributing to the emergence of modern mobile phones or smartphones. People can communicate each other via mobile telecommunication network with broadband and Wi-Fi networking. Mobile phone usage behaviour has shifted from voice communication to data communication such as social network and internet browsing. This lead to people spending time on their mobile phone for almost 153 minutes per day on social media (BroadbandSearch, 2019). That is why mobile phone battery life can be drained rapidly. The hardware of a mobile phone is another determinant to deplete battery life. However, it seems that user behaviour directly affects a mobile phone. Many researches (Rahmati & Zhong, 2013) (Verkasalo, 2010) revealed that human usage behaviour affects energy consumption on a mobile phone. Finding the relationship between human behaviour and a mobile phone battery life will be discussed in chapter 4. It also shows an example of battery capacity and battery runtime of a mobile phone which referred from the battery life claimed by its manufacturer. It seems that a high capacity battery would be better than smaller one in terms of proving a battery runtime. This study will find out whether there is any relationship between battery life and battery capacity or not in chapter 4.

The disaster or emergency situation is an event resulting from nature or human activity causing a serious sudden disruption. While emergency means a situation that goes out of control and requires immediate attention (UK_Government, 2004). The occurrence of disaster or emergency may cause long duration of power outage resulting in the lack of basic communication service such as mobile telecommunication infrastructure. Therefore, disaster communication can be an alternative communication to assist people after a disaster or emergency occurs. Yet, disaster communication is still laid out and operated on mobile phone. There are many services providing upon disaster communication such as chat message, voice call, map, and so on. Therefore, it is necessary to know “How long does the battery runtime of a mobile phone need to last in disaster or emergency situation?” This thesis will answer this question in chapter 4 and chapter 6.

In addition, what is the best solution to extend a phone battery life during disaster or emergency situation? There are two ways discussed in the chapter which are traditional and untraditional mobile phone recharging. Normally, a mobile phone must be recharged from wall charge, USB, power bank. In disaster or emergency situation, there might be fewer opportunities to recharge via a traditional charge. Thus, alternative mobile phone charging strategies are an option to extend cell phone battery life. This thesis studies alternative phone charging strategies in disaster solution, and the results will be discussed in chapter 5.

The battery life of a mobile phone and disaster communication can be enhanced by changing mobile phone usage behaviour. However, it should be better providing that "Is there another way to save runtime battery of a mobile phone?" This chapter reviews the method to save the energy or enhance energy efficiency technique either for a mobile phone or for disaster communication which is practical. In chapter 7, "How to minimise energy consumption and maximise battery life of disaster communication?" will be discussed.

The next chapter, Chapter 3, introduces the research methodology including how the research is designed, how each research step is carried out, and how the data is to be presented.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter provides research approaches for this study. The chapter shows how this study was conducted regarding energy related factors on a mobile phone in disaster/emergency situation including research design, data collection, data analysis and results, and ethical issues of human factors on mobile battery life, information about alternative charging strategies for a mobile phone, data analysis on the time of power failure related to a mobile phone battery life, and experimental energy consumption analysis and results on disaster communication device.

3.2 Research design

The procedural research is reported in four major chapters of this thesis. Each chapter comes with a research question to focus on and has different aspects to explore in terms of energy and battery for a mobile phone and related communication device. However, there are relationships and identical goals to address and answer the research question about a mobile phone battery life.

The research questions in this study are as follows:

RQ1: How human behaviour can affect battery life on a mobile phone?

RQ2: What is supplementary energy required for a mobile phone and mesh communication?

RQ3: What is the minimum battery runtime required to sustain communications platform during the acute phase of a typical disaster?

RQ4: How can battery runtime be extended on a disaster communication platform?

In order to answer the research questions, chapter 4 was conducted to answer RQ1. Chapter 4 is to find out data collection regarding user’s behaviour when using a mobile phone. It was conducted via an online survey and a questionnaire distributed to participants during Feb 2015 to Jan 2016. This survey focuses on a mobile phone charging behaviour and useful information. RQ2 was answered by chapter 5, which is conducted using a survey about useful alternative mobile phone charging strategies from literature, grey literature, news, and sources from the Internet in the current market. Moreover, it proposed a devised model to calculate cost per recharge for each battery backup which can be useful and affordable for people. Also, one of the questions concerning an alternative source of mobile phone battery charging derived from the survey in chapter 4 was analysed to present in statistical term. Next, chapter 6 was conducted to answer RQ3. This chapter is to analyse power outage data related to interrupted customers. The data were achieved from the organisation working in the field of energy and power in Queensland, Australia, during 1 July 2005 to 30 June 2016 and South Australia during 2010/11. Apart from this, it investigated the issue on the distribution of power outages caused by a disaster and its impact on a mobile phone. Finally, chapter 7 answered RQ4. It proposed new techniques to reduce energy consumption on mesh communication platform prototype. This prototype was implemented to quantify energy consumption and proved whether battery life can last longer when used in normal communication or ordinary mobile phone without employing this technique or not. The details of the methods applied in each research step of this study are described in the next four sections.

3.3 Research steps for chapter 4

In this chapter, human behaviours are studied to determine whether it has an effect on a mobile phone battery life or not. Because battery life on a mobile phone is normally claimed by manufacturers that it has runtime to operate at least one day or more depending on a battery capacity (see in chapter 2). This reason mostly refers to mobile phone battery runtime when users spent time on their mobile phone.

3.3.1 Quantitative paradigm

Research approaches can be broadly divided into quantitative or qualitative (Muijs, 2004). The authors (Aliaga & Gunderson, 2006) described definition of a quantitative method as “explaining a phenomena by collecting numerical data that are analysed using mathematically based methods with particular statistical tools”

Quantitative methods are categorised by the collection of information that can be analysed numerically. The results are presented using statistical techniques, tables, and graphs. Also, it is associated with large and small scale researches with correlational research, experiments, action research and case studies (Cohen, Manion, & Morrison, 2007).

A quantitative approach is inquiry strategies such as surveys, experiments, and collecting data on predetermined instrument that result in statistic (Creswell, 2003). Moreover, quantitative researches are appropriately applied where the research questions asked of respondents lead to decent answers (Brannen, 1992).

In chapter 4, the quantitative method is used for analysing and presenting tables, graphs, and statistical correlation. These results could address and answer our objectives in research questions.

3.3.2 Research method approach

A survey was conducted by an online survey targeting at volunteers who have an experience in an emergency/disaster situation in the past five years. This survey inquired about human factors related to a mobile phone battery life in ordinary situation and in an emergency/disaster situation. The questionnaire was mainly divided into four sections including personal details, mobile phone details, mobile phone recharging and usage habits in normal situation and in an emergency/disaster situation. After completing the data collection process, the quantitative analysis of such data was carried out, and the results acquired will be presented by graphs, tables, and statistical correlation.

3.3.3 Questionnaire design

A questionnaire is an option for gathering information from respondents to contribute to research's findings. Appropriate and decent questions play a pivotal role in the questionnaire design. In this study, the questionnaire was conducted through the online survey which is convenient for respondents to access via URL (Uniform Resource Locator) or web link. The quantitative method approach was used for data collection and analysis. The questionnaire in this study included personal details, mobile phone details, mobile phone recharging and usage habits and mobile phone recharging and usage habits in an emergency/disaster situation. Closed-ended questions were selected for each section. The check box questions included single and multiple answers depending on each question. Also, there were checklist questions and questions requiring short answer in this questionnaire. In order to encourage respondents to answer all the questions, the questionnaire excluded sensitive questions and was confidential and anonymous.

3.3.4 Data collection

This chapter includes data collections from the online survey using quantitative methods. The online survey data collection was obtained from the questionnaire administered to people who had experienced or worked in the field of disaster or emergency situation. The unsupervised method was used for the online survey in which the respondents can manage the survey process themselves (Zhang, Kuchinke, Woud, & Velten). These data were recorded in a web database of lime survey. One criticism of unsupervised surveys is that the participants can actually misread or misunderstand questions and users may not answer survey questions completely honestly (Kitchenham & Pfleeger, 2002).

3.3.4.1 Online survey

The online survey was a web-based questionnaire provided using the survey tool Lime survey. Lime survey is a convenient tool to create a questionnaire on web link. This link was shown on http://csem.flinders.edu.au/phonesurvey.

3.3.4.2 Targeted respondents and sampling selection

The targeted respondents for the online survey were the volunteers who have had any experience, work, or volunteer in an emergency/disaster environment in Australia. In this research, we enquired many organisations collaborating with The Serval project which is South Australian Fire and Emergency Services Commission (SAFECOM) (Goverment_of_South_Australia, 2015) and nominated organisation by SAFECOM, Arkaroola Wilderness Sanctuary Flinders Rangers, South Australia (Arkaroola_Wilderness_Sanctuary, 2016) and South Australian Country Fire Service (CFS) (South_Australian_Country_Fire_Service, 2015). Those organisations were willing to assist us to distribute questionnaire to their network. The reasons of choosing these targeted respondents are as follows:

- They worked or volunteered in an emergency/disaster environment
- They had experienced in disaster/emergency situation in the past five years
- They used a mobile phone in daily life

Before recruiting respondents from the organisations listed above, the letter of introduction and the approval letter were sent by the researcher to those organisations. Those organisations would distribute them to their members, network, and community. Participants who were interested to answer this survey would answer questionnaire via web link attached in introduction letter. A number of respondents completing questionnaire was reported and monitored by the admin of Lime Survey Facebook page. The researcher received answers from 117 participants in the organisations. Also, there were incomplete responses from 7 respondents. Therefore, the sample size for online survey used in the data analysis was 117.

3.3.5 Data analysis

The sources of collected data to be analysed is the data from the online survey. Data analysis was conducted through a descriptive approach using Microsoft Excel spreadsheet, the Statistical Software Package for Social Science (SPSS) version 22, and R project for statistical computing version 3.32.

According to (Cohen et al., 2007) (Williams, 2017), it was stated that descriptive statistics are used to describe or summarise data in ways that are meaningful and useful. They also emphasise descriptive statistics as being at the key or important things of all quantitative analysis. This analysis presents the collected data from the online survey.

3.3.6 Ethical issues

This study was conducted following Flinders University regulations. Prior to conducting the surveys, the research project was approved by the Social and Behavioural Research Ethics Committee of Flinders University (Project No: 6233). The research project was also approved by the South Australian Fire and Emergency Services Commission (SAFECOM) (Goverment_of_South_Australia, 2015) and nominated organisation by SAFECOM, Arkaroola Wilderness Sanctuary Flinders Rangers, South Australia (Arkaroola_Wilderness_Sanctuary, 2016) and South Australian Country Fire Service (CFS) (South_Australian_Country_Fire_Service, 2015) to participate in the online survey. For online survey procedure, objectives of the study, description of the study and the letter of introduction from the researcher were attached in the emails containing the link to the online survey. The participants in the online survey were free to stop filling in the questionnaire.

3.3.7 Discussion based on research methodology for RQ 1

To answer research questions in this thesis, finding a research methodology to acquire related data information about usage behaviour on mobile phone is needed. Survey research (Ponto, 2015) is a powerful instrument that can help enquire targeted questions to obtain information about behaviours and preferences.

Quantitative questionnaires (Nardi, 2018) can gain information insight from respondents. This information will be analysed and reported on basis of the quantitative data. It is mainly intended to indicate that "Does human behaviour affect a mobile phone?" Questions about mobile phone usage was designed to cover either general situation or disaster or emergency situation. It can be divided into three main question groups including a mobile phone battery life, a mobile phone battery recharging behaviour, and a mobile phone feature usage.

It is quite sensitive in ethical issues because it relies on the preferences of respondents to answer questions. Therefore, this survey was strictly considered under Flinders University, Social and Behavioural Research Ethics Committee. Then, it was distributed to the organisations involved with disaster or emergency situation within South Australia, Australia. All research should obtain informed consents from participants (Bryman, 2012). The participants were given information about the objectives of the study before starting the online questionnaire.

There were 117 respondents who answered the online questionnaire. This number was quite small in terms of data analysis. It was not expected for a small sample size; this was a limitation of this research. However, it was analysed by using powerful statistical technique, Spearman's correlation technique, to address the effect of sample size (Schober, Boer, & Schwarte, 2018). It was applied to assess the relationship between a mobile phone recharging and a mobile phone behaviour usage. The remaining results were described by using descriptive statistics through tables and graphs to estimate approximate required quantity of mobile phone battery life in disaster or emergency situation.

3.4 Research steps for chapter 5

This chapter was to study alternative phone charging strategies in a disaster situation. A mobile phone always goes flat very quickly when used in a general situation or even in a disaster situation due to the level of battery life and a mobile phone hardware. This chapter surveyed categories of phone charging techniques both in traditional ways and unusual ones for a disaster or emergency situation in off-grid and rural area. Also, the criteria of cost per recharge were proposed in this chapter. The survey results about alternative phone charging from respondents was presented and discussed.

3.4.1 Research method approach

The survey was conducted by searching web pages, grey literatures, and news technology from the Internet. It was difficult to survey literature based on academic literature such as IEEE, Scopus, ACM, Science direct, Google scholar, and CiteSeer. This survey explained and presented regarding categories of mobile phone charging in ordinary, non-ordinary, and future innovative charging techniques. An alternative phone charging is given precedence in this study for finding effective cost or cost assessment. Another survey was conducted by online survey from chapter 4. One question about alternative source of mobile phone battery charging was the answers from respondents. This result was analysed by showing percentage of usage.

3.4.2 Data collection

The data collection of the first survey was derived from related websites concerning mobile phone charging solutions. The keywords in this survey are crucial to find out and achieve our objectives, including an alternative mobile phone charging, an off grid phone charging, a mobile phone charging in disaster, battery backup for a mobile phone, and energy backup for a mobile phone. In terms of cost per recharge, it is necessary to know price and cost of each charging solution. Web pages such as amazon.com, ebay.com and related web sites were explored the price.

The data for the second survey were obtained from one of the questionnaires from the survey in chapter 4 about alternative sources of phone charging. This question was included in a mobile phone recharging and usage habits section. The number of respondents answered in this question was 117.

3.4.3 Alternative mobile phone charging strategies

From the survey results, it can be divided into five categories as follows:

- solar powered charging
- kinetic charging, hand cranked charging, and thermoelectric charging
- motor-vehicle charging
- bicycle powered charging
- wind powered charging.

Each aspect of the alternative mobile phone charging strategies was determined by the questions below:

- How fast can they charge a mobile phone?
    - This is because in disaster or emergency situation there might be less time to recharge a mobile phone. Time for a mobile phone charging is considered the first priority and depends on the current and voltage output.
- Is it appropriate in disaster or emergency situation?
    - Some charging strategies are designed for normal situation. In disaster or emergency situation, they might not be applicable due to power outages. Sometimes, it might be inconvenient or practical to use in such circumstances.
- How portable are they?
    - A size is significant in disaster or emergency situation.

3.4.4 Framework for creating criteria assessment of alternate solution for mobile phone charging in disaster and emergency situation

There are three main criteria to consider as followed:

- Criteria 1: the purchase cost of an alternative energy source, ordinarily in US dollars.
- Criteria 2: A number of devices can be charged per day
- Criteria 3: Amortised cost per recharge (CPR)

All of these criteria considered the cost of the alternative charging method that must be reasonable and match with its efficiency.

3.4.5 Data analysis

The first data collection based on framework in section 3.4.3 and 3.4.4 was analysed and presented in the table showing a cost per recharge over 3 days, cost per recharge over 1 year, purchase cost, USB ports, and maximum input power of charging solution.

The second data collection was conducted through the online survey. The descriptive data analysis was employed using the Statistical Software Package for Social Science (SPSS) version 22. The results presented proportion of alternative source phone charging chosen by respondents in terms of percentage comparing each other.

3.4.6 Discussion based on research methodology for RQ 2

According to the characteristics of a mobile phone battery life, it can last within 24 hours by average (GSMArena, 2017a). Normally, mobile phone is charged with main plugs or power bank. However, during power outages in a disaster or emergency situation, the power supply might not be available to recharge a mobile phone. To answer the research question "What supplementary energy is required to a mobile phone and disaster communication?" This was addressed by the exploration of alternative phone charging in current technology.

The keywords on section 3.4.2 were searched on web pages, grey literatures, and tech news. As their information is not cited from the academic sources, this can be a limitation of finding alternative mobile phone charging strategies. Fortunately, it was found that it can be divided into seven categories as in section 3.4.3. To find out which category was appropriate in a disaster or emergency situation, such factors as the purchase of cost, number of devices charged, and amortised cost per recharged (CPR) were examined. During a disaster or emergency situation, there might be fewer opportunity to recharge a mobile phone frequently. Therefore, a mobile phone battery charging time (Affam & Mohd-Mokhtar, 2019) should be wisely concerned to figure out appropriate alternative charging strategies as related to information in section 3.4.3. Also, the chosen alternative phone charging methodologies can be applied with disaster communications by using the similar criteria of a mobile phone.

Another methodology to answer the research question is a survey from respondents who has the experience in a disaster or emergency situation. This is conducted with the questionnaire in RQ 1, which enquires about alternative sources to increase time of a mobile phone battery life. The survey can make a conclusion about a hypothesis whether which alternative mobile phone strategies are appropriate in a disaster or emergency situation.

3.5 Research steps for chapter 6

This chapter studies the distribution of power outages in a disaster or emergency situation related to impact of a mobile phone battery life. In particular situation, a battery life is very crucial for a mobile phone. Therefore, average duration without electricity or communication network is to be a guidance whether mobile phone battery life should operate longer than ordinary situation. Moreover, this result will be a reference source for The Serval Project in order to implement mesh device being able to operate as long as possible.

3.5.1 Data collection

In order to obtain the data about power outages in a disaster or emergency situation, this research acquired many operators or companies in the field of energy, electricity, and power across Australia to be analysed as case studies. The emails on behalf of The Serval project were sent to those operators. However, there was one of the companies, Ergon Energy Company, responded and replied invaluable information source including interrupted duration after a disaster situation (power outages) and customer interrupted from a disaster situation in Queensland. Customers interrupted from a disaster provided the data such as the first customer to last customer affected, date, and time. Useful information was collected by Keegan Oliver Engineering manager network performance, (Ergon Energy Company) since June 2005 to June 2016.

Another small data collection obtained from SA Power Networks Company and collected by Rocco Logozzo, Network performance & regulatory manager. These data were the breakdown of the number of customers affected by unplanned interruptions from a disaster situation for different duration in year 2010/11 from South Australia.

3.5.2 Data analysis

The data analysis was conducted through the descriptive approach using Microsoft Excel spreadsheet and R project for statistical computing version 3.32. Tables and graphs presented results in order to conclude relationship between average power outage duration in each year and customers interrupted from a disaster situation.

Moreover, this chapter proposed the devised model to analyse relationship between power outage duration and its impact on mobile phone battery life to figure out number of days or hours of flat phone. This model assisted people to approximately estimate a mobile phone battery life whether it is sufficient to operate in a disaster or emergency situation. Also, person-days or person-hours with flat phone model was proposed to estimate people affected from particular environment. This model was implemented with power outage analysis program (Gardner-Stephen, 2017) with assumed mobile phone charging behaviour pattern of people in daily life representing results through histogram graph illustrating the relationship between the disaster events in Queensland and the number of flat phone in that period of power outages. The results reflected the information of the entire 11 years of power outages resulting from a natural disaster occurring in Queensland since 2005 to 2016. Finally, this model can assist us to understand the distribution of duration of power outages and its impact on mobile phone.

3.5.3 Discussion based on research methodology for question RQ 3

The power outage in consequence of a disaster or emergency may last more than 24 hours. Haiti earthquake in 2010 (CNN_Library, 2016a) was an example of the situation that lacked the communication system and experienced the power failure for a week. It was reported that most a mobile phone battery life died within 24 hours by average (GSMArena, 2017a). Without electricity supplies during the power outage, a mobile phone is unable to operate at that time after going flat.

The research (Gething & Tatem, 2011) revealed that a mobile phone can improve emergency response in a disaster situation. This can be enhanced by tracking and reporting the latest situation via a mobile phone. Another research (Sung, 2011) showed that a mobile phone distributes latest situation and information sharing via mobile application. That is why a mobile phone should be available as long as possible in a disaster or emergency situation.

Therefore, the research question, “What is the minimum battery runtime required to sustain communications during the acute phase of a typical disaster?” needs to be addressed. The questionnaire from the survey in RQ1 enquires about the duration of mobile phone needed to last before the battery goes flat in a disaster or emergency situation. This can help estimate the duration of a mobile phone battery during disaster. Also, it can be a criterion of battery life of disaster communication systems.

In addition, to test the hypothesis regarding power outage duration affecting a mobile phone battery life, the data collection about power outages from the mentioned companies in section 3.5.1 was needed. It was used together with the power outage analysis program to indicate distribution of power outage occurring in Queensland, Australia. Also, this power outage analysis program can examine the relationship of mobile battery life comparing with total number of flat mobile phone during power outage duration.

3.6 Research steps for chapter 7

In this chapter, the quantifying energy consumption and proof of Wi-Fi ad-hoc or peer-to-peer communications are experimented based on energy efficiency concept by using the Serval mesh. This requires broadcast transmission between smartphones that are in range of one another. Because of the very limited communications range of the Wi-Fi in most mobile handsets due to their small internal antennae, it is expected that it will be common for handsets to not be in communications range of other handsets for extended periods of time. Also, the limited range of communications means that the duration of potential contact between handsets may be very short, potentially just a few seconds. Therefore, there is a need to ensure that communications can be established very rapidly, ideally within milliseconds.

To meet this use case, it is proposed that the Wi-Fi radio in each device remains off. Once activated, the Wi-Fi radio is kept activated for a short period of time to allow any transmission to occur. This experiment was implemented by the concept of Wi-Fi on/off in different duration, known as ultra-low energy Wi-Fi standby technique. Based on the hypothesis that turning Wi-Fi off frequently can help save power on mesh device, it will probably then increase battery life or save energy.

Moreover, this experiment was measured by using a current meter which showed the current state of device between Wi-Fi on and off.

3.6.1 How to setup the experiment

Serval mesh device is a wireless router device running Serval software to communicate with another mesh device. GL-AR150 is a nominated device for this experiment as Serval mesh device. Another hardware used in the experiment is custom-designed 2.4GHz wireless energy sampler or known as energy sampler. This energy sampler has an objective to detect Wi-Fi signal matter developed by RFdesign company (RFDesign, 2016). This energy sampler functioned to detect Wi-Fi packet to wake up GL-AR150 by turning Wi-Fi on for receiving packet from transmitter side.

Also, the experiment employed an EFM32 Pearl Gecko starter board running software which monitored the output of the energy sampler looking for edges. Whenever an edge was detected, the EFM32 would send a character via the UART serial interface for reception by the GL-AR150. It was originally attempted to connect the energy sampler to the GL-AR150's serial UART.

In the experiment, GL-AR150 measured current drawn or Ampere units in different states. It comprised Wi-Fi on and Wi-Fi off. Moreover, energy sampler measured power consumption separated from GL-AR150 device. Another current was measured while energy sampler connected with GL-AR150 on Wi-Fi on, receiving packet, and Wi-Fi off state.

In addition, a series of experiments were run in an automated manner, testing the effect of packet size, wake-data interval and Wi-Fi hold time.

If the experiment can prove successful, then an obvious area of future work would be to design a system that incorporated a passive receiver and appropriate Wi-Fi transceiver in a more integrated package which would allow the actual energy savings to be accurately measured.

3.6.2 Data collection

Current measurement of GL-AR150 and energy sampler in Wi-Fi on, receiving packet and Wi-Fi off state were collected and recorded into a text file. Also, testing the effect of packet size, wake-data interval and Wi-Fi hold time in different scenarios were collected on log file into GL-AR150 receiver side.

3.6.3 Data analysis

Current drawn on GL-AR150 and energy sampler while turning Wi-Fi on and off were presented in result table as current units. In terms of the experiment of effect of packet size, wake-data interval and Wi-Fi hold time were run in an automated manner. Mean percentage of wake and data packets versus the time gap between wake and data packet fit to a sigmoid function represented in the graph result. Also, the percentage of wake and data packets versus packet size fit to a sigmoid function and percentage of wake and data packets versus Wi-Fi hold-on time fit to a sigmoid function were presented line graph.

3.6.4 Limitation of this experiment

This experiment was conducted at Flinders University, Tonsley Campus, College of Science and Engineering building. There had been a lot of operating Wi-Fi network covering in this building. This experiment mainly used Wi-Fi signal detection technique to control Wi-Fi on and off of Serval mesh device. It was impossible to experiment in the building without Wi-Fi noise signal in the background. Some Wi-Fi energy was still seen while performing the experiment. Even though there was packet loss while experiment was performing, the results of experiment series showed the feasibility of sufficient successful data packet receiving in many Wi-Fi ambiences.

3.6.5 Discussion based on research methodology for RQ 4

Many researches in disaster communication were carried out on wireless ad-hoc network (Kobel, Baluja Garcia, & Habermann, 2013). One of many obstacles in developing and implementing disaster communication based on Wi-Fi ad hoc network was the energy consumption (Gomez, Riggio, Rasheed, & Granelli, 2011) (Kanakaris, Ndzi, & Azzi, 2010) (Allard, Minet, Nguyen, & Shrestha, 2006). To test a hypothesis and answer the question, "How can extend battery runtime on disaster communication platform?", there was an experiment on Wi-Fi ad-hoc or peer to peer communications based on a nominated device called as mesh extender (The_Serval_Project_Team, 2017b). The intention of the experiment was quantification of energy consumption drawn while Wi-Fi peer to peer communication was established between each other. In order to prove that proposed energy efficient techniques can be implemented to eliminate energy consumption of ad-hoc Wi-Fi by using high standby technique (Gudan, Shao, Hull, Ensworth, & Reynolds, 2015) (Kongsiriwattana & Gardner-Stephen, 2017). The experiment was conducted in Laboratory at Tonsley building, Flinders University.

There was a limitation in this study. There were many Wi-Fi signals surrounding in the building which, in turn, led to the signal interference (Haenggi & Ganti, 2009) while communicating in large, small, or specific area. It may be inevitable to lose signal while transmitting even though it in Faraday cage (Ohmura, Ogino, & Okano, 2014), where Wi-Fi signal cannot penetrate through. However, this experiment was intended to study in the real environment because in a disaster or emergency situation Wi-Fi signal interference during communication is unavoidable.

In the experiment, there were three scenarios regarding the hypothesis on the relationship among energy consumption on Wi-Fi ad-hoc communication while transmitting and receiving which are the percentage of packet received to interval between wake and data packet, size of wake and data packets to percentage of packet received, and Wi-Fi hold-on time to percentage of packet received. This will answer the question, "Is it feasible to reduce energy consumption on Wi-Fi ad hoc or peer to peer communication?" Also, a digital multimeter was connected to receiver and transmitter upon nominated devices while transmitting and receiving. This can measure a current drawn while operating in the experiment.

To sum up, this study was experimented as a prototype to prove that an ad-hoc Wi-Fi communications system can be created. Though it cannot be directly implemented on the current mobile phone model which is a limitation of this experiment, this methodology can satisfactorily answer the research questions.

3.7 Overview of research method approach

The four research chapters can be summarised in figure 3.1 below:

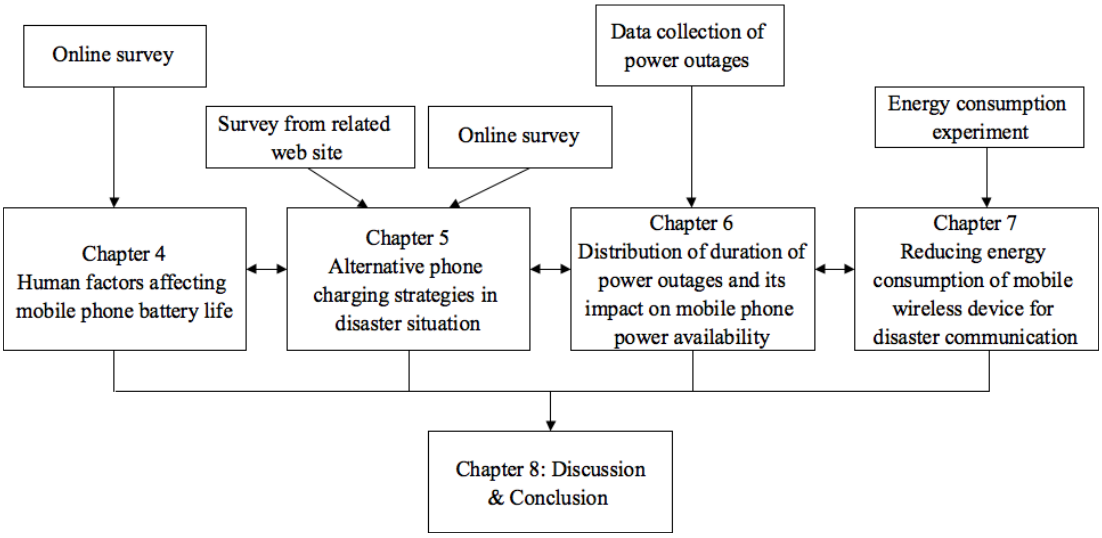


Figure 3.1: The research method approach

Figure 3.1 shows the process of data collection and data analysis used in this study. Firstly, the survey was conducted. The online survey is a web-based questionnaire targeting the people who have worked or volunteered or experienced in an emergency/disaster environment. Then, the quantitative data analysis was carried out and revealed the results through graphs, tables, and statistical correlation. The purpose of conducting the survey was to find and prove that human factors in terms of their usage behaviour can have an impact on a mobile phone battery life. Aside from this, it aims at estimating and finding out an approximate battery runtime of a mobile phone in a disaster or emergency situation from the survey results.

Secondly, the two surveys were concurrently conducted. One was carried out through an online survey concerning alternative sources for charging a mobile phone from mobile phone recharging behaviours and usage habits section in chapter 4. Another was the survey from related websites regarding alternative mobile phone charging strategies. Then data analysis and results were conducted and compared. The aim of conducting the two surveys was to primarily find out which phone charging approach is appropriate and inexpensive in disaster or emergency situation.

Thirdly, power outage data from Queensland and South Australia derived from electric and power operator companies were analysed percentagewise in terms of power outage duration and people affected from such power outage duration. Also, the model about a flat mobile phone during power outage and a phone battery life was proposed to find out the relationship between two variables. The intention of this chapter was to contemplate and understand the impact of a mobile phone while disaster occurred.

Fourthly, the energy consumption experiment was proposed, and the devised technique was presented to prove the concept of appropriately reducing the energy consumption in a smartphone or a mobile phone. This experiment aimed to prove that disaster communication can be enhanced in terms of energy to extend the time to use in a disaster or emergency situation. Finally, this study discussed and concludes all findings from chapters 4, 5, 6 and 7 to chapter 8.

In summary, the research approach employed in this study is quantitative using sources of data collection: the online survey in chapter 4, the survey regarding phone charging strategies from the Internet in chapter 5, the study on distribution of power outages and its impact on mobile phone battery life in chapter 6, and the way to reduce energy consumption on disaster communication platform in chapter 7.

3.8 Conclusion

This chapter introduced the research methodology including research design, research steps from each chapter, and the overview of the research method approach. In this study, the quantitative research approach, such as the survey from related information from the Internet and energy consumption experiment on disaster communication, was used to collect and analyse the data.

This study aims to answer research questions mentioned in the research design section discussed through four major chapters. Also, each chapter straightforwardly explains the relationship between a mobile phone or disaster communication and energy or battery life shown in figure 3.2.

In the next chapter, the issue whether human factors affect a mobile phone battery life will be presented. The findings of the survey are compared and discussed.

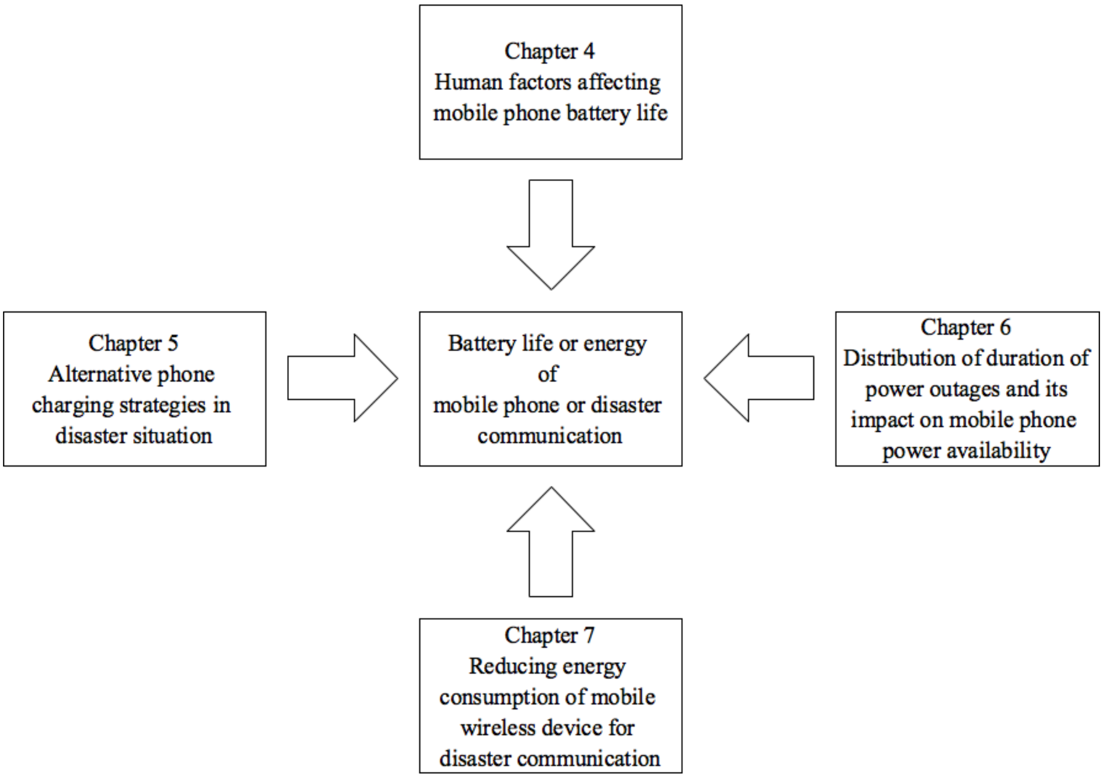


Figure 3.2: Relationship of each chapter to mobile phone or disaster communication

CHAPTER 4: HUMAN FACTORS AFFECTING MOBILE PHONE BATTERY LIFE

This chapter provides the survey information of the underlying human factors affecting a mobile phone battery life that was analysed by using descriptive and correlation statistics.

4.1 Introduction

A key question of this thesis is "how long does a mobile telephone need to last between recharges for use in emergencies and disaster situations?" As documented in the literature review, this is an evidence gap in the literature that makes it very difficult to determine whether mobile telephones last long enough to be useful in emergency and disaster situations, and if not, by what margin, and therefore, what magnitude of interventions might be required to ensure that they can last long enough. This chapter presents data that seeks to fill this and related evidence gaps in this area. Also, to answer question “how human behaviour can affect battery life on a mobile phone?”

The primary instrument that was employed to address this evidence gap and enable the research questions to be answered was a survey of mobile telephone use, charging, battery life and other useful data. A number of the questions were designed to answer the specific questions above as well as other questions that addressed factors that we suspected may be relevant. As a number of the questions was speculative in nature, the interested reader is directed to Appendix 1, where the complete set of questions in the survey are listed together with the data about the responses to those questions.

4.2 User Surveys

This thesis surveyed human factors in relation to a mobile phone battery life for people who use their phone daily and/or have experienced any emergency/disaster contexts. This survey was conducted in data collection phase via online survey (http://csem.flinders.edu.au/phonesurvey). The target group was a volunteer who has had an experience in an emergency/disaster situation in the past five years. Throughout the year 2014, the researcher has attempted to collect data from New Zealand Red Cross, which has been in the collaboration with The Serval Project Team so far. It had been one year from Jan 2014 to Dec 2014 to distribute questionnaire via online survey to participants. Unfortunately, there was no respondent from this organisation answering the survey. In the early 2015, we had changed and collaborated to new organisations to assist us in distributing the survey to their members and network, which is South Australian Fire and Emergency Services Commission (SAFECOM) (Goverment_of_South_Australia, 2015) and nominated organisation by SAFECOM, Arkaroola Wilderness Sanctuary Flinders Rangers, South Australia (Arkaroola_Wilderness_Sanctuary, 2016) and South Australian Country Fire Service (CFS) (South_Australian_Country_Fire_Service, 2015). These three organisations approved and allowed their staff and internal network volunteer who was interested to participate in completing the survey. This survey process took over one year since Feb 2015 to Jan 2016. The number of respondents still fell short of our expectations. However, this minimum data was enough to assist in answering major objective of this chapter.

The survey is to enquire about the questions concerning mobile phone human factors question including battery recharging, usage habits and related issues in ordinary situation and in an emergency/disaster situation. The total number of respondents completing in the survey were 117. There were 101 out of 117 participants completed questionnaires section either in general usage or emergency/disaster contexts. Consequently, these data will be analysed to determine feasibility to reduce energy usage and extend a mobile phone battery life making use of human factors. In the meantime, the relationship between human factors in general usage and in emergency/disaster situation will be also clarified in section 4.3.

4.3 Results and Analysis

In this section, quantitative analysis technique (Saunders, Lewis, & Thornhill, 2009) was used for to analyse in terms of descriptive statistics, describing table/frequency distribution of data, graph chart to figure out results from questionnaire. Related questions are to be categorised and described in the following section.

4.3.1 Participants' demographic information

Table 4.1 shows the total number of participants categorised by gender and age. The total number participants were 117 completing the questionnaire in this survey. Male and female respondents were 51.3% and 48.7% respectively. In terms of age, the average respondents were 30 to 59 years old, accounting for 29.1%, 20.5% and 27.4%

Table 4.1: Respondents profile of survey

Categories	Respondents	Percentage
Gender		
Male	60	51.30%
Female	57	48.70%
Ages		
20 - 29	14	12.00%
30 - 39	34	29.10%
40 - 49	24	20.50%
50 - 59	32	27.40%
60+	13	11.10%
Total Respondents	N=117	

Table 4.2 and 4.3 indicate the number of mobile phone users completed mobile phone recharging and usage habits in general situation, representing 100% from 117 respondents. In the meantime, 101 out of 117 participants answered question in mobile phone recharging and usage habits in an emergency/disaster situation section, accounting for 86.3%. Respondents completing this section must have experienced, worked, or volunteered in an emergency/disaster situation in the past five years.

Table 4.2: Number of mobile phone users using in general situation

Mobile phone users	Respondents	Percentage
Using a mobile phone in general situation	117	100.00%

Table 4.3: Number of mobile phone users having an experienced, worked, or volunteered in an emergency/disaster situation

Mobile phone users	Respondents	Percentage
Having an experienced, or worked, or volunteered in an emergency/disaster situation	101	86.30%
No work or volunteer in an emergency/situation	16	13.70%
Total	117	100.00%

4.3.2 Mobile phone profile

Table 4.4: shows the percentage of mobile phone brands and operating system from mobile phone users in this survey. The vast majority of respondents used iPhone, accounting for 57.3% out of total users. Samsung was the second popular brand used among mobile phone users, representing 29.9%. In terms of mobile phone operating system, iPhone OS (IOS) was the major operating system (57.3%), followed by Android operating system (40.2%) and feature phone operating system (2.6%).

Table 4.4: Mobile phone profile

Description		Frequency	Percentage
Mobile phone brands	IPhone	67	57.30%
	HTC	3	2.60%
	LG	5	4.30%
	Motorola	1	0.90%
	Nokia	2	1.70%
	Samsung	35	29.90%
	THL W11	1	0.90%
	Feature phone*	3	2.60%
	Total	117	100.00%
Mobile phone operating system	Android	47	40.20%
	IOS	67	57.30%
	Feature phone*	3	2.60%
	Total	117	100.00%

* Feature phone refers to Nokia brand, which was not a smartphone and its model was not identified by users

4.3.3 Mobile phone recharging in general situation and related information (N=117)

The following provides information of mobile phone recharging behaviours in terms of general situation from the survey, for instance, how long a mobile phone usually last before going flat, how long a mobile phone is required to last before going flat, how often a mobile phone is recharged, how often a mobile phone goes flat before recharging, how many percent a battery remains when a user decide to recharge a mobile phone, what time a user discharge a mobile phone, how long a mobile phone takes until it is fully charged and how long a mobile phone takes to recharge each time.

4.3.3.1 Duration of mobile phone usually last before the battery goes flat

Table 4.5 shows the duration of mobile phone percentagewise. The result indicated that 22.00% of respondents used their mobile phone up to 22-24 hours or one day.

Approximately 17.90% and 16.20% of mobile phones were able to last about 48 hours or two days and 10-12 hours or half day respectively.

Table 4.5: Percentage of a mobile phone usage duration before the battery goes flat

Duration of mobile phone	**Percentage (%)**
1-3 hours	1.70
4-6 hours	4.30
7-9 hours	10.30
10-12 hours	16.20
13-15 hours	4.30
16-18 hours	7.70
19-21 hours	1.70
22-24 hours	22.00
36 hours	0.90
48 hours	17.90
72 hours	8.50
96 hours	2.60
120 hours	1.70
Total	100.00

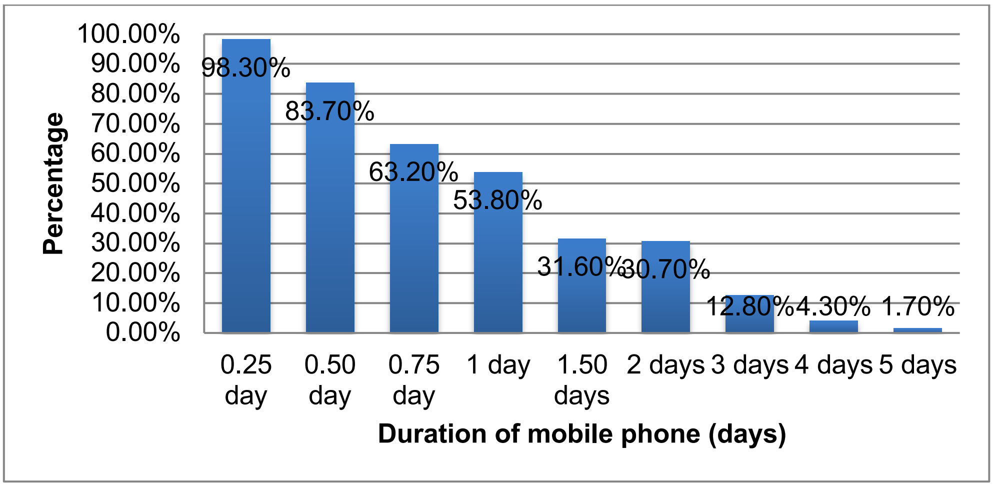


Figure 4.1: Cumulative percentage of mobile phone operating in days after the last recharge

Figure 4.1 derived from table 4.5 presenting cumulative percentage of a mobile phone operating in days after the last recharge. At least for a day, about 53.80% of people could spend time on their mobile phone. Also, 30.70 % of them revealed that their mobile phone could operate at least for two days. The 1.7 % of participants stated that the longest duration that their mobile phone can last was five days or more.

Above all, the figure 4.1 and table 4.5 can imply that most mobile phone is able to operate within 24 hours. Some reflects that a mobile phone can last 48 hours or more. It can be inferred that some respondents probably left their mobile phone in a standby mode.

4.3.3.2 Duration of mobile phone requiring to last before going flat

Table: 4.6 presents the required duration of a mobile phone in percentage. This result indicated that roughly 22.20% and 17.90 % of participants were able to use their mobile phone for 22-24 hours and 48 hours respectively.

Figure 4.2 derived from table 4.6 presents user requirement for a mobile phone duration in general situation. It shows that just over a half of participants required a mobile phone to operate one day. It should be noted that around 2.6% expected their mobile phone to have up to seven days of battery life.

Interestingly, the information that a mobile phone is expected to last for 24 hours compared to the results of a battery performance in real life revealed that the respondents mostly used and expected 24 hours of battery life.

Table 4.6: Percentage of an expected mobile phone duration before going flat

Duration of mobile phone	**Percentage (%)**
1-3 hours	2.55
4-6 hours	2.55
7-9 hours	9.40
10-12 hours	9.40
13-15 hours	10.30
16-18 hours	6.00
19-21 hours	6.00
22-24 hours	22.20
48 hours	17.90
72 hours	8.50
120 hours	2.60
168 hours	2.60
Total	100.00

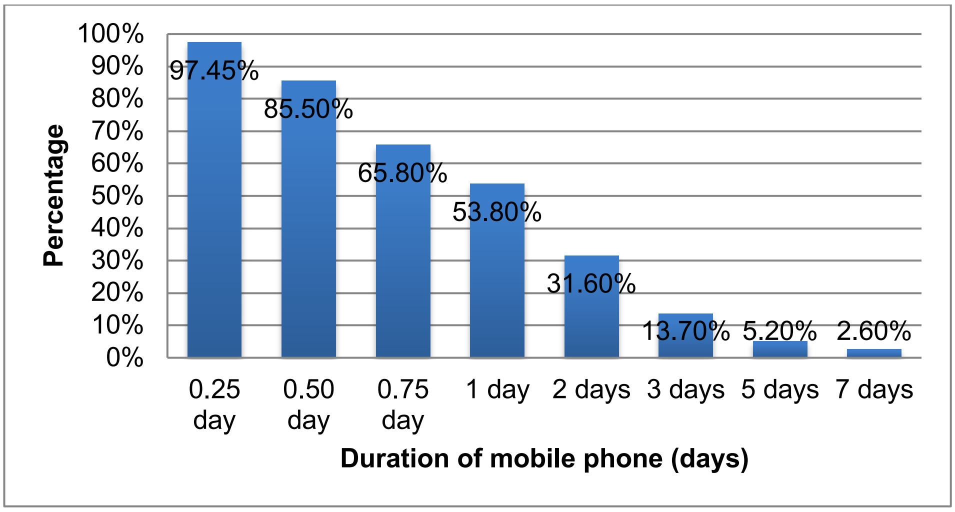


Figure 4.2: Cumulative percentage of am expected mobile phone duration in days after the last recharge

4.3.3.3 Frequency of mobile phone recharging

Figure 4.3 presents that 56.40% of the participants recharged their mobile phone once per day while 17.9% recharged it twice a day. Only a minority, accounting for 8.50 percent, recharged their phone once per two days. This result proves that a mobile phone duration in general situation was about between half a day and one day or between one day and two days related to the result in section 4.3.3.1.

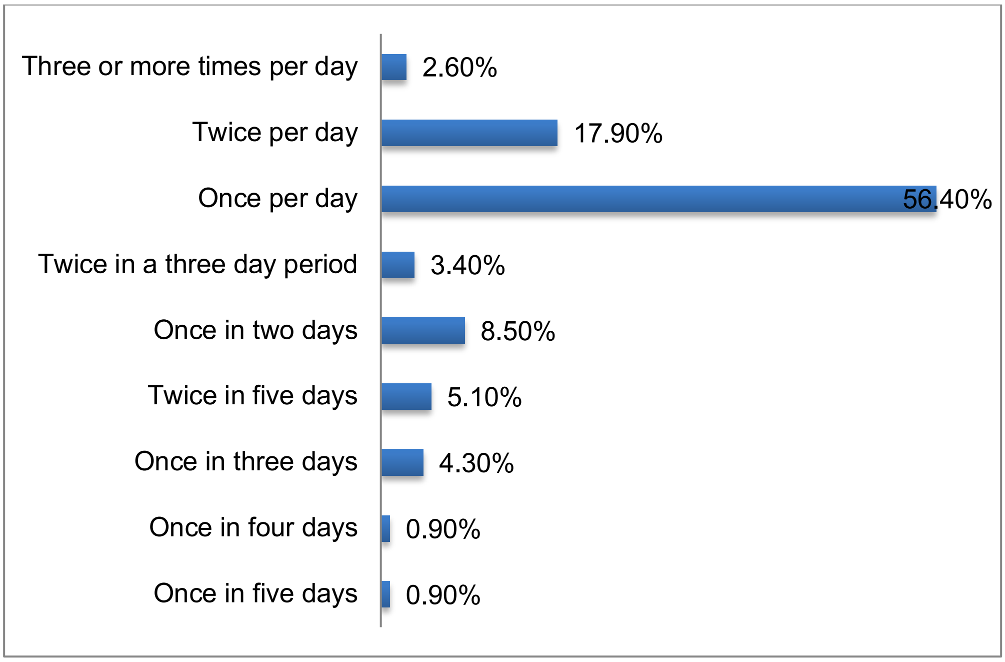
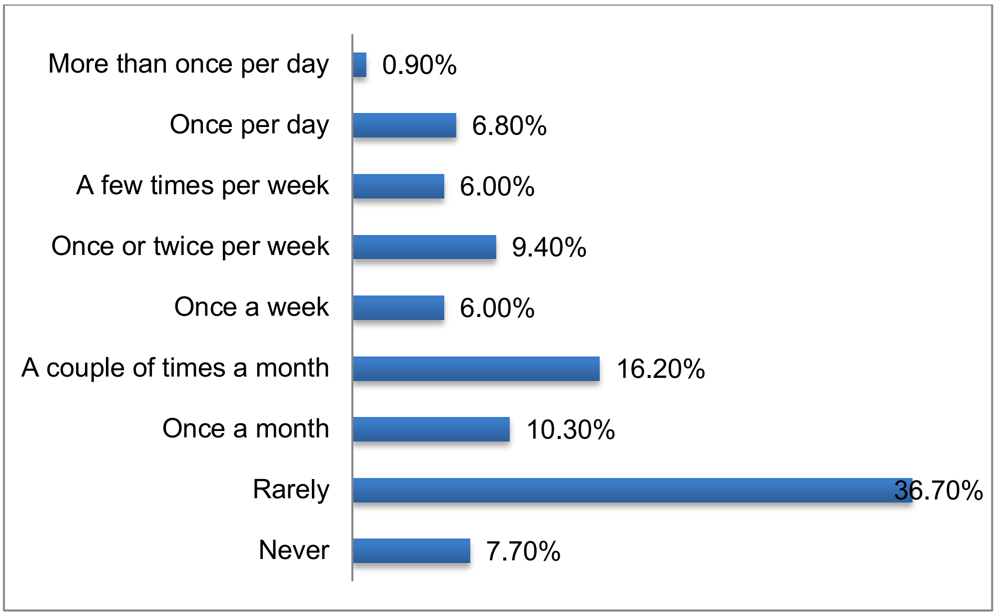


Figure 4.3: Frequency of mobile phone recharging

4.3.3.4 Frequency of mobile phone going flat before recharging



Figurer 4.4: Frequency of mobile phone going flat before recharging

Figure 4.4 presents how often people left their mobile phone until going flat. 36.7% of respondents stated that they rarely left the phone die while 16.20% did a couple of times a month. Approximately one-tenth did not charge a mobile phone until it went flat once or twice a week, accounting for 10.30% and 9.40% respectively. It is possible that people could leave their mobile phone and forgot to recharge it. Furthermore, those who did so more than once per day, once per day, and a few times per week made up 13.70% of the diagram. Because of user behaviour, they might spend their time in vital communication features or entertainment features without awareness of a phone battery life. This is related to the data in section 4.3.4.

4.3.3.5 Percentage of battery remaining when users decide to recharge mobile phone

Figure 4.5 demonstrated the battery level percentage before users decide to recharge a mobile phone. 24.80% of participants decided to charge their phone when it reached 20 per cent of battery. In the meantime, slight above two-tenth recharged their mobile phone when it reached between 0 to 9 per cent battery level, accounting for 21.40%.

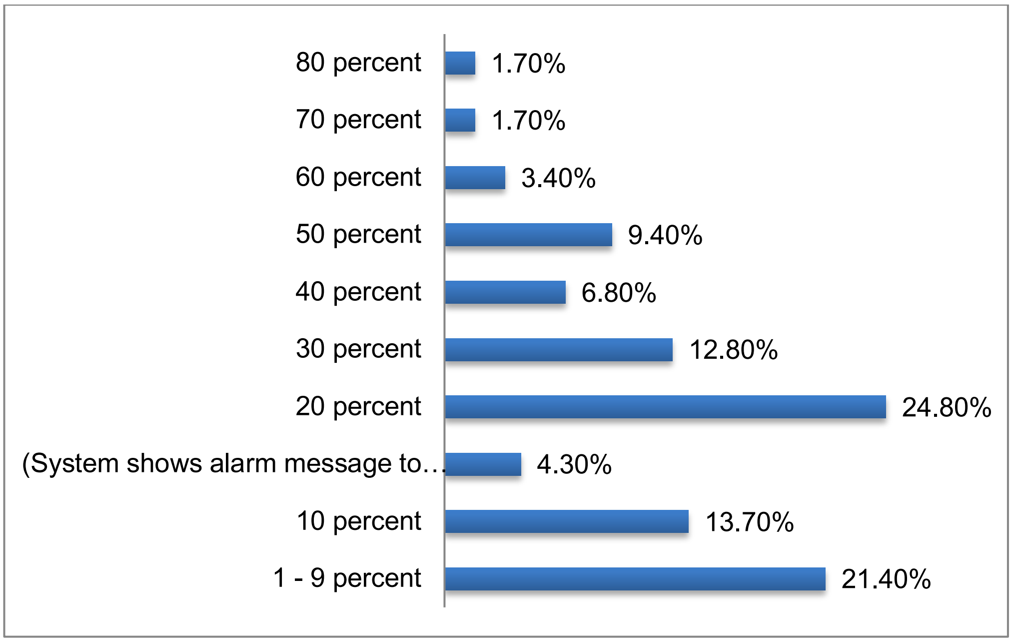


Figure 4.5: Percentage of battery remaining when users decide to recharge mobile phone

4.3.3.6 Time to discharge a mobile phone

Figure shows when participants disconnected the mobile phone from rechargeing. Almost half of the respondents decided to unplug the mobile phone when it was fully recharged while 28.20% and 17.90% of them did so when needing to go out of after getting up in the morning respectively. From this perspective, it can be assumed that when respondents were able to reach to a main plug or a battery backup to recharge a battery, they always recharged their mobile phone immediately.

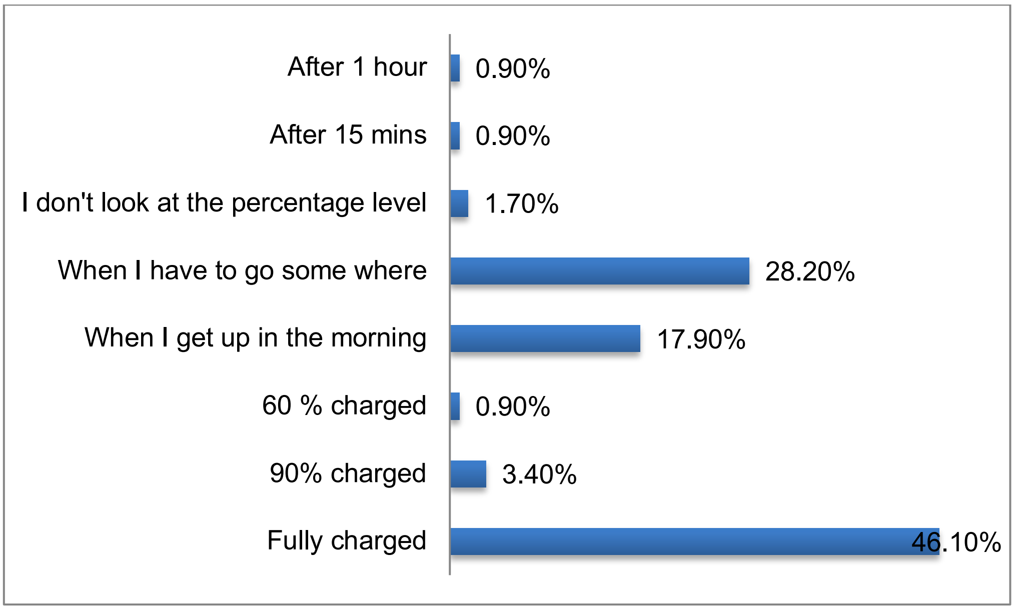


Figure 4.6: Time to discharge a mobile phone

4.3.3.7 Duration of mobile phone recharging to fully charge

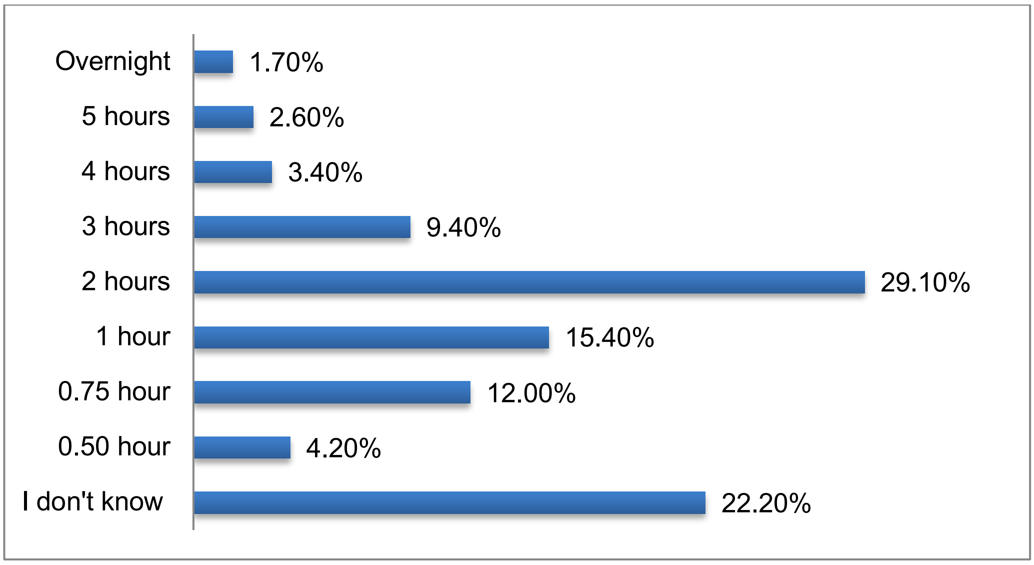


Figure 4.7: Duration of mobile phone recharging to fully charge

Figure 4.7 presents that respondents spent their time to recharge their mobile phone by average about 2 hours (29.10%). However, it depends on power sources output to supply a mobile phone. High-Ampere-output charger can recharge battery rapidly. Normally, one and a half hour to two hours is acceptable to charge a mobile phone until it is fully charged. Interestingly, 22.2% of participants were not sure how long a mobile took to a full charge. It possibly means that they spent time recharging their mobile phone overnight.

4.3.3.8 Duration of mobile phone recharging for each recharging

Figure 4.8 illustrates the duration of a mobile phone charge for each time. About 55.60% of respondents recharged their mobile phone overnight which means they did so before going to sleep. This can support the results from section 4.3.3.7 in which respondents answered that "I don't know the duration of a mobile phone recharging to fully charge". In addition, 12.80% and 11.10% of participants spent two hours and one hour respectively in recharging a mobile phone each time. These results are also in accordance with those discussed in section 4.3.3.7 which the respondents took 2 hours to recharge a mobile phone.

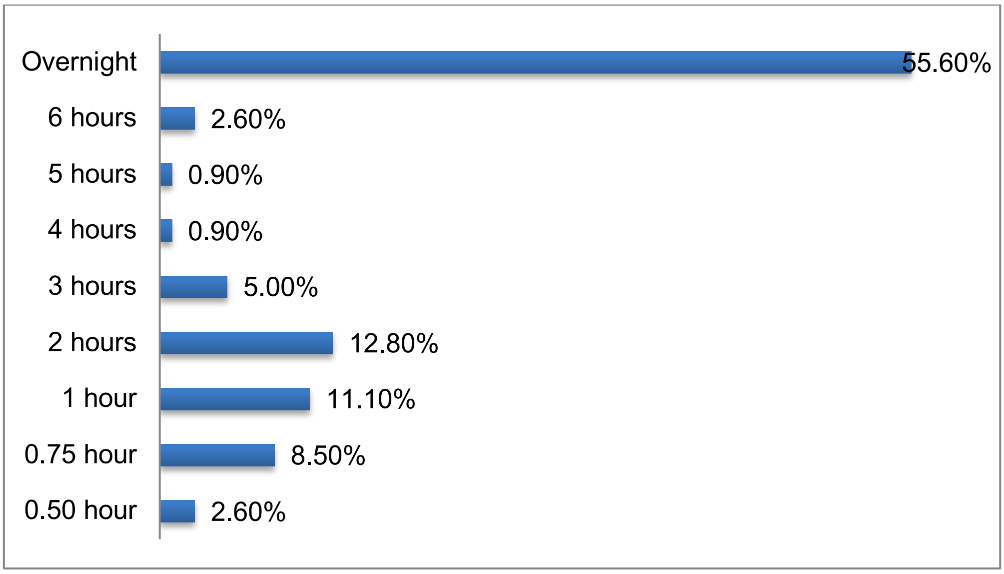


Figure 4.8: Duration of mobile phone charging for each recharging

4.3.4 Mobile phone usage in general situation (N=117)

This section illustrates the information of a mobile phone usage in general situation including the frequency of a mobile phone feature usage, the duration of using each mobile phone feature over a day, the percentage of a mobile phone usage for entertainment and for vital communication.

4.3.4.1 Definition of mobile phone usage for entertainment and vital communication

- Entertainment features on a mobile phone consist of camera, games, audio and video player, and audio and video streaming. These features gave users satisfactory and enjoyable experiences during the period of time.
- Vital communication features on a mobile phone comprise voice call, SMS, voice mail, web browsing, chat application, voice and video application, Email, maps and GPS, and social network application. All of these features can be useful for the communication between users.

4.3.4.2 Frequency of mobile phone feature usage

This section describes the respondents’ mobile phone feature usage determined by vital communication and entertainment features

Vital communication features

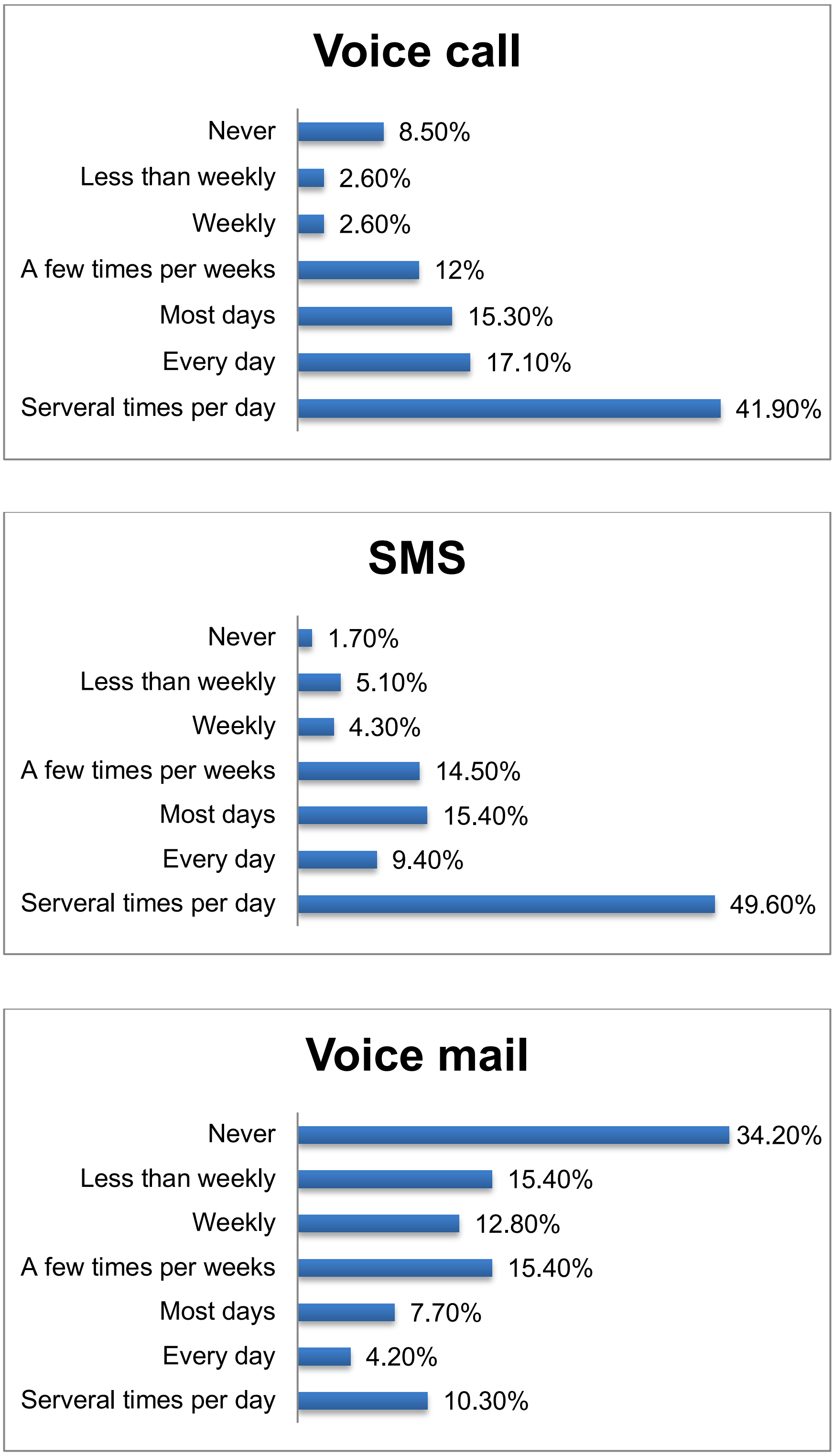


Figure 4.9a: Frequency of vital communication feature usage on a mobile phone

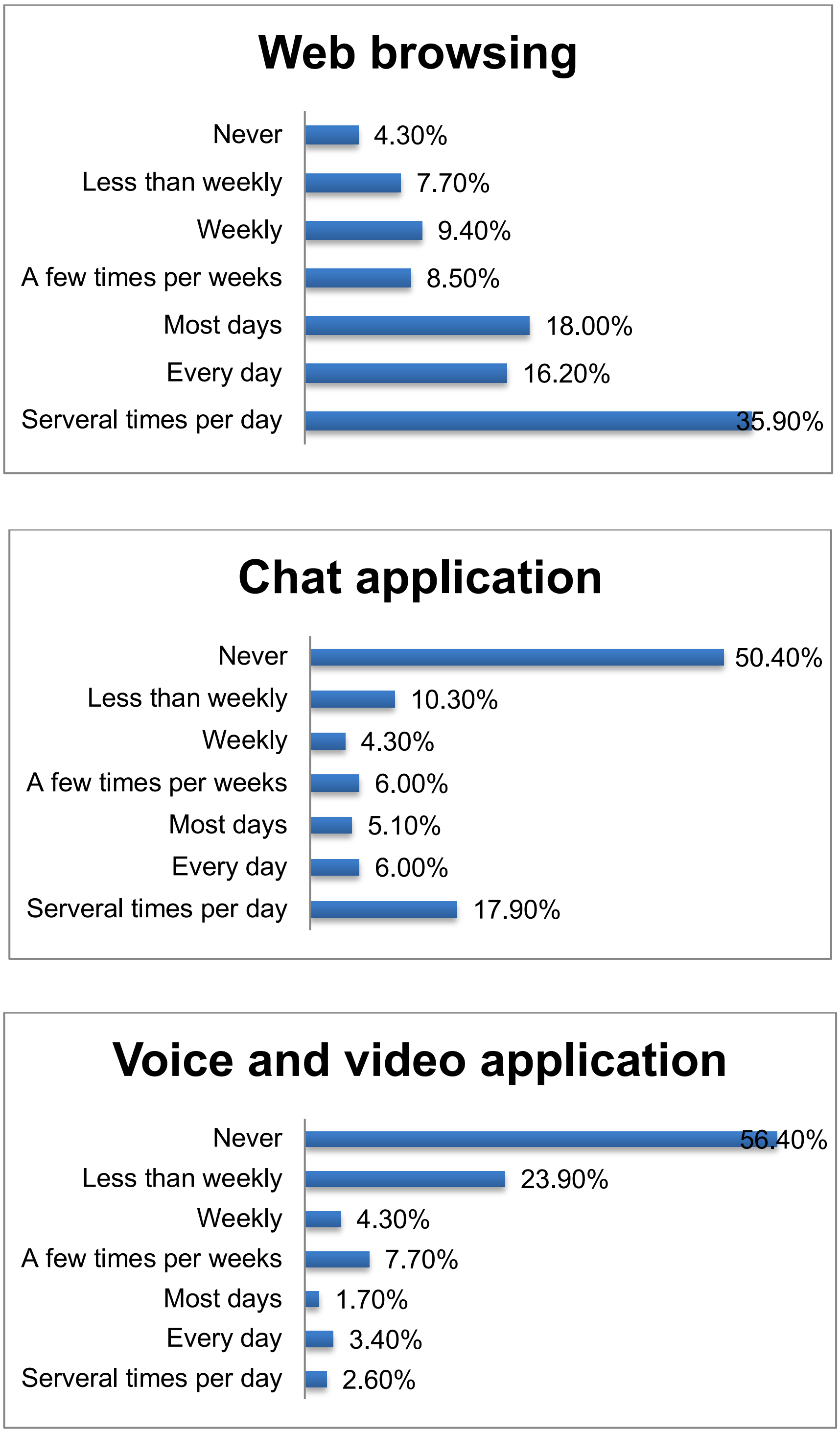


Figure 4.9b: Frequency of vital communication feature usage on a mobile phone (continued)

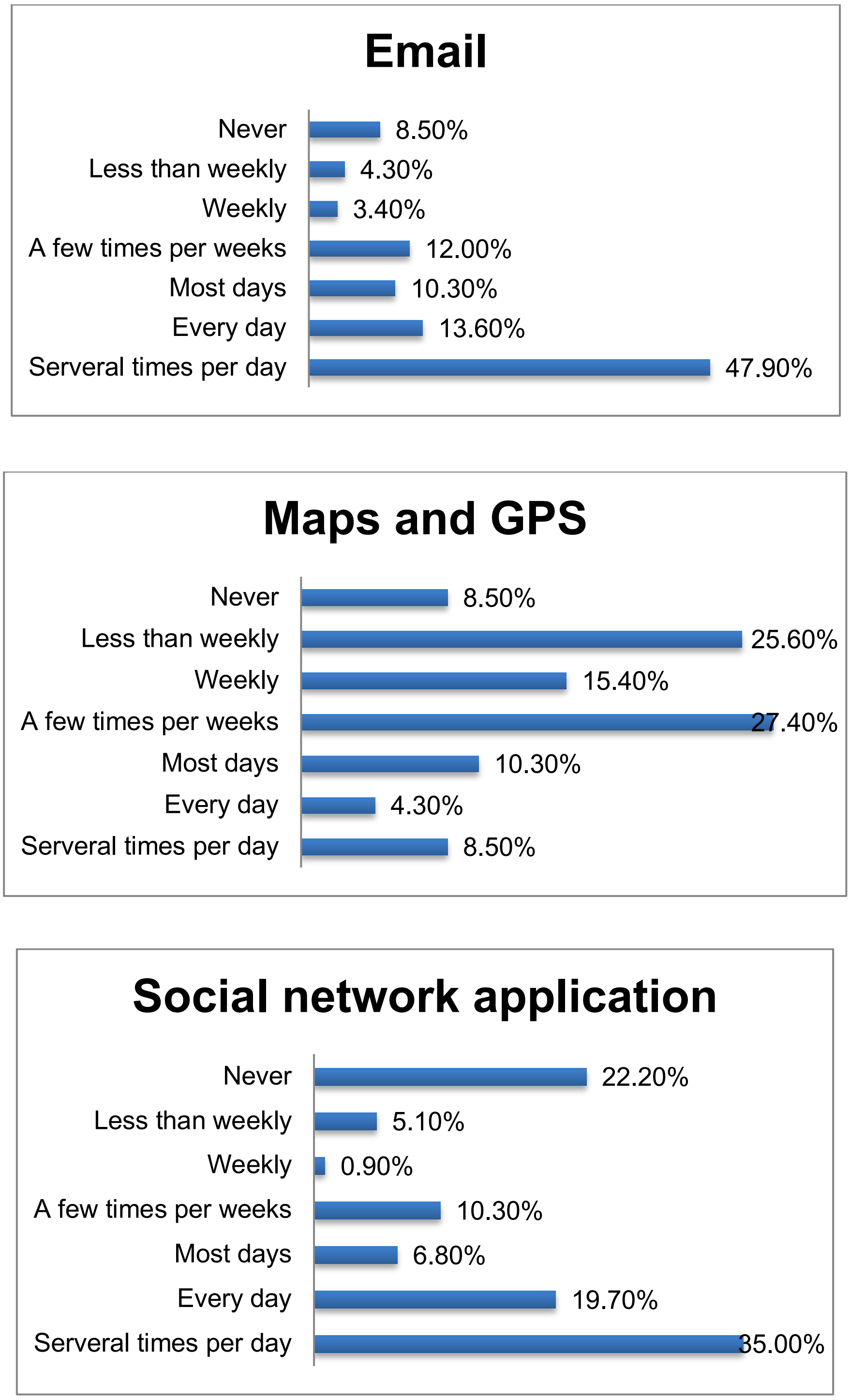


Figure 4.9c: Frequency of vital communication feature usage on a mobile phone (continued)

Figure 4.9a, b, and c indicated the group of vital communication feature usage on a mobile phone including voice call, SMS, voice mail, chat application, voice and video application, Email, maps and GPS and social network application.

It is shown that a voice call, SMS, email, web browsing and social network application were used several times per day, accounting for 41.90%, 49.60%, 47.90%, 35.90% and

35.00% respectively. This is understandable since they are main features of a mobile phone. On the other hand, 32.40%, 50.40% and 56.40% of respondents never used these features including voice mail, chat application and voice and video application respectively. In case of maps and GPS, the average usage was less than a week and a few times per weeks, accounting for 25.60% and 27.40% respectively.

Entertainment features

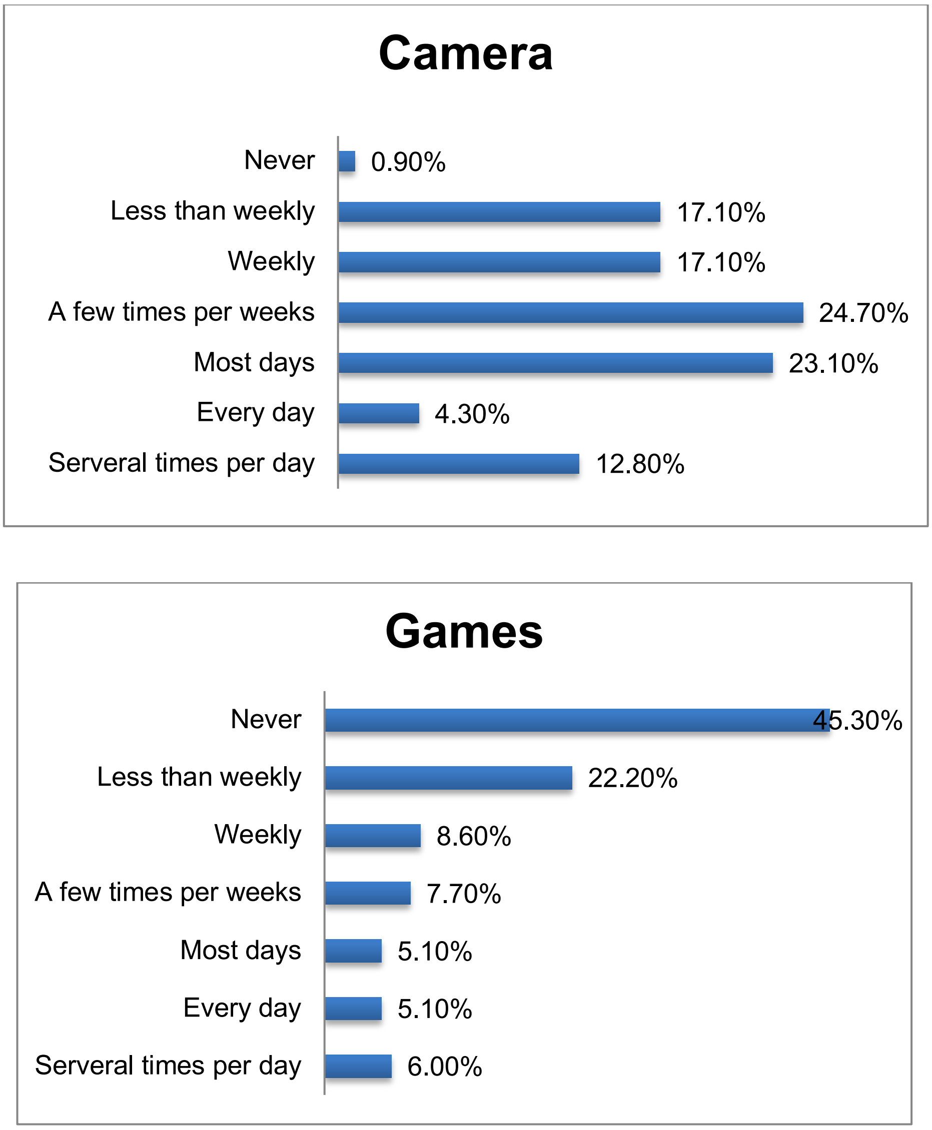
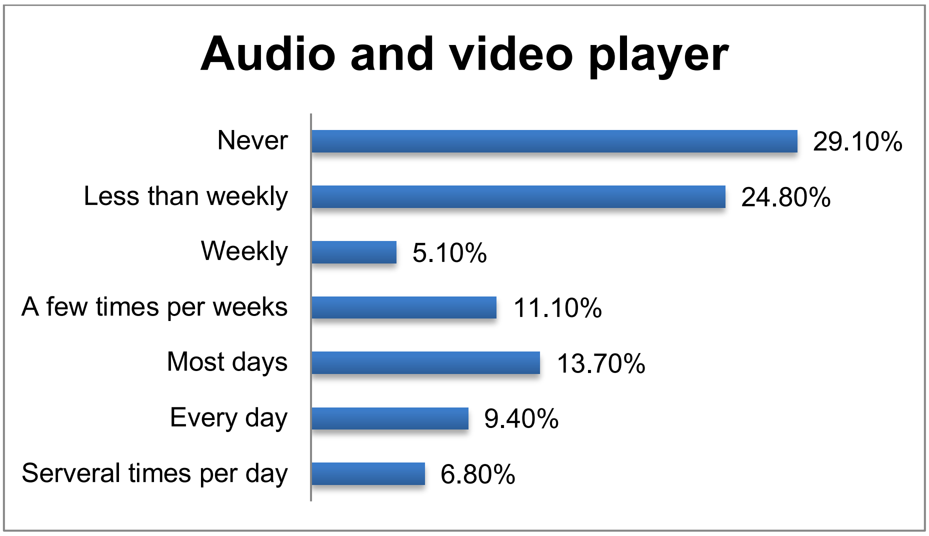


Figure 4.10a: Frequency of entertainment feature usage on a mobile phone



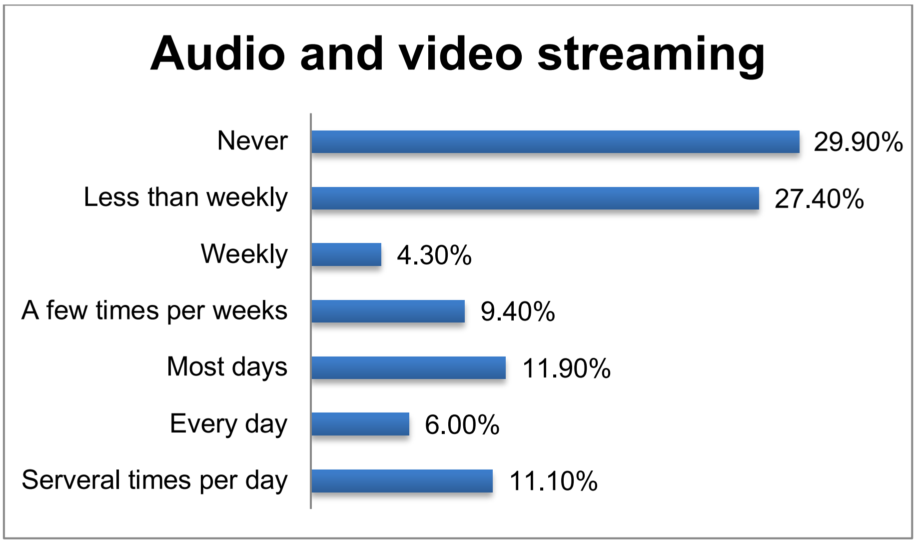


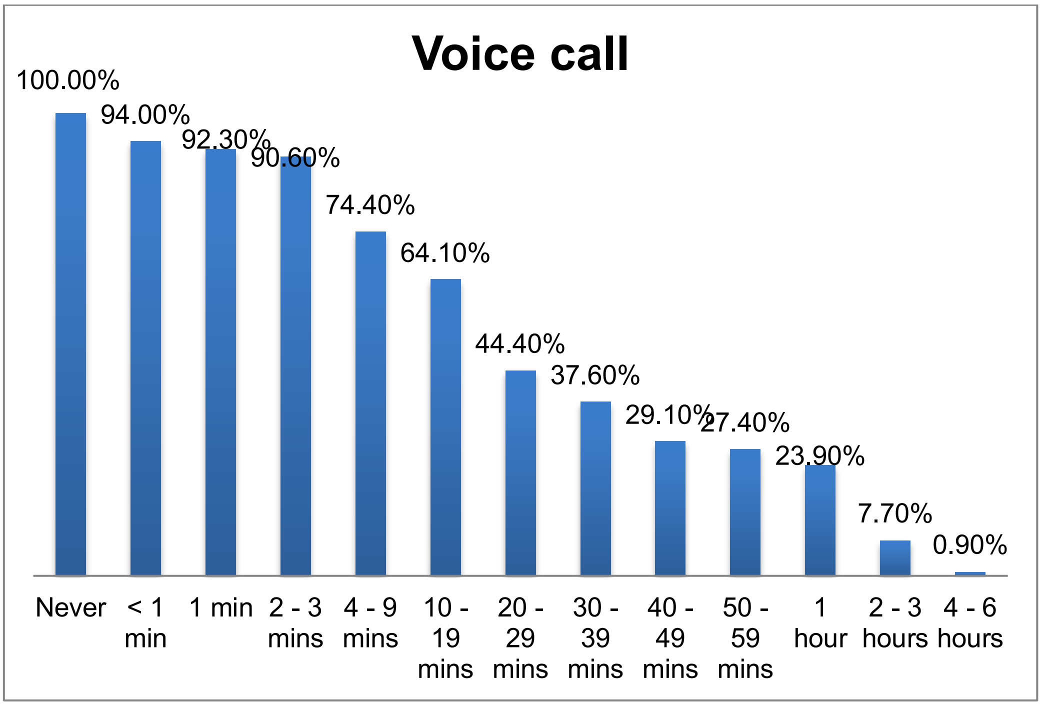
Figure 4.10b: Frequency of entertainment features usage on mobile phone (continued)

Figure 4.10 a and b show group of entertainment feature usage on a mobile phone including camera, games, audio and video player, and audio and video streaming. The number of respondents using a camera a few times per week and most days by average made up 24.70% and 23.10% of the chart. For games, 45.30% of respondents never used this feature while 29.10% and 24.80% used audio and video less than weekly compared to 29.90% and 27.40% for audio and video streaming.

4.3.4.3 Duration of using mobile phone feature over a day

In this section, the duration of mobile phone feature usage over a day categorised by vital communication and entertainment features is described

Vital communication features



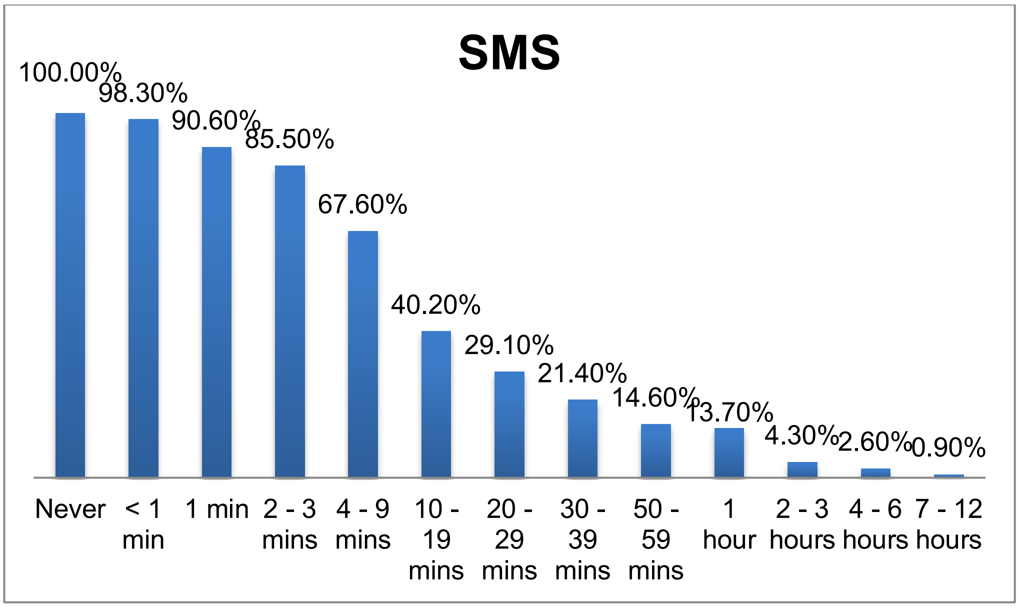
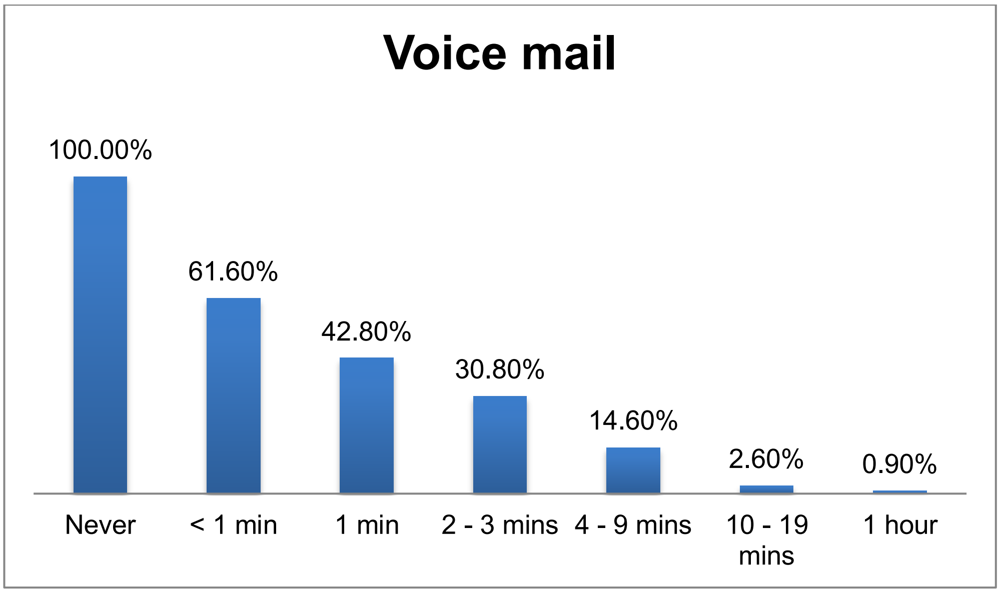


Figure 4.11a: Cumulative percentage of duration of vital communication feature usage over a day



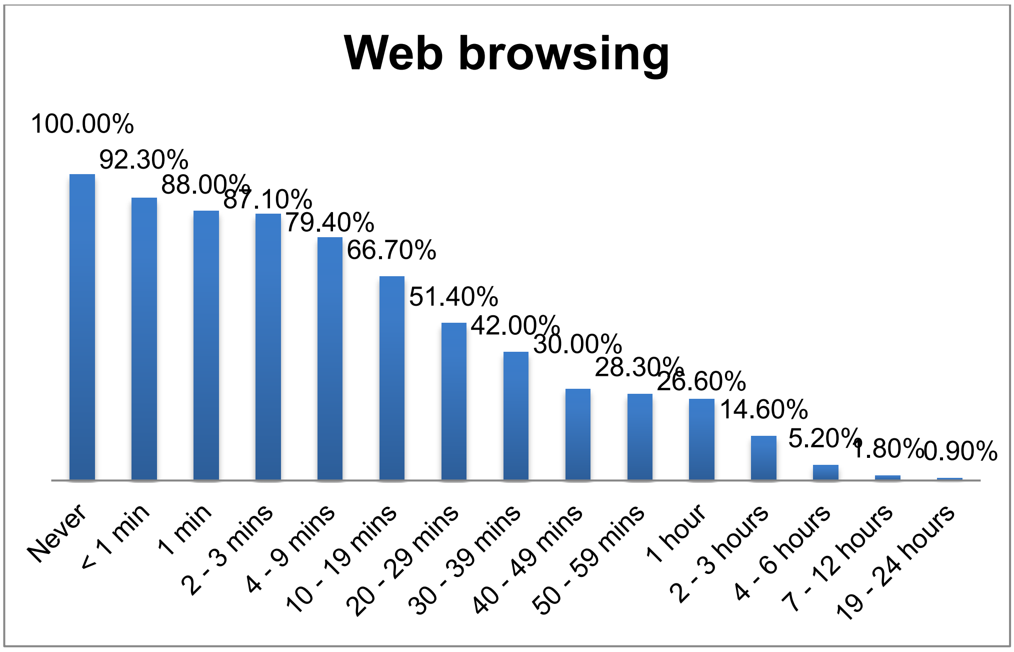


Figure 4.11b: Cumulative percentage of duration of vital communication feature usage over a day (continued)

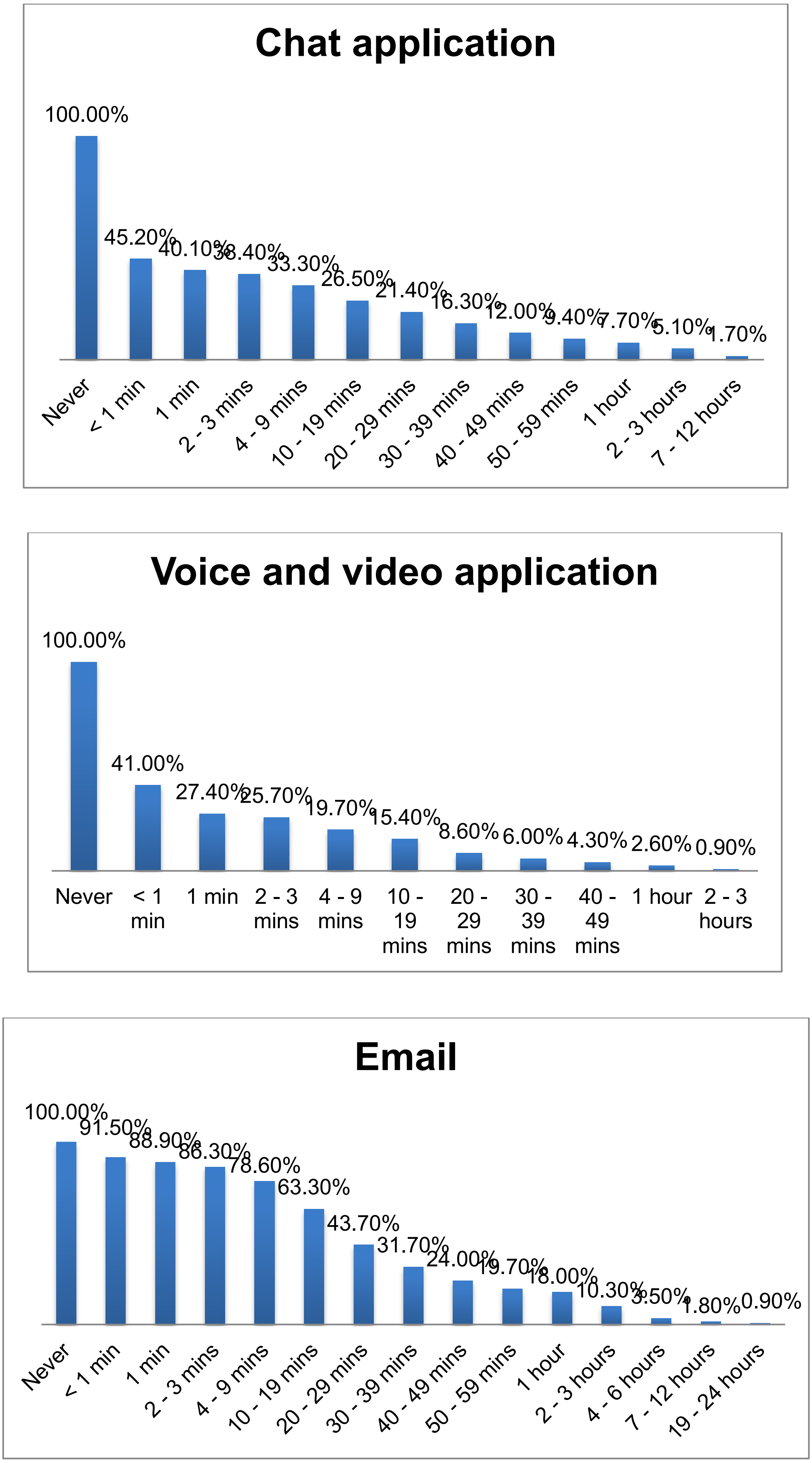


Figure 4.11c: Cumulative percentage of duration of vital communication feature usage over a day (continued)

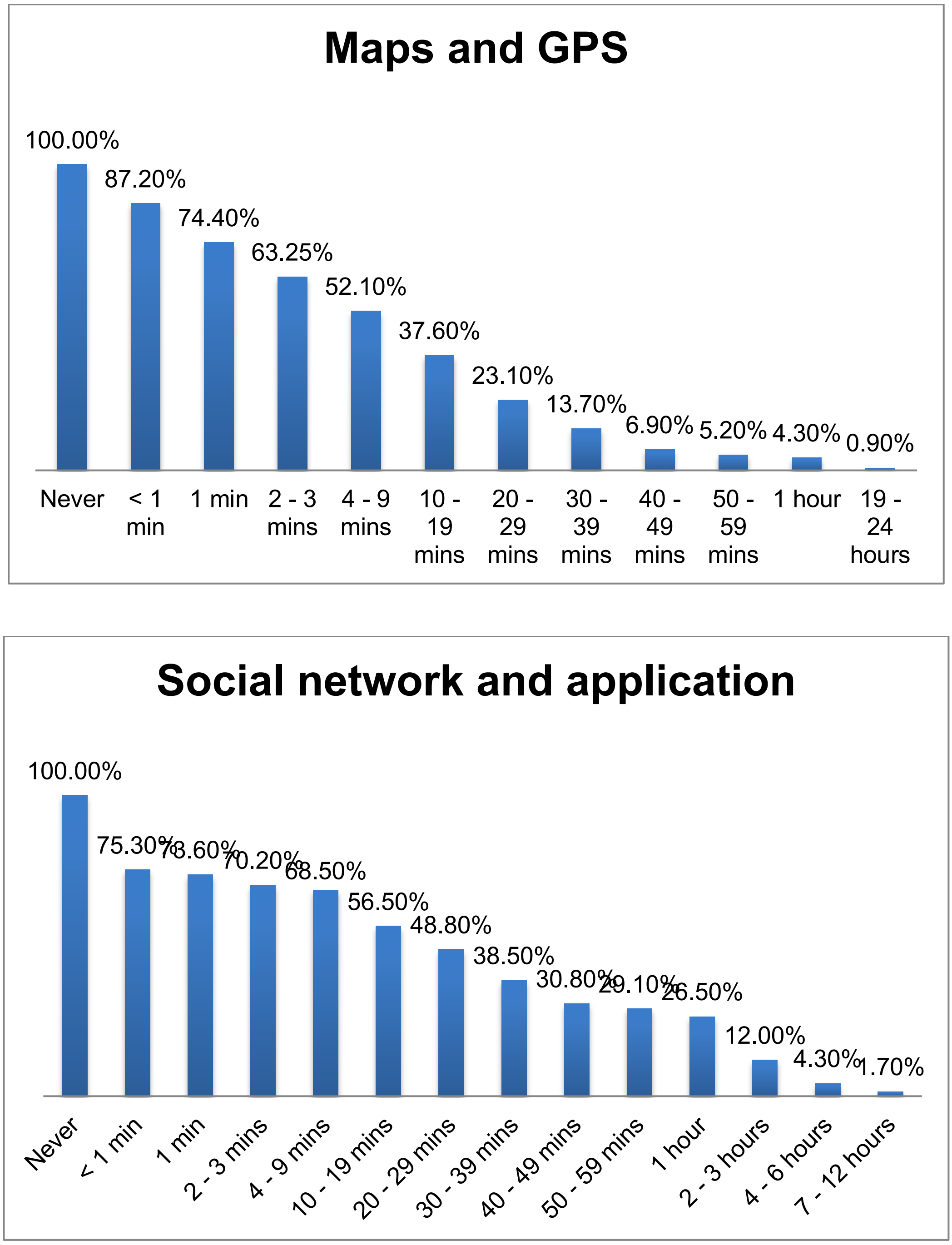


Figure 4.11d: Cumulative percentage of duration of vital communication features usage over a day (continued)

Figure 4.11a, b, c and d show duration of vital communication feature usage on a mobile phone over a day including voice call, SMS, voice mail, web browsing, chat application, voice and video application, Email, maps and GPS and social network application.

To clarify the figure 4.11a, b, c, and d, the table 4.7 shows the summary of cumulative percentage of vital communication feature usage in significant duration. Also, table 4.8 shows the exact percentage of feature usage duration between 0 min and 1 hour.

Table 4.7: Summary of cumulative percentage of vital communication feature usage on a mobile phone in period of time

Features	**1 min**	**30-39 mins**	**1 hour**	**2-3 hours**	**4-6 hours**
Voice call	92.30%	37.60%	23.90%	7.70%	0.90%
SMS	90.60%	21.40%	13.70%	13.70%	4.30%
Voice mail	43.80%	-	0.90%	-	-
Web browsing	88.00%	42.00%	28.60%	14.60%	5.20%
Chat application	40.10%	16.30%	7.70%	5.10%	-
Voice and video application	27.40%	6.00%	2.60%	0.90%	-
Email	88.90%	31.70%	18.00%	10.30%	3.50%
Maps and GPS	74.40%	13.70%	4.30%	4.30%	-
Social network application	73.60%	38.50%	26.50%	12.00%	4.30%

Table 4.7 shows the summary of duration of vital communication usage for each feature. These data indicate cumulative percentage of significant duration such as one minute, 30-39 minutes, one hour, 4-6 hours and 4-6 hours. For instance, according to figure 4.11a and table 4.7, 23.90% of respondents spent their time at least one hour to use a voice call feature.

It should be noted in case participants have limited time, say 1 minute, they prefered to use voice communication. However, users were inclined to spend their time on web browsing and social network application from 30 minutes to one hour.

Table 4.8 shows the essential summary of exact percentage of vital communication usage in each feature between 0 min and 1 hour. For example, the percentage of a voice call shown in figure 4.11a at the use of 0 min can be calculated by 100 % minus 94% of <1min duration, which at 94% is cumulative percentage of remaining duration. As a result, the actual percentage of the respondents choosing the duration of 0 min is 6.00%.

Moreover, the result implies that a mobile phone usage behaviour on web browsing and social network application is more than that of voice call. The two applications indicate a high percentage at one hour compared to a voice call, which is 26.50% to

16.20% as well as 19.70% to 8.50% at 30 -39 minutes. This report (BroadbandSearch, 2019) showed the increase of social network usage in daily life, reflecting that people tend to spend their time on social network more than a voice call.

Table 4.8: Summary of exact percentage in vital communication feature usage on mobile phone in period of time

Features	**Never (0 min)**	**10-19 mins**	**20-29 mins**	**30-39 mins**	**40-49 mins**	**50-59 mins**	**1 hour**
Voice call	6.00%	19.70%	6.80%	8.50%	1.70%	3.50%	16.20%
SMS	1.70%	11.10%	7.70%	6.80%	-	0.90%	9.40%
Voice mail	38.40%	1.70%	-	-	-	-	0.90%
Web browsing	7.70%	15.30%	9.40%	12.00%	1.70%	1.70%	12.00%
Chat application	54.80%	5.10%	5.10%	4.30%	2.60%	1.70%	2.60%
Voice and video application	59.00%	6.80%	2.60%	1.70%	1.70%	-	1.70%
Email	8.50%	19.60%	12.00%	7.70%	4.30%	1.70%	7.70%
Maps and GPS	12.80%	14.50%	9.40%	6.80%	1.70%	0.90%	3.40%
Social network application	24.70%	7.70%	10.30%	7.70%	1.70%	2.60%	14.50%

Entertainment features

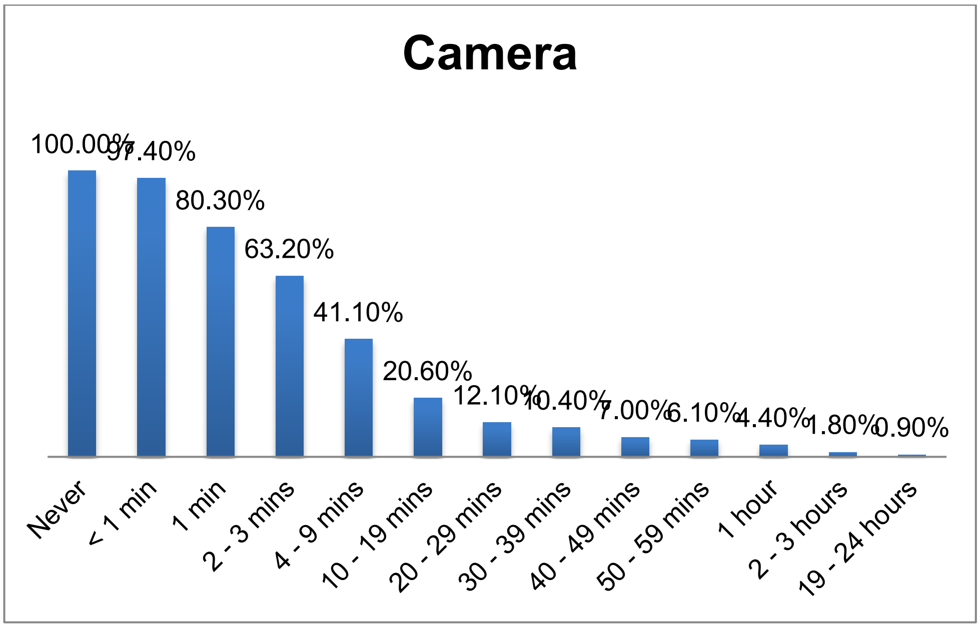
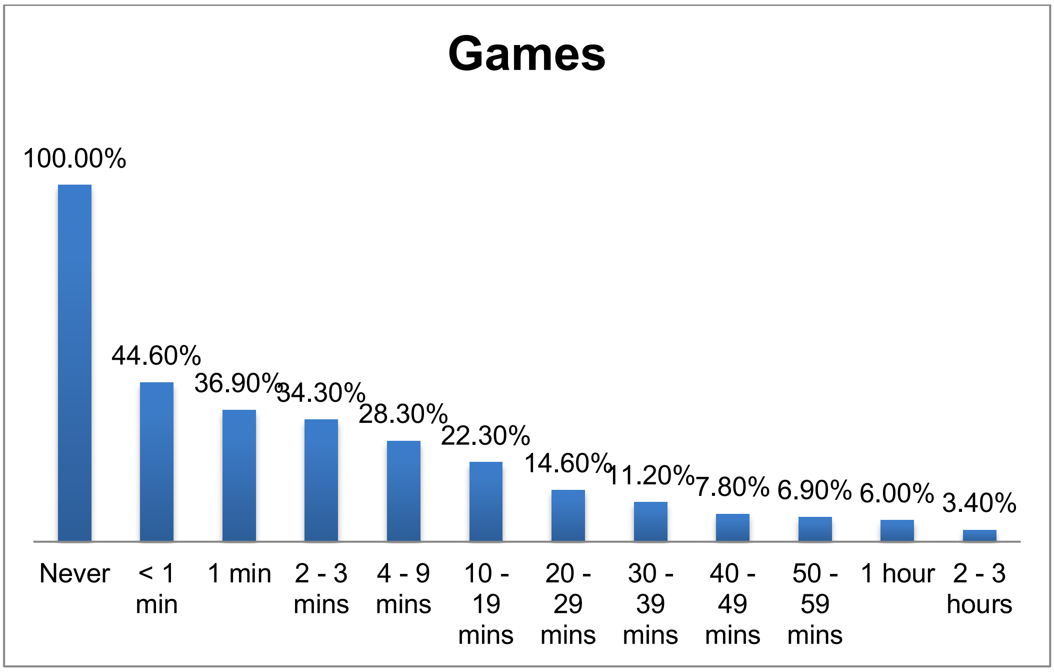


Figure 4.12a: Cumulative percentage of duration of entertainment feature usage over a day



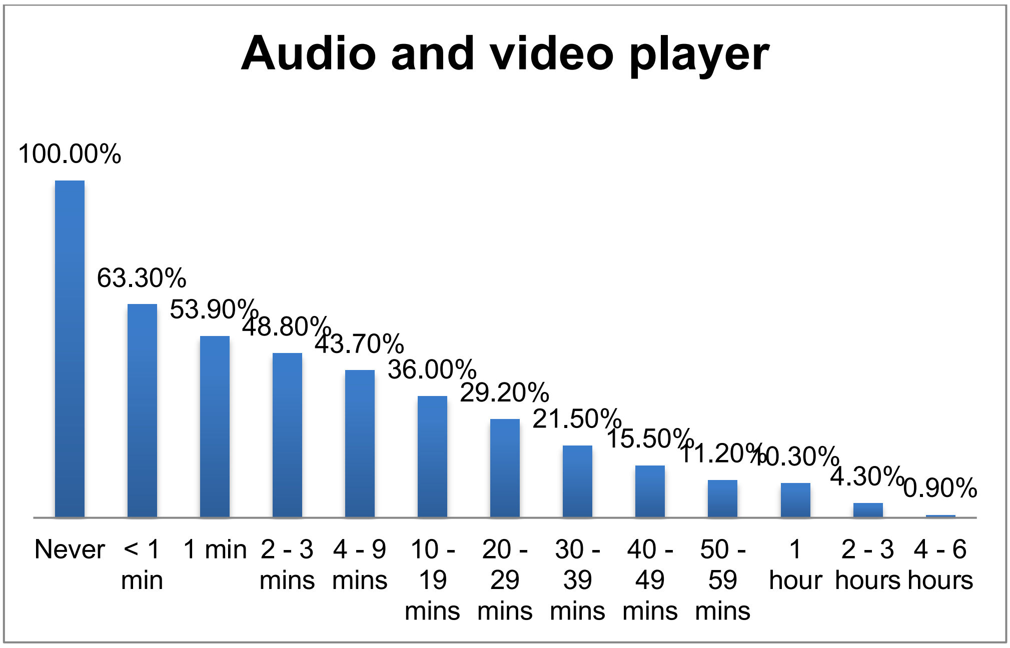


Figure 4.12b: Cumulative percentage of duration of entertainment feature usage over a day (continued)

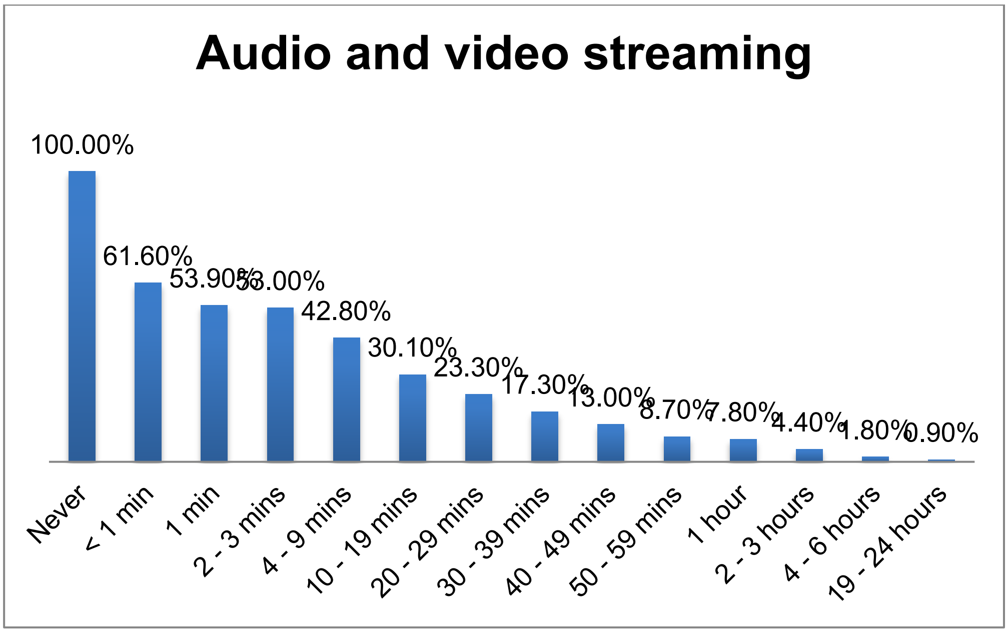


Figure 4.12c: Cumulative percentage of duration of entertainment features usage over a day (continued)

Figure 4.12a, b, and c present the duration of entertainment feature usage on a mobile phone over a day including camera, games, audio and video player and audio and video streaming.

To elaborate the information shown in figure 4.12a, b, and c clearly, table 4.7 shows the summary of cumulative percentage of entertainment feature usage in significant duration. Also, table 4.8 shows exact percentage of feature usage from 0 minute to 1 hour.

Table 4.9: Summary of cumulative percentage of entertainment feature usage on a mobile phone in period of time

Features	**1 min**	**30-39 mins**	**1 hour**	**2-3 hours**	**4-6 hours**
Camera	80.30%	10.40%	4.40%	1.80%	-
Games	36.90%	11.20%	6.00%	3.40%	-
Audio and video player	53.90%	21.50%	10.30%	4.30%	0.90%
Audio and video streaming	53.90%	17.30%	7.80%	4.40%	1.80%

Table 4.9 shows the summary of time spent on entertainment determined by each feature. These data indicate cumulative percentage of significant duration such as one

minute, 30-39 minutes, one hour, 4-6 hours and 4-6 hours. For example, according to figure 4.12a and table 4.9, 4.40% of participants spent their time using camera for one hour.

Table 4.10: Summary of exact percentage in entertainment feature usage on a mobile phone in period of time

Features	**Never (0 min)**	**10-19 min**	**20-29 mins**	**30-39 mins**	**40-49 mins**	**50-59 mins**	**1 hour**
Camera	2.60%	8.50%	1.70%	3.40%	0.90%	1.70%	2.60%
Games	55.40%	7.70%	3.40%	3.40%	0.90%	0.90%	2.60%
Audio and video player	36.70%	6.80%	7.70%	6.00%	4.30%	0.90	6.00%
Audio and video streaming	38.40%	6.80%	6.00%	4.30%	4.30%	0.90%	3.40%

Table 4.10 shows essential summary of exact percentage of entertainment usage in each feature between 0 minute and 1 hour. For example, the percentage of a camera in figure 4.12a used for 0 min can be calculated by 100 % minus 94% of <1min duration, which at 97.40% is cumulative percentage of remaining duration. As a result, actual percentage of this choice is 2.60%.

4.3.4.4 Average percentage of mobile phone usage for entertainment and vital communication

A mobile phone usage can be defined as follows:

- By mean time users spend on their mobile phone by concerning the duration for each usage.
- By battery use means user concerns over mobile phone usage on battery life.

Table 4.11 reveals the percentage of average mobile phone usage that users spent their time on entertainment and vital communication feature determined by time and by battery use. 117 respondents decided to use entertainment feature, considering from time for approximately 33.04% and considering from a battery use for 37.05%. In comparison, the participants used vital communication, 56.17% considering from time and 52.17% from a battery use.

Table 4.11: Comparison of mobile phone usage on entertainment and vital communication feature by time and by battery use in average percentage

Mobile phone usage	By time	By battery use
For entertainment	33.04%	37.05%
For vital communication	56.17%	52.17%

4.3.5 Relationship between duration of mobile phone after recharging battery and duration of mobile phone feature usage over a day

Practically, the duration of a mobile phone battery after recharged is related to the duration of mobile phone features usage over a day. When a mobile phone runs any application feature, a battery life was usually depleted rapidly, depending on mobile phone features usage duration. In this thesis, the meaning of duration of a mobile phone features usage over a day including the summary of usage duration of voice call, SMS, voice mail, web browsing, chat application, voice and video application, email, maps and GPS, social network application, camera, games, audio and video player, and audio and video streaming.

However, to identify, “Is there relationship between two variables?” Correlation coefficient method in statistical technique was considered as appropriate method to analyse in terms of quantitative analysis. Normally, the duration of mobile phone features usage over a day and the duration of a mobile phone battery after recharged should be continuous variables which are measured as interval scale. Nevertheless, there was limitation of data collection process since variables in our questionnaire were designed as categorical variables. It was not possible to analyse using correlation technique from the existing data. It was necessary to define new variables measured as interval scale instead of the existing ordinal scale. The middle of each value in related existing variable was considered in order to generate new variable. For example, 1-3 hours was defined as 2 hours or 2-3 mins was defined as 2.5 mins or 0.416 hour. The unit of minute was converted to the unit of hour instead. These new variables were only used in order to explain whether practically both variables have significant correlation in terms of statistic technique compared to a mobile phone battery life related to mobile phone features usage or not.

Because the sample size used in this thesis was rather small (N = 117), the aforementioned variables were tested using normal distribution before selecting the suitable statistics. It was shown that the data set was not well modelled by the normal distribution. Therefore, Spearman’s correlation was used to analyse the association between the duration of a mobile phone battery after recharged and the duration of a mobile phone feature usage over a day. The data are presented in table 4.12.

Table 4.12: Nonparametric correlations of the duration of a mobile phone battery after recharged and total duration of mobile phone feature usage (sample size = 117)

			Duration of a mobile phone battery after recharged (hours)	Duration of a mobile phone features usage over a day (hours)
Spearman’s rho	Duration of a mobile phone battery after recharged (hours)	Correlation Coefficient	1.000	-.415**
		Sig. (2-taild)		.000
		N	117	117
	Duration of a mobile phone feature usage over a day (hours)	Correlation Coefficient	-.415**	1
		Sig. (2-taild)	0.00	
		N	117	117

** Correlation is significant at the 0.01 level (2-tailed)

From table 4.12, the result found that there was significant correlation between the duration of a mobile phone battery after recharged and the duration of a mobile phone feature usage over a day (p-values = 0.01). Therefore, there was a significant relationship between these two variables. A mobile phone battery life is relatively depleted rapidly depending on mobile phone features usage.

4.3.6 Relationship between duration of mobile phone after recharging battery and duration of mobile phone features usage connecting the Internet or Wi-Fi

Some mobile phone features require the connection to Wi-Fi or the Internet in order to operate such as web browsing, chat application, voice and video call application, email, maps, social network application, audio and video streaming application.

As Wi-Fi and Internet data function consumes too much energy when turning on, they are considered one of the critical energy consumption factors which are necessary to identify their relationship toward both variables in such statistical technique. According to the previous section, the data were tested a normal distribution before selecting suitable statistics. It was shown that the data set was not well modelled by the normal distribution. Therefore, Spearman’s correlation was used to analysis association between duration of a mobile phone battery after recharged and duration of mobile phone features usage connecting the Internet or Wi-Fi from number of 117 respondents, presented in table 4.13.

Table 4.13: Nonparametric correlations of the duration of a mobile phone battery after recharged and the duration of a mobile phone feature usage connecting to the Internet or Wi-Fi (sample size = 117)

			Duration of a mobile phone battery after recharged (hours)	Duration of mobile phone feature usage when connected to the Internet or Wi-Fi (hours)
Spearman’s rho	Duration of a mobile phone battery after recharged (hours)	Correlation Coefficient	1.000	-.420**
		Sig. (2-taild)		.000
		N	117	117
	Duration of mobile phone feature usage when connected to the Internet or Wi-Fi (hours)	Correlation Coefficient	-.420**	1
		Sig. (2-taild)	0.00	
		N	117	117

** Correlation is significant at the 0.01 level (2-tailed)

From table 4.13, it is found that there was a significant correlation between the duration of mobile phone battery after recharged and the duration of a mobile phone feature usage when connecting to the Internet or Wi-Fi (p-values = 0.01). Hence, a mobile phone battery life is relatively depleted rapidly as it is influenced by a mobile phone feature usage connecting to the Internet or Wi-Fi.

4.3.7 Mobile phone recharging in disaster/emergency situation and related information (N=101)

As for a mobile phone recharging in disaster/emergency situation, this section provides information including the duration of a mobile phone battery before going flat, the minimum runtime requirement of a mobile phone battery life, the frequency of mobile phone recharging, the percentage of battery remaining before recharged, the time to discharge a mobile phone, and the maximum acceptable time for a mobile phone recharging.

4.3.7.1 Duration of mobile phone battery before going flat in disaster/emergency situation

Table: 4.14 shows percentage of a mobile phone battery duration which indicated that most users expect it to last about 24 – 48 hours or two days in disaster/emergency situation.

Table 4.14: Percentage of the expected duration of a mobile phone battery before going flat in disaster/emergency situation

Duration of mobile phone	**Percentage (%)**
1-3 hours	5.90
4-6 hours	4.00
7-9 hours	6.90
10-12 hours	7.90
13-15 hours	7.90
16-18 hours	5.90
19-21 hours	4.00
22-24 hours	23.70
48 hours	22.80
72 hours	4.00
96 hours	1.00
120 hours	2.00
168 hours	4.00
Total	100.00

Figure 4.13 derived from table 4.14 presents the cumulative percentage of a mobile phone expected to remain operating in days after its last recharge in disaster/emergency situation. 57.50% of participants expected to be able to use their mobile phone at least for one day while 33.80 % of them expected at least two days. The longest duration people expected from their mobile phone battery was seven days (4.00 %).

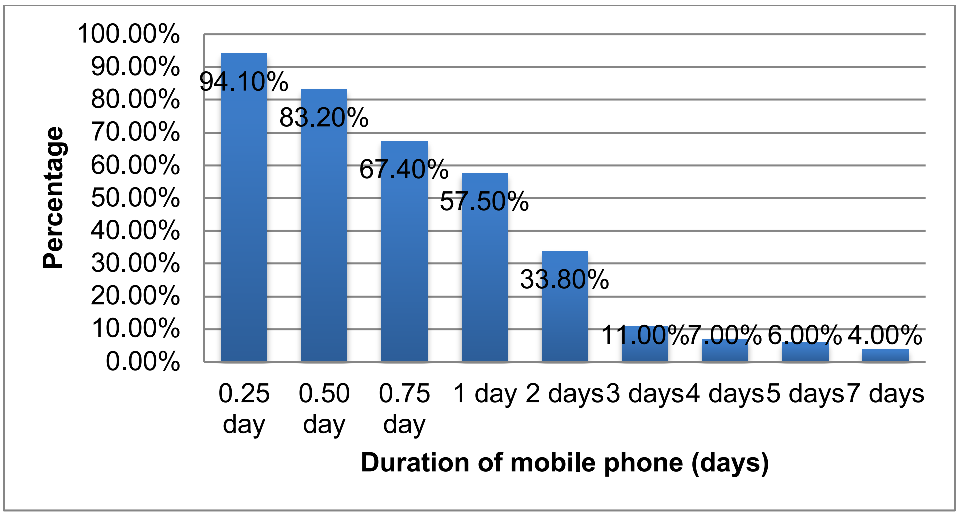


Figure 4.13: Cumulative percentage of a mobile phone expected to remain operating in days after last recharge in disaster/emergency situation

4.3.7.2 Minimum runtime requirement of mobile phone battery life in disaster/emergency situation

Table 4.15: Percentage of minimum battery runtime of a mobile phone expected to operate in disaster/emergency situation

Duration of mobile phone	**Percentage (%)**
15 mins	0.90
30 mins	5.00
45 mins	0.90
1-3 hours	5.90
4-6 hours	5.90
7-9 hours	5.00
10-12 hours	11.90
13-15 hours	5.00
16-18 hours	5.00
19-21 hours	2.00
22-24 hours	44.50
48 hours	4.00
72 hours	4.00
Total	100.00

Table: 4.15 shows the percentage of minimum battery runtime that should be able to operate in a disaster/emergency situation. 44.50% of the respondents needed the battery runtime to be approximately one day.

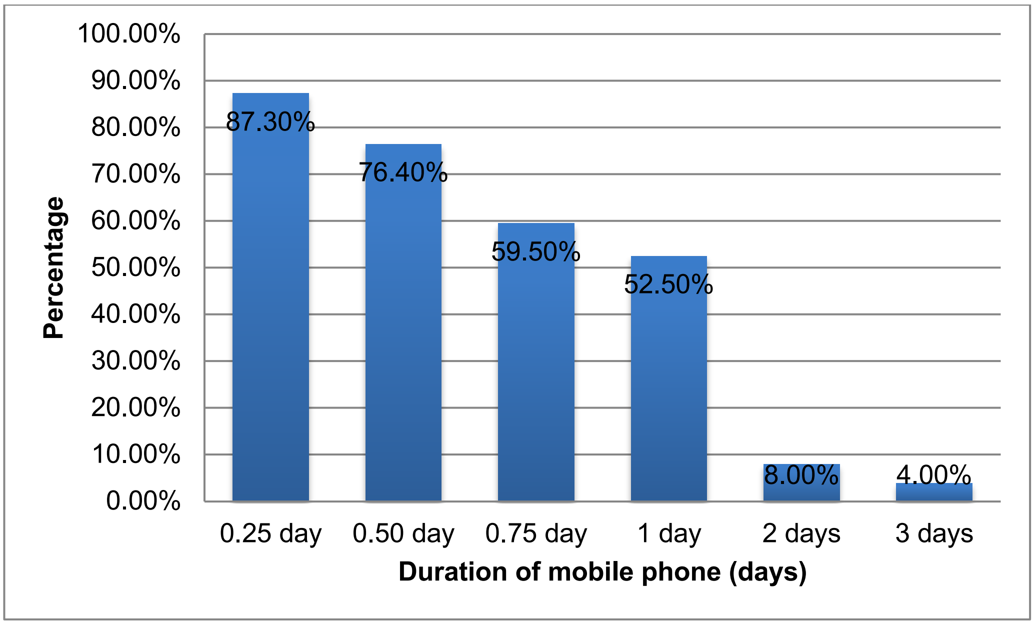


Figure 4.14: Percentage of minimum battery runtime requirement to operate in days after its last recharge in disaster/emergency situation

Figure 4.14 derived from table 4.15 presents the percentage of a mobile phone expected to have minimum battery life operating in days after recharged in disaster/emergency situation. 50% of the respondents needed the battery runtime to be approximately one day.

4.3.7.3 Frequency of mobile phone recharging in disaster/emergency situation

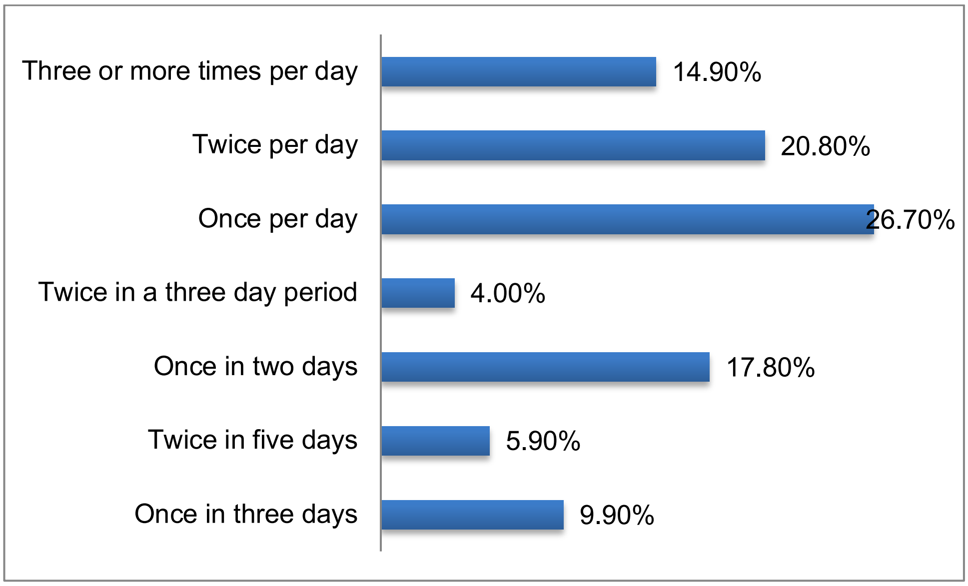


Figure 4.15: Frequency of mobile phone recharging in disaster/emergency situation

In disaster/emergency situation, 26.70% and 20.80% of the respondents would like to recharge their mobile phone once and twice a day respectively as shown in figure 4.15.

14.90% of them preferred to charge three or more time a day indicating that during a disaster/emergency situation user needed to often recharge a mobile phone since they concerned about unreliable opportunity to charge their mobile phone.

4.3.7.4 Percentage of battery remaining before recharging a mobile phone in disaster/emergency situation

Figure 4.16 shows the battery percentage level before uses decided to recharge a mobile phone. Most respondents chose to recharge a mobile phone when it reached 20 per cent level, accounting for 21.80% while 17.80%, 13.90%, and 14.90% of them chose to recharge at between 30 to 50 per cent respectively.

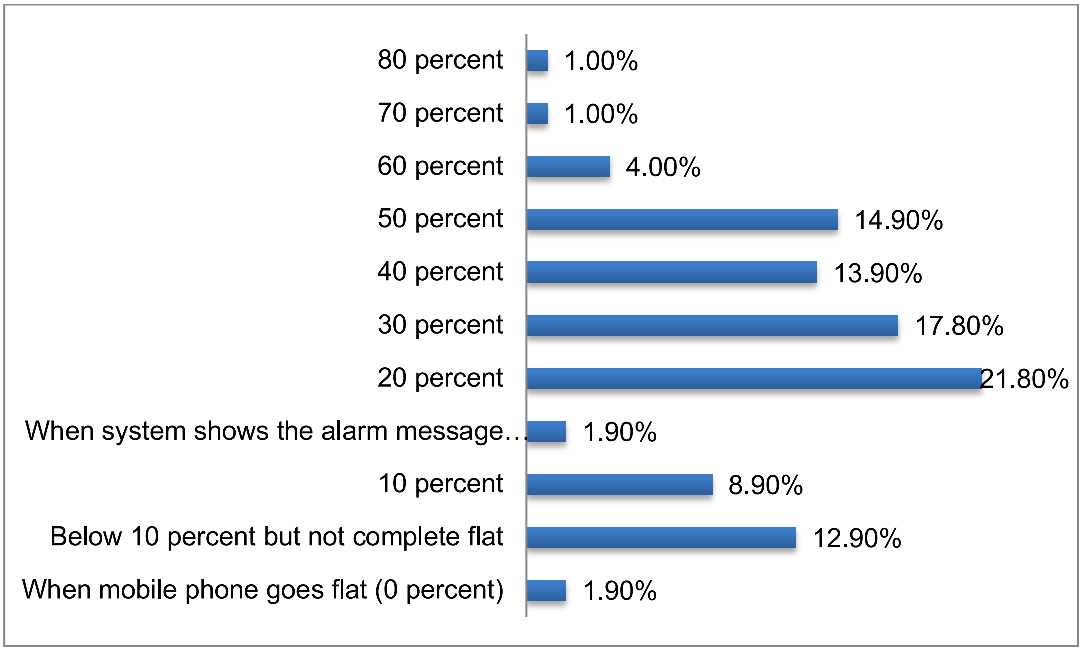


Figure 4.16: Percentage of battery remaining before users decided to recharge a mobile phone in disaster/emergency situation

4.3.7.5 Time to discharge a mobile phone in disaster/emergency situation

Figure 4.17 indicates that 57.30%. of respondents decided to disconnect a recharging mobile phone when they have to go somewhere else while 16.80% preferred a full charge

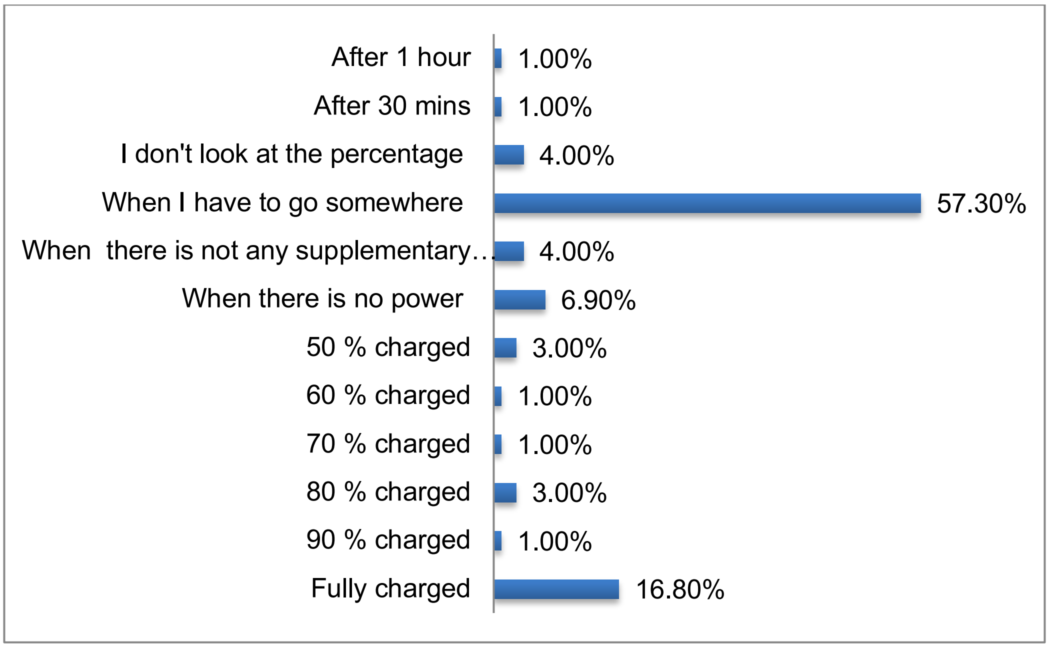


Figure 4.17: Time to discharge a mobile phone in disaster/emergency situation

4.3.7.6 Maximum acceptable time for a mobile phone recharging in disaster/emergency situation

From figure 4.18, 34.70% of the respondents thought that one hour long was the maximum acceptable time to recharge their mobile phone while 24.80% of them preferred half an hour.

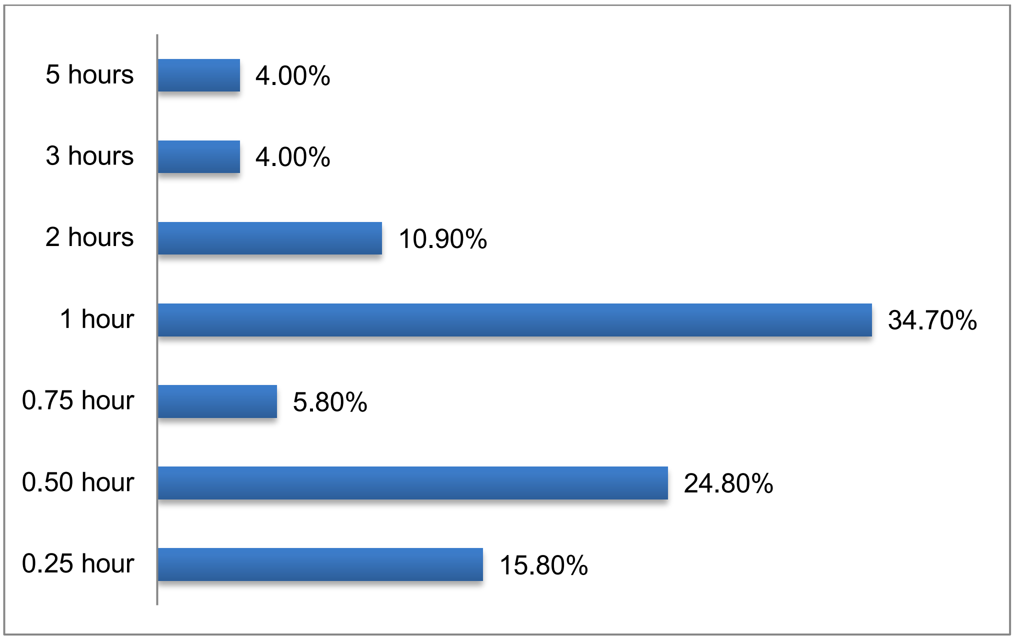


Figure 4.18: Maximum acceptable duration for mobile phone recharging in disaster/emergency situation

4.3.8 Mobile phone usage in disaster/emergency situation (N=101)

The following shows information about a mobile phone usage such as frequency of mobile phone usage, preferred frequency of mobile phone usage, and communication requirement in disaster/emergency situation.

4.3.8.1 Frequency of mobile phone usage in disaster/emergency situation

Figure 4.19 reveals that in disaster/emergency situation, 33.60% and 30.60% of the respondents attempted to use their mobile every few minutes and every half an hour respectively. This is not surprising since during a disaster people might often contact or communicate with other people via a mobile phone to update their status or situation.

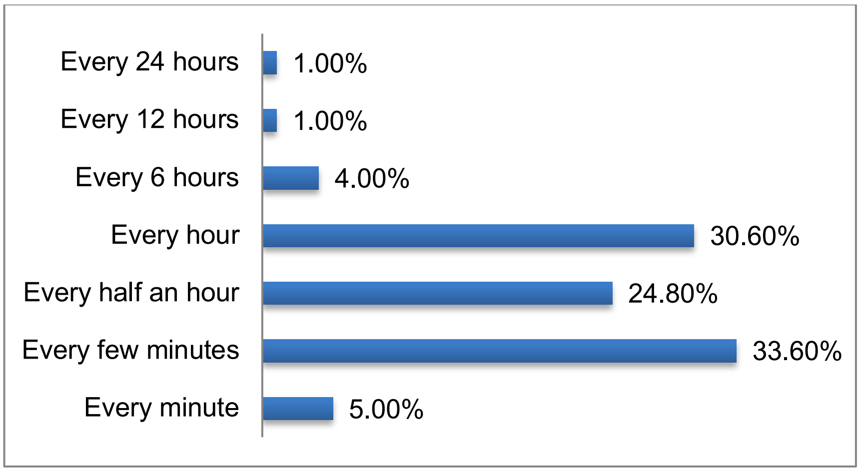


Figure 4.19: Frequency of a mobile phone usage in disaster/emergency situation

4.3.8.2 Preferred frequency of mobile phone usage in disaster/emergency situation

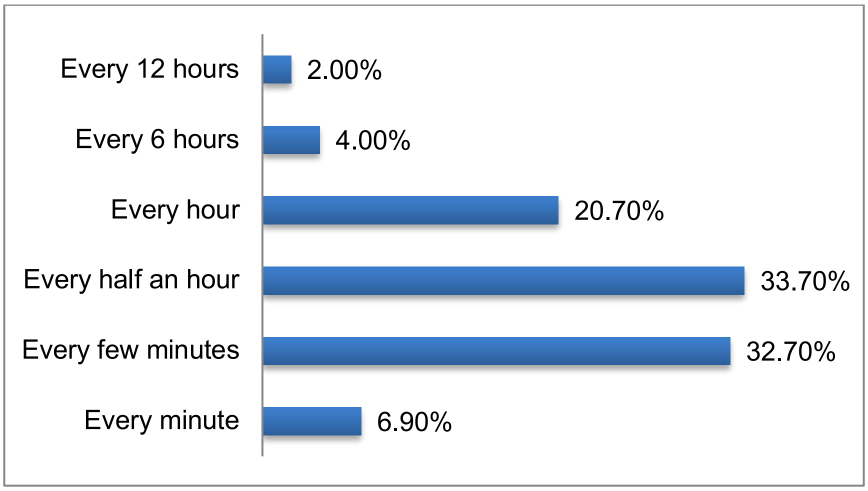


Figure 4.20: Preferred frequency of a mobile phone usage in disaster/emergency situation

Figure 4.20 presents the percentage of required mobile phone frequency usage which indicated that 33.7% and 32.7% of the respondents expected to use a mobile phone every half an hour and every few minutes respectively. This implies that people attempted to use their phone as frequently as possible. This result is significantly related to the data from section 4.3.8.1.

4.3.8.3 Communication service requirement in disaster/emergency situation

Table 4.16 demonstrates the communication service used by 101 participants. The most used communication service was voice communication and SMS at 60.99% and 17.53% respectively. This result reveals that people mostly prefered to talk with other people while an abnormal situation occurs.

Table 4.16: Average percentage of communication service requirement in disaster/emergency situation

Service	**Percentage (%)**
Voice communication	60.99
SMS	17.53
Voice mail	3.68
Maps and location service	8.86
File sharing	4.87
Other	4.07
Total	100.00

4.3.9 Factor preventing or impeding mobile phone usage in disaster/emergency situation (N=54)

This section describes the percentage of factors preventing or impeding mobile phone usage in disaster/emergency situation. There were 54 out of 101 respondents completing the multiple response questions. The respondents could complete more than one answer. Please consider table 4.17 for the conclusion of factors percentage.

Table 4.17 indicates each factor in the percentage of cases. In disaster/emergency situation, the massive 81.5% of respondents were concerned by the rapid battery depletion while 50% were worried by either a long time battery charging and limited charging option. 11.10% chose the failure of network infrastructure. To sum up, a battery life should be enhanced to last longer enough in disaster/emergency situation. This can be dealt by using alternative charging strategies or battery backup which will be discussed in chapter 5.

Table 4.17: The percentage of factors preventing or impeding mobile phone usage in disaster/emergency situation

		Responses		Percent of Cases
		N	Percent	
Factors	Battery goes flat too quickly	44	43.30%	81.50%
	Battery takes too long to recharge	27	26.00%	50.00%
	Limited charging options make recharging difficult	27	26.00%	50.00%
	Failure of network infrastructure	6	5.80%	11.10%
Total		104	100%	192.60%
Dichotomy group tabulated at value 1.				

4.4 Discussion

This section discusses the survey results regarding a mobile phone recharging and usage behaviour in general situation and disaster/emergency situation. It also discusses the results of the comparison between mobile phone recharging in general situation and a disaster/emergency situation. Finally, the discussion of user behaviour primary predictor of a mobile telephone battery life is to be considered in this section.

4.4.1 Discussion of results based on mobile phone recharging and usage behaviour in general situation

Considering a mobile phone recharging in general situation, the survey included the questions divided into three categories as follows:

The question about a mobile phone battery life including the duration that a mobile phone usually lasts before going flat and the duration of that mobile phone is expected to last before going flat.

The question regarding a mobile phone recharging behaviour including the frequency of a mobile phone recharging, the frequency of a mobile phone going flat before recharged, the percentage of a battery remaining when users decide to recharge a mobile phone, the time to discharged a mobile phone, the duration that a mobile phone takes until it is fully charged and the duration that a mobile phone takes of each recharge.

The question concerning a mobile phone feature usage including the frequency of mobile phone feature usage and the duration of mobile phone feature usage per day.

4.4.1.1 Question about a mobile phone battery life

The first aim of this study is to find out how long a user's mobile phone can last in general situation. Table 4.5 summarises the responses to question about how long a mobile phone usually lasts before the battery goes flat. It is clear from the responses that 22.20 % of participants stated that the battery life lasting around 22-24 hours or one day would meet their self-identified target battery life in general situation whereas 40.1% of them, according to table 4.6, responded that a battery life lasting around 24-48 hours would meet their self-reported requirement. This was in accordance with an intuition that 24 hours of a mobile phone battery life would be sufficient in general situation.

4.4.1.2 Question about a mobile phone recharging behaviour

A mobile phone recharging behaviour shown in section 4.3.3.3 implied that the respondents frequently recharged their mobile phone once per day (56.40%) which was related to the information that a mobile phone usually lasts mostly one day as shown in section 4.4.4.1. It can be assumed that user behaviour in recharging a mobile phone is once per day. In terms of the level of a battery that will lead participants to recharge their phone, as seen from section 4.3.3.5, most people are likely to recharge during when the battery reaches 1-20 % level which can be converted into a cumulative percentage as 64.2%. This is not the recommended battery level to recharge a mobile. The author (Jary, 2015) suggested that do not charge Li-On battery when it is below 20 % and the appropriate battery level when users should start to recharge their battery ranges from 40 to 80 %. That means people can probably prolong a battery lifetime and keep their mobile phone battery in a good condition in long term.

In section 4.3.3.6, it should be noted that 46.10% of the respondents mostly unplugged their mobile phone when it was fully charged. 28.20% and 18.90% of respondents stated that their reason to do so were that they had to go somewhere and they unplugged when they got up in the morning. When compared to the duration of a mobile phone recharging until it is fully charged as discussed in section 4.3.3.7, it is clear that 29.10% of participants stated that their phone took two hours until it was fully charged. On the other hand, 22.20% of them were not aware how long it takes. For the duration taken in recharging a mobile phone in section 4.3.3.8, 55.60% of the participants decided to charge their cell phone overnight. These groups of question can reflect that the participants prefered to recharge their mobile phone until it was fully charged and left them overnight. In the meantime, for each recharge they were not aware of how long they recharged their mobile phone or at least they might leave it for two hours. This is quite interesting because there have been many reports (GRIFFITH, 2019) (VILLAS-BOAS, 2019) stating that leaving a battery to be charged overnight or keeping it plugged in despite a full charge may cause high-stress or high tension-state to a battery. It has a negative impact on a lifespan of a mobile phone in the long run. In the issue of a mobile phone being flat before getting recharged, it is rather clear that the participants rarely forgot to recharge a mobile phone or may leave it uncharged at least several times a month or once a month.

4.4.1.3 Question about a mobile phone feature usage

In general situation shown in figure 4.11a, b, c, and d, people mostly spent their time on a mobile using voice call, SMS, web browsing, email, social network application. These are common features that they used several times per day. This can be interpreted that a mobile phone usage behaviour may focus on vital communication. On the other hand, when compared with entertainment features including camera, games, video and audio player and audio and video streaming. Users mostly used less than weekly or never except for the camera which was used between most days and a few times per weeks. In comparison, figure 4.12a, b, and c showed cumulative percentage of the duration of mobile feature usage over a day, the majority of participants still used their vital communication features more than entertainment features. At the present, the latest report (BroadbandSearch, 2019) showed that people are incline to use social media in 153 minutes per day in 2019 compared to 2018 which was 144 minutes. This means that voice communication is probably replaced by social media in the near future. The trend shirts from using vital communication to social media applications. This increasing popularity is still a factor that rapidly depletes a mobile phone battery. Another thing acquired from these sections is that a mobile phone usage behaviour directly affects a battery runtime.

For the relationship between a mobile phone feature usage and mobile phone duration, it is clear that these two variables are correlated. However, there was a limitation to analyse the data from categorical variables. Those related variables must be converted to interval scale or continuous data since the correlation technique employs normal distribution criteria. a normal distribution must be tested before selecting the suitable statistics. It is shown that the data set is not well modelled by the normal distribution. Therefore, Spearman's correlation was considered to analyse relevant variables. The results showed that there were correlations between the duration of a mobile phone battery after recharged and the total duration of mobile phone features usage over a day (sample size = 117) showed that the correlation was significant at the 0.01 level (2-tailed), p-values = 0.01, significant = 0.000. Also, we analysed in terms of the correlation between the duration of mobile phone battery after recharge and the duration of mobile phone feature usage when connected to the Internet or Wi-Fi (sample size = 117), which showed that correlation is significant at the 0.01 level (2-tailed), p-values = 0.01, significant = 0.000.

To sum up, duration of a mobile phone battery depends on the duration of mobile phone feature usage; particularly when a mobile phone was connected to Wi-Fi or the Internet (Kalic et al., 2012). A mobile phone battery life is most likely to deplete quickly and people tends to recharge it frequently. Also, in section 4.3.4.4 people mostly spent their time on vital communication features more than entertainment features which can be classified by battery use and by time. The results showed that it was not quite different in terms of battery use and time usage. For entertainment features, 37.05% of the participants considered battery use and 33.04% of them considered time. Meanwhile, for vital communication features, 52.17% chose battery use while 56.17% chose the time factor.

4.4.2 Discussion of results, based on mobile phone recharging and usage behaviour in emergency/disaster situation

Based on a mobile phone recharging behavior in a disaster/emergency situation, the survey contained the questions which can be divided into three groups as follows:

The questions about a mobile phone battery life in terms of the duration that a mobile phone needs to last before the battery goes flat and the minimum runtime requirement of a mobile phone battery life.

The questions regarding a mobile phone recharging behaviour including the frequency of mobile phone recharging, the percentage of battery remaining before users start to recharge their mobile phone, the time to discharge a mobile phone, and maximum acceptable time for mobile phone recharging.

The questions about mobile phone usage including the frequency of mobile phone usage, the preferred frequency of mobile phone usage, communication service requirement, and factors preventing or impeding mobile phone usage in disaster/emergency situation.

4.4.2.1 Question about mobile phone battery life in disaster/emergency situation

The starting point was to seek to fill the key evidence gap around the perceived battery life required for a mobile telephone to be useful and effective during an emergency or disaster. By useful and effective, it means that the mobile phone should have sufficient battery charge to be used when required during a disaster. This means that it must have sufficient battery life to sustain an operation when the opportunities to recharge become available. To answer this question, the survey included the following question regarding "The duration that a mobile phone needs to last before the battery goes flat and the minimum runtime requirement of mobile phone battery life", shown in section 4.3.7.1 and 4.3.7.2. Table 4.14 and table 4.15 summarise the responses to this question. It is clear from the responses that 44.50% of participants, as shown in table 4.15, stated that a battery life of at least 24 hours would satisfy their self-identified target battery life for a mobile phone in an emergency situation and that a battery life of 24 - 48 hours would meet the self-reported requirement of 23.70 and 22.80% of the participants. This agreed with an intuition that at least 48 hours or not over 72 hours would be sufficient in disaster/emergency situation.

4.4.2.2 Question about mobile phone recharging behaviour in disaster/emergency situation

According to the previous section discussing about how long the participants expect a phone battery to last, it is revealed that mobile phones are able to last in disaster/emergency for around 24 hours which was absolutely not long enough while a disaster struck. In terms of the level of battery that people will start to recharge their mobile phone, the survey in section 4.3.7.4 showed that 68.40% of participants started charging when the level of batter reached 20 to 50 per cent. Moreover, figure 4.17 presented that 57.30% of the respondents decided to unplug their mobile phone when they had to go somewhere else. Therefore, people's mobile phones are not likely to be fully charged when a disaster strikes (since they often occur without warning), and that as a result the average expected time a phone can last before going flat will in fact be only some percentage of the self-reported battery life as shown from the survey results.

In term of frequency of mobile phone recharge in section 4.3.7.3, the results were presented in figure 4.15. It is shown that people were inclined to recharge their mobile phone once, twice, and thrice or several times per day for 26.70%, 20.80% and 14.90% respectively. This means that in disaster/emergency situation there might be power shortage impeding the recharge of a mobile phone. This was assumed from the number of a mobile phones that were charged twice per day and three or more times per day were almost equal to once per day.

It is this "discounted" figure that should then be compared with the 48 hours figure. From this result, there is the duration gap about 24 hours based on response mobile phone battery life usually last 24 hours in disaster/emergency situation to fulfil to 48 hours. As a result, a mobile phone charging behaviour can make a significant impact on how long a mobile phone can last before going flat. In disaster/emergency situation, people should therefore recharge their mobile phone at low percentage-level as possible or attempt to keep their mobile phone in maximum level as much as they can recharge a mobile phone frequently. One other thing, the best way to keep a mobile phone last longer is to turn it off and turn it on only during the significant event. Therefore, a power supplementary or battery backup is an alternative solution to be able to increase battery life of a mobile phone (see chapter 5 for further information)

4.4.2.3 Question about mobile phone usage in disaster/emergency situation

When disaster strikes, it is crucial to use communication service to communicate during that situation. People are most likely to frequently use their mobile phone as main communication device. The results shown in section 4.3.8.1 showed that participants use mobile phone every few minutes, every half an hour, and every hour showing in percentage at 33.60%, 24.80% and 30.60% respectively. On the other hand, the preferred frequency of using a mobile phone in section 4.3.8.2 showed that 32.70% of participants chose to use it every few minutes, 33.70% for every half an hour and 20.70% for every hour. From these results, it is clear that the frequency of a mobile phone usage is likely to be every few minutes and every half an hour. The frequent use of a mobile phone affects battery life directly. It is inevitable to recharge a mobile phone frequently because a mobile phone battery drains rapidly. Therefore, in disaster/emergency situation people should be concerned about a mobile phone usage and a mobile phone recharging behaviour to keep a mobile phone last long enough.

For the issue of useful communication service in section 4.3.8.3, the most popular communication services chose by the respondents were voice call and SMS, accounting for 60.99% and 17.53% respectively. Both services are fundamental function for general mobile phone. Absolutely, it depends on telecommunication service available. Provided that a disaster strikes, a mobile phone infrastructure system might be damaged or malfunction which lead to mobile phone functions being unable to operate in this situation. Therefore, alternative communication is necessary to be used as optional communication. That means mobile ad hoc network like The Serval Project can temporarily replace major communication system.

From question in section 4.3.9, the factor preventing or impeding a mobile phone usage in disaster/emergency situation chose by 54 out of 101 participants or 81.50% was that the battery goes flat too quickly. This means a mobile battery life is very crucial in disaster/emergency situation. Good solutions to tackle with those factors in section 4.3.9 are, firstly, people should be aware to save a mobile phone battery life by not using any service during a disaster or after the event. Secondly, people should provide an alternative charging solution such as battery backup to recharge mobile phone any time. This can help overcome the problems that impede a mobile phone usage in a disaster situation.

4.4.3 Discussion of user behaviour primary predictor of mobile telephone battery life

Further complications arise when it is needed to predict the battery life of the particular model of a phone. Table 4.18 illustrates this, by comparing manufacturer's claims of battery life and talk time, as listed on GSMArena.com.

While there are limitations in the statistical power of these data due to the relatively small sample size (n = 101 by respondent from total n =117 respondents because some model has no information about talk time or standby time, for n = 25 by model of mobile phone), there is no statistically significant correlation between the manufacturer's claimed standby time by model (p = 0.7236) or talk-time by a model (p = 0.5814). No statistical significance was discovered, even when combining a multiple-linear regression considering both factors (p = 0.7549).

This lack of correlation is obvious when the data are plotted in Figures 4.21 and 4.22, with no apparent patterns visible. While standardized comparisons among products of a given class are not without their problems; for example, fuel efficiency standards for cars are often out by between 10% and 50% (Wu et al., 2015), they are still typically predictive of the relative performance of different exemplars. However, here there was no evidence that manufacturer's standby and talk time claims are predictive of the battery life of their products as used by our respondents. When the battery size of the various devices is also considered, there is also no correlation visible in our data (p = 0.6811). This overall picture where the manufacturer's claims and the size of the battery suggests that the impact of these figures are eclipsed by some other factor. From survey results, that factor is simply the pattern of use of devices by users. From the entire sample of n = 117 respondents, it was found that there was a simple linear relationship between the number of hours per day that a user made use of features on their phone, and the battery life of their phone (correlation coefficient = -0.415, p < 0.001), and the number of hours per day that a user made use of Wi-Fi or other internet connectivity from their device (correlation coefficient = -0.420, p < 0.001). All of these correlation results were analysed by Spearman Rank-Order Correlation Test.

To be clear, there was no evidence that the manufacturer's claims of stand-by or talk time for mobile phones, nor the battery size of a mobile phone, are reliable as a general predictor of actual battery life of one model of a mobile phone over another.

That is, on the basis of survey results, this cannot recommend potential purchasers of mobile phones to pay attention to the manufacturer's claimed standby or talk time, or even to the size of battery. End-user behavior is the most significant factor that this research is aware of.

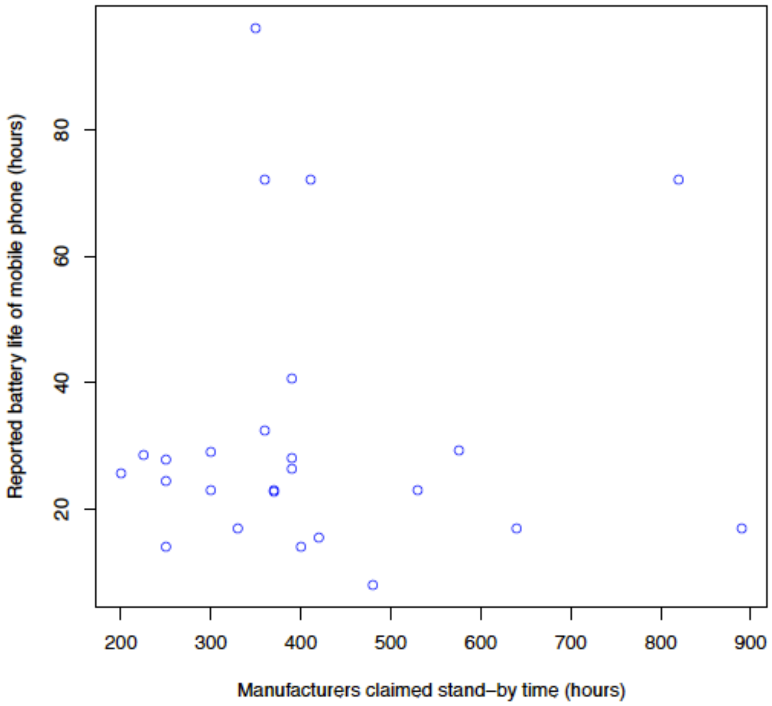


Figure 4.21 Scatter-plot of reported mobile phone battery life, versus manufacturer's claimed maximum standby time

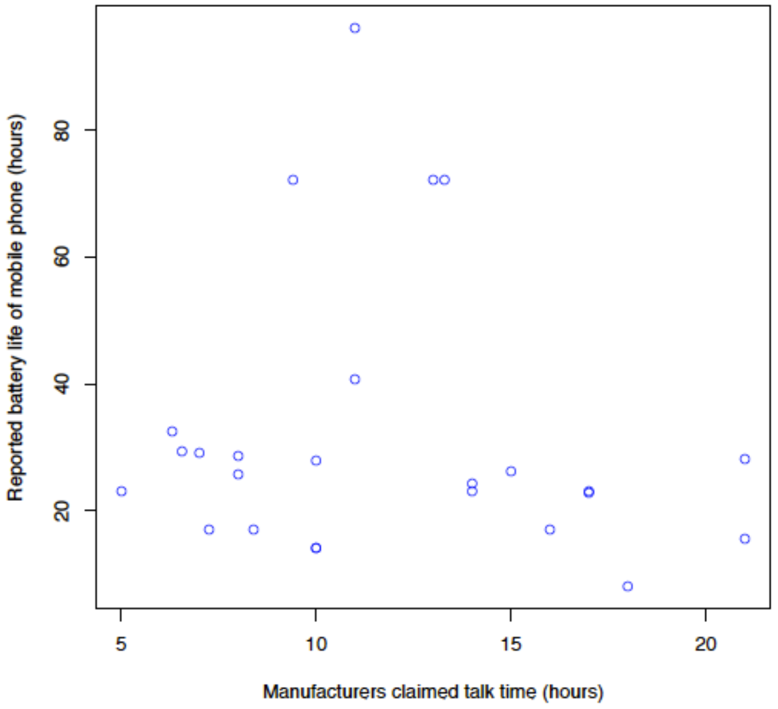


Figure 4.22 Scatterplot of reported mobile phone battery life, versus manufacturer's claimed maximum talk time

These statements must be conditioned by the relatively small size of the sample, both in terms of number of respondents and the number of models of mobile phones considered. Further investigation is warranted in this regard to determine whether these observations apply in general, or whether there is some predictive value in these figures when subjected to deeper scrutiny. It is particularly recognised that asking mobile phone owners to self-report the battery life of their phones is an in-exact science, and that a more rigorous study, where the battery life of various models of phones is directly measured, e.g., through the use of a special application, would be a more appropriate means of obtaining definite data to answer this question.

Table 4.18 shows the comparison between manufacturer's claimed performance and reported performance by respondents. Mean reported battery life obtained from the survey enquiring questions about mobile phone duration usually last before the battery goes flat. In the meantime, reported battery life as percentage of claimed standby time was calculated by comparing between mean reported battery life and claimed stand by time to show how these two values are different in percentage.

Table 4.18 Comparison of manufacturer's claimed performance to reported performance by respondents

Model	**Mean reported battery life (hours)**	**Claimed standby time (hours)**	**Claimed talk time (hours)**	**Reported battery life as percentage of claimed standby time**
iPhone 3GS	23.0	300	5	7.7%
iPhone 4	29.1	300	7	9.7%
iPhone 4S	25.7	200	8	12.9%
iPhone 5	28.6	225	8	12.7%
iPhone 5S	27.9	250	10	11.2%
iPhone 5C	14.0	250	10	5.6%
iPhone 6	24.3	250	14	9.7%
Samsung Galaxy S	29.3	576	6.55	5.1%
Samsung Galaxy S II	17.0	640	8.4	2.7%
Samsung Galaxy S II	40.7	390	11	10.4%
Samsung Galaxy S IV	22.7	370	17	6.1%
Samsung Galaxy S V	28.0	390	21	7.2%
Samsung Galaxy Note	72.0	820	13.3	8.8%
Samsung Galaxy Note II	17.0	890	16	1.9%
Samsung Galaxy Note III	15.5	420	21	3.7%
Samsung Galaxy Alpha	96.0	350	11	27.4%
Samsung Galaxy Grand 2	23.0	370	17	6.2%
Samsung Galaxy Duo	17.0	330	7.25	5.2%
HTC One	8.0	480	18	1.7%
HTC Desire	32.5	360	6.3	9.0%
LG Nexus 4	26.3	390	15	6.7%
LG Optimus G	72.0	411	13	17.5&
Nokia Lumia 520	72.0	360	9.4	20.0%
Nokia Lumia 920	14.0	400	10	3.5%
Sony Xperia Z	23.0	530	14	4.3%

4.4.4 Discussion of effects of the sample size, the selection of participants, and participants' knowledge about the performance of their phone

The targeted respondents for the survey were the volunteers who have had any experience, work, or volunteer in an emergency/disaster environment in Australia. This study paid attention to explore the background of a mobile phone usage behaviour. Specially, the battery runtime of a mobile phone in general situation comparing with disaster situation is necessary. The results can answer the question "What is minimum battery runtime required to sustain communication during typical disaster?" Also, the result can reveal that there is relationship between a mobile phone usage behaviour and battery life, which can answer question, "How does human behaviour affect battery life on a mobile phone?" Therefore, the selection of participants in this study mainly focus on people who only have worked or volunteer in an emergency/disaster environment.

This study did not focus on the background knowledge about the performance of participants' phone. Because the questionnaire enquired about basic questions which was not involved in the knowledge of user about their phone performance at all. Therefore, the knowledge of a phone performance is not significantly related to mobile phone usage behaviour. However, there are other factors that are significantly related to a mobile phone usage behaviour which are gender and age. This study (Osman, Talib, Sanusi, Shiang-Yen, & Alwi, 2012) showed that male respondents tend to use a mobile phone more than female respondents. Also, younger people mostly spend their time on a mobile phone compared to the older people.

In terms of the sample size in this study, it is interesting that the number of sample size, 117 participants, is rather small. Normally, a large sample size should be better than a small one. But, there were not many responses from volunteers to answer the survey. Fortunately, Spearman's correlation was used to analyse the association between the duration of mobile phone batter after recharged and the duration of a mobile phone usage. The results showed (p-values = 0.001) in table 4.12 and 4.13. This p-values demonstrates clearly that the sample size still resulted in sufficient statistical power to resolve the key questions that were posed. This can be acceptable and answer the question that human behaviour affects a mobile phone battery life significantly.

4.5 Conclusion

This chapter described, presented, and discussed the survey results regarding human factors on a mobile phone battery life both in general situation and in disaster/emergency situation.

A decent mobile phone battery life in general situation should last around 24 hours. However, the respondents expected at least 48 hours as it was greatly convenient for them. From survey results, it can be assumed that a mobile phone battery life directs variation to frequency of mobile phone recharging. If a mobile phone was frequently recharged, it is clear that mobile phone battery life will be depleted quickly.

In general situation, a mobile phone was intentionally recharged overnight and it may be unplugged when it was fully charged or the users go somewhere else or get up in the morning. This recharging behaviour is normal. Nevertheless, if people a aware of how to charge their mobile phone correctly, it will help keep the Li-On battery in a good condition for a long period of time.

A mobile phone features can be classified into two groups including vital communication and entertainment features. Users mostly used vital communication features more than entertainment features. However, mobile phone features connecting to Wi-Fi or the Internet can affect a mobile phone battery life because a Wi-Fi or the Internet function depletes battery life rapidly. This suggests that people should be concerned about a mobile phone feature usage each time if they need to save their mobile phone battery life.

In disaster/emergency situation, the minimum of mobile phone battery duration was 24 hours. In the meantime, a battery life of mobile phone should last at least 48 -72 hours, so it will meet of users' expectation in a disaster/emergency situation. For a mobile phone recharging behaviour in a disaster/emergency situation, the battery level that people will start to recharge can also affect a battery life. People should be aware to recharge their mobile phone appropriately when the battery reaches below the specific level. The battery backup or supplementary should be applied in a disaster/emergency situation to recharge mobile phone. In terms of the relationship between talk time and stand by time from manufacturers compared to the reported battery life of mobile phone, there was no correlation or significant in statistical term since users used their mobile phone depending on a situation and environment. This outcome can emphasise that human behaviour affects a mobile phone battery life.

To sum up, there are four main approaches that are possible to solve the problem of a phone battery life, two on the energy supply side and the other two on the energy consumption side: (1) increase the battery storage of mobile devices; (2) increase the opportunities for recharging; (3) improve the fundamental energy efficiency of mobile devices: and (4) alter end-user behaviour so as to reduce energy consumption on a mobile phone.

The next chapter will describe which alternative phone charging strategies are appropriate in disaster situation. Also, cost analysis model is proposed in order to wisely choose the alternative phone charging solutions.

CHAPTER 5: ALTERNATIVE PHONE CHARGING STRATEGIES IN DISASTER SIUTATION

5.1 Introduction

From the previous chapter, the researcher has established that the battery life of mobile phones is insufficient to meet the self-reported needs of emergency and disaster response personnel. In this chapter, it focuses on methods for recharging mobile phones without reliance on main electricity supply. That is to say, this chapter explores the feasibility of obtaining the necessary endurance of mobile phones during disasters by identifying means of recharging them as required. Also, it aims to answer the question, “What is supplementary energy required to a mobile phone and disaster communication?”

The remainder of this chapter presents criteria of alternate energy solutions for mobile phone charging. Also, survey results from people likely using alternative sources is to be presented in this chapter. A search of academic literature using the following search terms on Google Scholar, Science direct, Scopus, IEEE, ACM and CiteSeer failed to identify any academic literature. This chapter contains mostly various references from technology news and relevant information about a mobile phone charging from webpage instead.

5.2 Supplementary energy for mobile phone

Currently, there are many supplementary energy sources in the world being able to transform different energy form into electricity form such as solar, wind, natural gas, fuel, thermal, hydropower, and so on. However, the aforementioned energy sources have to be wisely chosen in each appropriate situation. In disaster or emergency situations, renewable energy sources are an option to increase operation of mobile phones as long as possible. The possibility of using mobile phones in such situations tends to massively increase because everyone needs to communicate or inform situation to other people. Unfortunately, the big trouble of mobile phones is battery life which is unable to operate for longer than one day or several days depending on a mobile phone specification. Consequently, a mobile phone must be frequently recharged from main source as much as possible due to unpredictable situation. Nevertheless, in the disaster or emergency contexts, it is difficult or has fewer opportunities to access electrical power supply. Alternative phone charging is considered to use in such situation.

Before exploring categories of mobile phone charging in the next section, this thesis will classify major related energy form which is able to be applies in recharging mobile phone as follows (Sharma & Kar, 2015):

Solar energy (Kumar, Richhariya, & Sharma, 2015) mainly consists of two categories: solar thermal and photovoltaic. The objective of solar thermal is to converse sunlight to heat. On the other hand, photovoltaic converts sunlight to electricity. The solar mobile phone charging relies on the photovoltaic technology in order to accomplish such purpose. The advantages of solar energy can be divided into three aspects: standalone system, renewable source energy, and less maintenance. However, there are some disadvantages of this technology. It is costly, takes up a large land area, and requires battery replacement.

Wind energy (Warudkar, 2015) is one of an alternative renewable energy that is clean, plentiful, widely distributed, no gas emission, and inexhaustible. There are two types of wind machine at the present: horizontal-axis wind turbine and vertical-axis wind turbine. The popular type of wind turbine implemented in transforming wind to electricity is horizontal-axis wind turbine. The advantages of wind power are that it is free and convenient to install. However, the disadvantage is that it depends on strength of wind which is unstable and, thus, the energy is not constantly generated.

Biomass is the energy deriving from humans, plants, animals, or marine life. It mostly includes firewood, alcohol, methane, and liquid fuel deriving from reprocessing of kitchen oil or engine oil (Martín, 2016). All of these sources are to transform thermal energy or heat to electricity by particular transformation device.

5.3 Categories of mobile phone charging

At the present, there are many types of mobile phone charging in the marketplace. To clearly elaborate this topic, this section will be divided into three major categories as follows:

5.3.1 Ordinary mobile phone charging

The definition of ordinary mobile phone charging in this thesis is that "people can access, afford, or use this charging technology in daily life from general market and provided mobile phone."

5.3.1.1 Wall Charger

This device comes with a mobile phone. People can recharge their mobile phone by plugging it into general power outlet anywhere provided. Currently, there are many products providing various Universal Serial Bus or USB ports together with wall charger for supporting mobile phone recharge more than one device at the same time.

5.3.1.2 Laptop or desktop computer providing USB port

This is a common alternative to charge a mobile phone with laptop or desktop computer. Because, basically, computers usually provide Universal Serial Bus: USB port to support peripheral device working with those computers, regardless of any mobile phone charging issue. Providing a USB port is an added benefit. USB port can be approximately divided into five versions as shown in table 5.1 (Lendino, 2016) (Universal_Serial_Bus_Organisation, 2017) (Battery_University, 2017).

Table 5.1: USB specification

Version	Voltage/Current
USB 1.0	5V/0.5A
USB 2.0	5V/0.5A
USB 3.0	5V/0.9A or 5V/1.5A
USB 3.1	5V/1.5A or 5V/3A
USB type C	5V/1.5A or 5V/3A

Nevertheless, there are many USB chargers providing amount of unit of current differing from a standard USB port such as 5V/2.1, 5V/2A, 5V/1.8, or 5V1A. It is negligible because it does not directly affect a mobile phone charging.

5.3.1.3 Backup battery known as power bank

There are a variety of power bank products sold in a computer or mobile phone shop. People can enjoy the backup battery from a wide array of sizes and capacities. The specific units in terms of battery storage are milliamp-hour (mAh) and Watt-hour (Wh). The meaning of mAh (GSMArena, 2017b) is how much electricity is charged to battery in unit of electric charge in one thousand of an ampere-hour. In terms of Wh, it means that the unit of energy is equivalent to power (Wattenhofer, Li, Bahl, & Wang) multiplied by time (hours). It measures the amount of work generated or performed, which Watt-hours is the amount of energy at a specific period of time (MyEnlighten, 2017). Power bank comes with various capacities ranging from 2,000 mAh to 30,000 mAh or more depending on manufacturers (Best-Power-Banks, 2017). How many times a power bank can be charged depends on a battery capacity. For example, the power bank with 9,000 mAh capacity and a mobile phone with 1,500 mAh battery capacity can be calculated by using equation 5.1 (Cable_Click, 2014) as below:

$$\text{Power bank rating (mAh)} \times \text{Efficiency x Device depletion} \div \text{Device capacity (mAh)} \qquad \text{(Equation 5.1)}$$

Where

- Power bank rating is the capacity of a power bank (mAh)
- Power bank efficiency rating is transferred rate of power (80 % or 0.8 by average)
- Device depletion is a state of battery or wasted charging potential (80% or 0.8 by average)
- Device capacity is the capacity of a mobile phone (mAh)

From above example and the equation 5.1, the result is 9,000 mAh × 0.8 × 0.8 ÷ 1,500 mAh = 3.84 times by average to recharge a mobile phone. The equation 6.1 can be applied to other charging strategies in the following sections.

5.3.2 Commercial mobile phone charging in disaster or emergency situations, off-grid and rural area

The meaning of a mobile phone charging is that people can recharge their phone in some place, both indoors and outdoors, but mostly outdoors, such as in a particular area without electrical supply or in disaster or emergency situations. There are various commercial mobile phone charging strategies in specific area which can be divided into five categories as follows:

5.3.2.1 Solar charging solutions

This solution transforms sunlight to electricity, collecting on backup battery. This method mainly consists of solar panel and battery capacity (EasyAcc, 2016). Another factor to consider when deciding to choose this charging strategy is that it must concern about Watt on solar panel. Using high watt on large solar panel can guarantee that a mobile phone can be recharged faster than using a small panel with low Watt. However, a large solar panel is also costly in the same way. For the backup battery, it depends on its size and capacity to connect to solar panel. Output power must be taken into consideration when it comes to charging a mobile phone. In case users need to charge quickly, they need to consider about number of output current such as, 1A, 2.1A or more.

Types of solar portable panel for mobile phone can be classified into three types including CIGS, Monocrystalline, and Polycrystalline (Pierotti, 2016) (Maehlum, 2015).

- CIGS: Copper Indium Gallium Selenide is a thin film solar cell. It is portable, flexible and cheap, but tend to degrade quickly.
- Monocrystalline is a panel which is rugged and durable than CIGS. It is made from black silicon crystal. The efficiency is better than CIGS in normal sunlight as well as polycrystalline. Nevertheless, its performance is slightly less efficient than CIGS in low light or cloudy situation.
- Polycrystalline does not differ from monocrystalline except its bluish hue. It is normally implemented in bigger solar manufacturers to save money. In terms of portable usage, monocrystalline is popular than polycrystalline as a portable solar panel.

5.2.3.2 Kinetic, hand crank, and thermoelectric charging solutions

There are many thermoelectric charging solutions in commercial market. Thermoelectric device converts to electric power, depending on different temperature to accelerate mobile phone charging. In this study, it can be classified into two main devices as follow:

- Pot and kettle charging is boiled water converting thermo to electricity. One interesting product is the power pot, which claims its USB current output at 5W, 5V/1A (Werner, 2013).

- Bio charging usually generates electricity from burnt wood. One product is called Campstove produced by the Biolite company (BioLite, 2017), claiming its USB current output is at 2W/5V by average.

In terms of kinetic and hand crank solutions, there are two solutions based on related and similar techniques to recharge mobile phone in the same way. The movement technique is implemented and contemplated to generate electric power. The disadvantage of these solutions is it spends much time to recharge a mobile phone depending on movement or cranking.

5.3.2.3 Bicycle dynamo-based charging solutions

Dynamo is an electrical generator producing direct current or DC to any device supplied by DC power (Edison_Tech_Center, 2014). Nowadays, it has been also implemented to recharge a mobile phone. There are mainly three components including dynamo or generator hub, USB charger kit, and battery backup (ALLEN, 2013). This method allows a device to use electric power to directly recharge a mobile phone via USB charger kit or collet power in battery backup. It depends on the usage.

5.3.2.4 Motor vehicle charging solutions

This solution is very convenient to recharge a mobile phone in a car or even a motorbike. Normally, a battery in a car or a motorbike provides DC electric voltage during 6V-24V. Therefore, users must provide USB car charger to plug it in to their car. As for a motorbike, users have to provide USB port socket charger plugging onto a motorbike battery in order to charge their mobile phone. The intention of USB car charger (Fitzpatrick, 2015) and USB port socket charger for a motorbike (Hinchliff, 2014) is to provide USB socket and convert high DC voltage to 5V or 3.3V, depending on a mobile phone voltage.

5.2.3.5 Wind turbine charging solutions

The concept of wind turbine charging is based on electrical generator; blade was spin by wind power to generate electrical energy. In terms of mobile phone charging, it is related to kinetic charging because it uses the concept of movement energy to convert electricity. For example, a portable wind turbine based on mobile phone recharging is Hymiwind product (Layton, 2009). Users can attach this product with a bicycle or a motorcycle while riding to somewhere for recharging a mobile phone. This product is not costly, still requires much time to recharge owing to the production of low Watt output. Besides, there are two prominent products which are trying to develop a charging solution from wind power which are Trinity turbine (O'callaghan, 2014) and Micro wind turbine (Yam, 2016). However, it is high-priced for mobile phone recharging. Also, every charging depends on wind force and circumstance.

5.2.3.6 Trade off about commercial mobile phone charging strategies, disaster or emergency situations, off-grid and rural area

Table 5.2 (Flipsy.com, 2015) summarised advantages and disadvantages of five mobile phone charging strategies. It should be noted that the motor vehicle charging solution is more economical when compared to other solutions. In each solution, it depends on the usage and situation. The hand crank method is suitable for emergency or disaster situation because it does not require addition device to recharge a mobile phone other than a hand crank device and manual power.

Table 5.2 Advantages and disadvantages of each mobile phone charging strategies

Mobile phone charging strategies	**Advantages**	**Disadvantages**
Solar charging	- Portable - Easy to access energy source from the sun anywhere - Various panel size to decide	- Depending on sunlight - Overcast condition - Period of time to recharge phone, depending on panel size - Not efficient all the time
Kinetic charging	- Portable - Unlimited power source, depending on movement - Appropriate to emergency or disaster situation	- No efficient and long time period to charge a mobile phone - Manual power requirement

Table 5.2 Advantages and disadvantages of each mobile phone charging strategies (continued)

Mobile phone charging strategies	**Advantages**	**Disadvantages**
Hand crank charging	- Portable - Recharge anytime when required - Suitable for emergency or disaster situation	- Spend much time to charge mobile phone - Manual power requirement - It must crank while charging mobile phone, if there is battery backup
Thermo electric charging	- Suitable while camping or cooking	- Water or wood and heat source required
Bicycle charging	- Portable - Charge mobile phone while riding bicycle	- Bicycle required and not charge when you do not ride a bike. - Special adapter required - Expensive cost for starter kit (Dynamo kit)
Motor vehicle charging	- Portable - Low cost	- Depending on a battery of a motor vehicle
Wind charging	- Free charging where wind is available	- Depending on wind power to charge battery - Expensive cost for specific product - Depending on position charging to catch the wind

5.3.3 Alternative innovation of mobile phone recharging

This section will discuss the alternative charging methods in terms of their conceptual idea, innovation, and products currently available in the market.

5.3.3.1 Radio frequency charging solutions

Radio frequency or RF charging technique can harvest energy while phone communicates by transmitting or receiving to the air through other devices. It can convert RF signal to direct current which is enough to supply mobile phone. There are commercial and prototype products in the market. Freevolt technology (Woollaston, 2015) and Nokia lab technology (Habitat, 2017) are example of RF phone charging at the moment.

5.3.3.2 Wireless charging solutions

Wireless charging solution (Proxi, 2016) uses electromagnetic field to transfer electricity to receiver device from transmitter device to charge battery. It uses resonant inductive coupling to transmit low-power signal between two devices. Generally, on the receiver side is a mobile phone which has a receiver coil to communicate with a transmitter coil at a source device (Hildenbrand, 2017). The wireless charging method takes time to recharge when compared with the regular charging method. At present, there is a variety of brands offering a wireless charging feature with a mobile phone to support this charging solution (Hill, 2016).

5.3.3.3 Fuel with water charging solutions

The concept of fuel with water charging uses hydrogen from water to react with fuel-cell charger (Gibbs, 2013) to generate electric power supplying to a mobile phone. Technically, hydrogen gas and oxygen from the air react with water to produce one oxygen and two hydrogen atoms: H2O. Then, this chemical energy releases atoms to react with a fuel cell which pushes ions from one electrode to many electrodes like regular battery. This product (Morley, 2016) claims that it is sufficient to recharge a mobile phone and prolong the battery life for approximately 10 hours per one fuel-cell kit. One other charging solution is a plant charging (Mora, 2016), which uses micro-organic biological activator with electrical circuit that is able to function as a fuel cell. Instead, this idea employs water in small tray to plants. Likewise, this solution needs water to react with activator to produce oxygen and hydrogen. Then it produces ions from one electrode to the other to generate electricity for a mobile phone.

5.4 Criteria assessment of alternate energy solution for mobile phone charging in disaster and emergency situation

Most of this section was from this paper (Kongsiriwattana & Gardner-Stephen, 2016a), it was contemplation about assessment criteria of mobile phone charging, especially in disaster and emergency situation.

Since the primary objective was to support effective communications in disaster and related situations, the criteria generation process sought to understand the key metrics of relevance. Although more sophisticated criteria were considered, in the end it was concluded that the most universally relevant criteria were those pertaining to purchase cost, the amortized cost per device recharged, and the number of devices that can be recharged per unit time. For simplicity, criteria pertaining to shipping, e.g., weight and volume of each unit, as well as the presence or not of hazardous materials, such as lithium batteries and/or flammable fuels, were excluded.

To calculate the metrics against each criterion, the following approach was used.

5.4.1 Criteria 1: Purchase Cost

The purchase cost of an alternative energy source is simply its purchase cost, generally in US dollars.

5.4.2 Criteria 2: Number of devices that can be charged per day

The number of mobile devices that can be charged per day is based on a nominal mobile device with a 5Wh battery with 80% charging efficiency (Communication, 2005), based on a survey of mobile devices available to the authors. That is, it is based on being able to supply 5Wh ÷ 80% = 6.25Wh to the device. The maximum energy, which can be supplied by a solution per day is divided by 6.25 Wh. For devices with larger batteries, a simple linear factor can be applied.

The energy supply per day is the minimum of:

1. The amount of energy that the solution can output per day
2. The amount of energy that it can gather for output per day

In calculating the energy output per day, it simplifies the calculation by considering it in terms of nominal USB ports, since most mobile telecommunications devices today are able to be recharged from a USB port, and for those that cannot, a simple linear relationship can be calculated. For USB ports it is considered devices that have one or more 0.5A, 1A or 2A USB ports.

For 0.5A USB ports, the port can carry 0.5A × 5V = 2.5V A (Equation 5.2)

It is assumed that mobile devices can be modeled as simple resistive loads, and thus the Power Factor = 1.0, and thus each 0.5A USB port will carry 2.5V A × 1.0 = 2.5W. 1A USB port will carry 1A × 5V × 1.0 = 5W, and 2A USB port will carry 2A × 5V × 1.0 = 10W, which is correspondingly higher. Throughout this section, we use 0.5A USB port as calculated example of each solution. We further assume that a rational user of an energy supply solution requires some sleep and, from our own experience, will likely have numerous other distractions during any given 24 hours of an emergency or disaster response. Therefore, it is assumed that within 24 hours there will be merely 16 hours that are usable for charging the devices. This includes making allowance for when devices are not rotated on the charger in an optimal manner, i.e., removing a device as soon as it is fully charged and replacing it with another.

Thus, a 0.5A USB port can deliver 2.5W × 16hours = 40Wh. Applying the nominal 6.25Wh required to recharge one device. It is found that a single 0.5A USB port can be used to recharge 40Wh ÷ 6.25Wh = 6.4 devices per day. Calculating energy input is more complicated as it should take the various losses in the path into the consideration. This varies based on the type of device under consideration. In all cases, it is assumed that most mobile devices are only able to draw at most 2A from a USB port. Consequently, while some solutions may offer more current, that additional current is effectively unusable.

5.4.2.1 Solar Charging Solutions

For solar charging solutions that do not track the sun, it must allow a factor for the derating of the solar panel due to it not pointing directly at the sun. To correct this, it applies a factor of 70% to the nominal output of the panel (panel factor) (Maehlum, 2013) (Home_power, 2017), to take into account suboptimal pointing. This is based on a sampling of the claims in difference in output between fixed panel and dual-axis tracking solar installations. It is impossible to compute an exact value, because it will depend on the orientation of the particular solar installation.

It is further assumed that a solar panel will produce for only 8 hours per day on average. This may be over generous, particularly for the weather in crisis and disaster situations, where the possibility may be as low as zero. Any error in our selection of this approximate figure will be common to all calculations for devices in this class, and therefore will have no effect on their relative cost. Of the energy captured by the solar panel, it is assumed that storing this into the battery will have an efficiency of approximately 70%, unless the device uses a maximum power point tracker (MPPT) (Northern_Arizona_Wind&Sun, 2017), in which case it applies a factor of 80%, reflecting the higher efficiency of such devices. It is assumed that the low-cost consumer-grade solar charging solutions is not equipped with an MTTP and, therefore, 70% figure for the storage factor was used. Finally, it is assumed that the battery and output side of a solar charging solution will have an efficiency of 80% (Solar_Facts, 2016) (retrieval factor). Thus, it is computed the total energy that can be made available by a solar charging solution as figure 5.1 and equation 5.3:

$$= \text{panel rating W} \times 8\text{hours} \times \text{panel factor} \times \text{storage factor} \times \text{retrieval factor}$$

$$= \text{panel rating W} \times 8\text{hours} \times 70\% \times 70\% \times 80\%$$

$$= \text{panel rating} \times 3.136\ \text{Wh} \qquad \text{(Equation 5.3)}$$

* Panel rating = Input power of solar panel

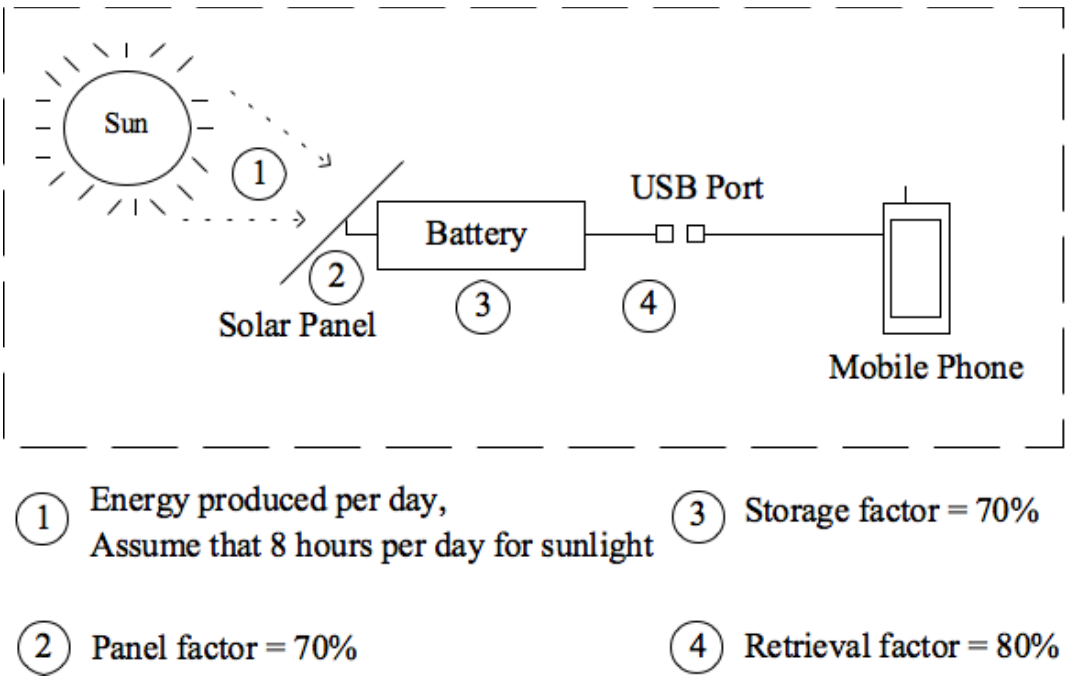


Figure 5.1: Total energy from solar charging solution

5.4.2.2 Kinetic, Hand-Cranked and Thermoelectric Solutions

For Kinetic, Hand Crank, and Thermoelectric solutions, it is assumed that these methods have no battery, but simply provide one or more USB charging ports. For thermoelectric solution which can generate electricity from heat (to be precise, from differences in temperature), it is assumed that this alternative can be used for 16 hours per day. The logic here is similar to that described previously in that people require sleep, are typically busy with many tasks, and that it is unreasonable to expect that an operator will be 100% optimal in their handling of the recharging of devices, i.e., replacing devices on the charger as soon as the previous device is fully charged. Any error in this reasoning will only have a modest impact on the absolute cost of each device, and no impact on their relative cost as any such error will have been applied to all such devices. Since these devices typically are rated on the output power at the USB port, the energy supply per day is simply in equation 5.4:

$$= \text{output power rating W} \times 16\text{hours}$$

$$= \text{output power rating} \times 16\text{Wh} \qquad \text{(Equation 5.4)}$$

Hand cranks and other kinetic chargers can only be used for 4 hours per day, reflecting the need for substantial manual labor to drive them, and we thus compute the available energy per day to be 4/16 = of that of thermoelectric solutions. It is shown in equation 5.5:

$$= \text{output power rating W} \times 4\text{hours}$$

$$= \text{output power rating} \times 4\text{Wh} \qquad \text{(Equation 5.5)}$$

5.4.2.3 Bicycle Dynamo based Solutions

Bicycle dynamos typically provide 3W at 6V, i.e. 0.5A, based on the prevailing industry standard. In practice, to use this to charge a mobile telecommunications device, it requires the use of a 5V regulator. As the input and output voltages are so close, a simple linear regulator is perhaps the most efficient solution and provides the equivalent of one 0.5A USB port. Researcher has constructed and tested such system, confirming feasibility of this approach. It is assumed that it would not be possible to operate a bicycle for more than 8 hours per day on average, with a lower value being more likely, given the difficulty of pedaling a bicycle for more than 8 hours per day, the competing demands for time and energy (especially since access to sufficient food may not be assured) during disaster response, and the difficulties in optimally rotating devices as soon as they are charged, as previously described. Given that dynamo chargers consume energy that would otherwise be used to power lighting on a bicycle, we can also make the reasonable assumption that rational actors would not attempt to ride such bicycles during the night, without lighting. Total energy is indicated in equation 5.6:

$$= \text{output power rating W} \times 8\text{hours}$$

$$= \text{output power} \times 8\text{Wh} \qquad \text{(Equation 5.6)}$$

5.4.2.4 Motor-Vehicle solutions

For motor-vehicle based solutions, whether using the battery of a motorcycle, car, or truck, it is simply assumed that the very large battery capacity of a vehicle allows as many USB ports as available to be charged simultaneously for 16 hours per day. That is, the input energy budget is assumed to not be a limiting factor and, thus, is disregarded.

5.4.2.5 Wind power

Finally, for wind power systems a similar approach to solar panels was used for solar power systems with batteries, derating for both charging (storage factor) and discharging efficiency (retrieval factor), which 80% was assumed for each. It is then derated for suitable wind being available only 50% of the time (wind rate), although it is freely admitted that this is a rather arbitrary figure, given that the wind environment is likely to be highly variable between disaster events. Even windy events such as cyclones seem unlikely to us to offer better than 50% wind availability because most wind power systems have both minimum and maximum allowable wind-speed. Thus, the figures for wind power should be considered rather optimistic, and merely indicative. Thus, the total available energy is assumed to be in equation 5.7 and figure 5.2 below:

$$= \text{rated power W} \times 24\text{hours} \times 50\% \times 80\% \times 80\%$$

$$= \text{rated power} \times 7.68\text{Wh} \qquad \text{(Equation 5.7)}$$

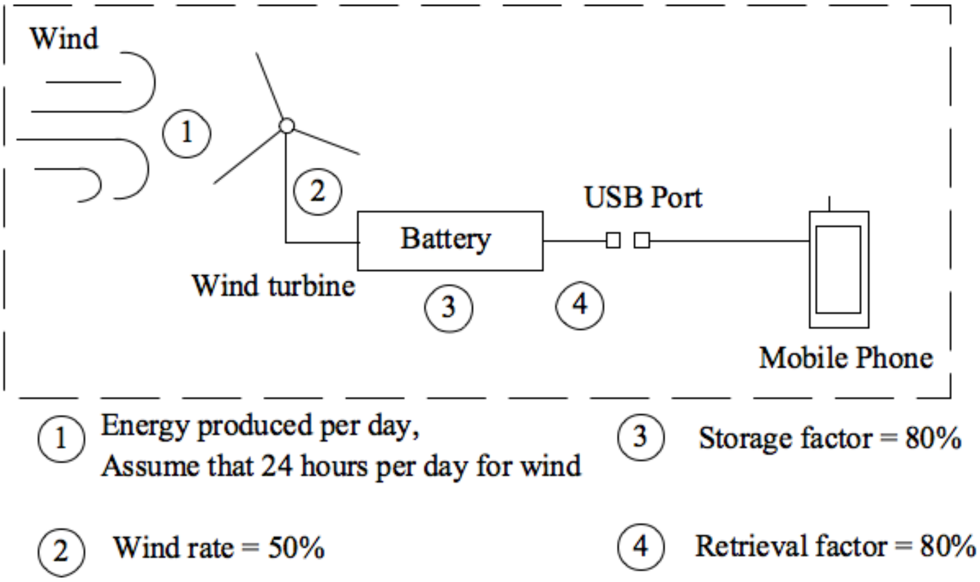


Figure 5.2: Total energy from wind charging solution

5.4.3 Criteria 3: Amortized Cost Per Recharge (CPR) (3 days and 1 year)

Finally, knowing the number of devices that can be recharged per day and the capital cost of a solution can help compute the amortized cost per device charged. It is done this for device lives of 3 days and 1 year. The former assumes that a device is used only during the acute phase of a disaster while the latter assumes that the device continues to play an important role in the recovery stage of a disaster. For the 1-year value, this is calculated on a nominal 300 days year to allow for the likely situation that the device will not be used every day of the year, although it is still assumed that the intensity of use will remain the same. No effort has been made to determine whether any of the particular devices are capable of lasting for a full year, so the cost per recharge (CPR) over a year should be considered minimum cost figures with costs likely to be somewhat higher in reality.

To illustrate how this was calculated in practice, let consider the first item in Table 5.3, the “PowerAdd 7200mAh.” That device has a single 1A USB port and a 0.9 W solar panel. To determine the number of devices that can be charged per day, we need to calculate the minimum number of devices that can be charged via its USB ports, and the number of devices that can be charged using the available energy, according to Criteria 2. From Criteria 2, we can interpolate that a 1A USB port can charge 2 × the number of devices per day compared to a 0.5A USB port, i.e., 2 × 6.4 devices per day = 12.8 devices per day. Applying the equation presented above for solar panels in equation 6.3, we discover that a 0.9 W solar panel can charge only 0.9 W × 3.136 h ÷ 6.25 Wh = 0.45 devices per day. As this is less than aforementioned 12.8 devices per day, the device is capable of recharging only 0.45 devices per day, i.e., it would take just over two days for this unit to gather enough energy using its solar panel to successfully recharge a single device. Dividing the purchase price of $99 by 3 days × 0.45 and 300 days × 0.45, we obtain 3-day and 1-year CPR of 99 ÷ 1.3548 and 99 ÷ 135.48 = $73.08 and $0.73, respectively. In terms of other solution, it can be calculated similar to that of solar charging solution. Then, apply each equation with input power to calculate and find out the total energy and cost per recharge results.

Table 5.3: Sample of alternative energy sources for recharging mobile devices (solar powered)

Product or solution				
URL/source				
Cost per recharge (CPR) over 3 days	**Cost per recharge (CPR) over 1 year**	**Purchase Cost**	**USB ports (maximum current in Amperes)**	**Maximum input power**
PowerAdd Apollo 7200mAh				
http://www.ebay.com/itm/BrandNew-Portable-USB-Charger-Power-Bank-W-Solar-Panel-7200mAh-Free-Shipping-/ 221658503029				
$73.08	$0.73	$99	1A	0.9Watts
PowerAdd Apollo2 10000mAh				
http://www.ebay.com/itm/Poweradd-10000mAh-2-USB-Solar-Power-Bank-External-Battery-Charger-For-Cell-Phone-/301802172428				
$13.28	$0.13	$19.99	1A and 2.1A	1 Watts
SunJack 7W Solar Charger with 4000 mAh battery				
https://www.amazon.com/dp/B00OVCGC0U				
$6.64	$0.06	$69.95	2A	7 Watts
Sunjack 14W Portable Solar Charger with 8000 mAH battery				
https://www.amazon.com/dp/B00E7Z06LC				
$5.69	$0.05	$119.9	1A and 2.1A	14 Watts
Sunjack 20W Portable Solar Charger with 2x8000mAh battery				
https://www.amazon.com/dp/B00L87VKOO				
$5.48	$0.05	$164.9	2A and 2A	20 Watts

Table 5.3: Sample of alternative energy sources for recharging mobile devices (solar powered, continued)

Product or solution				
URL/source				
Cost per recharge (CPR) over 3 days	**Cost per recharge (CPR) over 1 year**	**Purchase Cost**	**USB ports (maximum current in Amperes)**	**Maximum input power**
Cobra Compact Solar Charger CPP 100 6000 mAh				
https://www.amazon.com/dp/B00IZGWOY6				
$17.90	$0.17	$32.33	2.1A	1.2Watts
Cobra CPP 300 SP Dual Panal Charger				
https://www.amazon.com/dp/B00IZGWUCM				
$13.01	$0.13	$46.99	2.1A and 2 x 1A	2.4Watts
Nexcon Solar Charger 5000 mAh				
https://www.amazon.com/Nexcon-Charger-Rain-resistant-Shockproof-Portable/dp/B00N2D7J5G				
$13.28	$0.13	$19.99	1A and 1A	1Watts
Levin SolPad Travel Solar Charging				
https://www.amazon.com/Levin-trade-Efficiency-Waterproof-USB-Charged/dp/B00N3NC4UA				
$13.28	$0.13	$59.99	1A	3Watts
Zebora Powerful Portable Solar Charger Equipped with 2 Foldable Solar Panels				
https://www.amazon.com/Zebora-Powerful-Portable-Equipped-USB-charged/dp/B00Q5Y6EW8				
$8.19	$0.08	$36.99	1A and 2A	3Watts
Zebora Powerful Portable Solar Charger Equipped with 4 Foldable Solar Panels				
https://www.amazon.com/Zebora-Powerful-Portable-Equipped-USB-charged/dp/B00XT481K0				
$5.31	$0.05	$47.99	1A and 2A	6Watts
Apollon Portable Outdoor Foldable Solar Chager P15				
https://www.amazon.com/SMARTTECH-Apollon-Portable-Foldable-P15/dp/B0132GJFT0				
$4.43	$0.04	$99.99	3A x 2	15Watts
Apollon Portable Smart Solar Pad Charger S6000				
https://www.amazon.com/SMARTTECH-Apollon-Portable-Smart-S6000/dp/B0132IC964				
$16.60	$0.16	$24.99	1.5A x 2	1Watts
Voltaic Systems ”6.0W Fuse” Portable Solar Panel and 4,000mAh				
https://www.amazon.com/Voltaic-Systems-Portable-Charger-Battery/dp/B00H9V6LWY				
$13.93	$0.13	$129	1A	6.15Watts
Voltaic Systems ”6.0W Kit” Portable Solar Panel and 4,000mAh				
https://www.amazon.com/Voltaic-Systems-Portable-Battery-Samsung/dp/B00NY6FP7K				
$9.72	$0.09	$90	1A	6.15Watts

Table 5.3: Sample of alternative energy sources for recharging mobile devices (solar powered, continued)

Product or solution				
URL/source				
Cost per recharge (CPR) over 3 days	**Cost per recharge (CPR) over 1 year**	**Purchase Cost**	**USB ports (maximum current in Amperes)**	**Maximum input power**
Voltaic Systems ”Amp” 4.0W Portable Solar Charger and 4000mAh				
https://www.amazon.com/Voltaic-Systems-Portable-Charger-4000mAh/dp/B00429IMXW				
$14.95	$0.14	$99	1A	4.4Watts
Voltaic Systems ”Milliamp” Portable Solar Charger and 4,000mAh				
https://www.amazon.com/Voltaic-Systems-Milliamp-Portable-Charger/dp/B00VKMIIZQ				
$17.82	$0.178	$59	1A	2.2Watts
SUNKINGDOM 8WSolar Charger				
https://www.amazon.com/SUNKINGDOM-Ultra-thin-Portable-PowermaxIQ-Technology/dp/B00MHNMS94				
$2.49	$0.02	$29.99	1A	8Watts
SUNKINGDOM 5WSolar Charger				
https://www.amazon.com/SUNKINGDOM-Portable-Foldable-PowermaxIQ-Technology/dp/B00MRT5TOY				
$2.66	$0.02	$19.99	1A	5Watts
Solar Charger External Battery, ZeroLemon Solar Juice 6000mAh				
https://www.amazon.com/External-ZeroLemon-Portable-Charging-Technology/dp/B00NIOGKLS				
$14.39	$0.14	$25.99	1A and 2.1A	1.2Watts
Solar Charger External Battery, ZeroLemon Solar Juice 10000mAh				
https://www.amazon.com/ZeroLemon-SolarJuice-10000mAh-Portable-Technology/dp/B00NIOGKNQ				
$16.60	$0.16	$29.99	1A and 2.1A	1.2Watts
Solar Charger External Battery, ZeroLemon Solar Juice 20000mAh				
https://www.amazon.com/ZeroLemon-SolarJuice-20000mAh-Portable-Technology/dp/B00NIOGKL8				
$22.14	$0.22	$39.99	1A and 2.1A	1.2Watts
Opteka BP-SC8000 Ultra High Capacity (6000mAh)				
https://www.amazon.com/Opteka-BP-SC8000-Capacity-Charging-EcoPanel/dp/B00E9AMWMG				
$9.76	$0.09	$49.95	1A x 2	3.4Watts

Table 5.4: Sample of alternative energy sources for recharging mobile devices (hand cranked)

Product or solution				
URL/source				
Cost per recharge (CPR) over 3 days	**Cost per recharge (CPR) over 1 year**	**Purchase Cost**	**USB ports (maximum current in Amperes)**	**Maximum input power**
Eton BoostTurbine 2000mAh Portable Backup Battery Pack with Hand Crank Back-Up Power				
https://www.amazon.com/Eton-BoostTurbine-2000mAh-Portable-NBOTU2000R/dp/B009OYSIVQ				
$3.893	$0.03	$14.95	1A	2.5Watts
Eton NBOTU4000B Rechargeable USB Battery Pack with Hand Turbine Power Generator				
https://www.amazon.com/Eton-NBOTU4000B-Rechargeable-Battery-Generator/dp/B00EPY0QY2				
$18.22	$0.18	$69.99	1A	2.5Watts
ReVIVE ReStore VTL 2000mAh Power Bank				
https://www.amazon.com/ReStore-2000mAh-Power-Emergency-Flashlight/dp/B012K0O7BK				
$5.205	$0.05	$19.99	1A	2.5Watts

Table 5.5: Sample of alternative energy sources for recharging mobile devices (other kinetic method)

Product or solution				
URL/source				
Cost per recharge (CPR) over 3 days	**Cost per recharge (CPR) over 1 year**	**Purchase Cost**	**USB ports (maximum current in Amperes)**	**Maximum input power**
nPower PEG Personal Energy Generator				
https://www.rei.com/product/849998/npower-peg-personal-energy-generatorn#tab-reviews				
$39.45	$0.39	$200	1A	< 0.01Watts
AMPY Move Wearable USB Portable Motion Charger External Battery				
https://www.amazon.com/AMPY-Wearable-Portable-Charger-External/dp/B0189QLH6C				
$19.53	$0.19	$99	1A	<0.01Watts
The Voltmaker kinetic smartphone charger				
http://www.gizmag.com/voltmaker-kinetic-charger/28065/				
$17.96	$0.17	$69	1A	<0.01Watts

Table 5.6: Sample of alternative energy sources for recharging mobile devices (Thermoelectric effect)

<table>
<tr><th colspan="5">Product or solution</th></tr>
<tr><th colspan="5">URL/source</th></tr>
<tr><th>Cost per recharge (CPR) over 3 days</th><th>Cost per recharge (CPR) over 1 year</th><th>Purchase Cost</th><th>USB ports (maximum current in Amperes)</th><th>Maximum input power</th></tr>
<tr><td colspan="5">BioLite Wood Burning Campstove</td></tr>
<tr><td colspan="5">https://www.amazon.com/BioLite-BL-CSA-Wood-Burning-Campstove/dp/B00BQHET9O</td></tr>
<tr><td>$8.460</td><td>$0.08</td><td>$129.9</td><td>1A</td><td>2Watts</td></tr>
<tr><td colspan="5">KettleCharge</td></tr>
<tr><td colspan="5">http://www.bioliteenergy.com/products/biolite-kettlecharge</td></tr>
<tr><td>$3.124</td><td>$0.03</td><td>$119.9</td><td>1A</td><td>10Watts</td></tr>
<tr><td colspan="5">Power Practical 5 PowerPot</td></tr>
<tr><td colspan="5">https://www.amazon.com/Power-Practical-PowerPot-Charge-Devices/dp/B00UI994WI</td></tr>
<tr><td>$2.122</td><td>$0.03</td><td>$63.63</td><td>1A</td><td>2.5Watts</td></tr>
</table>

Table 5.7: Sample of alternative energy sources for recharging mobile devices (bicycle powered)

<table>
<tr><th colspan="5">Product or solution</th></tr>
<tr><th colspan="5">URL/source</th></tr>
<tr><th>Cost per recharge (CPR) over 3 days</th><th>Cost per recharge (CPR) over 1 year</th><th>Purchase Cost</th><th>USB ports (maximum current in Amperes)</th><th>Maximum input power</th></tr>
<tr><td colspan="5">Tigra Sport BikeCharge Dynamo and Bicycle USB Charger</td></tr>
<tr><td colspan="5">https://www.amazon.com/Tigra-Sport-BikeCharge-Bicycle-Charger/dp/B00OMSYR9Q</td></tr>
<tr><td>$13.43</td><td>$0.13</td><td>$129</td><td>1A x 2</td><td>2.5Watts</td></tr>
<tr><td colspan="5">Shimano DH-3N80 Dynamo Front (Hub32H Front Rim Brake)</td></tr>
<tr><td colspan="5">https://www.amazon.com/Shimano-DH-3N80-Dynamo-Front-Brake/dp/B002J9E8KI</td></tr>
<tr><td>$9.830</td><td>$0.09</td><td>$94.37</td><td>N/A</td><td>2.5Watts</td></tr>
<tr><td colspan="5">Shimano DH-S501 Alfine Dynamo Disc Hub (32H Front)</td></tr>
<tr><td colspan="5">https://www.amazon.com/Shimano-DH-S501-Alfine-Dynamo-Disc/dp/B007M817QE</td></tr>
<tr><td>$10.40</td><td>$0.1</td><td>$99.89</td><td>N/A</td><td>2.5Watts</td></tr>
<tr><td colspan="5">Shimano DH-S501 Alfine Dynamo Disc Hub (36H Front)</td></tr>
<tr><td colspan="5">https://www.amazon.com/Shimano-DH-S501-Alfine-Dynamo-Disc/dp/B007M817QE</td></tr>
<tr><td>$10.41</td><td>$0.1</td><td>$99.94</td><td>N/A</td><td>2.5Watts</td></tr>
<tr><td colspan="5">Shimano DH-S501 Alfine Dynamo Disc Hub (36H OLD 100mm)</td></tr>
<tr><td colspan="5">https://www.amazon.com/Shimano-DH-S501-Alfine-Dynamo-Disc/dp/B007M817QE</td></tr>
<tr><td>$10.40</td><td>$0.1</td><td>$99.89</td><td>N/A</td><td>2.5Watts</td></tr>
</table>

Table 5.8: Sample of alternative energy sources for recharging mobile devices (car, motorbike or other vehicle or vehicle-battery powered)

Product or solution				
URL/source				
Cost per recharge (CPR) over 3 days	**Cost per recharge (CPR) over 1 year**	**Purchase Cost**	**USB ports (maximum current in Amperes)**	**Maximum input power**
12V 3.1A Motorcycle Dual USB Port Cell Phone Charger Charging LED Volt Voltmeter				
http://www.ebay.com.au/itm/12V-3-1A-Motorcycle-Dual-USB-Port-Cell-Phone-Charger-Charging-LED-Volt-Voltmeter-/401084752341				
$0.074	<$0.01	$8.6	1A and 2.1A	200Watts
12 Volt 3.1 Amps (1A & 2.1A) Dual USB Port Power Outlet Socket Power Supply Charger				
https://www.amazon.com/RCLITE-Waterproof-Charger-Motorcycle-Vehicles/dp/B01FSDNSTI				
$0.104	<$0.01	$11.99	1A and 2.1A	200Watts
Cllena Motorcycle BMW DIN Hella Socket Dual USB Charger				
https://www.amazon.com/Cllena-Motorcycle-Socket-Charger-iPhone/dp/B015IXZ4CC				
$0.182	<$0.01	$20.99	1A and 2.1A	200Watts
5V/2.1A Motorcycle Mobile Phone GPS Dual USB Output Power Supply Adapter Charger Socket				
https://www.amazon.com/Floureon-Waterproof-Motorcycle-Adapter-Charger/dp/B019SMH9KE				
$0.130	<$0.01	$14.99	1A and 2.1A	200Watts
Car Charger, Eleckey 2.1A Dual USB Port Car Charger				
https://www.amazon.com/Charger-Eleckey-Samsung-Galaxy-Motorola/dp/B00T2KFSTW				
$0.078	<$0.01	$11.99	2.1A x 2	200Watts
LP 36W 7.2A Rapid USB Car Charger 3-Port In Car Charger				
https://www.amazon.com/Technology-Charging-Iphone6s-External-USB-Powered/dp/B00P0ZPSBG				
$0.043	<$0.01	$9.99	2.4A x 3	200Watts
Dual USB Car Charger				
https://www.amazon.com/Charger-Perfect-Electric-Multiple-including/dp/B00XZX5I5Q				
$0.058	<$0.01	$8.99	2.4A x 2	200Watts
AmazonBasics 4.0 Amp Dual USB Car Charger				
https://www.amazon.com/AmazonBasics-Charger-Android-Devices-Output/dp/B00IEFXDO8				
$0.052	<$0.01	$7.99	2A x 2	200Watts
Car Charger, Qualcomm Certified Quick Charge 2.0 USB Car Charger				
https://www.amazon.com/Charger-Qualcomm-Certified-Adaptive-Portable/dp/B01B8Y3YYA				
$0.171	<$0.01	$13.19	5A	200Watts
USB Car Charger, LOOP 2.4A				
https://www.amazon.com/Charger-Intelligent-Charging-Tablets-Blackberry/dp/B01CM9I4TK				
$0.129	<$0.01	$9.95	2.4A	200Watts

Table 5.9: Sample of alternative energy sources for recharging mobile devices (wind powered)

Product or solution				
URL/source				
Cost per recharge (CPR) over 3 days	**Cost per recharge (CPR) over 1 year**	**Purchase Cost**	**USB ports (maximum current in Amperes)**	**Maximum input power**
Portable Trinity Turbine Power Station 50				
https://gearjunkie.com/portable-turbine-power-station				
$9.609	$0.09	$369	1A	50Watts
New 400W Watt DC 12V Wind Turbine Generator with Hybrid Controller Home System				
http://www.ebay.com.au/itm/like/121423804312				
$0.230	<$0.01	$340	12V only (no USB ports	400Watts

The tables list the metrics for a hopefully representative sample of alternative energy solutions that were identified: Table 5.3 presents a sample of the wide variety of solar-powered solutions. Table 5.2 and 5.5 present a sample of hand-powered and other kinetic-motion based chargers, respectively while Table 5.6 presents a number of thermoelectric effect-based chargers. The two tables, Tables 5.7 and 5.8 list some of the wide ranges of bicycle and motor vehicle (or motor-vehicle battery) based solutions. Very few personal-sized wind powered solutions were discovered, particularly where sufficient technical information was available to compute meaningful metrics, the only exemplars listed in Table 5.9.

5.5 Survey results of alternative sources of mobile phone battery charging (N=117)

From research survey, the results of the question, “Do you use any alternative source of power to increase the time before you need recharge your mobile phone at a mains plug?” are shown in table 5.10 and 5.11.

The percentage of cases in table 5.10 derived from number of responses chosen (N) divided by number of total participants in this survey (117). On the contrary, percent derived from number of responses chosen (N) divided by total responses chosen.

Table 5.10: The percentage of alternative sources of power to increase the time before recharging mobile phone

		Responses		Percent of Cases
		N	Percent	
Factors	Laptop or desktop USB port	50	31.65%	42.75%
	Solar, wind or similar independent power source	3	1.90%	2.55%
	Accessory power outlet from car, or similar	51	32.30%	43.60%
	Oversize battery or external battery backup for mobile phone	26	16.45%	22.20%
	No, never	28	17.70%	23.95%
Total		158	100%	135.05%
Dichotomy group tabulated at value 1.				

According to table 5.10, it was shown that participants mostly chose accessory power outlet from car or similar items and laptop or desktop USB port to recharge their mobile phone about 43.60% and 42.75% respectively. On the other hand, oversize battery or external battery backup was 22.20%. It was almost similar to a no, never choice at 23.90%. Interestingly, battery backup is very popular for mobile phone users but less popular than laptop or desktop USB port. This is because laptop or desktop is mostly used in daily life, so people can plug their mobile phone all the time. Car battery charger is also cheaper than any alternative sources which means people can easily acquire this item to recharge their mobile phone. As for alternative source such as solar, wind or similar independent power source, it was 2.55%, which is considered unpopular according to survey results. Also, it is costly as opposed to other alternative solutions. However, this option is very crucial in disaster or emergency situations since the opportunity to find out sources for recharging a mobile phone is rare and arduous due to particular environment. These alternative sources are probably popular providing that it is inexpensive in the future.

Table 5.11 summarises responses of participants classified by categories of alternative power sources. 23.10% of participants recharge their phone on a power outlet from a car which is somehow close to those charging through the laptop or desktop USB port which accounts for 20.50%. It should be noted that, according to table 5.9 and 5.10, there is a relationship between car charging and USB port from laptop or desktop. Also, the number of percentages of 10.25 % can confirm that participants mostly choose to recharge their mobile phone through both methods.

Table 5.11: Number and percentages of responses in each alternate power source

Charging categories	Number	Percentage
[1]	24	20.50%
[2]	1	0.85%
[3]	27	23.10%
[4]	6	5.15%
[5]	28	23.95%
[1] + [2] + [3] + [4]	1	0.85%
[1] + [3] + [4]	7	6.00%
[2] + [3] + [4]	1	0.85%
[1] + [3]	12	10.25%
[1] + [4]	6	5.10%
[3] + [4]	4	3.40%
Total	117	100.00%

[1] Laptop or desktop USB port
[2] Solar, wind or similar independent power source
[3] Accessory power outlet from car, or similar vehicles
[4] Oversize battery or external battery backup for mobile phone
[5] No, never

5.6 Discussion

This section discusses two major results including the cost analysis of alternative solutions for mobile phone charging in disaster or emergency situations and the survey results from participants to use alternative source for recharging their phone.

5.6.1 Discussion, based on alternative mobile phone recharging strategies

With regard to the alternative mobile phone charging solutions in disaster or emergency situations, there are five categories including solar power charging solution, kinetic, hand crank, and thermoelectric charging solution, bicycle dynamo-based charging solution, motor vehicle charging solution, and wind turbine charging solution. Each solution has different physical characteristics to recharge a mobile phone. This study will place an emphasis on which types of mobile phone recharging are affordable, pervasive, and efficient.

From assessment in section 5.4, one of the first revelations of the data is that the amortized cost per recharge varies considerably, even within a category. For example, among the solar recharging options, the CPR over amortized over 3 days varies between \$2.49 and \$73.08. The situation is similar in most other categories, with price-per-recharge varying by around an order-of-magnitude, with some notable exceptions, in particular the kinetic chargers. At the low-cost end of devices in solar category, the devices lack a storage battery, and thus are considerably cheaper for a given size of solar panel – which is important since for the solar powered devices, the bottle-neck is typically the solar panel, not the battery capacity. Conversely, the most expensive options are the battery packs provided with a token solar panel, perhaps as a marketing aid. For humanitarian deployments involving air-travel, the absence of a battery may have the further advantage of greatly simplifying the shipping process of the hardware. Without a lithium battery, such devices would not be considered as hazardous materials. The sole easily portable wind turbine that we were able to obtain sufficient data for has an operational cost near the expensive end of the range seen for solar devices and is thus not competitive at this time although further developments may change this. As an example of the rapid progress in this sector, the second wind powered generator that we considered, rated at 400W has the potential to be very cost effective. However, it has only 12V output and would require additional equipment to provide 5V USB ports. Furthermore, the blades are 1.2m long and would require considerable mounting equipment which, altogether, would likely double the cost of the unit compared with the bare turbine. Moreover, the reported power curve indicates that it provides up to 400W only when wind speeds reach 10.5m/sec, and not more than 35m/sec. Accordingly, it is suspected that the actual attainable performance of such unit would be much less than suggested and therefore CPR would be greater by perhaps by a factor of 4x - 10x, and this still assumes that there would be a steady supply of wind within the operational range of the unit for at least 12 hours per day which, for us, seems to be rather optimistic.

A common issue with both solar and wind power is that they are dependent upon agreeable weather conditions. Given that many disasters include a weather-based element, it may not be wise to depend upon agreeable weather for post-disaster energy supply. The other categories avoid this problem in various ways.

All kinetic chargers (excluding hand-cranked devices) are extremely expensive in practice owing to their extremely limited ability to harvest energy. The reviews from major technology magazines of such devices have confirmed that, for at least one device in this category, 60 hours of activity would be required to provide sufficient energy for a single charge (Hollister, 2009), with others performing only marginally better (Lasky, 2012).

Hand-cranked kinetic chargers are appreciably more affordable both in terms of purchase price and utility as they are able to generate orders of magnitude more energy per unit time. If a passive means of energy generation is required, without reliance on the sun, then the thermoelectric generators have a lower CPR and have the further advantage that they have no moving parts and may therefore last longer.

Bicycle-based chargers can be seen as a variation on hand cranked chargers with the disadvantage that they are often more expensive to purchase resulting in higher CPR as calculated. However, bicycle-based solutions have the potential advantage in that it is much easier to peddle a bicycle for long periods than to crank a hand crank quickly. Bicycle-based solutions have the further advantage that they have a practical day-to-day application outside of disaster events, and thus it may be feasible to encourage their adoption ahead of time, for example, through a community subsidy program in at-risk communities so that this generation capacity can be available immediately when required.

The final categories are those that depend on motor vehicles and/or their batteries. This category requires the lowest cost to operate as they have the benefit from the considerable economy of scale that exists for automotive accessories, and the fact that motor vehicles already include the necessary generation and storage facilities (alternator and battery), leaving only voltage regulation and provision of appropriate connectors to be solved. Consequently, low-cost 3-port USB adapters for motor vehicles are available for less than US$10.00 and can be used to charge dozens of devices per day. Again, the absence of any lithium battery in such devices not only reduces the cost, but also greatly simplifies transportation by air when required. This combination of low-cost, both per recharge and per unit, and ease of transportation makes this category stand out from the other categories surveyed.

In summary, motor-vehicle based solutions remain the most economical solution and with easier transportation prospects than most other categories and thus is the recommended option provided that motor vehicles are available to be leveraged as the energy generation and storage infrastructure. Costs still vary by 4x within this category and so as with most other categories, it is recommended to take care in the selection of particular solutions to obtain the best value for money. When motor vehicles are not able to be used or will not be sufficient as a complete solution, then low-cost solar, hand cranked kinetic or bicycle-based solutions may be appropriate. Other kinetic charging solutions appear not to have a budget-friendly price. With their very slow charging rates and the worst utility, they should only be considered as a last resort until their underlying technology improves. The cost per recharge ranking from cheap to expensive was presented in table 5.12.

Table 5.12: Cost per recharge from criteria assessment ranking from inexpensive to expensive

Rank	Charging solutions
1	Motor vehicles
2	Hand crank
3	Thermoelectric
4	Low-cost solar
4	Bicycle
6	Wind
7	Kinetic

5.6.2 Discussion, based on survey results of alternative sources of mobile phone battery charging

The survey results shown in table 5.10 indicated that accessory power outlet from car or similar vehicle and laptop or desktop USB port were mostly alternative charging for a mobile phone. From the participants, the oversize battery or external battery backup for a mobile phone comes as a second choice. On the other hand, a mere 2.55% of participant chose solar, wind or similar independent power source as a phone recharging method. However, there were 28 people out of 117 who did not know about alternative charging solutions from the given list. Interestingly, the battery backup or the power bank which should be mostly used by people because they offer various capacities and sizes to satisfy different demand was, in turn, ignored from users in this survey. Furthermore, according to the table 6.11, accessory power outlet from car or similar vehicle and laptop or desktop USB port were still the first option people chose to recharge their mobile phone. Also, people may recharge their phone both via accessory power outlet from car and laptop or desktop USB port at the same time.

From survey results in table 5.10 and 5.11 and ranking of cost per recharge assessment in table 5.12, it can be concluded that the car or motor vehicle charging strategy is the most well-known and inexpensive choice to recharge a mobile phone compared to other solutions.

5.7 Conclusion

There are many options available for recharging mobile devices without reliance on main electricity supply. Motor vehicle-based solutions are the cheapest to purchase and cheapest to operate in case vehicles are available. Failing this, solar, thermoelectric, hand-cranked kinetic and bicycle-based solutions form the next tier of utility and economy but each has drawbacks compared to motor vehicles. Accordingly, it is recommended that they be used to complement motor-vehicle based solutions. The new and emerging technologies such as personal wind turbines and thermoelectric offer promise as their underlying technologies mature. We refrain from recommending any particular product from any given category as the availability and pricing of consumer electronics devices change constantly. Therefore, any specific guidance will become rapidly outdated.

To sum up, the motor vehicle solution has the potential to be an alternative charging solution as it is affordable and effective. The disasters taking place in Australia mostly occurs from natural disaster such as cyclone, severe weather, flooding, bushfire, and etc. A disaster is unpredictable and can strike without a warning. Since, generally, people own a vehicle, the recommendation of this research is that every car should have a USB charging port, or people should buy UBS adapters to use in their car. This is the single mode cost effective intervention to keep people’s car or phone charges overtime or while disaster and emergency situations strike unexpectedly.

The next chapter presents the duration of power outages and its impact on mobile phone power availability. It explores the relationship of a flat mobile phone and battery life. The relationship of power outages and natural disaster will also be discussed.

CHAPTER 6: DISTRIBUTION OF DURATION OF POWER-OUTAGES AND ITS IMPACT ON MOBILE PHONE POWER AVAILABILITY

This chapter aims to study and understand distribution of duration of power-outages and its impact on a mobile phone via data analysis from data collection deriving from energy and power electricity network about power outages in Queensland and South Australia, Australia. The results were shown and discussed relationship of duration of power outages and impacts of mobile phone battery life to power outages to find out how long the battery life of mobile phone should last in disaster contexts?

6.1 Introduction

In early 2017, Cyclone Debbie caused widespread damage and disruption to electricity supply and other infrastructure in Queensland and New South Wales (Tapim, 2017). This circumstance placed considerable strain on citizens and respondents alike as they sought to find ways to keep their mobile telephones charged. Despite the advance warning of the cyclone, news reports suggested that considerable portions of the population were not prepared for the extended duration of power loss that occurred, and in some cases continued for weeks.

Communications is the key to effective humanitarian response, and energy is the key to effective communications. Therefore, when the power goes out, phones and cell towers go dark, impairing humanitarian response as well as the safe and effective function of society. It is, therefore, critical to understand the statistical distribution of blackouts so that contingencies and planning can be evidence based. However, when it is sought to identify literature that provided data on the statistical distribution of blackout durations, it was unable to locate any. It is therefore resolved to correct this situation. Through the enquiry to the South Australian and Queensland electricity network operators, it was able to obtain such data which was presented in this thesis.

Through analysis of eleven years of fine-grained data from the Queensland electricity network covering the years 2005 through 2016, it becomes apparent that widespread and long-lasting blackouts are not uncommon in this region. It also becomes apparent that while many blackout incidents are resolved within 8 hours, there exists a long tail of cases where the power remains out for days, and even weeks.

In this chapter, a simple mobile phone battery life model is used to define the number of mobile phones that would be flat on an hour-by-hour basis over the eleven years. This chapter addresses research question needing to understand the relationship between three factors: phone battery life, duration interrupted, and number of people affected by power outages. These three factors help the study to find out the appropriate mobile phone battery life or estimated sustaining communications battery runtime in disaster events or time without electricity supply.

Data sources from Queensland and South Australia power and energy network were analysed by presenting power outage duration and customers affected from this situation in terms of percentage and number of people. Also, power outage duration having an impact on a mobile phone model was proposed to interpret the relationship of different phone battery runtime compared with the number of people without electricity or number of flat mobile phone at disaster occurring at different duration by line graph. This model can answer or estimate research question: "how long mobile phone battery runtime should last?"

6.2 Definition of power outage in this thesis

A power outage is the duration without electric power in short or long periods of time in particular area. It is also called a power blackout or blackout, power cut, power failure. There are many opportunities that power outage may occur such as in a disaster or emergency situation, fault of power stations, short circuit, overload at electric system, and etc. In this thesis, it is mainly focused on power outage occurring as a result of disaster or emergency situation.

Power outages are classified into three main different events, relating to the outage affected by people and interrupted duration:

- A massive loss of power caused by power line failure.
- A drop-in voltage in an electrical power supply may occur resulting from a damage on equipment or an operation error, which normally known as brownout.
- A blackout or power outage occurs from power station fault, which may last from a minute to a weeks or month, depending on electrical network recovery.

6.3 The importance of telecommunications access post-disaster

Large scale power outages occur and affect many people around the world each year (Klinger, Landeg, & Murray, 2014). Even single events, such as tree contact tripping a high-tension transmission line, on only moderately loaded electricity networks can lead to rapid collapse of a network (Pourbeik, Kundur, & Taylor, 2006). Although in many cases, a postmortem examination reveals that improvements can be made to networks to reduce the risk of such events in the future (Pourbeik et al., 2006), it is not possible to completely avoid them as the systems have ultimately become fragile, in part because of their complexity (Rosas-Casals, 2010). Moreover, the failure and later restoration of electricity networks is closely coupled with the availability of telecommunications services, especially mobile telecommunications (Krishnamurthy, Kwasinski, & Dueñas-Osorio, 2016) (Kwasinski, 2011) (Townsend & Moss, 2005) (Giovinazzi et al., 2017). This has particular implication for emergency and disaster response. As in many cases, the cause of the electricity network failure is a broader impacting event, such as an earthquake or extreme weather conditions (Tapim, 2017) (Krishnamurthy et al., 2016) (Henson, 2016). These impacts can affect millions of people for many hours to days, depending on the particular event (Stori, 2011) (ABC_News, 2016).

The result is to compound the already difficult circumstances faced by people living in affected areas, depriving them of potentially life-saving access to health care and other functional needs (Jan & Lurie 2012). These deprivations can affect both official disaster response activities (Deb, Bose, & Bandyopadhyay, 2012) (Ei Sun, 2003) and informal citizen to citizen response activities alike (Nguyen, Vu, & Minh, 2016) (Haddow & Haddow, 2014a) (Haddow & Haddow, 2014b) (Meier, 2012) (Gultom & Joyce, 2014).

6.4 Data collection from Energy and Power electricity network

In this thesis, researcher has attempted to enquire data about power outage data causing by disaster or emergency situation from many companies or organisations about energy or electricity across Australia. There were two companies responding and replying invaluable data to the researcher. Data collection derived from Keegan Oliver, Engineering manager network performance, Regional Asset Manager North, Ergon Energy Company (Ergon_Energy_Company, 2016) and Rocco Logozzo, Network performance & regulatory manager, SA Power Networks Company

(SA_Power_Networks, 2016), Queensland and South Australia. These data were about power outage.

Queensland data was a major data source for analysis and results in this thesis. These data provided information about power outage since 1 July 2005 to 30 June 2016, including the date of customer affected by power failure until it recovers, the duration of a disaster, and number of customers interrupted from power outage. Besides, data from South Australia during 2010/11 was analysed in this chapter.

6.5 Major disaster events in South Australia State 2010/2011 and Queensland State since 2005 to 2016

In this thesis, there will be a presentation of huge events caused by natural disasters in South Australia in 2010/2011 and Queensland since 2005 to 2016 were summarised in table 6.1 and 6.2 respectively. In order to clarify this information, year and events were included in the tables below:

Table 6.1: South Australia State major disaster events in 2010/2011 (Government_of_South_Australia, 2011) (ABC_Riverland, 2010).

Year	Month	Disaster Events
2010/2011	September 2010	Blackout & Storm Damage & Flooding across SA
	December 2010	Flash Flooding across SA
	November 2010 – March 2011	Significant Rural Fires in SA

Table 6.1 presents major disaster events occurred in South Australia 2010/2011 such as flooding and bushfires. It should be noted that most events occurred during the end of quarter of 2010 to the first of quarter of 2011. Storm mostly occurred during September, and bushfires mostly occurred during summer season on December to February.

Table 6.2: Major natural disaster events in Queensland since 2005 to 2016 (Queensland_Government, 2014a) (Queensland_Government, 2016c) (Australia_Government, 2017) (Ergon_Energy_Company, 2016)

Year	Month	Disaster Events
2005	March	Severe Tropical Cyclone Ingrid Level 5 and Far Nth QLD Flooding
	June	SW QLD Storms
	June - July	Currumbin Hill Landslide,
	October	Isis and Biggenden Bushfires
	November - December	Central and Sth QLD, Severe storms
2006	January	Bowen & Bodekin Shires Flooding, Far Nth QLD Storms and Flooding
	March	Nth & Central QLD Flooding
	March - April	Severe Tropical Cyclone Larry Level 5 & Tropical Cyclone Monica Level 3 and Flooding
2007	January – February	Nth & West QLD Flooding, Tropical Cyclone Nelson Level 2
	March	Tara Storms
	June	Nth & West QLD Flooding
	August	SE & Nth Coast QLD, Tropical Low
	October	Central & Sth QLD Storms, Central West QLD Flooding
	December	SE QLD East Coast Tropical Low
2008	January	SE QLD East Coast Tropical Low, QLD Monsoonal Flooding
	February	SE & West QLD Storms & Flooding
	February - March	QLD Monsoonal Flooding
	May - June	SE QLD Storms
	June	SW QLD Flooding
	November	QLD Storms & Flooding
	December	Baralaba Storms
2009	January	Tropical Cyclone Charlotte Level 1, Tropical Cyclone Dominic Level 2
	February	Tropical Cyclone Ellie Level 1
	March	Severe Tropical Cyclone Hamish Level 5
	April	Sunshine Coast, Gympie & Fraser Coast Flooding
	May	SE QLD Tropical Low
	September - October	Widespread Bushfires
	November	SW QLD Flooding
	December	Nth, Central & SW QLD Flooding, QLD Monsoonal Flooding

- Nth = Northern, SW = South west, QLD = Queensland
- Sth = Southern, SE = South east

Table 6.3: Major natural disaster events in Queensland since 2005 to 2016 (Continued)

Year	Month	Disaster Events
2010	January - March	QLD Monsoonal Flooding
	January	Nth, Central & SW QLD Flooding
	January	Tropical Cyclone Neville Level 2, Tropical Cyclone Olga Level 2
	March	Tropical Cyclone Uliui Level 3, Tropical Cyclone Paul Level 2
	September	SW QLD Tropical Cyclone Low and Flooding
	October	SE QLD Flooding
	November - December	QLD Flooding
	December	Tropical Cyclone Tasha
2011	January - February	QLD Flooding
	January	Tropical Cyclone Anthony Level 2
	February	Severe Tropical Cyclone Yasi Level 5
	February - March	QLD Monsoonal Flooding
	April	SW QLD Flooding
	August - October	Bushfires
	October	Nth QLD Localised Heavy Rainfall
	November - December	Sth QLD Flooding
2012	January	SE QLD Heavy Rainfall & Flooding
	January - February	West QLD Tropical Low
	February	Far Nth QLD Tropical Low
	February - March	North Coast Storms & Flooding & East Coast Hybrid Low
	March	Nth & Far North QLD Heavy Rainfall & Flooding, East Coast Tropical Low
	October - December	Far Nth QLD Bushfires
	December	SW QLD Bushfires
2013	January	Tropical Cyclone Oswald Level 1 & Tropical Low & Flooding
	February	Longreach Flooding
	February - March	Central & Sth QLD Tropical Low
2014	January	Tropical Cyclone Dylan level 2, QLD East Coast, Flooding Central Coast QLD
	February	North East QLD Monsoonal Rainfall & Flooding, Central and Western QLD Flooding & Rainfall
	March	Widespread Rainfall QLD Flooding
	April	Severe Tropical Cyclone Ita Level 5 Nth QLD Cost & Flooding
	December	Severe Thunder storms QLD

- Nth = Northern, SW = South west, QLD = Queensland
- Sth = Southern, SE = South east

Table 6.4: Major natural disaster events in Queensland since 2005 to 2016 (Continued)

Year	Month	Disaster Events
2015	January	Central QLD & Sth East QLD Flooding & West QLd Flooding
	February	Severe Tropical Cyclone Marcia Level 5 Central QLD, Far Nth QLD Flooding
	March	North Tropical Cost QLD Rainfall & Flooding
	April	SE & Sth QLD Flooding, Heavy Rainfall
	May	Flooding QLD
	June	Shower & Thunderstorms QLD
	November	Localised & Thunderstorms QLD
	December	Tropical Low Nth & Far Western QLD
2016	January	Western QLD Severe Storms
	February	Central Western QLD Heavy Rainfall&flooding
	March	Shower & Thunderstorms Western QLD, EX Tropical Cyclone Winston QLD Cost, Far North West QLD Flooding
	May	Widespread Heavy Rainfall North Tropical Coast QLD
	June	Heavy Rainfall Sth QLD Coast, SE & Western QLD Flooding
	July - August	Heavy Rainfall & Moderate Flooding QLD
	September	Widespread Rainfall Western & Sth QLD, Flooding

- Nth = Northern, SW = South west, QLD = Queensland
- Sth = Southern, SE = South east

Table 6.2 to 6.4 present major disaster events occurred in Queensland State since 2005 to 2016 including bushfires, landslide, flooding, tropical cyclone, heavy rainfall, storms and thunderstorms.

It is noticed that most disaster events occurred from flooding especially during first, second, and fourth quarter of each year. Flooding mostly occurred as a consequence of a cyclone, heavy rainfall, storms, thunderstorms and monsoon. There were some disaster events occurring from bush fire during October to December in 2005, 2009, 2011 and 2012. This is because it is a spring and summer season in Australia. Also, there were disaster events occurring in a third quarter of the year such as in 2005, 2007, 2008, 2011, 2015, and 2016. To sum up, Queensland always encounters natural disaster from flooding every year and still continues to confront this unavoidable situation because of a specific geographical location.

6.6 Data analysis and results

6.6.1 Results of relationship of power outages and customers interrupted during 2010 to 2011, South Australia state from SA Power Networks Operator

South Australia is a state in the south of Australia, with a population of 1,706,500 as of March 2016 (Australian_Bureau_of_Statistics, 2016). It is located between latitudes 26 and 38 south. Although the bulk of the state has an arid to semi-arid climate, the vast majority of the population lives in the Mediterranean climatic zone in the south of approximately latitude 32. The largest population center, Adelaide, is located at approximately latitude 35.

The primary natural hazard is bush fire due to the hot dry summers. The main population center of Adelaide is effectively protected from large tsunami by the topography of the gulf on which it is located, in particular, through the shielding effect of Kangaroo Island (Power & Wilson, 2016).

The secondary natural hazard in South Australia is most probably earthquake, due to the intra-plate seismicity of the Adelaide Geosyncline (Sinadinovski, Greenhalgh, & Love, 2006) (Greenhalgh & Singh, 1988). The magnitude 5.4 earthquake of 1954 demonstrated that even a relatively small earthquake presents a significant hazard for Adelaide due to the predominance of unreinforced masonry (URM) dwellings, not dissimilar to the situation in Adelaide’s sister city of Christchurch, New Zealand (Moon et al., 2014) (Ingham & Griffith, 2011). It is not coincidental that these two reports concerning NZ include authors from Adelaide.

More recently, vulnerabilities of the power grid have been exposed with the entire state power grid shutting down for several hours leaving many residents with no electricity for up to several days after a powerful tornado with peak wind speeds of 259km/hour tore down a series of high-tension electricity transmission towers (Henson, 2016). This event also helped finally put to rest the fallacy that Australia does not suffer tornadoes. It also created a situation where emergency telephone calls could not be placed across much of the State for several hours as the battery backup of telephone exchanges and cell towers were exhausted before power was restored in most areas.

Request for blackout data in South Australia predated these tornadoes and the associated whole-of-state blackout that followed and is therefore not reflected in the data. However, it is a significant single event demonstrating how unexpected risks that have the potential for major impacts can exist. The data provided by the South

Australian electricity network operator consisted of a brief summary of the number of customers with electricity supply interruptions during 2010 to 2011 (Table 6.3). It did not indicate the time of day of the blackouts.

Table 6.5 is the complete data that was supplied. It shows a breakdown of the number of customers affected by unplanned interruptions for different duration bands for one of most recent unfavourable reliability performances in 2010 to 2011. Year 2010 to 2011 were significantly impacted by severe weather conditions beyond control of SA Power Network Operator. In 2010 to 2011, South Australia State's population was 1,596,568 persons (Australian_Bureau_of_Statistics, 2012).

From this table, it is clear that only a very small proportion of customers lost power for more than eight hours. Power outage duration from 0 to 4 hours affecting customers was almost equal to the number of populations of the entire State. However, as the subsequent state-wide blackout have shown and as the data from Queensland will also show, the annual variability in blackout incident and duration mean that the long-term distribution may be substantially different. Moreover, it also shows that almost ten thousand of residents lived without power for more than eight hours during that year. This still represents a significant aggregate potential need for communications

Table 6.5: Customers with interrupted electricity supply during 2010 to 2011 in South Australia (SA_Power_Networks, 2016)

Power outage duration	Customer (persons)
0 – 4 hours	1,578,029
4 – 8 hours	189,465
8 – 12 hours	26,225
12 – 16 hours	16,606
16 – 20 hours	13,379
20 – 24 hours	4,719
24 – 28 hours	4,035
28 – 32 hours	2,171
32 – 36 hours	623
36 – 40 hours	873
40 – 44 hours	481
44 – 48 hours	416
> 48 hours	601

6.6.2 Results of relationship of power outages and customers interrupted since 2005 to 2016 (11 years), from Ergon Energy Company, Queensland State

In contrast to the highly summarised data provided by the South Australian electricity network operator, the Queensland network operator provided a highly detailed data set covering every single unplanned power outage from the 1st of July 2005 – 30 June 2016, indicating the number of customers affected by each incident, the time of the first customer losing power, and the time when the last affected customer had their supply restored. The data, consisting of more than 39,000 separate blackout events, is too large to include in this paper, but may be requested directly from the Queensland network operator (Ergon_Energy_Company, 2016).

Queensland, which has a population of 4,827,000 as of March 2016, is located in the north of Australia from latitudes 10 to 29 south and ranges from tropical to sub-tropical. Since having an extensive coastline somewhat exposed to tsunami, the major hazards are flooding and cyclone.

Table 6.6 presents population in Queensland in each year since 2005 - 2016. This data refers to Queensland Government document online via website http://www.qgso.qld.gov.au/. All of this information can be investigated from attached reference in the table.

Table 6.6: Population in Queensland State since July 2005 to June 2016

Year	Population (Persons)	Reference
2005/06	4,053,444	(Queensland_Government, 2016b)
2006/07	4,182,062	(Queensland_Government, 2016b)
2007/08	4,293,915	(Queensland_Government, 2016b)
2008/09	4,425,103	(Queensland_Government, 2016b)
2009/10	4,548,700	(Queensland_Government, 2011)
2010/11	4,599,360	(Queensland_Government, 2012)
2011/12	4,560,260	(Queensland_Government, 2013)
2012/13	4,658,560	(Queensland_Government, 2014b)
2013/14	4,722,450	(Queensland_Government, 2015)
2014/15	4,780,700	(Queensland_Government, 2016a)
2015/16	4,844,733	(Queensland_Government, 2017)

6.6.2.1 Percentage of affected customers for each duration range and total affected persons

A number of significant events occurred during the period covered by the data (seen in table 6.2 to 6.4) (Queensland_Government, 2014a). What is clear from these tables is that Queensland suffers a substantial, but variable, number of significant weather events each year. There was substantial variation in the distribution of duration of blackouts in Queensland over the eleven years covered by the data as seen in Tables 6.7a and 6.7b. Also, as is evident from the South Australian data, the percentage of persons without power for more than 24 consecutive hours during each year is relatively low, always < 6%. Nonetheless, when multiplied by the several million people affected, the number of people living without electrical power for at least 24 consecutive hours during each year became almost ten thousand. Indeed, in some years, tens thousands of people lived without power for at least a week at a time.

The percentage was analysed in terms of interrupted duration or power outages and customers interrupted during outage duration more than 1 hour, 4 hours and 8 hours, 1 day, 2 days, 3 days, 7 days, 14 days, 21 days, 28 days, 30 days, 60 days and 90 days.

Table 6.7a: Power outages during 1 July 2005 to 30 June 2011

Power outage duration	**Percentage (%)**					
	2005/06	**2006/07**	**2007/08**	**2008/09**	**2009/10**	**2010/11**
1 sec +	100	100	100	100	100	100
1 hour +	45.35	46.80	41.95	39.29	39.05	40.88
4 hours +	6.79	4.01	5.90	3.73	5.96	11.50
8 hours +	4.12	1.35	1.96	1.25	3.36	8.09
1 day +	3.06	0.52	1.05	0.43	2.55	5.99
2 days +	2.37	0.21	0.35	0.14	1.63	4.45
3 days +	1.56	0.17	0.24	0.12	1.09	3.32
1 weeks +	1.06	0.15	0.07	0.08	0.49	1.02
2 weeks +	0.67	0.07	0.06	0.05	0.09	0.39
3 weeks +	0.38	0.05	0.05	0.03	0.09	0.14
4 weeks +	0.25	0.03	0.05	0.03	0.05	0.12
60 days +	0.00	0.03	0.04	0.01	0.03	0.08
90 days +	0.00	0.00	0.04	0.01	0.01	0.00

Table 6.7b: Power outages during 1 July 2011 to 30 June 2016 (Continued)

Power outage duration	**Percentage (%)**				
	2011/12	**2012/13**	**2013/14**	**2014/15**	**2015/16**
1 sec +	100	100	100	100	100
1 hour +	32.75	31.73	30.57	26.43	23.13
4 hours +	4.14	6.52	5.04	5.02	3.18
8 hours +	1.60	3.94	1.82	2.82	1.37
1 day +	0.71	1.95	0.67	1.74	0.71
2 days +	0.28	1.17	0.35	1.38	0.30
3 days +	0.19	0.75	0.21	1.16	0.22
1 weeks +	0.07	0.41	0.03	0.41	0.06
2 weeks +	0.05	0.27	0.03	0.01	0.04
3 weeks +	0.03	0.13	0.04	0.01	0.01
4 weeks +	0.02	0.09	0.00	0.01	0.00
60 days +	0.02	0.07	0.00	0.00	0.00
90 days +	0.01	0.06	0.00	0.00	0.00

From table 6.7a and 6.7b, the variation of power outage duration in each band and each year should be taken into consideration. Power outages took place longer than 1 day in 2005/06, 2009/10, 2010/11, 2012/13, and 2014/15 accounting for over 1.05% to 5.99%. In 2005/06 and 2010/11, the power outages were more than 7 days about 1.06% and 1.02% respectively. From the aforementioned years, the relationship of percentage and table 7.2 describing about major disaster events was shown. There were natural disasters occurring during period 2005/06, 2009/10, 2010/11, 2012/13, and 2014/15 consecutively. Therefore, power outages were likely to last for a long period of time.

Power outages lasted more than 3 days in 2006/07, 2008/09, 2011/12, 2013/14, and year 2015/16 showed the percentage at roughly below 0.22%. People living in disaster events were likely to have power recovery in near future. In 2007/08 and 2012/13, the periods of power outages lasted for a long time. The data indicated that 0.04% and 0.06% of power outages lasted more than 90 days since there were disaster events occurring almost throughout either year.

Table 6.8a: Customers interrupted during 1 July 2005 to 30 June 2011

Power outage duration	Customer (Persons)					
	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11
1 sec +	3,659,268	2,473,173	3,504,060	4,339,742	3,616,396	3,888,531
1 hour +	1,639,322	1,144,343	1,4618,879	1,693,726	1,402,003	1,577,740
4 hours +	586,483	329,975	552,288	483,009	553,940	759,029
8 hours +	248,527	98,986	206,519	161,737	215,311	444,111
1 day +	112,022	12,824	36,748	17,930	91,931	232,043
2 days +	80,107	5,126	12,202	6,099	58,843	172,147
3 days +	57,133	4,298	8,297	5,099	39,390	128,384
1 weeks +	38,743	3,777	2,413	3,333	15,569	39,329
2 weeks +	24,621	1,619	2,113	1,990	2,984	14,158
3 weeks +	14,021	1,234	1,623	1,420	2,777	4,682
4 weeks +	9,059	712	1,608	1,186	1,654	4,022
60 days +	89	706	1,304	266	837	2,408
90 days +	5	75	1,302	265	251	2

Table 6.8b: Customers interrupted during 1 July 2011 to 30 June 2016 (Continued)

Power outage duration	Customer (Persons)				
	2011/12	2012/13	2013/14	2014/15	2015/16
1 sec +	3,845,974	3,792,037	3,816,646	4,873,698	4,900,025
1 hour +	1,246,892	1,194,889	1,155,389	1,282,951	1,126,102
4 hours +	425,770	511,563	475,751	532,038	390,714
8 hours +	158,906	246,771	190,923	244,450	155,275
1 day +	27,338	73,722	25,545	84,713	34,766
2 days +	10,945	42,815	13,278	66,844	14,480
3 days +	7,185	27,278	7,992	56,143	10,827
1 weeks +	2,765	14,334	991	19,863	2,739
2 weeks +	1,750	8,217	807	531	1,902
3 weeks +	1,263	3,861	803	520	245
4 weeks +	736	2,572	0	275	81
60 days +	729	1,888	0	12	78
90 days +	329	1,618	0	0	36

From table 6.8a and 6.8b, please consider the variations of power outage duration related to customers interrupted by power outage in each period of time and each year. Power outages took place for more than 7 days in 2005/06, 2009/10, 2010/11, 2012/13, and in 2014/15 there were over 15,000 customers affected by the interruption of disaster events on average. On the other hand, the power outages lasted more than 7 days in 2006/07, 2007/08, 2008/09, 2011/12, 2013/14, and in 2015/16 there were below 3,800 customers interrupted from power outages by average. In year 2006/07 and 2008/09, the number of customers interrupted from power outages declined to 5,126 and 6,099 persons respectively at power outages more than 2 days. Also, there were 12,824 and 17,930 customers interrupted from power outages more than 1 day. This means that customers are likely to have power recovery in each disaster area.

In other words, in some year the power outages took place for longer periods of time depending on duration and category of disaster situations. The number of customers interrupted by power outages also relies on population in each area.

6.6.3 Power outage duration impacts on a mobile phone

Given that there can be over ten thousand people living without electrical power for days, or for weeks in some cases, it is of importance to understand how this phenomenon is related to a mobile telephone battery life. To explore this question, we conducted a survey of emergency response and related personnel, primarily within South Australia. We also constructed a simple model of mobile telephone battery life.

6.6.3.1 Survey of mobile telephone battery life

It is beyond the scope of this chapter to fully report on the results of the survey; however, a number of key points were uncovered.

1) Most smart-phones exhaust their batteries within a day: It was expected that the survey would confirm the short battery life of smart-phones, which it did, indicating that 32% of smartphone users reported that their batteries are usually exhausted within 14 hours, and 46% within 24 hours (Kongsiriwattana & Gardner-Stephen, 2016b).

A further interesting result was when we compared the reported model of a smart phone with the manufacturer's claimed battery life, we found that there was no statistical correlation.

That is, at least for our sample of self-reported battery life, manufacturer's claims of battery life were of no predictive value ($p = 0:7236$). What was highly predictive of battery life was the amount of time that users reported using their smartphones for internet and other purposes ($p < 0:0001$) (Kongsiriwattana & Gardner-Stephen, 2016b).

Overall, the short battery life of smart-phones is not surprising, as from a commercial perspective a full-day of use seems to be the threshold required for marketability.

Making the battery larger increases the size and cost of the device which reduces the market appeal in most cases. Therefore, the market forces at work ensure that smart-phones last only a day or so under typical use. Indeed, the only phones with very long battery life now are feature phones where the battery is already so small as to be negligible in size and cost, and where the primary market is in developing nations, where long battery life is still sought after in the market. That smart-phone battery lives are short with respect to the long tail of power outage durations is a reality that must be considered rather than hoping that it will magically resolve itself.

2) Most people recharge their phone at night: While it came as no surprise that the survey indicated that most people charge their phones at night, it confirms that the time of day at which a loss of power occurs has an important impact on rate at which mobile telephones go flat. The earlier in the day that a power-loss occurs, the more likely it is that any given mobile phone will be more fully charged. Conversely, if a power loss occurs late in the day, it is highly probable that many mobile telephones will be close to exhausting their batteries.

Otherwise stated, Smart phones, in particular, have a battery life of about a day and tend not to be charged during the day and thus are typically close to exhausting their batteries in the evening. Given the difficulty of scheduling disasters to occur exclusively at convenient times, this has significant implications for understanding the availability of communications during disasters and emergency situations.

6.6.3.2 Model of mobile phone battery life related to power outage duration in disaster/emergency situation

During period without electricity, power outages or blackout from disaster or emergency situation, a mobile phone is a significant device to communicate with other people. However, a mobile phone battery life is limited for a short period of time, mostly depending on a battery size or phone usage behaviour as discussed in chapter 4. Therefore, the duration of power failure and mobile phone battery life will be considered in this section to propose devised model about these factors affecting people with flat phone in this unexpected outage duration.

To create devised model, two variables comprising power outage duration in minutes and mobile phone battery life in hours is compared so as to find out the number of days that the phone battery is exhausted.

If the power outage duration is greater than a mobile phone battery life, the number of days that the phone is flat will be calculated by using equation 6.1 below:

$$\text{Days with flat phone} = \frac{\text{Power outage duration} - (\text{Mobile phone battery life} \times 60)}{24 \times 60} \qquad \text{(Equation 6.1)}$$

Where

- Days with flat phone is the number of days without battery life on mobile phone (days)
- Power outage duration is the period of time with no electricity supply (mins)
- Mobile phone battery life (hours) is the duration of battery with time unit changed from hours to minutes by multiplying 60 minutes
- 24 hours x 60 minutes is one-day unit

The unit of time in this equation can be changed to hour by multiplying 24 hours:

$$\text{Hour with flat phone} = \text{Day with flat phone} \times 24 \text{ hours} \qquad \text{(Equation 6.2)}$$

In terms of figuring out person-days with flat phone, please consider equation 6.3 below:

$$\text{Person-days with flat phone} = \text{Days with flat phone} \times \text{Number of interrupted people}$$

OR

$$\text{Person-hours with flat phone} = \text{Hours with flat phone} \times \text{Number of interrupted people} \qquad \text{(Equation 6.3)}$$

Where

- Person-days with flat phone is the number of total days which the phone stays flat compared to number of people who have a mobile phone (Person-days or Phone-days) or Person-hour with flat phone is the number of total hours which the phone stays flat compared to a number of people who have a mobile phone (Person-hours or Phone-hours)
- Days with flat phone is the number of days without battery life on a mobile phone (days) or Hours with flat phone is the number of hours without battery life on a mobile phone (hours)
- Number of interrupted people (persons) is the number of people affected from power outage counted by unit of persons

Figure 6.1 shows that a mobile phone lasted in one day or 24 hours. It started from 8.00 AM, 1 January 2017 at 100% charged. Approximately, it would go flat at 0 % at 8.00 AM 2 January 2017 by approximately. If power outage lasted for nine days, there would be eight days without batty life for a mobile phone. Therefore, people in disaster or emergency situation could not use their mobile phone at that period of time. As seen from figure 6.2 indicating a person day or person hour with flat phone calculation, it revealed how to calculate number of people with phone flat. According to this, there were three people achieving the impact from power outages.

To clarify equation 6.2, please consider figure 6.1 and 6.2 below:

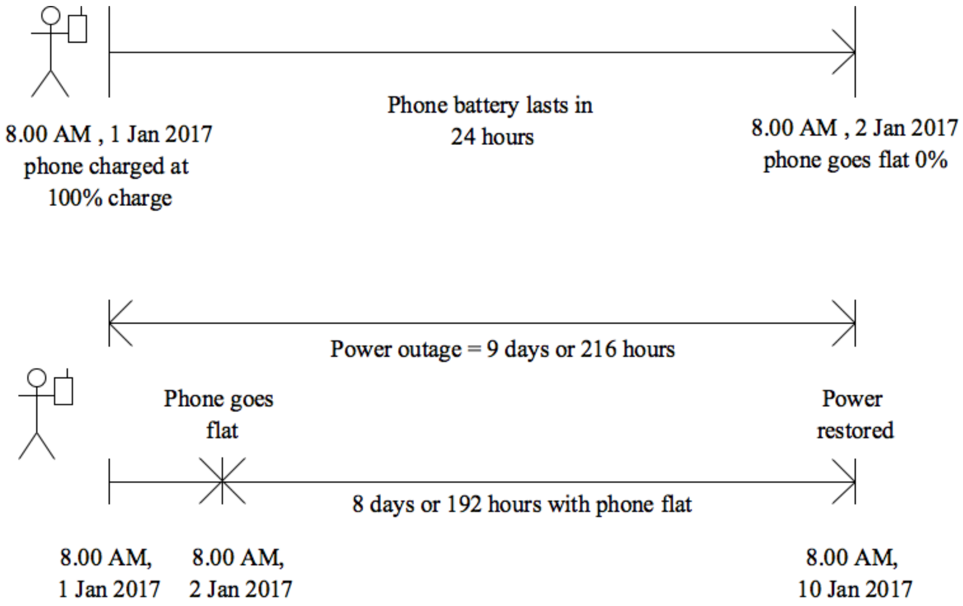


Figure 6.1: Example of mobile phone user with power outages

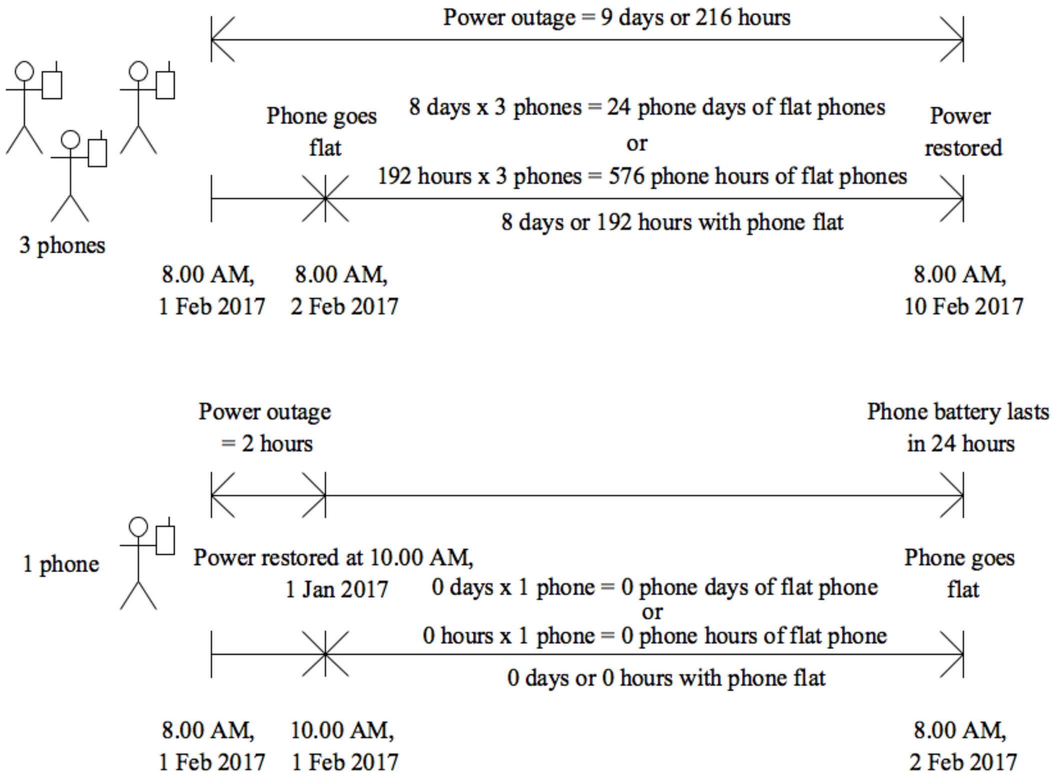


Figure 6.2: Person day or hour with flat phone calculation

From figure 6.2, it is shown that the duration of 8 days or 192 hours without mobile phone battery life is multiplied by three phones from three people. The result shows 24 phone days of flat phone or 576 phone hours of flat phone. On the other hand, if three people are affected from power source shortage, the number of day or hour with flat phone should be multiplied by three people (users) instead. Therefore, the result indicates 24 person-days or 576 phone-hours which means equation 6.3 is applied in this case. In other case, if power outage is equal to two hours and a mobile phone still lasts at 24 hours. Therefore, there is no flat mobile phone during power outages. The result is 0 days or 0 hour of flat phone.

From the equation 6.3, it can be applied with number of total day or hour with flat phone, which can explain how many people or phones lack power source in disaster or emergency situation.

6.6.3.3 Advantage of equation 6.1 and 6.2

It is interesting that why number of day or hour with flat phone in particular situation should be figured out. In disaster or emergency situation, the duration without power or electricity cannot exactly be estimated. However, our mobile phone battery life in daily usage can be evaluated. From equation 6.1 and 6.2, this assists to predict estimated duration or number of day or hour with flat phone. From the data, it can provide battery backup or alternative sources to sufficiently recharge a mobile phone.

In terms of equation 6.3, it is useful for statistical analysis to estimate number of person-days with flat phone. These data is to show how the disaster or emergency situation can have a tremendous impact on power, electricity, or even communication network to people in particular area.

6.6.3.4 Model of relationship number of flat mobile phone occurring during disasters situation and mobile phone battery life

The power outages prediction for response planning is important in disaster or emergency situation. These prediction models (Guikema et al., 2014) (Nateghi, Guikema, & Quiring, 2014) are able to estimate a number of storms, hurricanes, or typhoons affecting U.S energy infrastructure system. This persuades author to consider power outages related to a mobile phone to create a simple model of mobile phone battery life to determine the number of mobile telephones that would be flat at any particular point of time and that could be combined with the Queensland data to provide realistic estimation of impact of particular events. Our objective in doing so is to show the substantial peaks in the lack of means of communications expected to occur during emergencies and disasters, such as cyclone and flooding events in Queensland.

The idea of this model derived from equation 6.1 to 6.3 together with phone battery recharging pattern which is only defined to apply in this analysis. This model mainly used data source from Ergon Energy Company (Ergon_Energy_Company, 2016) in creating the model. To clarify such model the following scenarios are assumed:

- Mobile phone batteries are charged from 10.00 PM each night and become fully charged in 2 hours.
- A mobile phone is removed from charging station at 8.00 AM each morning and lasts before going flat. The charging duration is 8 hours.
- A mobile phone will self-discharge its battery life from 8.00 AM to 10.00 PM each day. The duration of battery life is 14 hours by average.
- One customer owns only one mobile phone.
- All customers live with no electrical power for the whole period of the outages.

Base on chapter 4, the results showed that most users recharged their phone overnight at 55.60%. Therefore, it was assumed that a mobile phone is recharged at 10.00 PM. Moreover, a mobile phone was fully charged within 2 hours at 29.10 %. As for the mobile phone disconnected from recharging, the results showed that people disconnected their phone when fully charged at 46.10%, when departing from the house at 28.30% and when waking up in the morning at 17.90%. That is why it was assumed that a mobile phone was removed from the recharging activity at 8.00 AM. Also, 20.5% of users from the survey in chapter 4 stated that they spent their time on a mobile phone about 10 to 15 hours a day.

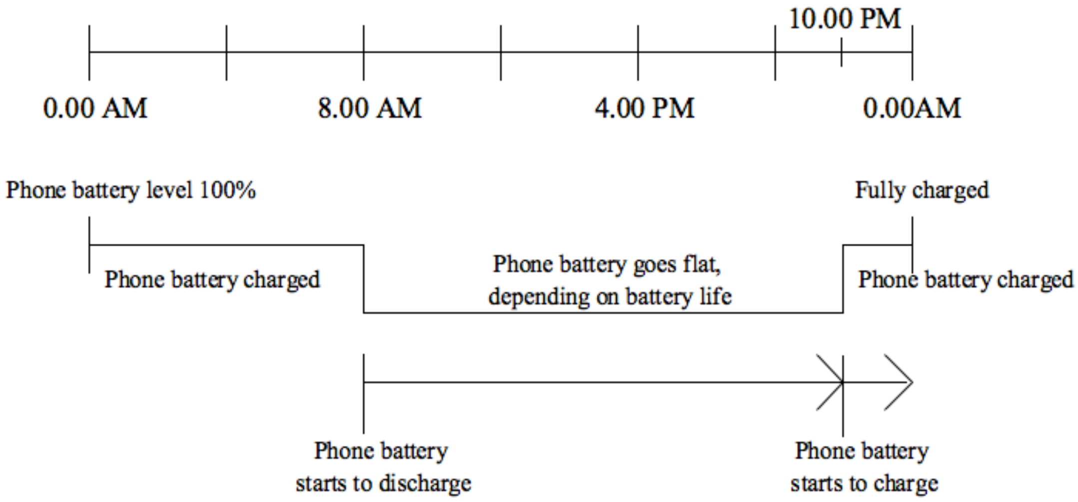


Figure 6.3: Scenario of a mobile phone charging and discharging model assumption

Figure 6.3 depicts the aforementioned assumption scenarios applied in power outage analysis program (Gardner-Stephen, 2017), which was implemented by The Serval Project Team. This program was analysed by using data source from Ergon Energy Operator and the analysis results was presented in section 6.6.2.1.

Please consider figure 6.4, in order to clarify and understand this proposed model thoroughly. In reality, the discharged rate of a mobile phone battery life depends on battery condition. Some mobile phone goes flat after having lasted for 24 hours or more. Other mobile phone goes flat within 24 hours, such as in 2 hours, 12 hours, and etc. From figure 6.4, if the battery life of customer’s phone lasts less than 14 hours, it means that the phone battery goes flat or completely exhausted before 10.00 PM until it requires the charging again. This situation indicates that the number of flat phones is likely to increase due to short or flat battery. On the other hand, if battery life lasts more than 14 hours, the number of flat phones is likely to decrease since there is still battery runtime left. A mobile phone is also recharged at 10.00 PM until it is fully charged and left until 8.00 AM in the next day.

Taking phone recharging conditions into account, if a battery is charged until fully charged. Some mobile phone needs to be charged more than or less than 2 hours. It depends on battery capacity and charging technology on each phone. If a battery is able to recharge quickly, the number of flat phones is likely to decrease because the battery has full capacity (long discharged time).

For the power outages which occur at different duration, if power outages occur after midnight but not over 8.00 a.m., a phone battery still maintains 100 % fully charged from the defined assumption. It goes flat from battery level 100 % to 0%, depending on battery life. The number of flat phones tend to increase more than the duration without power after a mobile phone is disconnected from its electricity source at 8.00 a.m. Assuming that there are power outages occurring at 1.00 a.m. and 8.00 a.m., there are two different points of time that should highlighted, which the total duration between these times are 7 hours (1.00 a.m. – 8.00 a.m.). If the charging started at 10.00 p.m., and the power outage occurs at 1.00 a.m., the phone will be charged for only three hours while if the power outage occurs at 8.00 a.m., the phone will be charged for 7 hours. This means that the number of flat phones with power outage occurring at 8.00 a.m. should be fewer compared to those with power outage happening at 1.00 a.m.,

If power outages occur from 10.00 PM onwards, the flat phone will rely on its remaining battery life. From the model assumption, it is the time to recharge battery. The number of flat phones is likely to escalate before 10.00 PM since a phone battery is not recharged or battery is almost flat or flat.

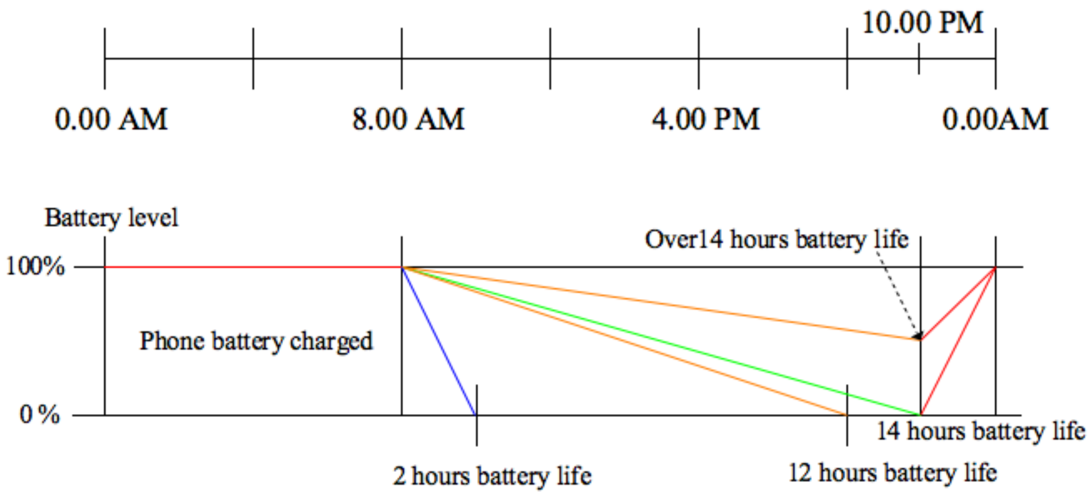


Figure 6.4: Phone battery recharged at different duration

To summarise, figure 6.3 and 6.4 merely aim at explaining a battery life aspect in terms of proposed model assumption. Parameters were defined from possibility of usage, appropriateness, and survey results from chapter 4, illustrating mobile phone battery recharging behaviour

To clarify entire explanation above in simple piecewise equation model, assuming that mobile phones are placed on to charge at 10:00 PM each evening, take 2 hours to fully charge, and are removed from their charger at 08:00 AM each morning. The battery level of the phone was reduced at a steady rate based on the specified battery life, indicated in hours. That is, the remaining battery charge level, r, is calculated according to:

$$r=\begin{cases} 1 & \text{midnight-8 AM} \\ \max\left(1-\frac{h-8}{b}\right),0 & \text{8 AM-10 PM} \\ 1-\min\left(1,\ \frac{22-8}{b}\right)\times\frac{24-h}{2} & \text{10 PM-midnight} \end{cases}$$

Where

- h is the time of day, measured in hours, e.g., 09:30 AM would be h = 9.5, 10.00 PM would be 22
- b is the battery life of the phone when fully charged, measured in hours
- r is the fraction of battery life remaining at a particular time, i.e., r = 1 indicates a fully charged battery and r = 0 indicates a flat battery

That is, phones are fully charged by 00:00, remain so until 08:00 AM (the first case of the equation) then stay discharged until 10:00 PM or until flat (the second case of the equation), and then reach full charge again by 00:00 (the third case of the equation). The max and min selectors act to prevent the equation yielding negative charge levels if the battery life being modeled is less than 22 - 8 = 14 hours when fully charged.

6.6.3.5 Relationship of mobile phone battery life and number of flat mobile phone occurring during acute disaster case example

This section describes relationship between a mobile phone battery life and a number of flat mobile phone occurring during disaster situation. According to power outages data from Queensland and table 6.2 to 6.4, there was a relationship among disaster events through 2005 to 2016. The data in this section were analysed based on the model in subsection 6.5.5.3. The results consist of a number of flat phones compared to the battery life of a mobile phone through 11 years data source and three interesting mass major events during 1 July 2005 to 31 June 2016, presented in table 6.9. It was analysed by describing through a bar graph about occurred number of customers without electricity supply or flat phone depending on mobile phone battery life during 0 hours, 24 hours, 72 hours, and 120 hours, presented in figure B.1 to B.17 (Appendix B). These durations can help interpret the variation of relationships between flat phones or customers without electricity, battery life, and disaster events significantly.

Table 6.9: The examples of massive disaster events for model analysis to show relationship between flat mobile phone and phone battery life (Queensland_Government, 2016c) (Ergon_Energy_Company, 2016)

Date	**Disaster Events**
17 to 20 March 2006	Severe Tropical Cyclone Larry Level 5
30 January 2011 – 3 February 2011	Severe Tropical Cyclone Yasi Level 5
15 to 21 February 2015	Severe Tropical Cyclone Marcia Level 5

Figure B.1 presents customers affected by disaster events since 1 July 2005 to 30 June 2016 throughout Queensland. According to table 6.2 to 6.4, there were disasters occurring through these years. Normally, a number of people dealing with this circumstance without electrical power was around 15,000 people in each year as seen from the graph. However, the number of people who lived without electricity supply reached the peak at January 2009, accounting for 260,000. Living without electricity supply had a huge impact on people in Queensland. Figure B.2 presents the duration of three major disaster events having an impact on Queensland. Cyclone Larry affected 100,000 people who lived without electricity. Cyclone Yasi caused difficulties more to about 200,000 people. While number of people living with no electricity supply increased to 250,000 people by average as a result of Cyclone Marcia. These are severe weather conditions occurring in Queensland every year and still persist.

Assuming that the number of people without electricity is the number of phones with flat batteries, it is, therefore, presumable that the number of flat mobile phone related to mobile phone battery life. Because the number of flat phone battery expresses direct variation to battery life. If we have mobile phone long battery life, number of flat phone battery is likely significantly less than short mobile phone battery life.

Figure B.3 shows customers living without electricity supply during 1 July 2005 to 30 June 2006. There was Cyclone Larry occurring until the end of impact during 17 – 20 March 2006. Number of people affected by this event was around 101,044. Figure B.4, B.5, B.6 and B.7 shows relationship between numbers of phones with flat batteries according to a battery life at 0 hour, 24 hours, 72 hours, and 120 hours during 1 March 2006 to 30 April 2006. Number of flat phone battery at battery life 0 hour, 24 hours, 72 hours and 120 hours are 101,044; 92,465; 51,561; and 38,590 respectively.

Figure B.8 shows customers living without electricity supply during 1 July 2010 to 30 June 2011. There was cyclone Yasi occurred until end of impact during 30 January to 3 February 2011. The number of people affected by this event was about 210,265 people. Figure B.9, B.10, B.11 and B.12 show the relationship between the number of phones with flat batteries according to phone battery life at 0 hour, 24 hours, 72 hours, and 120 hours during 1 January 2011 to 28 February 2011. The number of flat phone battery at battery life 0 hour, 24 hours, 72 hours and 120 hours are 210,265; 178,533; 112,891; and 67,246 respectively.

Figure B.13 shows customers living without electricity supply during 1 July 2014 to 30 June 2015. There was Cyclone Marcia occurring until the end of impact during 15 – 20 February 2015. The number of people affected by this event was around 136,542 people. Figure B.14, B.15, B.16 and B.17 shows the relationship between the number of phones with flat batteries according to phone battery life at 0 hour, 24 hours, 72 hours, and 120 hours during 1 February 2015 to 30 March 2015. The number of flat phone battery at battery life 0 hour, 24 hours, 72 hours and 120 hours are 136,542; 130,102; 107,694; and 86,450 respectively.

6.6.3.6 Relationship of a mobile phone battery life and total flat mobile phone battery according to model in section 6.5.3.4

Throughout 11 years duration of power outage data, the figure B.1 shows the relationship between mobile phone battery life and flat mobile phone battery life. It is interesting to understand how two variables are related: a phone battery life in 120 hours and flat phone battery life (hours), assuming that people in Queensland have only one mobile phone per person. Moreover, figure B.1 shows prominent interesting trend that if a mobile phone battery life lasts more than 20 hours, the number of flat phones is inclined to decrease. Another observation from this line graph is that the number of mobile a phone battery life during 15 hours to 40 hours still forms a slight curve while a battery life lasting from 45 to 120 hours or more than this shows a linear graph. This means that if there is much amount of battery life on a mobile phone, the opportunity that the phone will be flat declines. It strongly supports the assumption that a mobile phone battery life significantly correlates to a flat battery life. If people therefore have battery backup and alternate sources to recharge their mobile phone during power outages, they are likely to increase the time of mobile phone operation in disaster events. Hence, a flat phone battery life is likely to decline towards less hours, depending on a mobile phone battery life.

As a result, the number of customers living without electricity supply was affected by disaster events can form and answer the research question, say, how long mobile phone can last during a disaster.

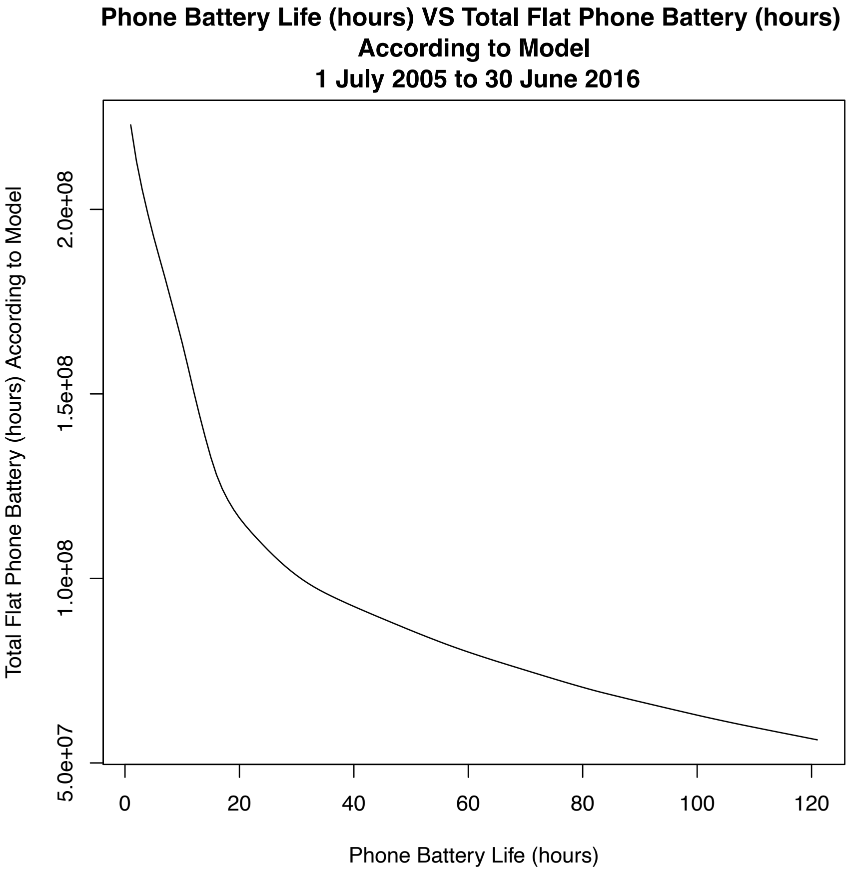


Figure 6.5: Phone battery life versus total flat phone battery according to model since 1 July 2005 to 30 June 2016

6.7 Discussion

This section discusses power outage data analysis results in terms of relationship between mobile phone battery life and flat phone battery according to power outage model analysis as well as power outage duration related to customers affected by power outages from disaster scenario. This discussion is based on major data sources from Queensland and some from South Australia.

6.7.1 Discussion, based on power outage duration and people affected by duration of power outages

Disasters are able to occur anywhere anytime in the world. In Australia, natural disasters have frequently occurred over the past years. From sample data derived from Queensland and South Australia, power outages mostly occurred from severe weather, flooding, bushfires, and etc. Below are the results from the lack of electricity supply occurring to people in Queensland and South Australia:

The number of people living without electricity in South Australia during 2010/11 in table 6.5 was 1,578,029 for about 0 – 4 hours. Interestingly, the number of people declined to 189,465 and 26,225 during 4 - 8 hours and 8 – 12 hours of power outages respectively. During 20 – 24 hours, the number dropped to 4,719 people. This phenomenon indicates the relationship between the length of power outage and people living without electricity. The power outage duration is likely to recover as fast as it can be depending on a situation.

For the results from Queensland demonstrated in table 6.8a and 6.8b, it revealed the duration of power outages since 1 July 2005 to 30 June 2016. In each year, there were disasters occurring across the state according to table 6.2 to 6.4. The power outage took place for more than 8 hours affecting 100,000 people in 2006/07 compared to 450,000 people in 2010/11. Yet looking at the statistics in 2006/07 and 2010/11, there were roughly 10,000 and 230,000 people affected by power outages more than 24 hours or 1 day. This suggest that it depends on the categories of different disaster situation occurring each year.

To be fine-grained about the length of power outage which affects people from two energy network sources, it is noted that the duration between 0 – 4 hours has the most impact on people as opposed to others. The length of time with no electricity, say about 0 – 24 hours, is still acceptable in terms of mobile phone battery life. Therefore, these power outage durations are the key factor to be taken into account when calculating flat mobile phone battery by using proposed power outage analysis model in section 6.6.3 to find out appropriate mobile phone battery life in disaster situation.

6.7.2 Discussion, based on duration of power outages and general mobile phone battery life

From table 6.7a and 6.7b through the year of 2005 to 2016, it indicated the percentage of power outage occurring in long or short period of time, depending on disaster events each year.

For the duration of power outage lasting longer than 24 hours or 1 day, it was roughly below 2.0 % or 1.0% by average. Even though it showed a little percentage, people affected from the lack of mobile phone battery life felt that the battery should be recharged within 24 hours. However, power outages tend to last longer than the battery life of a mobile phone operating under normal circumstance. Most mobile phone is used day by day based on the frequency of mobile phone recharged once per day by average in chapter 4. Also, the current maximum talk time of a flagship mobile phone claimed by manufacturer presented in chapter 2 is 34.49 hours by average. General mobile phones normally have a battery life which lasts least 24 hours by average when considered from talk time according to GSMArena.com.

In case that the power outages lasted more than 48 hours or 2 days, the percentages were roughly about 0.2% to 0.3% by average, unless there were a huge event or disaster occurring. For 72 hours or 3 days of power outage, it declined to 0.1% to 0.2% by average in normal season. From percentage results, even though it showed a little percentage after power outages occurred one day or longer. It showed that this is the gap of general mobile phone battery life that should be at least achievable about 48 hours to 72 hours to use during disaster or emergency. This can reflect the research question about minimum battery runtime during typical disaster is about 0 to 72 hours, which is acceptable.

6.7.3 Discussion, based on example of disaster events and flat phone battery life according to power outage analysis model

According to section 6.6.3.5 considering, in terms of customers affected by power outage duration, these data were analysed by the power outage analysis model. The results from this model was interpreted by using histogram graph showing the relationship between a flat mobile phone according to model in hours compared to battery life at such duration as 0 hour, 24 hours, 72 hours, and 120 hours.

As for the first example event, the incident of Cyclone Larry took place during 17 to 20 March 2006. From figure B.4, the occurrence of power loss reflected that there was a number of people affected from power outages after Cyclone Larry subsided after 2 or 3 days. This means that the catastrophe can affect people in different level depending on its severity. It might have immediate damages after the Cyclone struck the area, or the power outages might take place after the Cyclone abated for a while. Also, it depends on how long it takes people to respond or report to energy and power company about the occurrence of power outages. In terms of battery life on standby for 24 hours, 72 hours, and 120 hours, it can be suggested that the phone should last as long as possible. It can be seen from results shown in figure B.5 to B.7, the number of flat phone (assuming one phone per one person according to the model) dramatically declined, depending on a mobile phone battery life. Provided that people need to use a mobile phone as long as possible, people in disaster situation should find some place or use alternative sources to recharge their phone.

Cyclone Yasi was the second example. The event took place during 30 January to 3 February 2011. Figure B.9 showed that after Cyclone Yasi hit the area, there were some people affected during the first 2 or 3 days. The situation went worse after the 3 days and caused power failure. This event was similar of that of Cyclone Larry, depending on the responses from affected people to report loss of power. A mobile phone battery life can then last as long as possible and the number of flat phone eventually declines. From figure B.10 to B.12 the assumption about a mobile phone battery life with the number of flat phones is made.

The last example event was Cyclone Marchi which occurred during 15 to 21 February 2015. Figure B.14 showed that after Cyclon Marchi struck Queensland, the number of affected people living with no electricity supply were still fewer during the first of 3 or 4 days. The number of affected people increased in the similar pattern as those mentioned earlier. Then, if a battery life can last longer than that used in normal conditions. The number of flat phones ultimately declines.

6.7.4 Discussion based on mobile phone battery and total flat mobile phone battery according to model

From figure B1, it is noticeable that after about 15 to 40 hours of a battery life, and results in diminishing return in terms of the number of flat batteries. Also, the increase of battery life from the current level to 120 hours or longer reflected the relatively small contribution regarding the declination of the total number of flat phone battery and a mobile battery life. Between 15 to 40 hours of phone battery life, the graph started to transforms reflecting the high number of flat battery in hours gradually reducing. It is probably possible for a mobile phone to have a battery life that can last 2 days instead of 1 day. In order to achieve the result without phone costing a fortune, no point in fact is really going beyond that the cost of phone, the size of the phone increase linearly as we get very marginal improvement in resilience. Relating with survey in chapter 4 supports this point that mobile phone needs to last in emergency or disaster situation about 1 or 2 days, or 24 hours or 48 hours. That is not achievable for mobile phone in the general public, and the cost benefit does not seem to be reasonable.

For the total number of flat phone, it is impossible to come up with the reasonable phone battery range that will reduce negligible level in general public. Nonetheless, the number of flat phones drops from 220 million to 90 million by average with 2 or 3 days or 48 hours or 72 hours of battery life. That means a mobile phone battery life directly affects a flat phone battery life. Recently, Nokia 3310 model (Kelion, 2017) was relaunched again due to its long battery life. From this perspective, it is one of many pieces of evidence that people still need a phone with high efficient battery life more than that equipped with many features or high technology.

In general situation, from the survey in chapter 4, it is shown that people need a mobile phone to last between 1 to 2 days while in a disaster or emergency situation they prefer 2 days. If a battery goes flat in general situation, a mobile phone can be recharged in any place that provides electricity supply. On the other hand, the electricity supply during power outages or disaster can seldom be found. A mobile phone must be recharged in some particular place and cannot be recharged frequently depending on opportunity provided. The alternative recharge must be considered in a disaster or emergency situation. Therefore, a mobile phone battery needs to become more efficient so that it can meet people requirement.

Overall, the cheapest alternative to satisfy the power needs in emergency situation in Australia is the USB charger in the car which is the most effective way to help people maintain their phone battery status as discussed in chapter 5 explaining alternative phone charging strategies.

However, another way to save the power of a mobile phone is to turn it off while coping with power outage. This can help prolong a mobile phone battery as much as possible.

6.7.5 Discussion based on probabilistic loss-of-life estimate

From aforementioned section, it is able to establish an understanding of the probability of lives being lost as a result of the loss of telecommunications. It is made the assumption that if a blackout endures long enough to flatten a mobile telephone's battery, it is also likely to indicate that the battery backup at the local telephone exchange has also been exhausted, and therefore that the person has no alternative means of calling an ambulance. This assumption is strengthened by the roll-out of the Australian National Broadband Network using Fiber to the Node (FTTN) technology that does not provide a battery-backed land-line service.

From the data, it is able to determine that over the 11-year period, there were a total of 94,866,292 flat-telephone hours, i.e., the number of persons with flat mobile telephone batteries multiplied by the number of hours for which each was flat. Using the 2016 population of Queensland of 4,827,000 persons, and that there are 96,426 hours in eleven years, the total number of person-hours in that period was 465,448,302,000. Thus, assuming that the need for life-saving ambulance intervention is constant throughout the year, this corresponds to a probability of a given ambulance call not being able to be made p = $\frac{94{,}866{,}292}{465{,}448{,}302{,}000} = 0.0002$. That is, flat batteries due to blackouts probably prevented one in every 5,000 emergency calls to the Queensland Ambulance Service from being made. This slightly over-estimates the person-hours, as the population was slightly smaller in earlier years, making our estimate slightly conservative.

To understand the impact of these lost calls, it is important to understand the number of emergency calls that the Queensland Ambulance Service (QAS) receive, that are emergency call outs, i.e., where it is judged that the dispatch of an ambulance is required to avoid an immediate risk to life. The Government of South Australia also provides similar data (Goverment_of_South_Australia, 2016). For the 2014/2015 financial year, the latest year for which statistics could be found, Queensland experienced 694,983 emergency call outs (Queensland_Ambulance_Service, 2015) while South Australia experienced 124,310 during the same period, corresponding to a per-capita annual call-out probability of $\frac{694{,}983}{4{,}827{,}000} = 0.144$ for Queensland and $\frac{124{,}310}{1{,}706{,}500} = 0.0728$ for South Australia.

Correspondence with a career ambulance officer resulted in an estimate that between 5% and 10% of call-outs classified as emergencies result in the difference between life and death, for example, serious car accidents, broken legs where blood loss is a risk to life, or cardiac arrest. While this figure is only empirical, it is prima facie a reasonable starting point: It is clear that not all ambulance call-outs save lives and, at the same time, it cannot be too rare that emergency ambulance call-outs save lives, or else there would be no motivation to publicly fund an emergency ambulance service.

Combining all this, it can deduce that the emergency ambulance call-out rate is somewhere around 0.1 per capita per annum, and that approximately 5% – 10% of those call-outs will make the difference between life and death. Thus, between 0.5% and 1% of a given population will require life-saving ambulance attention per year. Taken conservatively, the per-capita probability of requiring life-saving ambulance attention is approximately p = 0:005. From the mobile telephone battery life model, it knows that emergency calls will not be possible with probability p = 0.0002 due to mobile telephones being flat. Thus, we estimate that the per-capita expected rate of loss of life due to flat mobile telephone batteries to be approximately 0.0002 x 0.005 = 0.000001.

That is, one life per million is expected to be lost each year in Queensland due to a flat mobile phone batteries following blackouts, corresponding to approximately 5 lives per year in total. Other states in Australia have differing blackout risk profiles, and so this figure may not be directly applicable to other states and nations where the risk profile is different.

It is also recognised that this figure is only approximate. The higher demand for emergency services during the events that cause blackouts may increase this figure. The probability of each emergency ambulance call-out saving a life may be either too high or too low. Also, while one person's mobile telephone may be flat, there may be other bystanders whose phone has a battery power and are able to make the call, reducing the figure or the correlated nature of the energy deprivation may mean that this is only rarely possible.

However, it seems reasonable to infer overall that lives are lost in Queensland and most probably in other states in Australia each year due to the inability to place phone calls due to long-duration of blackouts.

To put this into context, the risk of death due to the inability to call an emergency ambulance in Queensland alone, which it has estimated at 4.78 per year, is higher than the risk of dying due to being killed anywhere in Australia by Australia's infamously snakes spiders and other native poisonous creatures (approximately 3 per year (Welton, 2017) in total) and other deadly creatures (crocodiles: approximately 0.5 per year (Caldicott, 2005), sharks: approximately 1.1 per year (West, 2011)), which are responsible for a total of only 4.6 fatalities per year. That is, the inability to call emergency services due to the lack of mobile phone battery represents a small, but non-zero risk to life.

6.8 Conclusion

This chapter shows a shortfall of a mobile phone battery life in a disaster or emergency situation. It also presented the relationship among power outage duration, people affected by disaster in each events, flat phone battery, and a mobile phone battery life.

The result was analysed by using a mobile phone battery life related to simple power outages model to achieve concrete report through tables and figures.

The highly detailed data from the Queensland electricity network operator has allowed us to model the impacts of blackouts on the availability of mobile telecommunications from the perspective of the battery charge level of individual mobile telephones.

As expected from chapter 4 and 5, overlaying the historical blackout data from Queensland shows that there are expected to be a large number of people without access to mobile telecommunications following blackouts. Moreover, the full extent and frequency of long duration blackouts in Queensland has been revealed, highlighting the extent of this problem: In any given year there are tens thousands of people who lose power for more than a day resulting in potentially millions of person-days without access to telecommunications, which is likely to result in the loss of several lives per year.

The loss-of-life estimate itself is presently restricted to Queensland and may not be directly transferable to other jurisdictions, even within Australia, due to the differing risk profile. Also, the accuracy of the model and loss-of-life estimates could be improved with access to more specific data regarding the outcomes of ambulance call-outs, and the relative frequency of emergency calls during blackouts versus other times. These, together with exploring similar methods in other jurisdictions, are all potential areas for future work that would help understand the level of risk globally.

The relatively large numbers of people in both Queensland and South Australia who live without main power for longer than the batteries in their mobile telephones represents a significant challenge for disaster response that currently remains unresolved. While we have only attempted to estimate the direct loss-of-life that occurs, we have not attempted to model non-lethal bodily harm or damage to property that results from the inability to communicate. What is clear, however, is that the risk is real, and that measures should be taken to reduce it. Unfortunately, it is unfeasible to attempt to increase the battery life of mobile telephones sufficiently to bridge the resulting gap as it is discussed in chapter 5 and the reference (Kongsiriwattana & Gardner-Stephen, 2016a), it is better to focus on providing alternative means of keeping mobile telephones charged. As explained in chapter 5, the wide distribution of car USB chargers is probably the most cost-effective intervention at this point in time.

For the research question, “what the minimum battery runtime is required to sustain communications platform during the acute phase of a typical disaster,” the battery life on a mobile phone is not currently long enough to meet the needs in typical emergency or disaster situation in general mobile phone. There is a gap that what is needed versus what currently is in mobile phone battery life. The false needs of emergency response by extending up 2 or 3 days of phone battery life seems to be an achievable goal. However, it will not completely solve the problem. It would need the possibility of a long battery life to completely solve the unachievable problem. Also, it is unavoidable for people to bear additional cost when acquiring alternative ways to recharge their mobile phone

A mobile phone battery does not last long enough; it can never last long enough in any sensible reality. Therefore, the solution is either to improve the efficiency or eliminate power consumption of the phone (see in chapter 7) so that it can last longer. Still, reducing power consumption on a mobile phone partly helps. Assuming that a mobile phone can last to eighty hours from reducing power consumption on mobile phone, according to the graph in figure 6.5, though it helps negligibly increase the mobile phone battery life, it is still helpful. Yet, people still need the way to recharge their mobile phone; therefore, alternative mobile phone recharge should probably be the suitable option to increase the time of mobile phone operation in a disaster and emergency situation.

In the next chapter, energy saving/consumption on a disaster communication device will be described and the alternative energy saving techniques will be proposed.

CHAPTER 7: REDUCING ENERGY CONSUMPTION OF MOBILE WIRELESS DEVICES FOR DISASTER COMMUNICATION

This chapter describes information about proposed technique to reduce energy consumption on disaster communication device. Also, there were results of current drawn on that device to indicate that Wi-Fi On/Off affects much energy consumption. Finally, the results and limited factors are discussed.

7.1 Introduction

Smartphones or mobile phones are now ubiquitous, even in many lower income countries. They are particularly interesting for disaster communications, because they contain considerable computational and communications capabilities, in the form of a variety of radio transceivers, e.g., 2G/ 3G/ 4G cellular, Wi-Fi and Bluetooth.

During disaster/emergency situation, existing cellular network might be disrupted or broken for long time, which is unable to recover in the short period. Therefore, if there is self-organised communication network can replace in those situations, which is possible. This combination of various features in modern smartphone suggests that it should be possible to program smart-phones to form self-organising infrastructure-independent networks. This offers considerable hope and promise for personal disaster communications, precisely because they allow communications without relying on existing infrastructure that may be damaged or overwhelmed during and following disasters and other extreme events.

The Serval Project has proposed small and flexible reliable wireless communication network being able to overcome some limitation of lacking cellular network. The major capability of this project is to take advantage of Wi-Fi function to implement ad-hoc network via Wi-Fi communication. From this beneficial operation, smartphone can act as voice communication, SMS and file sharing like general mobile phone. However, Wi-Fi mode consumes much energy depleting battery life quickly. Hence, to prolong battery life and reduce energy consumption on Wi-Fi ad hoc mode is necessary and major point to pursue of this chapter

To answer the major question of this chapter which is, “How can extend battery runtime on disaster communication platform?” or a sub question, “Can it reduce Wi-

Fi energy consumption on Wi-Fi ad hoc network?", the hypothesis in this study is "Mobile phone or mesh device can save power by frequently turning Wi-Fi off to increase battery life." Hence, this chapter proposed ultra-low-energy Wi-Fi standby technique to command Wi-Fi function to switch on a mesh device during data receiving packet period and then turn Wi-Fi off while finishing or no packet receiving state. There were some limitations that The Serval Project team could not implement this technique on mobile phone directly, because it is highly sophisticated to implement on a mobile phone to turn Wi-Fi on or off. Moreover, quantification of energy consumption on mobile phone regardless of other functions is really difficult for energy measurement. Also, there is some constraint in experiment about Wi-Fi background to interfere while experimenting.

To prove that this ultra-low-energy Wi-Fi standby technique can reduce energy consumption especially while operating on Wi-Fi ad hoc network mode. The Serval Project proposed prototype device known as Mesh Extender (The_Serval_Project_Team, 2014a), which increases Wi-Fi range and operates on Wi-Fi ad hoc network. This device consists of two elements including Wi-Fi router device including GL-AR150 device and energy sampler module for energy sampling of Wi-Fi signal strength. Since the goal is to minimize Wi-Fi energy consumption, the results are in fact totally applicable, precisely because The Serval Project team has that it is possible to reduce the energy consumption compared with off-the-shelf Wi-Fi.

The results of a simple initial experiment validate the general feasibility of this approach, demonstrating that this scheme can be implemented using unmodified Wi-Fi hardware. The only changes to existing hardware and software are the addition of an ultra-low power radio frequency energy sampler and simple application-level software. In other words, while the hardware design of compatible smart phones would require modification, the changes are isolated and simple in nature and could be easily and affordably made by a single manufacturer rather than requiring the expensive, time-consuming, and logistically challenged process of developing a revised version of the Wi-Fi chipset. Of course, incorporation into Wi-Fi chipsets is not precluded in the longer-term.

7.2 Background of reducing energy consumption on ad-hoc Wi-Fi in The Serval Project

Realizing vision for resilient mobile telecommunications is, however, not without difficulties. First, most modern smartphones lack effective long-range peer-to-peer communications capabilities, with the exception of the cellular radio, which due to regulatory and competitive factors is not an option. Even where peer-to-peer communications was possible on such devices in the past, for example by using ad-hoc Wi-Fi on historical releases of the Android, Windows CE, or Symbian S40/ S60 operating systems. To the best of our knowledge, all major contemporary mobile operating systems no longer allow this. For instance, successive versions of Android have made it effectively impossible to access ad-hoc Wi-Fi. Despite repeated attempts by various parties, Google have declined to rectify this situation. In fact, the ad-hoc Wi-Fi capability has been completely removed from the patched Linux kernels used in modern Android phones, greatly complicating any effort to restore ad-hoc Wi-Fi capability to Android phones.

The loss of these capabilities is likely because of the lack of a compelling use-case that requires them. The peer-to-peer frameworks that have entered into recent versions of Android and iOS are focused on episodic near-by data exchange, such as sharing a photo or files to someone standing next to the user, or to connect a phone to a wireless printer. It is suspected that generalized, self-organising peer-to-peer communications has not materialized as a use-case due to several factors.

First, the range of communications of ad-hoc wireless is relatively limited, resulting in frequent network partitioning, and thus necessitating the use of store-and-forward communications in place of real-time streaming-oriented protocols, such as UDP or TCP. This in turn means that internet access and voice calls are not practical. However, in a disaster context, where any communications are better than none, these are not compelling limitations.

Second, the increased power consumption of ad-hoc Wi-Fi has historically been prohibitive. Android handsets which normally enjoy stand-by times of several days may be able to activate ad-hoc Wi-Fi for as little as an hour before completely exhausting their battery. This is primarily due to the high standby current of ad-hoc Wi-Fi, which is typically of the order of 1W. Unfortunately, this is inadequate to allow a smart phone to be useful during a typical disaster situation (see chapter 6).

It is this problem of power consumption that has prevented the development of usable systems, that can operate without any supporting infrastructure, and that has spurred the need for devices such as the Serval Mesh Extender (The_Serval_Project_Team, 2014a), which allow phones to operate as ordinary low-power Wi-Fi clients. While this can largely resolve the energy consumption problem and the devices are relatively small and low-cost, it curtails the benefits of peer-to-peer communications in disaster situations by resurrecting the need to supply and operating some sort of infrastructure.

For this reason, it remains imperative to find solutions to this open-question: how to construct self-organising infrastructure-independent communications networks consisting solely of smartphones with sufficiently low energy consumption so that battery life can remain long enough to be useful.

In this chapter, one means that we believe it can be achieved through leveraging recent advances in low-power wireless radio telecommunications and decentralized communications is explained. Specifically, it proposed how the standby power consumption can be reduced to micro-Watts of an ad-hoc Wi-Fi-based peer-to-peer communications network, while still allowing for full-speed Wi-Fi communications with wake-up times of milli-seconds.

7.3 Existing energy efficiency technique on low power wireless devices related to proposed technique

In this section, there will be explanation about related energy efficiency on low power wireless devices, which is shown as below:

7.3.1 ContikiMAC radio duty cycle protocol

The Contiki Media Access Control or ContikiMAC (Dunkels, 2011) has been proposed by Adam Dunkels. The Contiki MAC is an energy-optimized MAC for low powered devices, which allows radio receivers to be turned off approximately 99% of the time, delivering considerable power savings. This is achieved through a mechanism where radioactivity is detected through periodically sampling the received signal strength indication (RSSI) and only waking up the receiver when the RSSI value exceeds some threshold.

Contiki MAC is characterized by its simplicity: A transmitter needs to only repeat a data packet until it is acknowledged and to ensure that the packet meets a minimum length requirement. From the receiver side, the receiver is required only to sample the channel energy periodically. Selection of the sampling periods, minimum packet length, and phase-lock optimizations form part of the scheme which helps further minimize power consumption. This procedure is shown in figure 7.1 below.

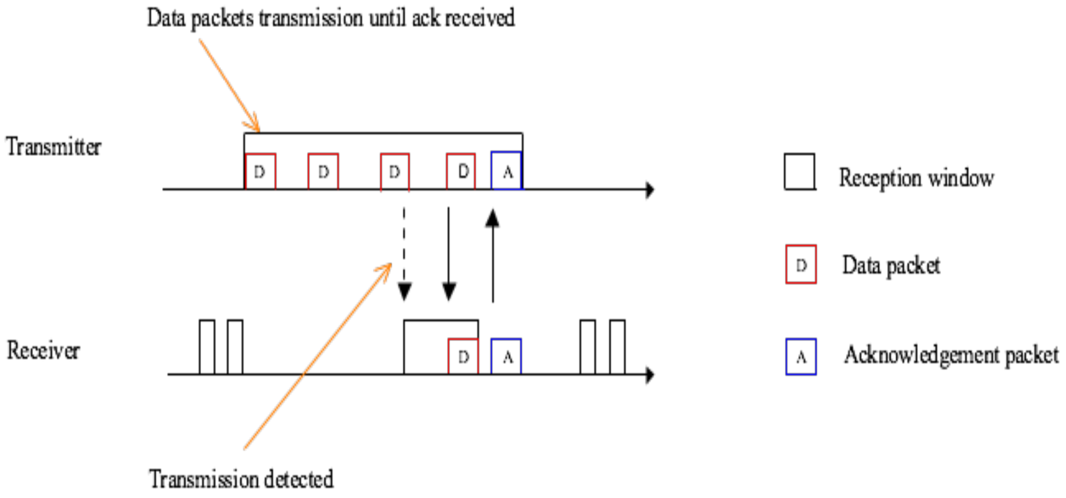


Figure 7.1: ContikiMAC procedure (Dunkels, 2011)

7.3.2 Ultra-Low-Power passive 2.4 GHz wireless receiver

Contiki MAC is designed around 802.15 (Yick et al., 2008), rather than 802.11 Wi-Fi. Wi-Fi transceivers do not include a standardized and low-power mechanism for measuring channel RSSI, which means that Contiki MAC cannot be directly applied to Wi-Fi. However, because of the simplicity of Contiki MAC, a modified scheme could be applied to Wi-Fi, provided that an appropriate low-power RSSI scheme can be identified. (Cook, Berny, Molnar, Lanzisera, & Pister, 2006) demonstrated the feasibility of a passive 2.4GHz receiver which offers the potential to obtain RSSI measurements with a power consumption of only 300 µW. This figure is so low – approaching the self-discharge rate of lithium ion batteries (Zimmerman, 2004) that it can be effectively ignored for the use case of mobile telephony.

7.3.3 S-MAC and T-MAC protocol

S-MAC concept (Wei, Heidemann, & Estrin, 2002) used periodic listen and sleep technique to allocate two frames of sensor node including active part and sleeping part. The objective of sleeping part is to turn radio off of sensor node to reduce energy consumption. On the other hand, active part is to be turned on radio to communicate with other node sensors.

T-MAC concept (Dam & Langendoen, 2003) was developed from S-MAC technique. This technique is to reduce active time frame depending on activation event occurred. If there is no activation event occurred, node will then go to sleeping state after end of TA. Activation event is communication message such as transmitted and received message. As for TA, it is determined after no activation event to be the end of active state or idle listening time frame. Therefore, active state can be active less than sleeping part as opposed to S-MAC technique. This technique can preserve energy more than S-MAC.

Figure 7.2 presents the comparison between S-MAC and T-MAC concept, showing difference of active or listening state between two protocols. T-MAC can vary listening state, depending on communication message or activation event while listening and sleep state of S-MAC is fixed at the same rate. Both techniques prove that energy consumption of sensor node can be reduced from turn sleep state more than active state.

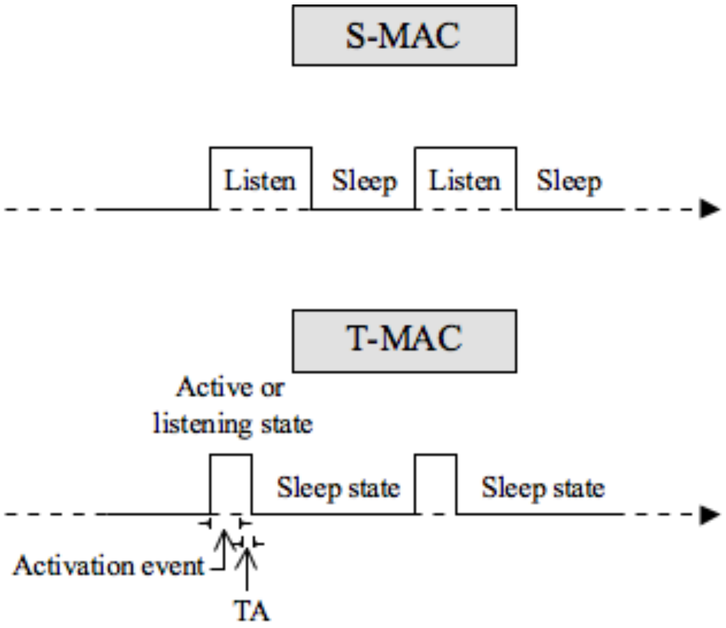


Figure 7.2: S-MAC and T-MAC technique (Wei et al., 2002)

7.3.4 WiseMAC protocol

This WiseMAC technique (El-Hoiydi & Decotignie, 2004) proposed sampling schedule the medium on sensor node to check any activity that occurs in radio channel. It consists of three states including doze or sleeping state, receiving or listening state, and transmitting state. Sampling rate of listening state has the similar constant period and short duration illustrated by TW. WiseMAC allows access point learn sampling rate of sensor node. When access point wants to transmit data, it must send at the right time on the receiving state of sensor node. If it transmits before the right time, it needs to wait until reaching the receiving state of sensor node. After that, the access point transmits minimum wake-up preamble time or TP to sensor node. Then, receiving and transmitting state of sensor node provides slot time for arriving data from access point and returning ACK from sensor node to access point via transmitting state.

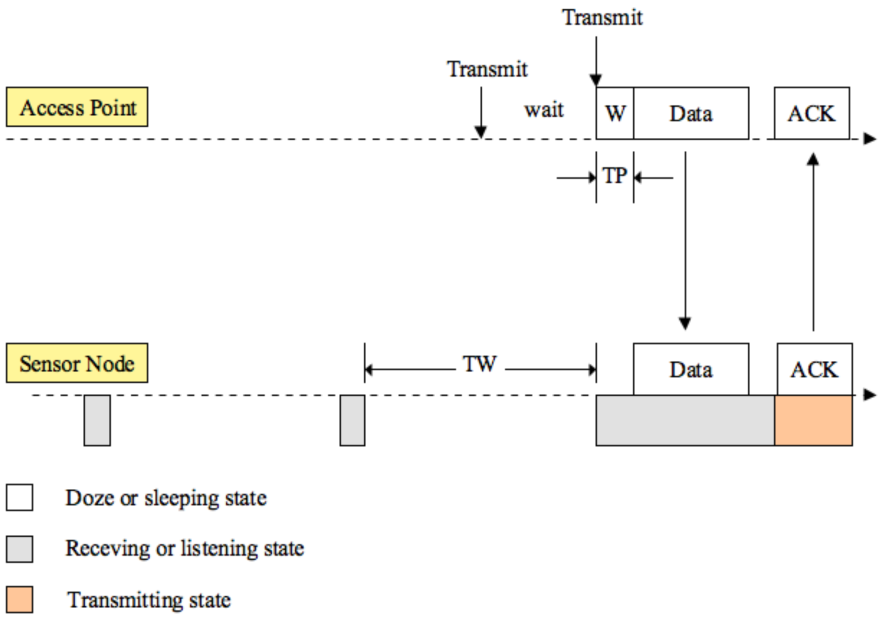


Figure 7.3: WiseMAC technique (El-Hoiydi & Decotignie, 2004)

7.3.5 B-MAC and X-MAC protocol

B-MAC protocol (Polastre, Hill, & Culler, 2004) uses clear channel assessment (CCA) and packet back offs for channel arbitration. Sensor node periodically wakes up as duty cycle to action with CCA to sample wireless channel. If energy or activity is detected on the channel, the node stays awake for receiving incoming packet. Then, it will go back to sleep state. B-MAC is the MAC protocol implemented on TinyOS and based on the physical layer for channel sensing.

X-MAC protocol (Buettner, Yee, Anderson, & Han, 2006) is a link layer protocol. X-MAC inserts destination address inside the short preamble, which can send packet to intended receiver directly. Receiver nodes, which do not want to receive packet, may go back to sleep immediately. Then, the receiver nodes continue its duty cycle as idle state which can save energy.

7.4 Design for ultra-low-energy Wi-Fi standby

By combining the developments described in section 7.3, in this thesis it was only restricted based on two existing achievements: first, the ContikiMAC protocol that provides means for energy efficient communications among devices and, second, a low power passive 2.4GHz receiver front end that provides the means for monitoring a Wi-Fi channel for activity with zero to negligible power consumption.

It was designed a scheme whereby an RSSI sampler is used to temporarily activate a Wi-Fi receiver. The target use-case is peer-to-peer communications between smartphones using the Serval Mesh (Gardner-Stephen, 2011) (Gardner-Stephen et al., 2012) (Gardner-Stephen, Bettison, Challans, & Lakeman, 2013) (P. Gardner-Stephen, R. Challans, et al., 2013) (P. Gardner-Stephen, A. Bettison, et al., 2013). Specifically, decentralized communications using ad-hoc Wi-Fi require broadcast transmission between handsets that are in range of one another. Because of the very limited communications range of Wi-Fi in most mobile handsets due to their small internal antennae, it is expected that it will be common for handsets to not be in communications range of other handsets for extended periods of time. Also, the limited range of communications means that the duration of potential contact between handsets may be very short, potentially just a few seconds. Therefore, there is a need to ensure that communications can be established very rapidly, ideally within milliseconds.

To meet this use-case, it is proposed that Wi-Fi radio in each device remains off until such time as: (1) the device wishes to transmit a packet; or (2) the RSSI sampler indicates activity on the channel. Once activated, the Wi-Fi radio is kept activated for a short period of time to allow any transmission to occur.

In addition, each Wi-Fi radio will periodically wake up to transmit a beacon packet several times to announce its presence. Unicast transmission on Wi-Fi makes use of an acknowledgment scheme (Klingler, Dressler, & Sommer, 2015). In ideal circumstances, the first transmission attempt of a Wi-Fi packet by a sender will cause the RSSI sampler to detect the transmission, and thus trigger activation of the Wi-Fi radio of the receiver. The second transmission of the packet will be correctly received by the receiver - that is to say, the Wi-Fi protocol will detect this only as a recoverable level of packet loss. Then, after a short period of time, the receiver will deactivate their radio receiver.

It is recognised that this scheme, while attractive in its simplicity and backward compatibility, does have several challenges.

First, all receivers in range will be awoken whenever a packet is transmitted, even if it is not intended for them. This will result in increased energy use by all nodes, especially those not participating in a conversation. This is somewhat mitigated by the short range of communications of Wi-Fi. It is also further mitigated if used in conjunction with systems such as the Serval Mesh, which operate using promiscuous protocols where every receiver takes notice of all transmissions regardless of whom they address to.

Second, the scheme assumes that the Wi-Fi radio of a receiver can be activated fast enough that the normal packet re-transmission protocol of Wi-Fi can be used. If the turn-on time of Wi-Fi is too slow, the sending party must take this into account and explicitly send two packets. Also, slow ramp-on and ramp-off times for Wi-Fi radios reduce the energy efficiency of the system. This can be resolved by developing improved Wi-Fi firmware and drivers that allow for faster turn-on and turn-off times.

Third, the use of a fixed RSSI activation threshold results in sub-optimal selectivity and sensitivity of transmissions. This could be mitigated through the use of a dynamic RSSI threshold.

As explained above, all of these challenges are manageable and/ or solvable, and we believe that such a scheme has the potential to reduce the power consumption of peer-to-peer mobile telecommunications. In the next section, we present a proof-of-concept to demonstrate the basic technical feasibility of such a scheme. It is, however, left as an open-question to determine the extent of energy savings that are possible using this scheme.

7.5 Proof-of-concept for ultra-low-energy Wi-Fi standby

To attempt to prove the feasibility of such a scheme, a prototype device was assembled consisting of three main components: The first device is portable wireless router to communicate with Wi-Fi detection node, consisting of two GL-AR150 low cost wireless router. This device has been implemented in The Serval Project known as mesh extender (The_Serval_Project_Team, 2014a). The second device is incorporated in the experiment is an EFM32 Perl Gecko starter board, functioning as protocol buffer. The third device uses concept of generating periodic duty cycle pulse running on sensor node or low-cost radio detection device. This device functions on frequency at 2.4 GHz used for detecting Wi-Fi signal known as custom-design 2.4 GHz wireless energy sampler. The three significant devices are described as below:

7.5.1 GL-AR150 low cost wireless router

This device operates on essential hardware known as GL-AR150 produced by GL Technologies (GL_Innovations, 2017) as the nominated device in this experiment. The GL-AR150 was chosen because they contain an Atheros 9331 SoC that are well known for their ability to operate in ad-hoc Wi-Fi mode without difficulty and because the GL-AR150 comes with OpenWRT linux v15.05 pre-installed. Software was written to run on the GL-AR150 that allows the Wi-Fi interface to be turned on and off as desired. Wi-Fi activation was triggered by the reception of a character on the serial UART interface. Wi-Fi would then remain on until a period of time passed, without receiving any Wi-Fi packets. This period is the Wi-Fi Hold Time.

Further software was written that ran in two parts, one on each GL-AR150. On the first, designated the experiment controller, the software would communicate to the matching software on the experiment slave via Ethernet to instruct it of the Wi-Fi hold time to be used for the experiment. The experiment controller would then send a series of broadcast Wi-Fi packets to the experiment slave in pairs, separated via a variable interval, the wake-data interval. The size of the packets also varied. If the experiment slave received either a wake or data packet, it would echo it back to the experiment controller, which would then record this event. The experiment slave is the device that was connected to the energy sampler, and would turn its Wi-Fi on and off.

There were various functions provided for usability and development including Wireless LAN (Wi-Fi), LAN, and WAN. The vital function used for operating device was Wi-Fi function which was used for implementing Wi-Fi ad hoc mode. To understand this device clearly, please consider specification on table 7.1, table 7.2, and figure 7.1.

Table 7.1: GL-AR150 hardware specifications (GL_Innovations, 2017)

Hardware Features	
Interface	1 WAN and 1 LAN Port (10/100 Mbps), 1 USB 2.0 Port and 1 micro USB Port
Button	1 Reset Button
Power Supply	5VDC/1.0A
Dimension (W x D x H), Weight	58 x 58 x 25 mm, 40 g
Antenna Type	PCB antenna or external
Power over Ethernet	Yes
Power consumption	< 1 watt
CPU	Atheros 9331 Soc 400M
ROM/RAM	16MB/64MB

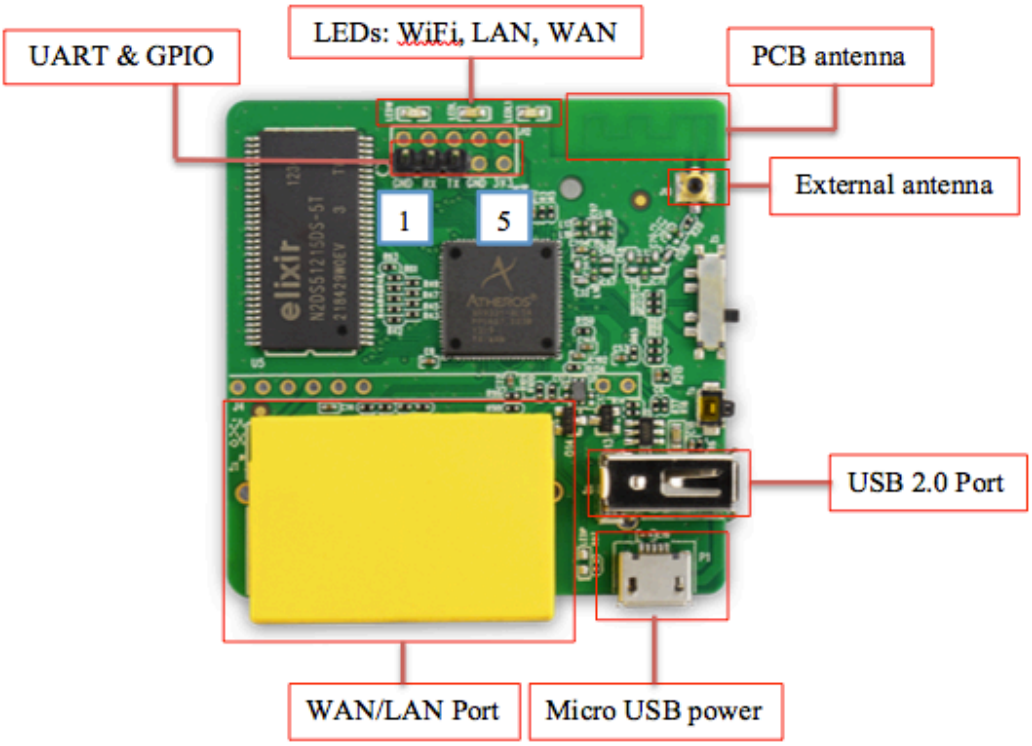


Figure 7.4: Internal hardware and wireless features of GL-AR150 device (GL_Innovations, 2017)

Table 7.2: GL-AR150 wireless specifications (GL_Innovations, 2017)

Wireless Features	
Wireless Standards	IEEE802.11b, IEEE802.11g, IEEE 802.11n 150 Mbps
Frequency	2.4 GHz
Sensitivity	-94dBm
Max output	18dBm

Figure 7.4 represents internal hardware and wireless features of GL-AL150. It consists of important elements such as WAN/LAN port, USB 2.0 Port, 5VDC power in, PCB and external antenna, LEDs indicator, and UART: Universal Asynchronous Receiver/Transmitter and GPIO: General-purpose input/output pin. UART and GPIO can represent pin out from pin 1 to 5 as follows:

Pin 1 = Gnd, Pin 2 = Rx, Pin 3 = Tx, Pin 4 = Gnd, and Pin5 = 3.3Vcc

- WAN/LAN Port is used for connecting with computer to command GL-AR150
- PCB and external antenna are provided for objective in receiving or transmitting Wi-Fi signal
- Micro USB power is power voltage from battery source or power supply 5VCC
- LEDs indicator shows status of Wi-Fi, WAN, and LAN while operating
- USB 2.0 port is port providing for general purposes

7.5.2 EM Perl Gecko starter board

EM32 Perl Gecko Starter Kit (Silicon_Labs, 2017) is a microcontroller board operating between GL-AR150 and energy sampler. Software was written for the EFM32 Pearl Gecko functioned as protocol buffer which monitored the output of the energy sampler, looking for edges. Whenever an edge was detected, the EFM32 would send a character via the UART serial interface for reception by the GL-AR150. It was originally attempted to connect the energy sampler to the GL-AR150's serial UART; however, the Atheros 9331 would ignore a proportion of the pulses, presumably because of glitch rejection logic on the serial UART interface.

In other words, protocol buffer aims to verify whether energy sampler can detect Wi-Fi packet from transmitter side or not. Protocol buffer merely detects Wi-Fi packet size at 2 ms or greater than this. Then, character R from protocol buffer is sent to GL-AR150 as soon as energy sampler already detects Wi-Fi packet as acknowledge message. The major intention of this protocol buffer is function as intermediate buffer between energy sampler and GL-AR150 in order to understand communication between UART of GL-AR150 and energy sampler. This EM32 Perl Gecko board was functioned on CPU model EFM 32 which only consumed current 3.07 mA while running as protocol buffer. As this experiment assumes that current drawn from this specific CPU was very low, we do not count this current consumption in our experiment. EM32 Perl Gecko Microcontroller is shown in figure 7.5 below.

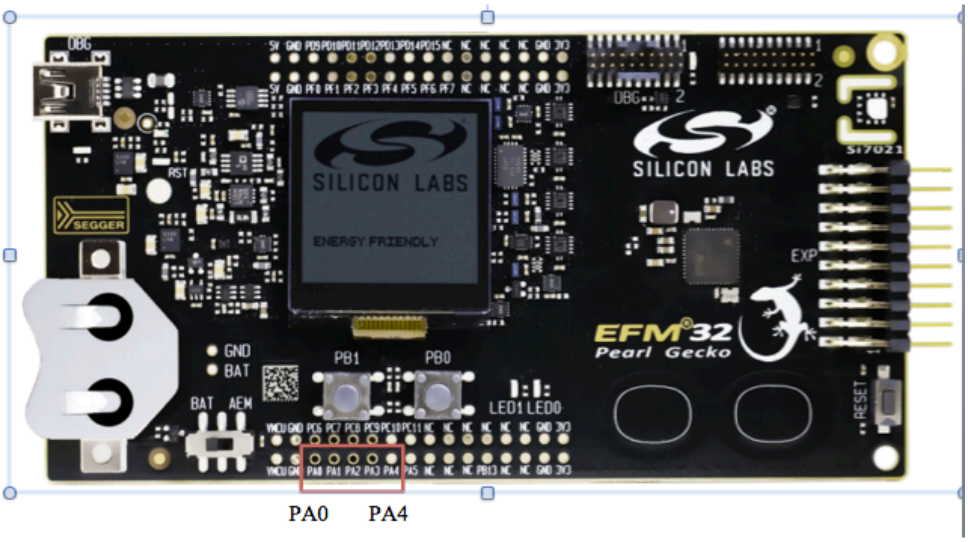


Figure 7.5: EM32 Zero Gecko Starter Kit (Silicon_Labs, 2017)

From figure 7.5, PA0 and PA4 pin of microcontroller board was used in the experiment as input/output connecting between energy sampler and GL-AR150. PA0 as output pin sends R character to Rx pin of GL-AR150 whereas PA4 as input pin receives Wi-Fi signal or packet from energy sampler.

7.5.3 Custom-design 2.4 GHz wireless energy sampler

In term of energy efficiency experiment, GL-AR150 was always connected with energy sampler module via protocol buffer. The energy sample, manufactured for us by RFDesign in Brisbane (RFDesign, 2016), is a small device which will output a 3.3V pulse train if the ambient energy level is above some threshold. The frequency of the pulse train, sensitivity level, and center frequency are all adjustable via variable resisters on the board. To clarify about the energy sampler component, it is shown in figure 7.6.

Figure 7.6 illustrates the energy sampler module. Each rectangular box is described as follows:

- Red: Rotating counter-clockwise to increase or decrease frequency is used for controlling pulse frequency
- Green: Rotating counter-clockwise is used for controlling pulse width of square pulse
- Blue: Rotating counter-clockwise to increase or decrease sensitivity is used for controlling sensitivity to detect or not detect Wi-Fi signal.
- Yellow: Vin is a power voltage received from EM32 micro controller board (3.3 V)
- Light Blue: Output (Tx) is periodic square pulse signal sending to protocol buffer

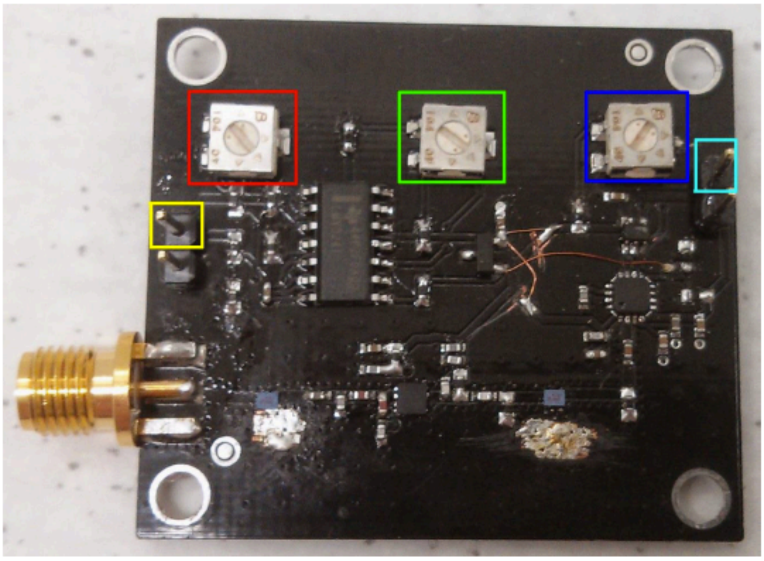


Figure 7.6: Energy Sampler Module (RFDesign, 2016)

7.5.4 Experiment slave set up of three related devices as receiver side

To clarify about relationship of the energy sampler, the EFM32 microcontroller and GL-AR150 connect each other for operating in the experiment, please see figure 7.7.

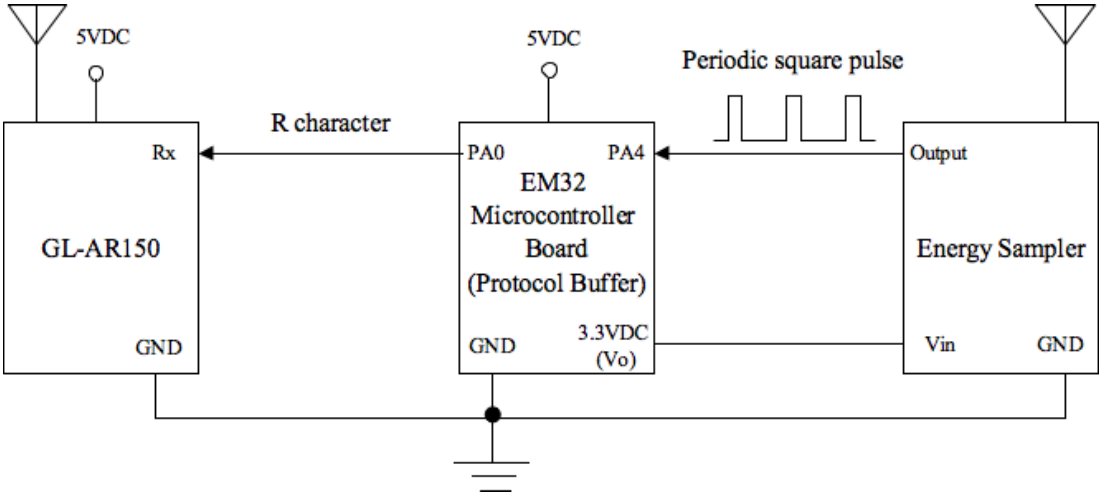


Figure 7.7 Experiment slave setup diagram

Figure 7.7: Experiment slave setup: Energy sampler detects Wi-Fi traffic and emits a pulse train. The EFM32 detects the pulses and sends valid serial characters to the UART of the GL-AR150, which then activates its Wi-Fi radio for a period of time.

In the experiment, 5VDC was separately supplied between GL-AR150 and EM32 microcontroller board known as protocol buffer. Energy sampler was also supplied by 3.3VDC from EM32 microcontroller board. However, the energy consumption was excluded on both device as EM32 microcontroller board consumes less power consumption while energy sampler consumes high power consumption. This experiment merely pointed out Wi-Fi energy consumption on GL-AR150 and how to eliminate energy consumption from Wi-Fi by our proposed technique.

Energy consumption on energy sampler is not counted in this experiment because there is potential to sample Wi-Fi energy via passive circuit. In the future, it will be possible to build a passive 2.4GHz RSSI sensor (Cook et al., 2006). Such sensor will be capable of detecting the presence of a transmission above an adjustable threshold without consuming significant energy. The use of such sensor is the first preference for this experiment. However, as we do not have the resources to fabricate a custom 0.13-micron integrated circuit, in this experiment, we use an active energy sampling circuit which is designed with cost-minimisation as the primary criteria rather than minimizing power consumption. Because it has been established that a fully passive sensor is possible, the energy consumption of the low-cost energy sampler used in this experiment is not included in the energy measurements of this experiment.

This paper (Gudan, Shao, Hull, Ensworth, & Reynolds, 2015) provides the basis for using the energy sampler which is currently used because technology exists that will allow it to sample the channel at negligible cost. A trigger from such circuit can be used to wake both device's Wi-Fi receiver and CPU, allowing them to remain in deep sleep while awaiting traffic. This has the potential to allow very low-power mesh networks without requiring any time synchronisation in order to achieve it in practical provided that it can wake the Wi-Fi up within a useful timeframe.

From figure 7.7, periodic square pulse is always sent out from energy sampler to protocol buffer via PA4 pin. It has an objective to verify Wi-Fi packet transmitting from transmitter side. Incoming Wi-Fi packet greater than 2 ms is allowed and detected by protocol buffer. After that, R character or acknowledge message is sent from PA0 pin to let GL-AR150 know that there is incoming Wi-Fi. Then, GL-AR150 is waked up from sleep state and ready to receive following Wi-Fi packet.

7.5.5 Overall of ultra-low-energy Wi-Fi standby concept

Basically, mechanism of wireless communication is that the transmitter sends data packet to the receiver; subsequently, the receiver replies acknowledgement packet to transmitter side respectively.

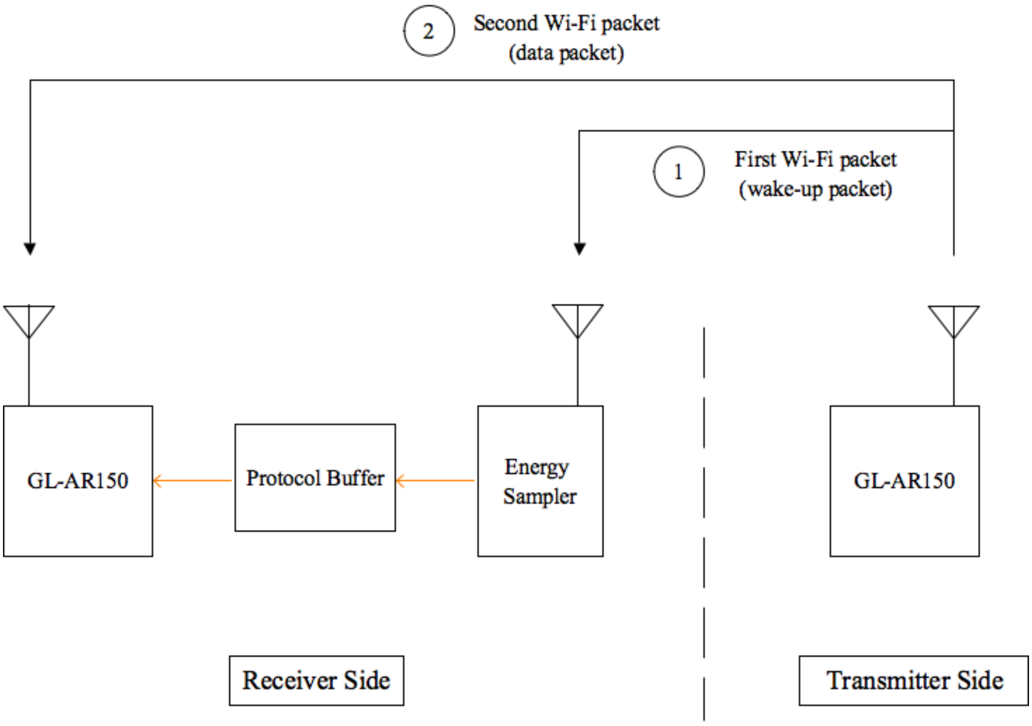


Figure 7.8: Communication between transmitter and receiver side in the experiment

The proposed technique slightly behaves differently from the ordinary communication way in that there are packets sending to receiver side twice which are first packet and second packet. First packet is called as wake-up packet which functions as wake-up or turn Wi-Fi on of GL-AR150. On the other hand, second packet is known as repeated packet which functions as data packet. Figure 7.8 clearly explains how Wi-Fi packet from the transmitter side is sent to the receiver side.

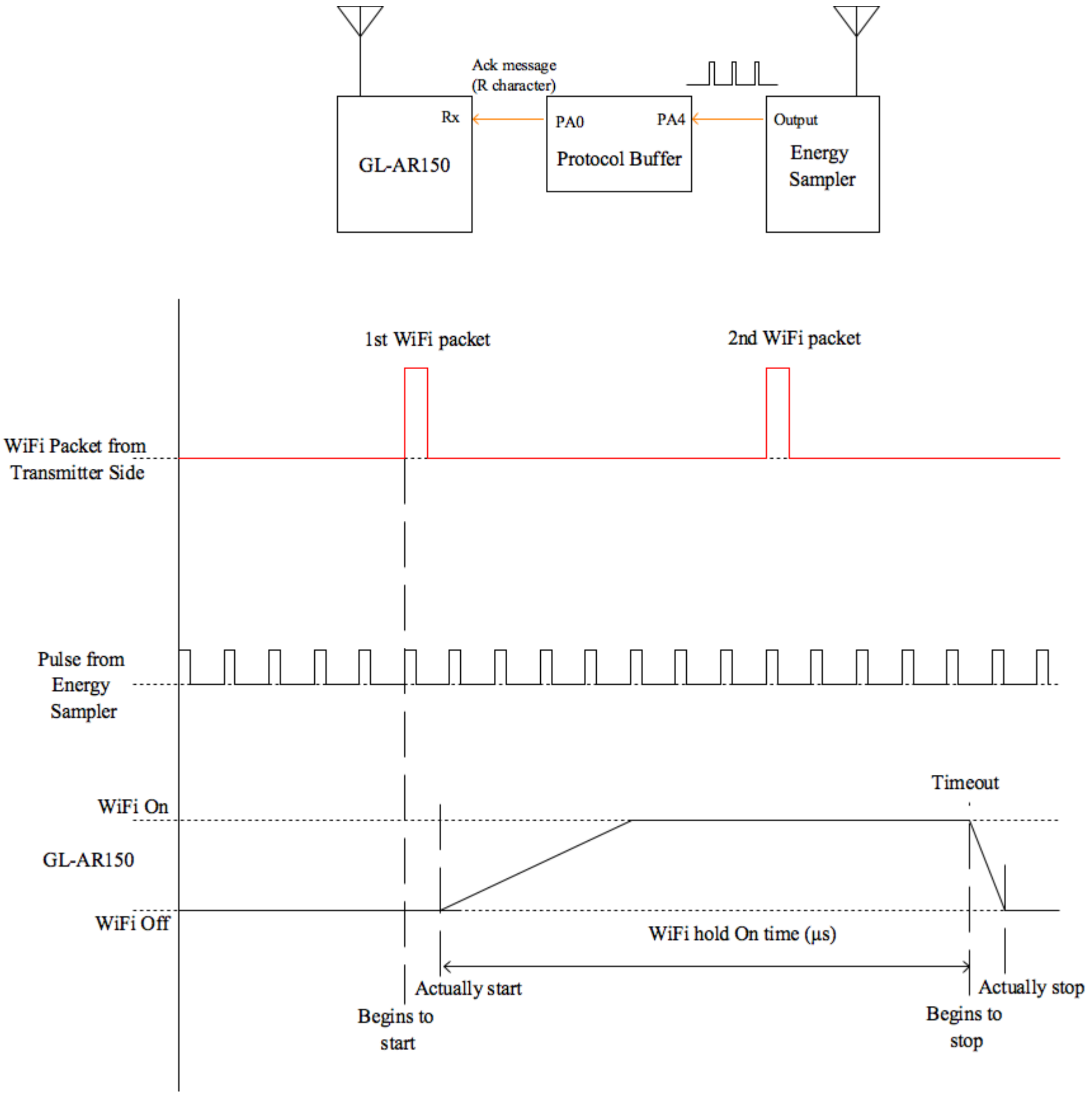


Figure 7.9: Procedure of GL-AR150 operates with energy sampler via protocol buffer by using ContikiMAC concept

Figure 7.9 shows procedure of GL-AR150 operating with energy sampler through protocol buffer. While Wi-Fi packet from the transmitter side arrives at the energy sampler at the receiver side, Wi-Fi packet which is greater than 2 ms is accepted from protocol buffer. Then, acknowledge message from protocol buffer is sent to GL-AR150 via UART on Rx pin by using R character. It is necessary to send negative pulse to let receiver or GL-AR150 know there is a character arriving at the receiver. This is restriction of UART or serial communication to code program.

The pulse which is less than 2 ms cannot be detected and ignored because in Flinders university laboratory there are a lot of Wi-Fi and beacon signal occurring from many access points. Beacon signal in figure 7.10 captured by oscilloscope shows many thin line pulses surrounding 1st Wi-Fi and 2nd Wi-Fi packet. Therefore, it is necessary to define Wi-Fi packet size to check the different between packet size whether it should be greater or less than 2 ms. If a packet size is greater than 2 ms, it can be detected by protocol buffer. If it is less than 2 ms, it cannot be detected. It is useful in distinguishing and discriminating whether which signal is packet or beacon or noise in background of Wi-Fi. Figure 7.11 shows Wi-Fi packet which is greater than 2 ms is detected and then R character message is sent to protocol buffer.

Afterwards, GL-AR150 accepts R character and turns Wi-Fi on in short period of time for receiving the following or second Wi-Fi packet. This short period of Wi-Fi status on is called as Wi-Fi hold on time. Wi-Fi function is turned off after Wi-Fi on timeout, and waiting for new first Wi-Fi packet in the next round of transmission.

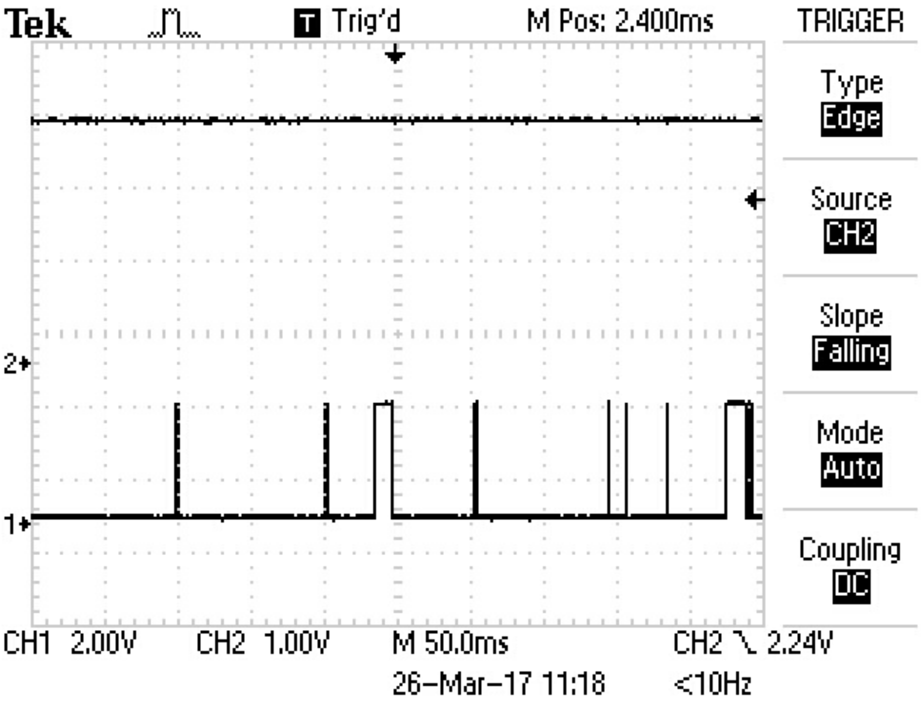


Figure 7.10: 1st Wi-Fi packet and 2nd Wi-Fi packet surrounding with beacon signal

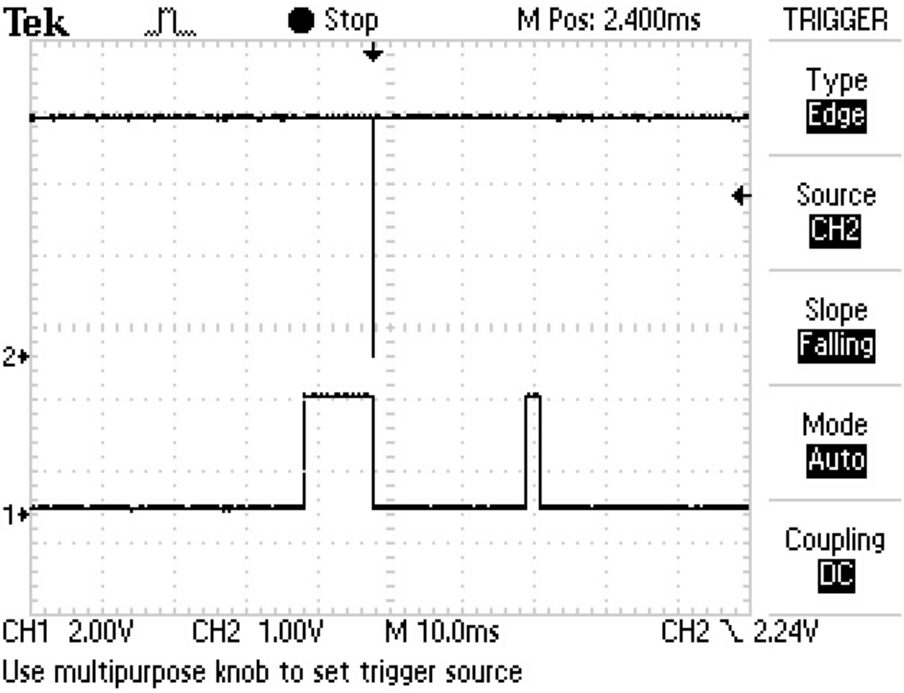


Figure 7.11: 1st Wi-Fi packet size which is greater than 2 ms detected by protocol buffer and R character (negative pulse) sent to GL-AR150 at receiver side

Please note that ultra-low-energy Wi-Fi standby technique concept has been applied from ContikiMAC. In this thesis, there is an objective to merely use this technique for reducing energy consumption on Wi-Fi ad hoc network at receiver side by turning Wi-Fi on while there is incoming packet and turning off Wi-Fi when without incoming packet.

7.5.6 Relationship of three major variables of ultra-low-energy Wi-Fi standby in the experiment

The system was configured in such a manner that the Wi-Fi antenna of the two GL-AR150s and of the energy sampler were placed in close proximity to ensure an adequate signal to noise ratio over the substantial ambient Wi-Fi traffic in the building. The sensitivity trim-pot of the energy sampler was adjusted until the false positive rate of packet detection dropped to approximately one packet per second.

It is recognized that the effects of the ambient Wi-Fi traffic on the GL-AR150s was not eliminated. That is, the GLAR150s may hold-off on transmitting a packet due to the 802.11 media access control protocols. This was considered an acceptable situation as it also strengthened the reality of the experiments.

In this way, a series of experiments was run in an automated manner, testing the effect of packet size, wake-data interval, and Wi-Fi hold time.

The wake-data interval was of interest as it provided an indirect indication of the latency of Wi-Fi activation: If the wake-data interval was too short, the Wi-Fi receiver would not have time to start up and receive the packet.

Similarly, the Wi-Fi hold time provides a means to measure the Wi-Fi deactivation latency: There will be a threshold to the hold time, below which packets are not reliably received, if the hold time plus the Wi-Fi deactivation latency are less than the wake-data packet interval.

Finally, by adjusting the packet size, it is possible to determine the minimum time required for the energy sampler to detect a packet. It is acknowledged that the energy sampler we used had limited sensitivity and that the receiver of (Cook et al., 2006) would likely be more sensitive. That is to say, if it could demonstrate that a relatively crude experiment was able to receive packets with reasonable reliability, it would be confident that the proposed method was feasible in practice with sufficient sensitivity to be useful in practice.

To ensure that the system in fact detected periods of Wi-Fi silence and disabled its Wi-Fi interface correctly, the number of wake packets received was also logged: If more than a negligible proportion of wake packets were received, this would be an indication that the system was not demonstrating sufficient selectivity.

The overall power consumption of the system was not of concern as the focus of this work was merely to determine whether such a system could be built using the limited resources available to the project. If the project proved successful, an obvious area of future work would be to design a system that incorporated a passive receiver and appropriate Wi-Fi transceiver in a more integrated package which would allow the actual energy savings to be accurately measured.

From the explanation above, there are three essential variables regarded in the experiment which are Wi-Fi hold time, effect of packet size, and wake-data interval and Wi-Fi hold time.

- Wi-Fi hold time is a duration of Wi-Fi on GL-AR150 at receiver side which is turned on in a short period of time in millisecond (ms) or microsecond (μs).
- Wake-data interval (Wi-Fi packet gap) and Wi-Fi hold time is a duration between 1st and 2nd Wi-Fi packet sent from transmitter in millisecond (ms) or microsecond (μs).
- Effect of packet size is the size of Wi-Fi packet sent from transmitter, which unit of size is byte or the unit of time in millisecond (ms) or microsecond (μs).

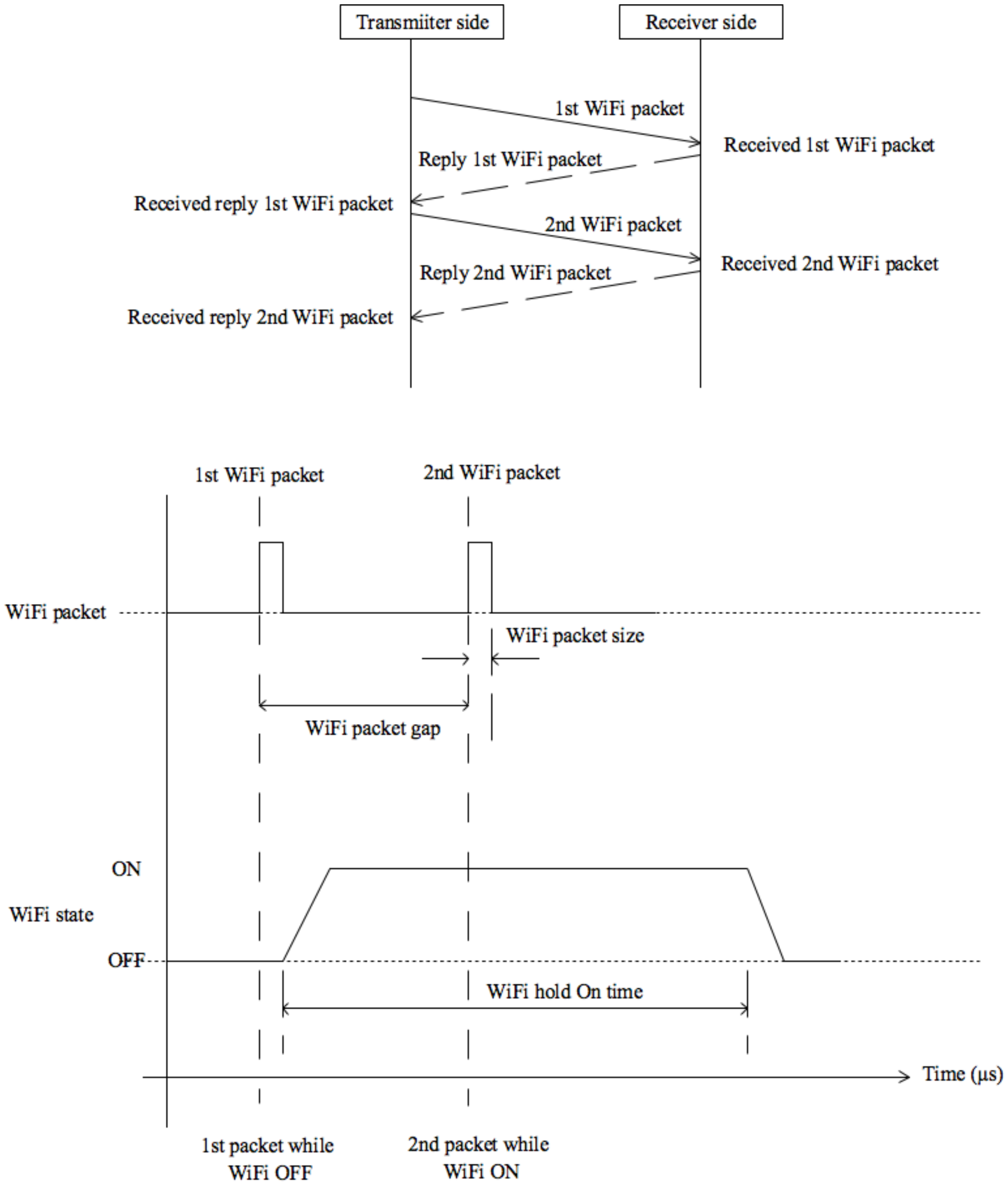


Figure 7.12: relationship of consistent three variables while communication occurs in the experiment

All of three variables related to each other in the experiment can be elaborated and shown in figure 7.12. In each round of Wi-Fi packet transmission in the experiment, there will be Wi-Fi packet sending to receiver twice. The transmitter begins sending Wi-Fi packet to receiver and transmitter and then checks reply message from the receiver. 1st Wi-Fi packet replying from receiver to transmitter side is counted that there is incoming of Wi-Fi packet. Then, transmitter starts sending 2nd Wi-Fi packet and waits for the reply from the receiver.

Interval or gap between 1st Wi-Fi packet and 2nd Wi-Fi packet is considered whether it should be long or short because of energy consumption issue. 1st Wi-Fi packet lets receiver side knows that Wi-Fi functioning on GL-AR150 must be turned on for a while. This is called a Wi-Fi hold time. Then, 2nd Wi-Fi packet data is actually sent to receiver side respectively. This 2nd Wi-Fi packet is considered as packet data sending to receiver side. Also, 2nd Wi-Fi packet must be sent when the Wi-Fi is on. After finishing 2nd Wi-Fi packet, the Wi-Fi hold time is turned off and data transmission completes session. Therefore, the Wi-Fi hold time is another major variable to consider in order to figure out how long the Wi-Fi status should be "on" The third variable that should be taken into consideration in the experiment is Wi-Fi packet size. Large packet size spends much time in transmission period more than short packet size. Hence, it is feasible to reduce energy consumption provided that appropriate packet size is selected in transmission system.

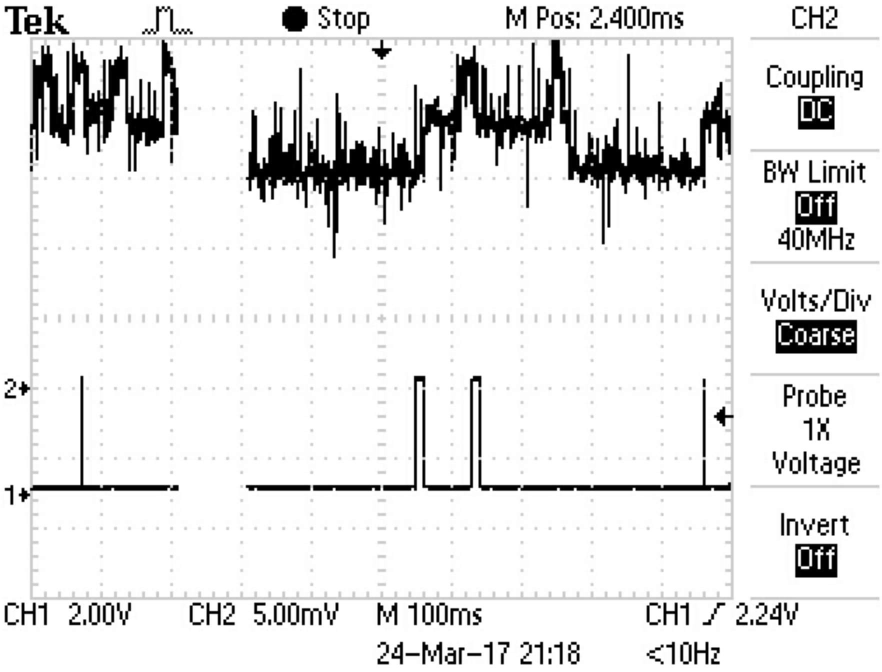


Figure 7.13: Wake-data interval and Wi-Fi hold time during 100 ms or 100,000 µs

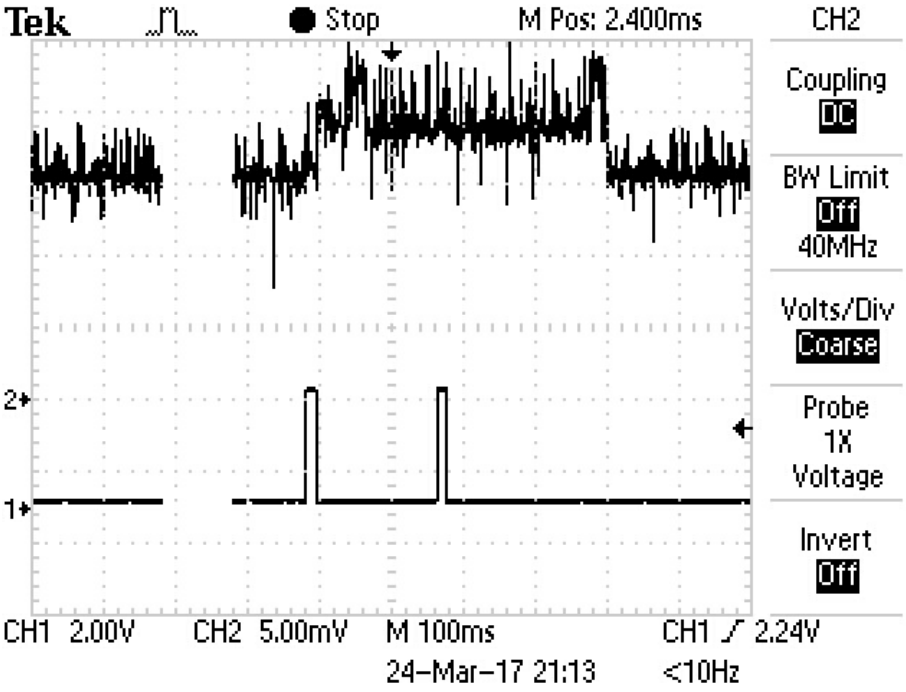


Figure 7.14 Wake-data interval and Wi-Fi hold time during 200 ms or 200,000 μs

Figure 7.13 and 7.14 shows example of three variables captured by using oscilloscope in real time experiment. It consists of Wi-Fi hold time, Wake-data interval, and Wi-Fi packet size respectively. Figure 7.13 shows Wake-data interval and Wi-Fi hold time during100 ms or 100,000 μs, Wi-Fi hold time 240 ms or 240,000 μs, and Wi-Fi packet size at period of time greater than 20 ms or 20000 μs. As for figure 7.14 shows Wake-data interval and Wi-Fi hold time during 200 ms or 200,000 μs, Wi-Fi hold time 400 ms or 400,000 μs, and Wi-Fi packet size at period of time greater than 20 ms or 20000 μs.

7.5.7 Experimental setup on two GL-AR150, energy sampler, and EM32 Perl Gecko board

The objective of this section is to demonstrates how to set up related devices both on receiver and transmitter side. This experiment was conducted in Telecommunications Research Laboratory Tonsley building at Flinders University. It was set up to prove that energy consumption on Wi-Fi can be eliminated by mostly turn Wi-Fi off while merely turning Wi-Fi on in case of data transmission.

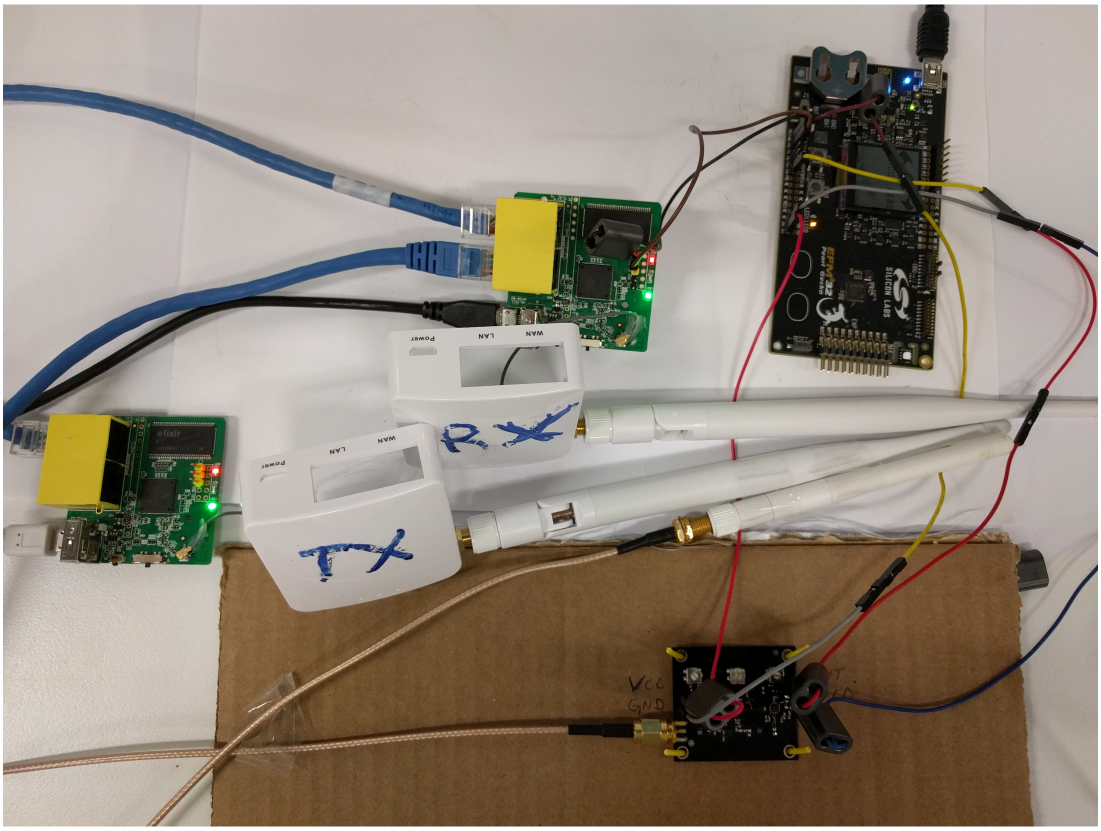


Figure 7.15: Experimental energy efficiency setup consisting of transmitter and receiver side

In the experiment, related devices were setup as shown in figure 7.15 including receiver side (Rx) and transmitter side (Tx). In our focused experiment, we need to measure current drawn on device at receiver side including GL-AR150 and energy sampler. Results of current drawn on GL-AR150 is about 88.5 mA in case of Wi-Fi on, and 58.5 mA in case of Wi-Fi off. For the energy sampler device, the current drawn is approximately 65.5 mA. This result indicates that the Wi-Fi on and off status affect energy consumption or current drawn in the experiment. Therefore, this current measurement result can show that proof of the concept in the experiment is likely to reduce energy consumption. The summary of current drawn results is shown in table 7.3 below.

Table 7.3: Current drawn on each device in the experiment

Device	Current drawn
GL-AR150 (Wi-Fi on)	88.5 mA
GL-AR150 (Wi-Fi off)	58.5 mA
Energy sampler	65.5 mA
GL-AR150 (Wi-Fi on) + Energy sampler	154 mA
GL-AR150 (Wi-Fi off) + Energy sampler	124 mA

7.6 Results and discussion

According to section 7.4, these experimental results are divided into three main points for investigating factors of energy consumption in Wi-Fi ad hoc communication. First, it examines the effects of changing interval between wake and data packet. Second, it considers adjusting the packet size on reliability of reception. Third, it considers the effects of changing Wi-Fi hold time. In each round, the experiment begins from transmitting the 1st Wi-Fi packet from transmitter to wake up receiver side. Afterwards, the 2nd Wi-Fi packet data are sent from transmitter to receiver side. The results were illustrated in three specific scenarios by sigmoid curve (Richards, 1959) depicted in figure 7.16, 7.17, and 7.18 respectively.

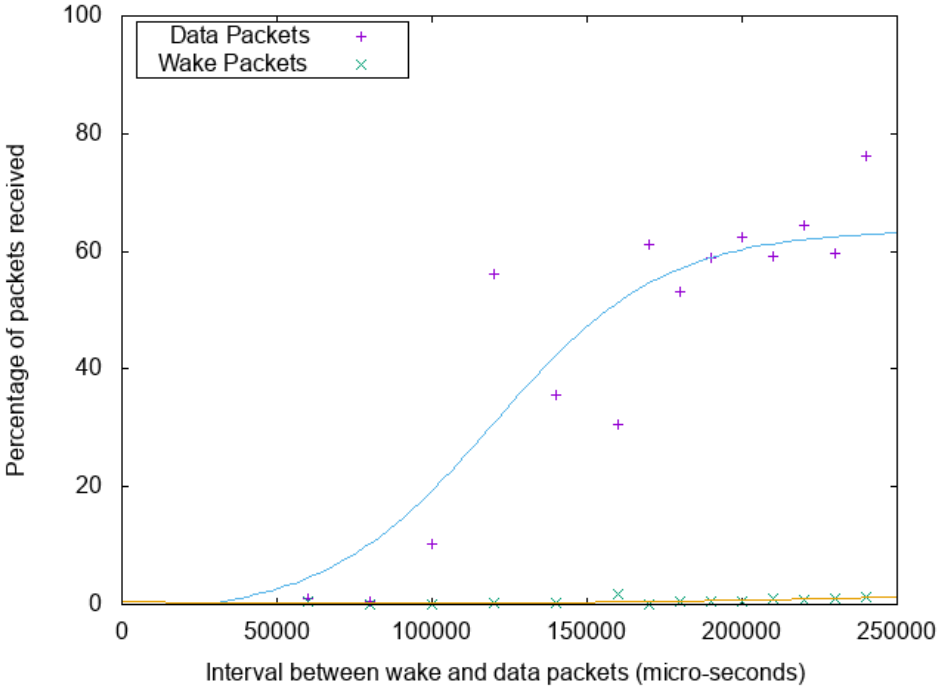


Figure 7.16: Mean percentage of wake and data packets versus gap in time between wake and data packet, fit to a sigmoid function. Packet size = 1450 bytes, Wi-Fi hold time = wake-data time + 20ms. n = 38

First, it can be seen that, across all experimental parameters, the false-positive rate, i.e., the percentage of wake packets received, was very low. This confirmed that the experimental hardware was capable of discriminating between the transmissions of the experimental controller and the ambient Wi-Fi noise of the environment

Second, it is seen that the percentage of data packets received exceeds 60% provided that the parameters are appropriately selected to ensure that the Wi-Fi packet is long enough to be detected that the wake and data packets are separated sufficiently in time to allow the Wi-Fi hardware to power back up and that the Wi-Fi hold time is long enough to allow for the wake-data delay. Despite the loss of close to half of the packets, this nonetheless confirms that the scheme is, in principle, feasible.

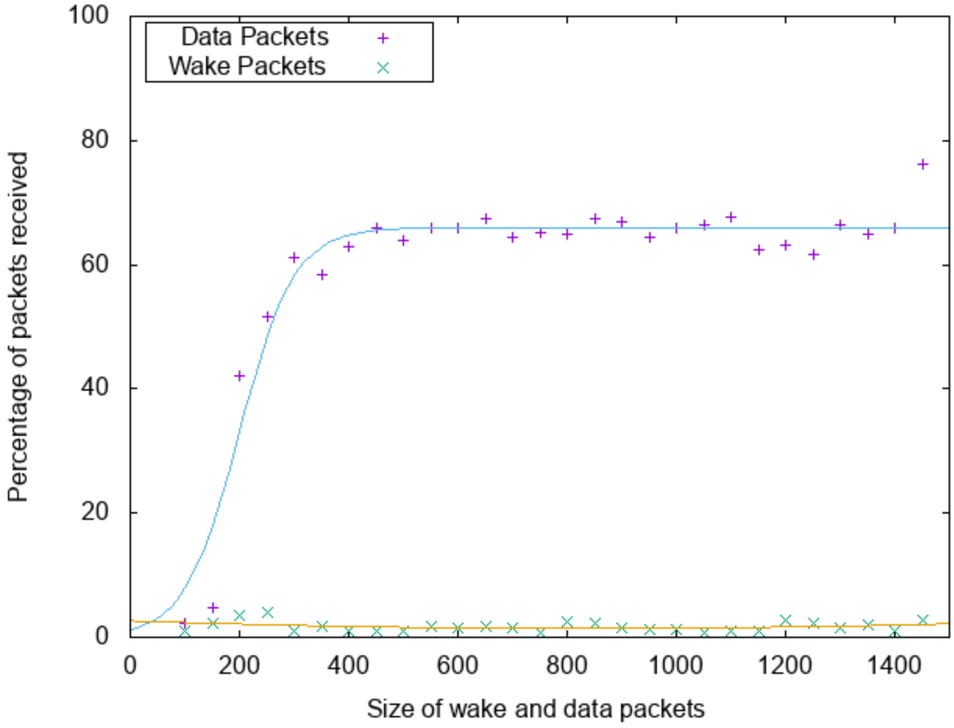


Figure 7.17: Percentage of wake and data packets versus packet size, fit to a sigmoid function. Wake-data time = 230ms, Wi-Fi hold time = 250 ms. n = 38

Regarding the probability of successful packet delivery, while the observed level of 60% sounds problematically low, it is in fact in agreement with the modeled rate of broadcast packet delivery on saturated Wi-Fi networks with 10 to 20 nodes (Oliveira, Bernardo, & Pinto, 2009). The experiments were conducted in a laboratory in a busy University building with many Wi-Fi devices in the laboratory as well as in the surrounding environment including many hidden senders in the form of the hundreds of high-power Wi-Fi access points and their clients that provide blanket Wi-Fi coverage of the building on adjacent floors.

Given this environment, that 60% of data packets successfully received in the absence of any packet re-transmission scheme suggested that the method would, in the absence of interference, result in close to 100% packet delivery. Indeed, as mentioned previously, closer examination of the data revealed that 100% packet delivery over a set of 20 repetitions would occur very frequently. In fact, while the mean packet delivery in each of these replicates was around 60%, the median packet delivery was 100% with more than 38% of replicates suffering zero packet loss.

Apparently, Wi-Fi networks are ubiquitous. It is unavoidable to implement or experiment without Wi-Fi interference even though it can be tested in Faraday Cage, where Wi-Fi signal cannot get through. The results from the experiment may be close to 100% packet delivery. However, this experiment needs to focus on feasibility of the proposed scheduling algorithm embedded within the devices. Also, it intends to prove possibility to send and receive data packet via Wi-Fi ad hoc in realistic networks environment.

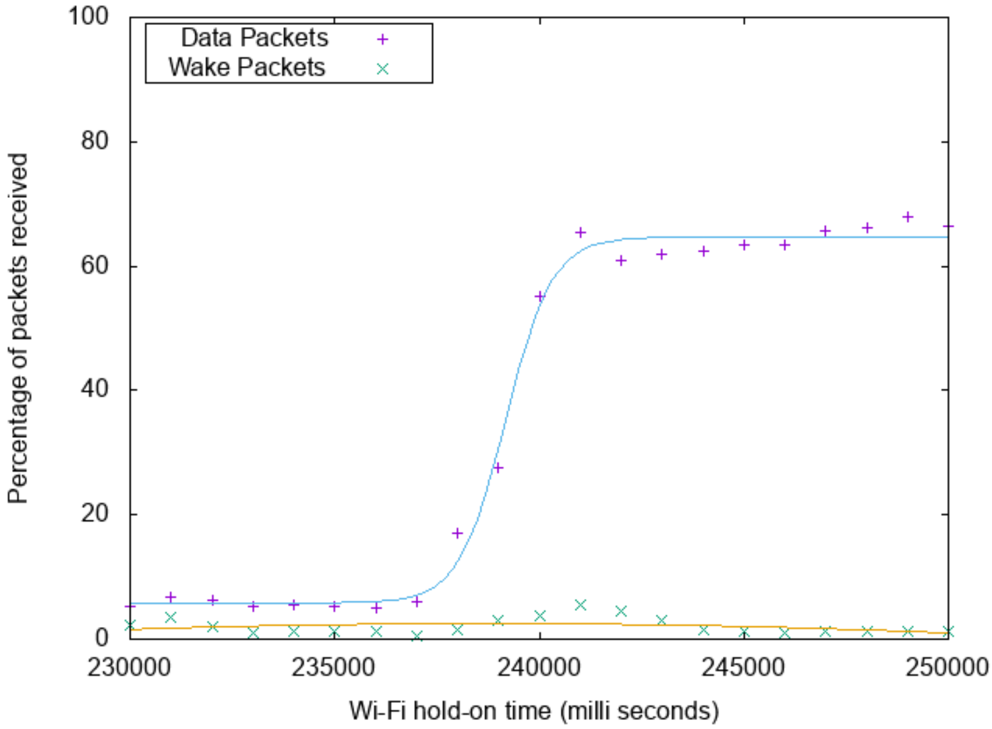


Figure 7.18: Percentage of wake and data packets versus Wi-Fi hold-on time, fit to a sigmoid function. Packet size = 1450 bytes, wake-data time = 240ms. n = 38

In terms of improving the performance when facing with realistic network environments, an obvious candidate would be to re-transmit the data packet several times to reduce the probability of none being received. Assuming for the moment that packet loss is statistically independent for each transmission, sending each packet up to five times would result in an overall delivery success rate of 100% - $(100\% - 60\%)^5$ = 100% - 1.02% = 99%. In short, there is ample grounds to believe that since we already have comparable broadcast delivery success as conventional 802.11 broadcast transmission, it would be possible to achieve similar packet delivery rates as 802.11 unicast through the adoption of the same strategies used to obtain the high delivery probabilities of 802.11 unicast traffic.

Indeed, while it is highly desirable to increase the percentage of successful delivery of packets in order to maximize performance, the current results would already allow the construction of a system that sends periodic Wi-Fi packets when waiting for a peer to come within range, and after only a few transmissions, communications would be established to a very high probability.

Given that broadcast Wi-Fi packets of 400 bytes, even at the default minimum 1Mbit/sec data rate, which requires only a few milli-seconds to transmit, it would be feasible to operate the Wi-Fi radio at a duty cycle of 1% or less, potentially saving considerable energy.

For the intended use-case of peer-to-peer mobile telephony, the increased energy consumption of re-transmissions would be negligible compared with the current energy consumption of ad-hoc Wi-Fi, and not dissimilar to that suffered when using Wi-Fi in infrastructure mode where re-transmission of 802.11 unicast frames is a frequent occurrence. Were the usecase instead low-powered IoT devices, then another solution may be required to obtain sufficiently energy efficiency. However that is not the use-case which is being targeted.

Considering the specific experimental parameters examined, it is apparent that performance plateaus once packets are ≥ 400 bytes, the wake-data interval exceeds about ≥ 200 milli-seconds, and the Wi-Fi hold time is not less than the wake-data interval. The sharp cut-off when the Wi-Fi hold time is reduced below the wake-data interval suggests that the operating instruction to turn off the Wi-Fi radio has almost instantaneous effect.

In contrast, there appears to be a minimum wake-data interval of ≥ 100 milli-seconds, and possibly ≥ 180 milliseconds. As spurious ambient Wi-Fi traffic can cause accidental Wi-Fi radio activation by the receiver, it is possible that the partial performance around 100 milli-seconds may simply be due to that effect. Also, it is quite plausible that the operating system takes a variable amount of time to reactivate the Wi-Fi radio based on its current activity at the time.

It recognises the limitations of proof-of-concept environment and leaves many questions unanswered. However, it is comfortable that it has proven that the concept is possible in principle at least.

For a device designed to activate Wi-Fi using our scheme, it would be possible to modify the Wi-Fi driver to power up the Wi-Fi radio front-end directly, much as the OpenWRT operating already does now when disabling the Wi-Fi interface.

That is, it is believed that it is possible to dramatically reduce the wake-delay interval, perhaps to as low as a few milli-seconds, i.e. to an imperceptibly short period. It is possible that this would also help to reduce the packet loss through reducing the temporal window between the wake and data packets.

This would be considerably simpler than modifying the proprietary closed-source Wi-Fi driver and/ or silicon to incorporate this feature. Indeed, an in-phone proof-of-concept could be constructed using a phone such as the FairPhone 2 (Nield, 2016), which has a USB port available on the rear of the phone adjacent to the battery compartment and to which an energy sampling device could be attached. The greatest challenge would be to compile a kernel that incorporates ad-hoc Wi-Fi and make it aware of the energy sampler device. This could be achieved within the scope of a doctoral or post-doctoral project, for example.

7.7 Conclusion and Future work

Through a relatively simple and inexpensive experiment, it has successfully demonstrated that it is possible to wake up a Wi-Fi receiver using only the transmissions of an unmodified Wi-Fi radio and an energy sampling device. This, together with the existence of a passive 2.4GHz radio front-end, establishes that it is, in fact, possible to create an ad-hoc Wi-Fi communications system where the Wi-Fi radio consumes no power when used to participate in a mobile ad-hoc network

(MANET), when there are no transmissions, for example, during the potentially very long periods between when devices come into Wi-Fi proximity.

Thus, it was argued that it is possible, without great engineering cost, to contemplate enhancements to the 802.11 standards family that facilitate true ad-hoc wireless communications at an acceptable energy budget and in the process to enable use cases not previously possible, such as peer-to-peer telephony without the support of any hardware apart from ordinary smartphones, and without unacceptably shortening the battery life of those devices.

A future work should focus on mitigations against the observed packet loss and create an advanced prototype that, ideally, includes the passive radio front-end and incorporates modified Wi-Fi firmware drivers that allow rapid powering up of the Wi-Fi radio with the purpose of demonstrating reduced energy consumption, and quantifying both what reduction in energy consumption is and how short the wake-data interval can be made. In this way, the characteristics of the proposed scheme can be more fully understood and their applicability to consumer hardware and mobile telephones in particular, better assessed.

Finally, development of a smart-phone-based proof-of-concept should be considered, including giving attention to the challenges of doing so which have been discussed.

CHAPTER 8: GENERAL DISCUSSION, CONCLUSION, AND FUTURE WORK

In order to answer the research questions posed in chapter 1, online survey, related survey, and related experiment are conducted. The results from these surveys and energy experiment are discussed in this chapter. Also, the conclusion of this research and the contributions of the research are discussed. Finally, the limitations of the research and recommendations for future research direction are presented.

8.1 Human behaviour factors affecting mobile phone battery life

The first research question was, "How human behaviour can affect battery life on a mobile phone?" This study investigated people's recharging and usage behaviour on a mobile phone. The study either placed an emphasis on an ordinary situation or disaster or emergency situation.

8.1.1 In General situation

This section provides three sub questions from the questionnaire survey about mobile phone recharging and usage in general situation. They are discussed below:

8.1.1.1 Question about mobile phone battery life

The ability to have a mobile phone that can operate all day without recharging is expected from many users who want to spend their time with any activity on a mobile phone. Some mobile phone listed on this reference (GSMArena, 2019) can operate on entertainment feature and vital communication about roughly 20 to 30 hours by average. Similarly, the results from this study found that people under general situation expected a phone battery life to last 22-24 hours or 1 day. Also, the survey revealed that user mostly use their mobile phone about 24 hours on a daily basis. It can be stated that the duration of 24 hours is an appropriate length of time expected for a mobile phone battery life in general situation. However, there are many factors to deplete a mobile phone battery life such as hardware, software, and usage behaviour. It is difficult to use a mobile phone without recharging within 24 hours. The question is how many times mobile phone should be recharged per day? The next section will be discussed in a mobile phone recharging behaviour.

8.1.1.2 Question about mobile phone charging behaviour

The previous section mentioned the factor to deplete a mobile phone battery life. A hardware of a mobile phone means CPU, wireless interfaces, GPS unit, OLED, camera, and so on. A software means an operating system such as Android, IOS, and various application running on operating system. Many researches (Fowdur et al., 2016) (Tawalbeh & Eardley, 2016) (Xiangyu et al., 2014) found that a hardware and software can deplete a mobile phone battery life rapidly. In this section, the research will study about user's mobile phone charging behaviour affecting a mobile phone battery life. The survey showed that mobile phones were mostly recharged once per day during overnight. The overnight charging habit of most people means that there is an increased risk if disasters occur in the evening, when batteries are most depleted. The intention of people was to recharge their phone until it was fully charged. Moreover, people decide to recharge their mobile phone while battery level shows 20 percent or less. Also, they expected the charge time to be 2 hours or less than this. This study is similar to the research conducted by (Dhir, Kaur, Jere, & Albidewi, 2012), in that it revealed people start to recharge their mobile phone between 6 PM and 8 PM when battery is approximately at 40% and between 1AM and 2AM when a battery is at 30 %. This means that people tend to recharge their mobile phone overnight.

8.1.1.3 Question about a mobile phone feature usage

Definition of a mobile phone feature in this thesis is the vital communication and entertainment feature. Vital communications refer voice call, SMS, web browsing, email, social network application. Entertainment features are camera, games, video and audio player and audio and video streaming. In terms of a mobile phone usage behaviour, there was evidence from chapter 4 that phone usage behaviour affected mobile phone battery life in terms of correlation statistical analysis. The result revealed that a mobile phone that is connected to the Internet or Wi-Fi significantly affected battery life (correlation coefficient = -0:420, $p < 0.001$). Also, the results showed that vital communications were used in daily life more than entertainment features. Some of the aforementioned communication features mostly need to connect to the Internet or Wi-Fi. It is understandable why phone battery life depletes quickly. Moreover, there were example from academic literatures proving that a phone usage behaviour affects a mobile phone battery life (Mikko V. J. Heikkinen et al., 2012) (Dhir et al., 2012) (Thiagarajan, Aggarwal, Nicoara, Boneh, & Singh, 2012).

Nowadays, people has changed their usage behaviour from voice call to social media instead. Report from news (BroadbandSearch, 2019) revealed that people spend their time on social media in 2018 for 144 minutes per day and for 153 minutes per day in 2019. The duration of time spent online is almost three hours per day in 2019 implying that a mobile phone battery might be drained rapidly as a result of social media application. This means they need to recharge their mobile phone more than once per day as mentioned in previous section. Hence, the battery backup such as power bank or alternative charging strategies are required.

8.1.2 In Disaster or emergency situation

This section provides three sub questions from the questionnaire survey about mobile phone recharging and usage in disaster situation as discussed below:

8.1.2.1 Question about mobile phone battery life in disaster/emergency situation

To meet the requirement to seek a gap of mobile phone battery life in disaster/emergency situation, the survey included the following question, "the duration that a mobile phone needs to last before the battery goes flat and minimum runtime requirement of mobile phone battery life." The results revealed that people expected their phone to be able to operate during 48 hours to 72 hours or 2 or 3 days which probably should be sufficient in abnormal situation. However, the duration of disaster occurred might be longer than 2 or 3 days. In Chapter 6, the study showed the information about power outages in Queensland and South Australia state, Australia. It was revealed that the duration of power outages after disaster strikes until post disaster expanded to 30 days or over. The ability of a mobile phone to last for 2 or 3 days during a disaster was not sufficient. Therefore, energy supplementary or alternative charging (Kongsiriwattana & Gardner-Stephen, 2016a) was mentioned to prolong a mobile phone battery life.

Actually, it is noted that the duration of power outage in the survey cited in chapter 6 mostly affected people during first 0 – 4 hours after a disaster struck. Therefore, having a mobile phone able to operate during 48 hours to 72 hours is acceptable and reasonable in reality.

8.1.2.2 Question about mobile phone recharging behaviour in disaster/emergency situation

Compared to a phone recharging behaviour in general situation, the result was significantly different. People inclined to recharge their phone twice, thrice or more times per day rather than once a day. Because, during disaster circumstance, it was possible to encounter electrical deficiency, power outages, or blackout for a long period of time. This was somehow in accordance with the results from the survey regarding the percentage of battery remaining before recharging. It was shown that 68.4% of participants chose to recharge their phone when it reached around 20% to 50 % battery level. Regarding the acceptable time to recharge a mobile phone, the survey revealed that the duration between 30 minutes and 1 hour to recharge a phone is reasonable.

According to the correlation among three variables discussed in the first paragraph of this section, people tend to recharge their mobile phone when the battery reaches the level between 20 and 50%. Also, they need to recharge a phone three or more time per day. Moreover, they prefer to charge a mobile phone not over 1 hour per time. In disaster or emergency situations, there might be less opportunity to seek power plugs due to power outages. They may use battery backup or alternative phone charging method to recharge their mobile phone. However, it is not quite convenient to recharge a phone quickly. Therefore, they just need to recharge phone in a short period of time to prolong their phone as much as possible. Also, they probably recharge their phone frequently. Three or more time per day is reasonable. It is assumed that frequency of a mobile phone recharging is needed in disaster or emergency situation.

8.1.2.3 Question about mobile phone usage in disaster/emergency situation

This survey revealed that people tend to use a mobile phone every few minutes, every half an hour, and every hour. Most communication service is voice communication mostly used in disaster or emergency situations. People prefer to contact others by talking more than using other ways of communication. This survey (Division & Bureau, 2011) showed that 74% of people still attempted to use voice call communication after the Great East Japan Earthquake. However, the communication, especially a mobile phone network, might not function during disaster or aftermath. It is needed to choose other communication service to communicate during events. That is why disaster communication (P. Gardner-Stephen, R. Challans, et al., 2013) (Gardner-Stephen, 2013b) is required in disaster or emergency situation.

8.1.3 User behaviour primary predictor of mobile telephone battery life

The two major things related to a mobile phone battery life that should be considered are the battery size and a mobile phone model. The study in chapter 4 and research

(Kongsiriwattana & Gardner-Stephen, 2016b) investigated that there was no notable correlation between the battery size and a mobile phone model showing its effect on the battery life. Even though, the big battery size can take advantage of high capacity to operate longer than the smaller version. However, there is no warranty that a mobile phone can last longer than normal. It depends on human factors which is a usage behaviour. It is straightforward that a mobile phone usage behaviour is the most significant factor concerning a phone battery life issue, particularly in s modern mobile phone, either under general or disaster and emergency circumstances.

8.2 Alternative phone charging strategies in disaster situation

The second research question in this study was “What is supplementary energy required to mobile phone and disaster communication?” This study investigated commercial phone charging strategies, particularly mainly used in disaster situation.

8.2.1 Alternative mobile phone recharging strategies

From the exploration, it was classified by the five major categories including solar charging solutions, kinetic, hand crank, and thermoelectric solutions, bicycle dynamo-based charging solutions, motor vehicle charging solutions, and wind turbine charging solutions.

A solar charging solution is an alternative method to recharge a mobile phone. The crucial factors that should be born in mind are weather and time to convert sunlight to electricity. Also, it depends on solar panel and power bank to keep energy in a storage. The news (Lee, 2019) showed that many products can take a long time to convert sunlight to electricity and charge into a power bank, many of which take about 25 – 30 hours when, in reality, they take longer time to charge than what manufacturers claim, depending on weather conditions. Moreover, it depends on a power bank storage to keep the energy. From the aforementioned news, some product indicated that the power bank with the capacity size of 25,000 mAh may be able to recharge a mobile phone for 10 times by average. Thus, capacity size of power bank affects duration time to transform sunlight energy into storage of power bank significantly. A small capacity size of power bank may decrease time to charge to storage, but it might recharge mobile phone 2 or three time depending on its battery capacity size. For the wind turbine charging solution, it is still dependent upon weather conditions similar to the solar charging method. Therefore, these two charging solutions might not be the best options for the post-disaster energy supply, depending upon weather conditions.

The kinetic charger has become popular for charging mobile phone. It functions based on the movement of human body, such as walking or running, to generate energy. However, it is extremely expensive in practice. And such activity must be at least 24 hours (Pershing, 2019) or up to 60 hours (Hollister, 2009) to provide energy for a single charge of a mobile phone. This is applicable in general situation, yet not appropriate in disaster situation.

Hand-cranked kinetic chargers are appreciably more affordable, both in terms of purchase price and utility, as they are able to generate the magnitude of energy per unit time. For realistic usage, it might be possible to recharge a phone in disaster situation by using a device. However, time to recharge a phone depends on capacity of the mobile phone. For example, if the phone is a 3000 mAh battery size, it should concern the amount of energy output generated from hand crank. Also, it might lose some energy as a result of the heat from the movement of hand crank. If hand crank supplies 500 mAh output in one hour, it should take approximately 6 hours to recharge mobile phone until it is fully charged starting from 0% battery level. In power outages situation, you might need it to recharge a mobile phone. Yet, other alternative phone charging method may be more interesting than this solution.

If a passive means of energy generation is required, without reliance on the sun, then the thermoelectric generators have a lower CPR, and have the further advantage that they have no moving parts. The latest product of BioLite reviewed by this citation (Skylis, 2019) claimed that it can generate 2600 mAh energy in 1 hour. It is somewhat fast in terms of generating electricity from waste heat. However, it is inconvenient to use for charging a mobile phone in disaster or emergency situations. No one wants to find woods to generate heat in critical time.

Bicycle-based chargers are often more expensive to purchase resulting in the higher CPR as calculated. However, bicycle-based solutions have more potential advantage in that it is much easier to paddle a bicycle for a long period. It tends to generate energy faster than hand crank. After a disaster occurs, people can use a bicycle to go somewhere while simultaneously recharging their phone. However, there is still an important factor to be concerned: the time to recharge a mobile phone is quite similar to that of hand crank method. Bicycle-based solution uses a dynamo to generate electricity. Most dynamo recharger (Denham, 2019) provides watt output including 1 Watt to 5 Watts. It can be said that high Watt will give high current which can charge a mobile phone quickly. However, as already mentioned in the beginning of this paragraph, the high Watts output is expensive to purchase.

Motor vehicles and/or their batteries. This method offers the lowest operation cost as they benefit from the considerable economy of scale that exists for automotive accessories, and the fact that motor vehicles already include the necessary generation and storage facilities (alternator and battery), leaving only voltage regulation and provision of appropriate connectors to be solved. Consequently, low-cost 3-port USB adapters for motor vehicles are available for less than US$10.00 and can be used to charge dozens of devices per day. Moreover, many cars currently provide USB outlet to support people to recharge a mobile phone. It is assumed that motor vehicles charging is necessarily. One requirement in charging a mobile phone using a USB adapter for motor vehicle is the power output. To quickly charge, the high Ampere and Watts should be used. After disaster strikes or aftermath, there might be no power supply. Thus, charging a mobile phone on a motor vehicle is possible in practice.

There are three criteria to assess which phone charging strategies should be used for recharging a mobile phone. First is the purchase cost of each strategy. Second is the number of devices that can be charged per day. Third is amortised cost per recharge or CPR. Applying each phone charging solution in this assessment revealed that motor vehicle solutions are the most economical solution and is the recommended option to use in disaster situation. Therefore, a car, truck, or motorbike should provide USB adapter kit for phone recharging purpose all the time.

If a cost per recharge is not the factor for consideration to decide which alternative phone charging should be used, then the other key factor that plays a pivotal role is a storage container or a battery backup or a power bank. Without a battery backup or a power bank, no charging solution can transmit energy to mobile phone. Even though some solutions can recharge a mobile phone directly, it takes a long recharging time. The amount of high capacity (mAh) and power (Watts) of battery backup should be concerned. The high capacity/power is better than less capacity/power after all.

8.2.2 Survey results of alternative sources of mobile phone battery charging

From the survey results, 51 out of 117 respondents chose accessory power outlet from car or similar vehicle. This helped confirm that a motor vehicle is a popular option for recharging mobile phone in either general or disaster situation. However, 28 out of 117 people never knew about alternative power backup. This revealed that people neglect supplement energy to recharge their mobile phone.

In disaster or emergency situation, one option to increase the opportunities to effectively recharge a mobile phone is employing and alternative mobile phone charging method. The motor vehicles solutions is the best option due to the cost and convenience. Nevertheless, people should consider the common energy supplementary devices such as battery backup or power bank and utilize them along with the alternative charging solution. Accordingly, the battery backup should be provided in disaster situation. As the information discussed in chapter 4 revealed that battery life of mobile phone in disaster situation could last from 48 to 72 hours. At least a day, a mobile phone could be recharged one time. For example, a mobile phone with the capacity size of 3,000 mAh should have a battery backup that is able to store energy for at least 9,000 mAh so that a mobile phone can be recharged at least three times or three days.

8.3 Distribution of duration of power outages and its impact on mobile phone power availability

This study conducted power outages analysis model to answer the third research question: “What is the minimum battery runtime required to sustain disaster communications platform during the acute phase of a typical disaster?”

The power outages analysis model produced histogram graph showing relationship between natural disaster occurring with number of flat phones. The results presented that there were many people or flat phones affected by long power outage duration after the disaster struck.

Interestingly, results from chapter 6 strongly confirmed that if the phone’s battery life takes many hours or many days, the number of a flat phone relatively decrease significantly. A mobile phone battery life ranging from 15 to 40 hours was slightly curve and the battery which is more than 40 hours to 120 hours showed linear declination of flat phone. Correspondingly, survey results in chapter 4 that in emergency or disaster situation required the battery life of 48 hours to 72 hours. In sensible reality, power outages nevertheless take long duration, more than 2 or 3 days, depending on situation. There is no absolute answer determining what minimum battery runtime in disaster situation or how long of power outage duration. However, It can be assumed from the results that 48 hours to 72 hours of battery life is reasonable to accept disaster situation, related to 72 hours golden time for rescue (Yang, Hou, Han, & Zhang, 2016) (Jang, Lien, & Tsai, 2009) (The_Straits_Times, 2016) after the disaster strikes. To solve phone battery life problems, the alternative phone charging method is still the way to figure out this shortage of energy.

8.4 Reducing energy consumption of mobile wireless devices for disaster communication

The final research question was, “How can a battery runtime be extended on disaster communication platform?” In other words, this study investigated the possibility to reduce energy consumption on Wi-Fi ad hoc network or disaster communication.

From the energy experiment on Huawei model IDEOS U8150 running Serval software (GSMArena, 2010) , it was found in the experiment that a meshing mobile phone (running Serval software) on Wi-Fi ad hoc network consumed energy quickly. The result indicated that a battery life is depleted from its full charge within around 3.5 to 4 hours or less, depending on a mobile phone condition and specification. When compared the specification with the phone and general usage (Gurunathan, 2011) it is claimed that a normal mobile phone could run at least half day or 12 hours. This is the drawback of Wi-Fi ad hoc communication.

In actual energy experiment, it was run on nominated GL-AR150 wireless router running with experimental software developed by The Serval project and custom-design 2.4 GHz wireless energy sampler device. It could not implement proposed energy efficiency method known as ultra-low-energy Wi-Fi standby technique on a mobile phone directly thanks to its highly sophisticated implementation. Therefore, the proposed technique was implemented into aforementioned devices instead since it is feasible to quantify and measure energy more conveniently.

The results revealed that the proposed technique could promisingly reduce energy consumption on Wi-Fi ad hoc network compared to the three different experimental scenarios. First, the effect of changing interval between wake and data packet should be examined. Second, the packet size on reliability of reception should be adjusted. Third, consider about effect of changing Wi-Fi hold time.

Normally, a Wi-Fi adapter (Carroll & Heiser, 2010) consumes more energy as opposed to other hardware components of a mobile phone. In the experiment, changing Wi-Fi hold time can mostly affect power consumption. Wi-Fi hold time means the on and off state of wireless device. Therefore, the short Wi-Fi hold time implies that it consumes energy less than the long Wi-Fi hold time at the receiver side. Table 7.3 can support this assumption. It is shown that the Wi-Fi on consumes 88.5 mA compared to Wi-Fi off which accounts for 58.5 mA.

According to the experiment, it was shown that 60% of data packets were successfully received, with the absence of any packet re-transmission scheme. It suggests that the method would, in the absence of interference, result in almost 100% packet delivery. However, there is another factor caused by packet loss while transmitting packet to receiver side. Such factor is the duration of Wi-Fi on and off or Wi-Fi hold time. Sometimes, Wi-Fi driver starts and stops in the short period of time. It might be two times longer than the normal time. According to figure 7.9 on chapter 7, firstly, Wi-Fi packet arrives at the receiver. The receiver begins to start Wi-Fi on; however, there is a gap between first start and actually start. Provided that this gap spends much time than normal situation, it might take much time to start Wi-Fi on. Secondly, Wi-Fi packet arrives at the receiver side, but the Wi-Fi is still off. This can be a factor of packet data loss. On the other hand, if Wi-Fi off stops before the seconds Wi-Fi packet arriving at the receiver side. The loss of packet data is to occur similar to previous scenario.

The results of the experiment of the three scenarios revealed that it would be possible to modify the Wi-Fi driver to power up the Wi-Fi radio front-end directly, like the OpenWRT is already able to perform now when disabling the Wi-Fi interface. In other words, it is believed that there is the possibility to dramatically reduce the wake-delay interval, perhaps to as low as a few milli-seconds, i.e., to an imperceptibly short period. It is possible to reduce the packet loss by reducing the temporal window between the wake and data packets.

Therefore, to implement this proposed proof-of-concept scheme into a mobile phone, it is recommended to use a phone that has a USB port available at the bottom of the phone or adjacent to the battery compartment, and to which an energy sampling device could be attached. Moreover, it would be to compile a kernel that incorporated ad-hoc Wi-Fi, and making it aware of the energy sampler device.

This proposed method is another alternative option for disaster communication to prove how to extend battery life of Wi-Fi ad-hoc communication. From the above paragraph, it is possible, without great engineering cost, to contemplate enhancements to the 802.11 standards family, which facilitate true ad-hoc wireless communications, at an acceptable energy budget, and in the process, to enable use cases which was not previously possible, such as peer-to-peer telephony without the support of any hardware apart from ordinary smartphones, and without unacceptably shortening the battery life of those devices.

This can answer research question that the improvement of energy efficiency on a mobile phone is unavoidable for the new generation of a mobile phone. The power saving mode (Soumya Kanti Datta, Christian Bonnet, & Navid Nikaein, 2012b) on an existing mobile phone cannot satisfy the demand of energy saving or power consumption efficiently. However, it is possible to improve power saving mode technique on a mobile phone since it is a software not hardware that is easy to implement on a modern mobile phone. Therefore, a mobile phone industrial manufacturers should be aware of how to prolong a phone battery life by improving energy efficiency technique more than focusing on solely increase batter size.

Finally, disaster communication emerges to the world as candidature or challenger for communication free without cellular tower or base station. It must be encouraged and improved performance for modern wireless technology. Also, energy efficiency issue still continues to enhance and develop in order to prolong a mobile phone or disaster communication battery life.

8.5 Conclusion

This section summarises the important outcomes related to this study about energy and related factors in sustaining mobile telecommunication in the following disaster contexts:

1) People need communications during disasters.
2) An average mobile phone battery life is approximately 22 to 24 hours by average as discussed in chapter 4.
3) Emergency respondents want a mobile phone’s battery life that can last at least 2 days as discussed in chapter 4.

4) The situation of power outages occurring after disaster or emergency events takes a long time to recover as discussed in chapter 6.
5) When a battery goes flat in disaster situation, the alternative phone charging methods are the solutions that help extend communication period under such circumstance as discussed in chapter 5.
6) Disaster or particular communication consumes more energy than normal or ordinary cellular network use. From the results of the experiments shown in chapter 7, a mobile phone battery operating in ad hoc Wi-Fi network mode lasts for 3 to 4 hours or less.

Basically, a phone battery life is too short even when people use their devices sparingly, some disasters can result in loss of power for several weeks, and it is simply infeasible to design mobile phones with batteries large enough to deal with this. Therefore, other means are required. One major factor as discussed above results from human factor in terms of individual usage. The way people use their phone is the biggest factor on how fast they will go flat. This can be partially mitigated by educating people on saving their phone energy in disaster situation. The principle knowledge such as unnecessary function should be turned off, GPS or Wi-Fi network should be turned on when people only need to use, and so on (Chris, 2015).

Another solution to save a phone's battery life is that it needs to improve energy efficiency on mobile phones. Power saving mode or battery saver on a modern mobile phone is currently an option to be turned on when there is an energy issue. Nonetheless, energy efficiency technique should be improved and developed to be more efficient than the current technology. In terms of disaster communication, a mobile phone operating in ad hoc network based on Wi-Fi consumes more energy than ordinary mode. The experiment in chapter 7 presented an example to reduce energy consumption based on Wi-Fi ad hoc network on mesh extender prototype. It was proposed as possible solution to improve energy efficiency on resilient communication. This should be implemented and developed in industrial phone manufacturers to improve energy consumption on a mobile phone which operates on ad hoc network. Another factor that can help mitigate energy issue is that a mobile phone should be produced with large battery size or high capacity. Nevertheless, the trade-off must made between high battery capacity and expensive phone cost. It is not a good idea to shift responsibility to consumers and unnecessarily increase their expenditure.

Disasters can inflict damages or cut off power for weeks as discussed in chapter 6. It is impossible for mobile phone's battery to operate for such particular events without being recharged. The possible solution is that a mobile phone needs to recharge using one of the alternative charging methods. There are many alternative strategies to recharge a mobile phone. For car or other motor vehicles, USB phone charging is the best option because it is inexpensive, affordable, and reasonable as discussed in chapter 5. Everyone should have a car or other motor vehicle that comes with the USB charger kit or adapter for this abnormal situation to recharge a phone.

Overall, all of this can solve the energy problem of mobile phones, but it does not solve problem of phone or cellular towers breaking. More work on infrastructure-free by The Serval project is currently improving resilience of cellular tower or communication without base station for supporting usage in disaster or emergency situation directly.

8.6 Contribution of the study

This study has filled important evidence gaps around sustaining mobile telecommunications during disasters, which has the potential to save lives. This study has also explored potential mitigations and solutions to this problem. Specific contributions in these areas include gathering or generating evidence in support of the following:

1. That battery life of mobile phones is relatively short, and cannot be predicted based on manufacturer's claims.

2. That user's habits are one of the greatest determinants of mobile phone battery life, which creates opportunities for improving battery life during disasters through user education or behaviour modification.

3. That power outages during disasters can last for many weeks, and that it is therefore infeasible to try to create mobile phones that are "disaster proof" in terms of having sufficient battery capacity to endure such events.

4. That this situation makes it necessary to find alternative means of charging mobile phones in the absence of mains power, and that certain options, such as the use of vehicular USB chargers, are cheaper and more effective than others.

5. That there are potentials paths to reducing the power consumption of mobile phones when forming ad-hoc wireless networks, for example, through the adoption of improved passive listening strategies that can allow zero idle power consumption.

8.7 Limitations of the study

There are several aspects of this study that limit the findings can be particularised as follows:

Firstly, the participants in the study about human factors on a mobile phone were from organisation related to emergency and disaster events in South Australia. The limitation of this study is that the sample size is relatively small. The sample size of participants is 117 people. There were only 105 out of 117 people who had any experience, work, and volunteer in an emergency or disaster environment. This limited sample size of respondents affects power of statistical analysis and the precision of results. However, the results can answer the question of relationship of human behaviour affecting mobile phone. Future research should increase sample size to at least 500 to 1000 people for an accuracy of the results and statistical analysis objective.

Secondly, there was a limitation of insufficient academic literature in alternative phone charging strategies. Most references were from technology news and related mobile phone charging method from web pages.

Thirdly, power outages information was only from Queensland and South Australia, Australia. The major result was analysed and compared with natural disaster occurred in Queensland state. In terms of comparison, if power outages can be gathered from every state across Australia, this can present relationship of power outages and disaster across Australia which can be useful information to understand distribution of duration of power outages depending on severe weather or disaster situation and its impact on mobile phone power availability in each state separately.

Finally, the energy consumption experiment could not propose energy efficiency based on ultra-low-energy Wi-Fi standby technique for Wi-Fi ad hoc network on mobile phone directly because it is highly sophisticated to implement Wi-Fi function on a mobile phone to frequently start and stop. Therefore, GL-AR150 and energy sampler prototype was proposed to use in energy consumption experiment instead. Further limitation in the experiment was that there was some interference from unexpected Wi-Fi signal beyond management while running the experiment. It was addressed by adjusting sensitivity of detecting Wi-Fi signal of energy sampler based on acceptable threshold to mitigate noise or interference from ambient Wi-Fi in our laboratory. However, in each experiment scenario, the results still had Wi-Fi noise in background which affected the experimental results. Some Wi-Fi packet, thus, may not be completely received and transmitted due to its loss on the way. However, ultra-low-energy Wi-Fi standby technique proved that it could save power consumption while Wi-Fi turns off more than turns on from period of time of transmitting and receiving Wi-Fi packet.

8.8 Future research direction

The major problem in ordinary communication is people cannot communicate during power blackouts or outages after disaster occurs owing to cellular base station breakdown. Consequently, resilient communication by The Serval project emerges as alternative disaster communication to reserve ordinary communication network in abnormal situation.

This research pays attention to energy on mobile telecommunication in disaster contexts. Therefore, energy efficiency technique on disaster communication should be pushed forward in development from prototype to mass production applying in sensible reality to find and compare which techniques of energy efficiency on mobile phone are the best for disaster communication. In experiment in chapter 7, it was proposed by using ultra-low-energy Wi-Fi standby technique. There is only experiment on two nodes to communicate each other. To prove that it is feasible to operate in practice, it should add more than two nodes and attempt to experiment in the same way to determine whether it is appropriate to reduce energy consumption or not. Another thing, the experiment should be tested in many environment or situations. For example, without Wi-Fi signal or less Wi-Fi signal. This can prove that the packet from transmitter sent to receiver still has errors or not. Finally, this Wi-Fi standby technique could be proposed and implemented on a mobile phone directly in the future.

Another thing that should be focused on the future research is implementing power management on a mobile phone (Soumya Kanti Datta et al., 2012b). This can assist mobile phone to last longer than its ordinary status. There is one nominated factor for this study. It is CPU power management (Gough, Steiner, & Saunders, 2015) (Shearer, 2008). CPU power management means a mobile phone stops working while there is no activity on a mobile phone, which is called a CPU on sleep status. This is an interesting topic that should be studied further.

Moreover, the survey about human factor affecting on a mobile phone should employ a larger amount of sample size to find out exactly appropriate mobile phone lifespan in disaster or emergency situation.

Bibliography

ABC_News. (2016). SA weather: Power 'gradually' returning after blackout plunged state into darkness. Retrieved from http://www.abc.net.au/news/2016-09-28/sa-weather-south-australia-without-power-as-storm-hits/7885930

ABC_Riverland. (2010). Latest Floods stories on ABC Riverland SA. Retrieved from http://www.abc.net.au/riverland/topics/disasters-and-accidents/floods/?page=4

Abdel Hamid, S., Hassanein, H. S., & Takahara, G. (2013). Introduction to Wireless Multi-Hop Networks *Routing for Wireless Multi-Hop Networks* (pp. 1-9). New York, NY: Springer New York.

Adeyeye, M., & Gardner-Stephen, P. (2011). The Village Telco project: a reliable and practical wireless mesh telephony infrastructure. *EURASIP Journal on Wireless Communications and Networking, 2011*(1), 78.

Affam, A., & Mohd-Mokhtar, R. (2019). *Application of Three Independent Sources to Mobile Phone Charging During Emergencies*. Paper presented at the In 10th International Conference on Robotics, Vision, Signal Processing and Power Applications Singapore.

Akyildiz, I. F., & Xudong, W. (2005). A survey on wireless mesh networks. *Communications Magazine, IEEE, 43*(9), S23-S30. doi:10.1109/mcom.2005.1509968

Aliaga, M., & Gunderson, B. (2006). *Interactive Statistics, 3rd Edition*: Pearson.

Allard, G., Minet, P., Nguyen, D.-Q., & Shrestha, N. (2006). Evaluation of the Energy Consumption in MANET. *Adhoc-Now 2006, Ottawa, Canada*.

ALLEN, T. (2013). Biologic ReeCharge: A Dynamo-Powered USB Charger for Smartphones & More. Retrieved from http://tomsbiketrip.com/biologic-reecharge-a-dynamo-powered-usb-charger-for-smartphones-more/

AlonsoEmail, W. J., Schuck-Paim, C., & Asrar, G. R. (2014). Global health and natural disaster alerts: preparing mobile phones to endure the unthinkable. *Earth Perspectives, 1*(1), 24.

Android. (2017). Android version. Retrieved from https://www.android.com/history/#/marshmallow

Apple_Inc. (2017a). Apple Company. Retrieved from https://www.apple.com/

Apple_Inc. (2017b). IOS 10. Retrieved from http://www.apple.com/au/ios/ios-10/

Arkaroola_Wilderness_Sanctuary. (2016). Arkaroola Wilderness Sanctuary Flinders Ranges, South Australia. Retrieved from http://www.arkaroola.com.au/

Ashish. (2017). GT Explains: Android Wakelocks, How to Detect and Fix Them. Retrieved from https://www.guidingtech.com/45384/android-wakelocks/

Atherton, M. (2016). Fukushima disaster facts and figures: What happened and what were the effects of the nuclear meltdown? Retrieved from http://www.ibtimes.co.uk/fukushima-disaster-facts-figures-what-happened-what-were-effects-nuclear-meltdown-1547993

Australia_Goverment. (2015). Natural disasters in Australia. Retrieved from http://www.australia.gov.au/about-australia/australian-story/natural-disasters

Australia_Government. (2017). Previous Tropical Cyclones. Retrieved from http://www.bom.gov.au/cyclone/history/

Australian_Bureau_of_Statistics. (2012). 2011 Census data shows a snapshot of South Australia. Retrieved from http://www.abs.gov.au/websitedbs/censushome.nsf/home/sa-45?opendocument&navpos=620

Australian_Bureau_of_Statistics. (2016). Australian Demographic Statistics, Sep 2016. Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/mf/3101.0

Balasubramanian, N., Balasubramanian, A., & Venkataramani, A. (2009). *Energy consumption in mobile phones: a measurement study and implications for network applications*. Paper presented at the Proceedings of the 9th ACM SIGCOMM conference on Internet measurement conference, Chicago, Illinois, USA.

Banerjee, A. (2017). How to fix Android battery drain issues and extend battery life. Retrieved from http://www.androidauthority.com/android-ios-battery-drain-708056/

Bankoff, G., Frerks, G., & Hilhorst, D. (2004). *Mapping vulnerability: disasters, development, and people*: Routledge.

Battery_University. (2017). Charging from a USB Port. Retrieved from http://batteryuniversity.com/learn/article/charging_from_a_usb_port

Baum, A. F., Raymond; Davidson, Laura M. (1983). Natural Disaster and Technological Catastrophe. *Environment and Behavior; Beverly Hills, Calif, 15*(3), 22.

Bengtsson, L., Lu, X., Thorson, A., Garfield, R., & von Schreeb, J. (2011). Improved Response to Disasters and Outbreaks by Tracking Population Movements with Mobile Phone Network Data: A Post-Earthquake Geospatial Study in Haiti. *PLOS Medicine, 8*(8), e1001083. doi:10.1371/journal.pmed.1001083

Best-Power-Banks. (2017). Best Power Banks Guides & Reviews 2016 & 2017. Retrieved from http://www.best-power-banks.com/

Bhalla, M. R., & Bhalla, A. V. (2010). Generations of mobile wireless technology: A survey. *International Journal of Computer Applications, 5*(4).

BioLite. (2017). CampStove. Retrieved from http://www.bioliteenergy.com/products/biolite-campstove

Böhmer, M., Hecht, B., Schöning, J., Krüger, A., & Bauer, G. (2011). *Falling asleep with Angry Birds, Facebook and Kindle: a large scale study on mobile application usage*. Paper presented at the Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services, Stockholm, Sweden.

Bolla, R., Khan, R., Parra, X., & Repetto, M. (2014, 10-12 Sept. 2014). *Improving Smartphones Battery Life by Reducing Energy Waste of Background Applications.* Paper presented at the Next Generation Mobile Apps, Services and Technologies (NGMAST), 2014 Eighth International Conference on.

Brannen, J. (1992). Combining Qualitative and Quantitative Approaches: An Overview', in J. Brannen (ed.) Mixing Methods: Qualitative and Quantitative Research. *Aldershot: Avebury*.

BroadbandSearch. (2019). Average Time Spent Daily on Social Media. Retrieved from https://www.broadbandsearch.net/blog/average-daily-time-on-social-media

Brown, B. (2019). How to Charge Your Phone When The Power Is Out. Retrieved from https://thepreppingguide.com/ways-you-can-charge-your-phone/

Bryman, A. (2012). *Social Research Methods, 4th Edition*: The United States: Oxford University Press Inc.

Buettner, M., Yee, G. V., Anderson, E., & Han, R. (2006). *X-MAC: a short preamble MAC protocol for duty-cycled wireless sensor networks*. Paper presented at the Proceedings of the 4th international conference on Embedded networked sensor systems, Boulder, Colorado, USA.

Byrne, K. (2014). Best battery life 2014 - 60 smartphones tested. Retrieved from http://www.expertreviews.co.uk/mobile-phones/1402071/best-battery-life-2014-60-smartphones-tested

Cable_Click. (2014). What Are Power Banks and How Do They Work? Retrieved from http://www.cablechick.com.au/blog/what-are-power-banks-and-how-do-they-work/

Cardei, M., Wu, J., & Yang, S. (2006). Topology control in ad hoc wireless networks using cooperative communication. *IEEE Transactions on Mobile Computing, 5*(6), 711-724. doi:10.1109/TMC.2006.87

Carroll, A., & Heiser, G. (2010). *An analysis of power consumption in a smartphone*. Paper presented at the Proceedings of the 2010 USENIX conference on USENIX annual technical conference, Boston, MA.

Celkon. (2015). Feature Phones: A Dying Phone Segment. Retrieved from http://www.celkonmobiles.com/blog/feature-phones-a-dying-phone-segment/

Chen, B., Jamieson, K., Balakrishnan, H., & Morris, R. (2002). Span: An Energy-Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Wireless Networks. *Wireless Networks, 8*(5), 481-494. doi:10.1023/a:1016542229220

Chen, X., Chen, Y., Ma, Z., & Fernandes, F. C. A. (2013). *How is energy consumed in smartphone display applications?* Paper presented at the Proceedings of the 14th Workshop on Mobile Computing Systems and Applications, Jekyll Island, Georgia.

Chris, P. (2015). Power efficiency: These are the most frugal smartphones currently on the market. Retrieved from http://www.phonearena.com/news/Power-efficiency-These-are-the-most-frugal-smartphones-currently-on-the-market_id73040

CNN_Library. (2016a). Haiti Earthquake Fast Facts. Retrieved from http://edition.cnn.com/2013/12/12/world/haiti-earthquake-fast-facts/

CNN_Library. (2016b). Hurricane Sandy Fast Facts. Retrieved from http://edition.cnn.com/2013/07/13/world/americas/hurricane-sandy-fast-facts/

Cohen, L., Manion, L., & Morrison, K. (2007). *Research Methods in Education Sixth edition*. London and New York: Routledge.

Communication, W. (2005). Battery Chargers and Charging Methods. Retrieved from http://www.mpoweruk.com/chargers.htm

Constandache, I., Gaonkar, S., Sayler, M., Choudhury, R. R., & Cox, L. (2009, 19-25 April 2009). *EnLoc: Energy-Efficient Localization for Mobile Phones.* Paper presented at the INFOCOM 2009, IEEE.

Cook, B. W., Berny, A. D., Molnar, A., Lanzisera, S., & Pister, K. S. J. (2006, 6-9 Feb. 2006). *An Ultra-Low Power 2.4GHz RF Transceiver for Wireless Sensor Networks in 0.13/spl mu/m CMOS with 400mV Supply and an Integrated Passive RX Front-End.* Paper presented at the 2006 IEEE International Solid State Circuits Conference - Digest of Technical Papers.

Correia, L. M., & Prasad, R. (1997). An overview of wireless broadband communications. *IEEE Communications Magazine, 35*(1), 28-33.

Cowan, J. (2009). Bushfire disaster: a tangled web of communication failures. Retrieved from https://www.abc.net.au/news/2009-06-02/bushfire-disaster-a-tangled-web-of-communication/1700858

Cox, C. (2014). *An Introduction to LTE, LTE-Advanced, SAE, VoLTE and 4G Mobile Communications* (Second ed.): John Wiley & Sons, Ltd.

Creswell, J. W. (2003). *RESEARCH DESIGN Qualitative,Quantitative, and Mixed Methods Approaches*. California, London, New Delhi: Sage.

Dam, T. v., & Langendoen, K. (2003). *An adaptive energy-efficient MAC protocol for wireless sensor networks*. Paper presented at the Proceedings of the 1st international conference on Embedded networked sensor systems, Los Angeles, California, USA.

Datta, S. K., Bonnet, C., & Nikaein, N. (2012a). *Android power management: Current and future trends.* Paper presented at the The First IEEE Workshop on Enabling Technologies for Smartphone and Internet of Things (ETSIoT).

Datta, S. K., Bonnet, C., & Nikaein, N. (2012b). *Android power management: Current and future trends.* Paper presented at the Enabling Technologies for Smartphone and Internet of Things (ETSIoT), 2012 First IEEE Workshop on.

Datta, S. K., Bonnet, C., & Nikaein, N. (2012, 18-18 June 2012). *Android power management: Current and future trends.* Paper presented at the 2012 The First IEEE Workshop on Enabling Technologies for Smartphone and Internet of Things (ETSIoT).

de Boer, J. (1990). Definition and classification of disasters: Introduction of a disaster severity scale. *The Journal of Emergency Medicine, 8*(5), 591-595. doi:http://dx.doi.org/10.1016/0736-4679(90)90456-6

Deb, D. D., Bose, S., & Bandyopadhyay, S. (2012). Coordinating disaster relief operations using smart phone/PDA based peer-to-peer communication. *International Journal of Wireless & Mobile Networks, 4*(6), 27.

Denham, A. (2019). All About The Best Dynamo USB Chargers For Bicycle Touring and Bikepacking. Retrieved from https://www.cyclingabout.com/best-dynamo-usb-chargers-bicycle-touring-bikepacking/

Dhir, A., Kaur, P., Jere, N., & Albidewi, I. A. (2012, 25-27 April 2012). *Understanding mobile phone battery - Human interaction for developing world A perspective of feature phone users in Africa.* Paper presented at the Future Internet Communications (BCFIC), 2012 2nd Baltic Congress on.

Diakakis, M., Deligiannakis, G., Katsetsiadou, K., & Lekkas, E. (2015). Hurricane sandy mortality in the Caribbean and continental north America. *Disaster Prevention and Management: An International Journal, 24*(1), 132-148. doi:10.1108/dpm-05-2014-0082

Division, T. S., & Bureau, T. (2011). Survey on Communication Conditions Just After the Great East Japan Earthquake. Retrieved from http://warp.da.ndl.go.jp/info:ndljp/pid/10367640/www.soumu.go.jp/main_content/000136157.pdf

Dunkels, A. (2011). The ContikiMAC Radio Duty Cycling Protocol. Retrieved from https://core.ac.uk/download/files/362/11434462.pdf

Eason, E. (2010). Smartphone Battery Inadequacy. Retrieved from http://large.stanford.edu/courses/2010/ph240/eason1/

EasyAcc. (2016). Solar Phone Charger: 5 Key Things to Know Before You Buy. Retrieved from https://www.easyacc.com/media-center/solar-charger-for-phone/

Edison_Tech_Center. (2014). Generators & Dynamos. Retrieved from http://www.edisontechcenter.org/generators.html

Edwards, L. (2015). 15 smartphones with 3,000mAh batteries or larger, made to last longer. Retrieved from http://www.pocket-lint.com/news/133069-15-smartphones-with-3-000mah-batteries-or-larger-made-to-last-longer

Ei Sun, O. (2003, 21-24 Sept. 2003). *Information and communication technology in the service of disaster mitigation and humanitarian relief.* Paper presented at the 9th Asia-Pacific Conference on Communications (IEEE Cat. No.03EX732).

El-Hoiydi, A., & Decotignie, J. D. (2004, 28 June-1 July 2004). *WiseMAC: an ultra low power MAC protocol for the downlink of infrastructure wireless sensor networks.* Paper presented at the Proceedings. ISCC 2004. Ninth International Symposium on Computers And Communications (IEEE Cat. No.04TH8769).

Encyclopedia, P. M. (2017a). Definition of: cellphone. Retrieved from https://www.pcmag.com/encyclopedia/term/39505/cellphone

Encyclopedia, P. M. (2017b). Definition of: feature phone. Retrieved from https://www.pcmag.com/encyclopedia/term/62894/feature-phone

Encyclopedia, P. M. (2017c). Definition of: Smartphone. Retrieved from https://www.pcmag.com/encyclopedia/term/51537/smartphone

Ergon_Energy_Company. (2016). Queensland power outage information during 2005 to 2016. Retrieved from https://www.ergon.com.au/

Eun-Sun, J., & Vaidya, N. H. (2002, 2002). *An energy efficient MAC protocol for wireless LANs.* Paper presented at the Proceedings.Twenty-First Annual Joint Conference of the IEEE Computer and Communications Societies.

Eurapean_Telecommunications_Standards_Institue. (2010). Emergency Communications (EMTEL). Retrieved from http://www.etsi.org/deliver/etsi_ts/102100_102199/102182/01.04.01_60/ts_102182v010401p.pdf

Facebook. (2017). Facebook. Retrieved from https://www.facebook.com/

Falaki, H., Mahajan, R., Kandula, S., Lymberopoulos, D., Govindan, R., & Estrin, D. (2010). *Diversity in smartphone usage.* Paper presented at the Proceedings of the 8th international conference on Mobile systems, applications, and services, San Francisco, California, USA.

Fitzgerald, R., Spriggs, J., & Keosothea, N. (2010). Enhancing communications in developing countries using SMS technology: the case of agricultural value chains in Cambodia. *International Journal of Continuing Engineering Education and Life Long Learning, 20*(1), 72-83.

Fitzpatrick, J. (2015). Stop Wasting Money on Device Specific Car Chargers and Start Using a Universal USB Charger. Retrieved from https://www.howtogeek.com/214300/stop-wasting-money-on-device-specific-car-chargers-and-start-using-a-universal-usb-charger/

Flipsy.com. (2015). Best Off-the-Grid Phone Chargers, Reviewed Retrieved from http://flipsy.com/blog/15/07/Best-Off-the-Grid-Phone-Chargers,-Reviewed

Fowdur, T. P., Hurbungs, V., & Beeharry, Y. (2016, 7-9 Jan. 2016). *Statistical analysis of energy consumption of mobile phones for web-based applications in*

Mauritius. Paper presented at the 2016 International Conference on Computer Communication and Informatics (ICCCI).

Friedman, R., Kogan, A., & Krivolapov, Y. (2013). On Power and Throughput Tradeoffs of WiFi and Bluetooth in Smartphones. *IEEE Transactions on Mobile Computing, 12*(7), 1363-1376. doi:10.1109/TMC.2012.117

Frodigh, M., Johansson, P., & Larsson, P. (2000). Wireless ad hoc networking: the art of networking without a network.

Gao, H., Barbier, G., & Goolsby, R. (2011). Harnessing the Crowdsourcing Power of Social Media for Disaster Relief. *IEEE Intelligent Systems, 26*(3), 10-14. doi:10.1109/MIS.2011.52

Gaonkar, S., Li, J., Choudhury, R. R., Cox, L., & Schmidt, A. (2008). *Micro-Blog: sharing and querying content through mobile phones and social participation*. Paper presented at the Proceedings of the 6th international conference on Mobile systems, applications, and services, Breckenridge, CO, USA.

Gardner-Stephen, P. (2011). The Serval Project: Practical Wireless Ad-Hoc Mobile Telecommunications. Retrieved from http://developer.servalproject.org/files/CWN_Chapter_Serval.pdf

Gardner-Stephen, P. (2013a). Serval Mesh Extender. Retrieved from http://www.servalproject.org/archives/1093

Gardner-Stephen, P. (2013b). The Serval Project. Retrieved from www.servalproject.org

Gardner-Stephen, P. (2017). Power Outage Analysis. Retrieved from https://github.com/gardners/power-outage-analysis/blob/master/analyse.c

Gardner-Stephen, P., Bettison, A., Challans, R., Hampton, J., Lakeman, J., & Wallis, C. (2013). Improving Compression of Short Messages. *Int'l J. of Communications, Network and System Sciences, 6*(12), 497 - 504. doi:10.4236/ijcns.2013.612053

Gardner-Stephen, P., Bettison, A., Challans, R., & Lakeman, J. (2013). The rational behind the serval network layer for resilient communications. *Journal of Computer Science, 9*(12), 1680 - 1685. doi:DOI : 10.3844/jcssp.2013.1680.1685

Gardner-Stephen, P., Challans, R., Lakeman, J., Bettison, A., Gardner-Stephen, D., & Lloyd, M. (2013, 20-23 Oct. 2013). *The serval mesh: A platform for resilient communications in disaster & crisis.* Paper presented at the Global Humanitarian Technology Conference (GHTC), 2013 IEEE.

Gardner-Stephen, P., Lakeman, J., Challans, R., Wallis, C., Stulman, A., & Y. Haddad. (2012). MeshMS: Ad Hoc Data Transfer within Mesh Network. *Int'l J. of Communications, Network and System Sciences, Vol. 5*(No. 8), pp. 496-504. doi:10.4236/ijcns.2012.58060.

Gething, P. W., & Tatem, A. J. (2011). Can Mobile Phone Data Improve Emergency Response to Natural Disasters? *PLOS Medicine, 8*(8). doi:10.1371/journal.pmed.1001085

Gibbs, S. (2013). myFC PowerTrekk review. Retrieved from http://www.techradar.com/reviews/gadgets/myfc-powertrekk-1143364/review

Giovinazzi, S., Austin, A., Ruiter, R., Foster, C., Nayyerloo, M., Nair, N. K., & Wotherspoon, L. (2017). *Resilience and fragility of the telecommunication network to seismic events: Evidence after the Kaikoura (New Zealand) earthquake* (Vol. 50).

GL_Innovations. (2017). GL-AR150. Retrieved from http://whttps://www.gl-inet.com/ar150/

Gomez, K., Riggio, R., Rasheed, T., & Granelli, F. (2011, 26-29 Sept. 2011). *Analysing the energy consumption behaviour of WiFi networks.* Paper presented at the Online Conference on Green Communications (GreenCom), 2011 IEEE.

Gonen, E. K., Hua, X., & Joshi, P. (2005, 7-7 Sept. 2005). *A Peer-to-Peer Architecture for Mobile Communications.* Paper presented at the 2005 2nd International Symposium on Wireless Communication Systems.

Google_Inc. (2017). About Google Company. Retrieved from https://www.google.com/intl/en/about/

Gough, C., Steiner, I., & Saunders, W. (2015). CPU power management. *In Energy Efficient Servers*(Apress, Berkeley, CA.), 21-70.

Goverment_of_South_Australia. (2015). South Australian Fire and Emergency Services Commission. Retrieved from http://www.safecom.sa.gov.au/site/home.jsp

Goverment_of_South_Australia. (2016). SA Ambulance Service reported ambulance incidents by priority. Retrieved from https://data.gov.au/dataset/sa-ambulance-service-reported-ambulance-incidents-by-priority

Government_of_South_Australia. (2011). South Australian Country Fire Service 2010 – 2011 ANNUAL REPORT Retrieved from https://safecom-files.s3.amazonaws.com/current%2Fdocs%2Fcfs_annual_report_20102011.pdf?Expires=1486400257&response-content-disposition=inline%3B%20filename%3Dcfs_annual_report_20102011.pdf&AWSAccessKeyId=AKIAJQ4Q62CAGOAFH3RA&Signature=XDM8pk%2FVvCukFJSoLDpFIVOmbNs%3D

Greenhalgh, S., & Singh, R. (1988). The seismicity of the Adelaide geosyncline, South Australia. *Bulletin of the Seismological Society of America, 78*(1), 243-263.

GRIFFITH, E. (2019). Charging Your Phone Overnight: Battery Myths Debunked. Retrieved from https://sea.pcmag.com/smartphones/19135/charging-your-phone-overnight-battery-myths-debunked

GSMArena. (2010). Huawei U8150 IDEOS. Retrieved from http://www.gsmarena.com/huawei_u8150_ideos-3513.php

GSMArena. (2017a). Battery Life Test Results. Retrieved from http://www.gsmarena.com/battery-test.php3?

GSMArena. (2017b). mAh. Retrieved from http://www.gsmarena.com/glossary.php3?term=mah

GSMArena. (2019). Battery life test results. Retrieved from https://www.gsmarena.com/battery-test.php3

Gudan, K., Shao, S., Hull, J. J., Ensworth, J., & Reynolds, M. S. (2015, 15-17 April 2015). *Ultra-low power 2.4GHz RF energy harvesting and storage system with −25dBm sensitivity*. Paper presented at the 2015 IEEE International Conference on RFID (RFID).

Guikema, S. D., Nateghi, R., Quiring, S. M., Staid, A., Reilly, A. C., & Gao, M. (2014). Predicting Hurricane Power Outages to Support Storm Response Planning. *IEEE Access, 2*, 1364-1373. doi:10.1109/ACCESS.2014.2365716

Gultom, D. I., & Joyce, Z. (2014). *Crisis communication capacity for disaster resilience: Community participation of information providing and verifying in Indonesian volcanic eruption*.

Gunaratna, G. T. C., Jayarathna, P. V. N. M., Sandamini, S. S. P., & Silva, D. S. D. (2015). *Implementing wireless Adhoc networks for disaster relief communication*. Paper presented at the 8th International Conference on Ubi-Media Computing (UMEDIA), Colombo.

Gupta, M., Jha, S. C., Koc, A. T., & Vannithamby, R. (2013). Energy impact of emerging mobile internet applications on LTE networks: issues and solutions. *IEEE Communications Magazine, 51*(2), 90-97.

Gurunathan, S. (2011). The Huawei IDEOS U8150 – Only the Price is Right. Retrieved from http://tech.firstpost.com/reviews/the-huawei-ideos-u8150-only-the-price-is-right-17984.html

Habitat. (2017). Phone case that charges your phone from the air. Retrieved from http://www.momentumenergy.com.au/habitat/technology/phone-case-that-charges-your-phone-from-thin-air/

Haddow, G. D., & Haddow, K. S. (2014a). Chapter Four - Disaster Coverage Past and Present *Disaster Communications in a Changing Media World (Second Edition)* (pp. 53-70): Butterworth-Heinemann.

Haddow, G. D., & Haddow, K. S. (2014b). Chapter Nine - Case Studies *Disaster Communications in a Changing Media World (Second Edition)* (pp. 155-181): Butterworth-Heinemann.

Haenggi, M., & Ganti, R. K. (2009). Interference in large wireless networks. *Foundations and Trends® in Networking, 3*(2), 127-248.

Halonen, T., Romero, J., & Melero, J. (2004). *GSM, GPRS and EDGE performance: evolution towards 3G/UMTS*: John Wiley & Sons.

Haraguchi, M., & Kim, S. (2016). Critical infrastructure interdependence in New York City during Hurricane Sandy. *International Journal of Disaster Resilience in the Built Environment, 7*(2), 133-143.

Heikkinen, M. V. J., & Nurminen, J. K. (2010, 6-9 Sept. 2010). *Consumer Attitudes Towards Energy Consumption of Mobile Phones and Services.* Paper presented at the Vehicular Technology Conference Fall (VTC 2010-Fall), 2010 IEEE 72nd.

Heikkinen, M. V. J., Nurminen, J. K., Smura, T., & Hämmäinen, H. (2012). Energy efficiency of mobile handsets: Measuring user attitudes and behavior. *Telematics and Informatics, 29*(4), 387-399. doi:http://dx.doi.org/10.1016/j.tele.2012.01.005

Henry, P. S., & Luo, H. (2002). WiFi: what's next? *IEEE Communications Magazine, 40*(12), 66-72.

Henson, E. (2016). Seven tornadoes hit SA on day of massive blackout: Bureau of Meteorology report. Retrieved from http://www.adelaidenow.com.au/news/south-australia/seventornadoes-%20hit-sa-on-day-of-massive-blackout-bureau-of-meteorologyreport/%20news-story/e888d155c01b910778132d68e93c9d6a

Hildenbrand, J. (2017). What is wireless charging and how does it work? Retrieved from http://www.androidcentral.com/wireless-charging-plain-english

Hill, S. (2016). 15 great wireless chargers to free yourself from cables. Retrieved from http://www.digitaltrends.com/mobile/best-wireless-chargers/2/

Hillebrand, F. (2002). *GSM and UMTS: the creation of global mobile communication*: John Wiley & Sons, Inc.

Hinchliff, M. (2014). How to power/charge motorcycle accessories. Retrieved from https://motorbikewriter.com/powering-motorcycle-accessories/

Hollister, S. (2009). Ampy Move review. Retrieved from https://www.cnet.com/products/ampy-move/review/

Home_power. (2017). PV System Derating. Retrieved from https://www.homepower.com/pv-system-derating

Hughes, D. J., Rowe, M., Batey, M., & Lee, A. (2012). A tale of two sites: Twitter vs. Facebook and the personality predictors of social media usage. *Computers in Human Behavior, 28*(2), 561-569.

IEEE_802.11ac. (2012). The Next Evolution of Wi-Fi Standards, A Qualcomm publication. Retrieved from https://www.qualcomm.com/documents/qualcomm-research-ieee80211ac-next-evolution-wi-fi

IFRC.org. (2017). What is a disaster? Retrieved from http://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/what-is-a-disaster/

Ingham, J., & Griffith, M. (2011). *The Performance of Unreinforced Masonry Buildings in the 2010/2011 Canterbury Earthquake Swarm*.

Jacquet, P., Muhlethaler, P., Clausen, T., Laouiti, A., Qayyum, A., & Viennot, L. (2001, 2001). *Optimized link state routing protocol for ad hoc networks.* Paper presented at the Proceedings. IEEE International Multi Topic Conference, 2001. IEEE INMIC 2001. Technology for the 21st Century.

Jadhav, S. S., Kulkarni, A. V., & Menon, R. (2014, 11-13 Sept. 2014). *Mobile Ad-Hoc Network (MANET) for disaster management.* Paper presented at the 2014 Eleventh International Conference on Wireless and Optical Communications Networks (WOCN).

Jan , S., & Lurie , N. (2012). Disaster Resilience and People with Functional Needs. *New England Journal of Medicine, 367*(24), 2272-2273. doi:10.1056/NEJMp1213492

Jang, H.-C., Lien, Y.-N., & Tsai, T.-C. (2009). *Rescue information system for earthquake disasters based on MANET emergency communication platform*. Paper presented at the Proceedings of the 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly, Leipzig, Germany.

Jary, S. (2015). How to properly charge a phone's battery: stop charging from zero to 100% and other tips. Retrieved from http://www.pcadvisor.co.uk/how-to/mobile-phone/how-charge-phones-battery-3619623/

Jhsph.edu. (2008). Disaster definitions. Retrieved from http://www.jhsph.edu/research/centers-and-institutes/center-for-refugee-and-disaster-response/publications_tools/publications/_CRDR_ICRC_Public_Health_Guide_Book/Chapter_1_Disaster_Definitions.pdf

Johnson, D., Ntlatlapa, N., & Aichele, C. (2008). Simple pragmatic approach to mesh routing using BATMAN.

Johnson, D. B., Maltz, D. A., & Broch, J. (2001). DSR: the dynamic source routing protocol for multihop wireless ad hoc networks *Ad hoc networking* (pp. 139-172): Addison-Wesley Longman Publishing Co., Inc.

Jones, C. E., Sivalingam, K. M., Agrawal, P., & Chen, J. C. (2001). A Survey of Energy Efficient Network Protocols for Wireless Networks. *Wireless Networks, 7*(4), 343-358. doi:10.1023/a:1016627727877

Ju, A., Jeong, S. H., & Chyi, H. I. (2014). Will social media save newspapers? Examining the effectiveness of Facebook and Twitter as news platforms. *Journalism Practice, 8*(1), 1-17.

K, P. (2014). What are wakelocks, how they affect the battery life of your Android device, and how to "Greenify" them. Retrieved from https://www.phonearena.com/news/What-are-wakelocks-how-they-affect-the-battery-life-of-your-Android-device-and-how-to-Greenify-them_id58739

Kalic, G., Bojic, I., & Kusek, M. (2012, 21-25 May 2012). *Energy consumption in android phones when using wireless communication technologies.* Paper presented at the 2012 Proceedings of the 35th International Convention MIPRO.

Kanakaris, V., Ndzi, D., & Azzi, D. (2010). Ad-hoc networks energy consumption: A review of the ad-hoc routing protocols. *Journal of Engineering Science and Technology Review, 3*(1), 162-167.

Kelion, L. (2017). Nokia 3310 mobile phone resurrected at MWC 2017. Retrieved from http://www.bbc.com/news/technology-39095127

Kelly, G. (2017). Nokia 3310 (2017) Vs Nokia 3310: What's The Difference? Retrieved from https://www.forbes.com/sites/gordonkelly/2017/04/13/nokia-3310-2017-vs-nokia-3310-whats-the-difference/#6159884e586a

Khan, A. H., Qadeer, M. A., Ansari, J. A., & Waheed, S. (2009). *4G as a next generation wireless network.* Paper presented at the Future Computer and Communication, 2009. ICFCC 2009. International Conference on.

Kitchenham, B. A., & Pfleeger, S. L. (2002). Principles of survey research: part 3: constructing a survey instrument. *ACM SIGSOFT Software Engineering Notes, 27*, 20-24.

Klinger, C., Landeg, O., & Murray, V. (2014). Power Outages, Extreme Events and Health: a Systematic Review of the Literature from 2011-2012. *PLoS Currents, 6*, ecurrents.dis.04eb01dc05e73dd1377e1305a1310e1379edde1673. doi:10.1371/currents.dis.04eb1dc5e73dd1377e05a10e9edde673

Klingler, F., Dressler, F., & Sommer, C. (2015, 16-18 Dec. 2015). *IEEE 802.11p unicast considered harmful.* Paper presented at the 2015 IEEE Vehicular Networking Conference (VNC).

Kobel, C., Baluja Garcia, W., & Habermann, J. (2013, 20-23 Oct. 2013). *A survey on Wireless Mesh Network applications in rural areas and emerging countries.* Paper presented at the Global Humanitarian Technology Conference (GHTC), 2013 IEEE.

Kongsiriwattana, W., & Gardner-Stephen, P. (2016a, 13-16 Oct. 2016). *The exploration of alternative phone charging strategies for disaster or emergency situations.* Paper presented at the 2016 IEEE Global Humanitarian Technology Conference (GHTC).

Kongsiriwattana, W., & Gardner-Stephen, P. (2016b, 13-16 Oct. 2016). *Smart-phone battery-life short-fall in disaster response: Quantifying the gap.* Paper presented at the 2016 IEEE Global Humanitarian Technology Conference (GHTC).

Kongsiriwattana, W., & Gardner-Stephen, P. (2017). *Eliminating the high stand-by energy consumption of ad-hoc wi-fi*. Paper presented at the In 2017 IEEE Global Humanitarian Technology Conference (GHTC).

Krishnamurthy, V., Kwasinski, A., & Dueñas-Osorio, L. (2016). Comparison of Power and Telecommunications Dependencies and Interdependencies in the 2011 Tohoku and 2010 Maule Earthquakes. *Journal of Infrastructure Systems*.

Kumar, A., Richhariya, G., & Sharma, A. (2015). Solar Photovoltaic Technology and Its Sustainability. In A. Sharma & S. K. Kar (Eds.), *Energy Sustainability Through Green Energy* (pp. 3-25). New Delhi: Springer India.

Kwasinski, A. (2011, 9-13 Oct. 2011). *Effects of notable natural disasters from 2005 to 2011 on telecommunications infrastructure: Lessons from on-site damage assessments*. Paper presented at the 2011 IEEE 33rd International Telecommunications Energy Conference (INTELEC).

Kwasinski, A. (2012). *Hurricane Sandy Effects on Communication Systems* (PR-AK-0112-2012). Retrieved from http://users.ece.utexas.edu/~kwasinski/preliminary%20telecom%20report%20v3%20comp.pdf

La, L. (2017). 6 phones with the best battery life. Retrieved from https://www.cnet.com/news/smartphones-best-long-battery-life/

LaMaire, R. O., Krishna, A., Bhagwat, P., & Panian, J. (1996). Wireless LANs and mobile networking: standards and future directions. *IEEE Communications Magazine, 34*(8), 86-94. doi:10.1109/35.533925

Lasky, M. S. (2012). Review: Tremont Electric nPower PEG. Retrieved from https://www.wired.com/2012/10/npower-peg/

Law, D., Dove, D., Ambrosia, J. D., Hajduczenia, M., Laubach, M., & Carlson, S. (2013). Evolution of ethernet standards in the IEEE 802.3 working group. *IEEE Communications Magazine, 51*(8), 88-96. doi:10.1109/MCOM.2013.6576344

Layton, J. (2009). How Wind-turbine Chargers Work. Retrieved from http://electronics.howstuffworks.com/gadgets/travel/wind-turbine-chargers1.htm

Lee, S. (2019). Best Solar Power Banks. Retrieved from https://www.renewableresourcescoalition.org/best-solar-power-banks/#1

Lendino, J. (2016). How USB charging works, or how to avoid blowing up your smartphone. Retrieved from https://www.extremetech.com/computing/115251-how-usb-charging-works-or-how-to-avoid-blowing-up-your-smartphone

Maehlum, M. A. (2013). What Factors Determine Solar Panel Efficiency? Retrieved from http://energyinformative.org/solar-panel-efficiency/

Maehlum, M. A. (2015). Which Solar Panel Type is Best? Mono- vs. Polycrystalline vs. Thin Film. Retrieved from http://energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/

Maher, P., Smith, N., & Williams, A. (2003). Assessment of pico hydro as an option for off-grid electrification in Kenya. *Renewable Energy, 28*(9), 1357-1369.

Martin, j. (2016). How to make your phone's battery last longer. Retrieved from http://www.techadvisor.co.uk/how-to/mobile-phone/how-improve-smartphone-battery-life-facebook-myths-3284240/

Martín, M. (2016). *Alternative Energy Sources and Technologies*: Springer International Publishing.

Mayner, A. P. L. (2013). *Definition of Disaster and Emergency Situation*.

Meier, P. (2012). How People in Emergencies Use Communication to Survive. Retrieved from https://irevolutions.org/2012/08/28/still-left-in-dark/

Metri, G., Agrawal, A., Peri, R., & Weisong, S. (2012, 3-5 Dec. 2012). *What is eating up battery life on my SmartPhone: A case study.* Paper presented at the 2012 International Conference on Energy Aware Computing.

Microsoft_Inc. (2017). Microsoft company. Retrieved from https://support.microsoft.com/en-au

Miki, T., Ohya, T., Yoshino, H., & Umeda, N. (2005). *The overview of the 4 th generation mobile communication system.* Paper presented at the Information, Communications and Signal Processing, 2005 Fifth International Conference on.

Miyashita, Y. (2012). Evolution of Mobile Handsets and the Impact of Smartphones. Retrieved from http://www.icr.co.jp/docs/Evolution_of_Mobile_Handsets_and_the_Impact_of_Smartphones.pdf

Moglen, E. (2015). FreedomBox Foundation. Retrieved from http://freedomboxfoundation.org/

Moon, L., Dizhur, D., Senaldi, I., Derakhshan, H., Griffith, M., Magenes, G., & Ingham, J. (2014). The demise of the URM building stock in Christchurch during the 2010–2011 Canterbury earthquake sequence. *Earthquake Spectra, 30*(1), 253-276.

Mora, M. (2016). Phone-osynthesis : Bioo Lite is a pot that uses plants to charge your phone. Retrieved from http://www.digitaltrends.com/home/bioo-charge-smartphone-from-plants/

Morley, N. (2016). This charger uses water to charge your phone. Retrieved from http://metro.co.uk/2016/01/14/this-charger-uses-water-to-charge-your-phone-5623781/

Motlhabi, M. (2008). Advanced Android power management and implementation of wakelocks.

Muijs, D. (2004). *Doing Quantitative Research in Education with SPSS*. London: Sage.

Murmuria, R., Medsger, J., Stavrou, A., & Voas, J. M. (2012, 20-22 June 2012). *Mobile Application and Device Power Usage Measurements.* Paper presented at the Software Security and Reliability (SERE), 2012 IEEE Sixth International Conference on.

MyEnlighten. (2017). What is the difference between a watt and a watt-hour? Retrieved from http://www2.enphase.com/myenlighten-help/tip/what-is-the-difference-between-a-watt-and-a-watt-hour/

Nardi, P. M. (2018). *Doing survey research: A guide to quantitative methods. Routledge.*: Routledge.

Nateghi, R., Guikema, S. D., & Quiring, S. M. (2014). Forecasting hurricane-induced power outage durations. *Natural hazards, 74*(3), 1795-1811.

Nguyen, D. T., Vu, P. T., & Minh, Q. T. (2016). Peer to Peer Social Network for Disaster Recovery. In D. Król, L. Madeyski, & N. T. Nguyen (Eds.), *Recent Developments in Intelligent Information and Database Systems* (pp. 123-132). Cham: Springer International Publishing.

Nield, D. (2016). Fairphone 2 review. Retrieved from http://www.techradar.com/reviews/phones/mobile-phones/fairphone-2-1315989/review

Northern_Arizona_Wind&Sun. (2017). What is Maximum Power Point Tracking (MPPT). Retrieved from https://www.solar-electric.com/mppt-solar-charge-controllers.html

O'callaghan, J. (2014). Forget plugs, charge your mobile with a WIND TURBINE: Portable propeller harnesses breezes to power up a phone. Retrieved from http://www.dailymail.co.uk/sciencetech/article-2604207/Trinity-portable-wind-turbine-charge-mobile-phone.html

Ohmura, N., Ogino, S., & Okano, Y. (2014). *Optimized shielding pattern of RF faraday cage.* Paper presented at the International Symposium on Electromagnetic Compatibility, Tokyo, Tokyo.

Oliveira, R., Bernardo, L., & Pinto, P. (2009). The influence of broadcast traffic on IEEE 802.11 DCF networks. *Computer Communications, 32*(2), 439-452. doi:http://dx.doi.org/10.1016/j.comcom.2008.11.023

Oliver, E. (2010). *Diversity in smartphone energy consumption*. Paper presented at the Proceedings of the 2010 ACM workshop on Wireless of the students, by the students, for the students, Chicago, Illinois, USA.

OpenWrt. (2015). OpenWrt. Retrieved from https://openwrt.org/

Osman, M. A., Talib, A. Z., Sanusi, Z. A., Shiang-Yen, T., & Alwi, A. S. (2012). A Study of the Trend of Smartphone and its Usage Behavior in Malaysia. *International Journal of New Computer Architectures and their Applications (IJNCAA), 2*(1), 274-285.

Paek, J., Kim, J., & Govindan, R. (2010). *Energy-efficient rate-adaptive GPS-based positioning for smartphones*. Paper presented at the Proceedings of the 8th international conference on Mobile systems, applications, and services, San Francisco, California, USA.

Pallardy, R. (2010). 2010 Haiti earthquake. Retrieved from https://www.britannica.com/event/2010-Haiti-earthquake

Patil, C. S., Karhe, R. R., & Aher, M. A. (2012). Review on Generations in Mobile Cellular Technology. *International Journal of Emerging Technology and Advanced Engineering, 2*(10), 614 - 619.

Patricelli, F., Beakley, J. E., Carnevale, A., Tarabochia, M., & Von Lubitz, D. K. (2009). Disaster management and mitigation: the telecommunications infrastructure. *Disasters, 33*(1), 23-37.

Patrick, M., & Munro, R. (2010). The unprecedented role of SMS in disaster response: Learning from Haiti. *SAIS Review of International Affairs, 30*(2), 91-103.

Paul, T., & Ogunfrunmiri, T. (2008). Wireless LAN Comes of Age: Understanding the IEEE 802.11n Amendment. *IEEE Circuits and Systems Magazine, 8*(1), 28-54. doi:10.1109/MCAS.2008.915504

Peary, B. D., Shaw, R., & Takeuchi, Y. (2012). Utilization of social media in the east Japan earthquake and tsunami and its effectiveness. *Journal of Natural Disaster Science, 34*(1), 3-18.

Perkins, C. E., & Bhagwat, P. (1994). *Highly dynamic Destination-Sequenced Distance-Vector routing (DSDV) for mobile computers*. Paper presented at the Proceedings of the conference on Communications architectures, protocols and applications, London, United Kingdom.

Perkins, C. E., & Royer, E. M. (1999, 25-26 Feb 1999). *Ad-hoc on-demand distance vector routing.* Paper presented at the Mobile Computing Systems and Applications, 1999. Proceedings. WMCSA '99. Second IEEE Workshop on.

Perrucci, G. P., Fitzek, F. H. P., Sasso, G., Kellerer, W., & Widmer, J. (2009, 17-20 May 2009). *On the impact of 2G and 3G network usage for mobile phones' battery life.* Paper presented at the Wireless Conference, 2009. EW 2009. European.

Perrucci, G. P., Fitzek, F. H. P., & Widmer, J. (2011, 15-18 May 2011). *Survey on Energy Consumption Entities on the Smartphone Platform.* Paper presented at the Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd.

Pershing, B. (2019). WHAT ARE KINETIC CHARGERS AND HOW THEY WORK? Retrieved from https://www.meee-services.com/what-are-kinetic-chargers-and-how-they-work/

Peter A Cameron, B. M., Mark Fitzgerald, Carlos D Scheinkestel, Andrew Stripp, Chris Batey, Louise Niggemeyer, Melinda Truesdale, Paul Holman, Rishi Mehra, Jason Wasiak and Heather Cleland. (2009). Black Saturday: the immediate impact of the February 2009 bushfires in Victoria, Australia. *The Medical journal of Australia, 191*(1), 11 -16.

Phone_Scoop. (2015a). Feature phone. Retrieved from http://www.phonescoop.com/glossary/term.php?gid=131

Phone_Scoop. (2015b). Smartphone. Retrieved from http://www.phonescoop.com/glossary/term.php?gid=131

Pierotti, L. (2016). How to Choose the Best Solar Charger . Retrieved from http://www.outdoorgearlab.com/Solar-Charger-Reviews/Buying-Advice

Polastre, J., Hill, J., & Culler, D. (2004). *Versatile low power media access for wireless sensor networks*. Paper presented at the Proceedings of the 2nd international conference on Embedded networked sensor systems, Baltimore, MD, USA.

Ponto, J. (2015). Understanding and Evaluating Survey Research. *Journal of the advanced practitioner in oncology, 6*(2), 168-171.

Portmann, M., & Pirzada, A. A. (2008). Wireless Mesh Networks for Public Safety and Crisis Management Applications. *IEEE Internet Computing, 12*(1), 18-25. doi:10.1109/MIC.2008.25

Pourbeik, P., Kundur, P. S., & Taylor, C. W. (2006). The anatomy of a power grid blackout - Root causes and dynamics of recent major blackouts. *IEEE Power and Energy Magazine, 4*(5), 22-29. doi:10.1109/MPAE.2006.1687814

Power, H., & Wilson, K. (2016). Making waves: the tsunami risk in Australia. Retrieved from http://theconversation.com/making-waves-the-tsunami-risk-in-australia-60623

Proxi. (2016). Wireless Charging. Retrieved from https://powerbyproxi.com/wireless-charging/

Queensland_Ambulance_Service. (2015). Staff update june 2015. Retrieved from http://www.ambulance.qld.gov.au/docs/Staff-Update-June-2015Final.pdf

Queensland_Government. (2011). Population growth highlights and trends, Queensland 2011. Retrieved from http://www.qgso.qld.gov.au/products/reports/pop-growth-highlights-trends-qld/pop-growth-highlights-trends-qld-2011.pdf

Queensland_Government. (2012). Population Growth Highlights andTrends, Queensland 2012. Retrieved from http://www.qgso.qld.gov.au/products/reports/pop-growth-highlights-trends-qld/pop-growth-highlights-trends-qld-2012.pdf

Queensland_Government. (2013). Population Growth Highlights and Trends, Queensland Retrieved from http://www.qgso.qld.gov.au/products/reports/pop-growth-highlights-trends-qld/pop-growth-highlights-trends-qld-2013.pdf

Queensland_Government. (2014a). Budget Paper Queensland's Natural Disasters 2013-14. Retrieved from http://www.parliament.qld.gov.au/Documents/TableOffice/TabledPapers/2013/5413T2788.pdf

Queensland_Government. (2014b). Population growth highlights and trends, Queensland 2014 Retrieved from http://www.qgso.qld.gov.au/products/reports/pop-growth-highlights-trends-qld/pop-growth-highlights-trends-qld-2014.pdf

Queensland_Government. (2015). Population growth highlights and trends, Queensland, 2015 edition Retrieved from http://www.qgso.qld.gov.au/products/reports/pop-growth-highlights-trends-qld/pop-growth-highlights-trends-qld-2015.pdf

Queensland_Government. (2016a). Population growth highlights and trends, Queensland, 2016 edition Retrieved from http://www.qgso.qld.gov.au/products/reports/pop-growth-highlights-trends-qld/pop-growth-highlights-trends-qld-2016-edn.pdf

Queensland_Government. (2016b). Population growth, regional Queensland. Retrieved from http://www.qgso.qld.gov.au/products/reports/pop-growth-reg-qld/index.php

Queensland_Government. (2016c). Queensland Flood Summary 2010 onwards. Retrieved from http://www.bom.gov.au/qld/flood/fld_history/floodsum_2010.shtml

Queensland_Government. (2017). Queensland population counter. Retrieved from http://www.qgso.qld.gov.au/products/reports/pop-growth-qld/qld-pop-counter.php

Rahmati, A., & Zhong, L. (2013). Studying Smartphone Usage: Lessons from a Four-Month Field Study. *Mobile Computing, IEEE Transactions on, 12*(7), 1417-1427. doi:10.1109/tmc.2012.127

RFDesign. (2016). Energy Sampler Module. Retrieved from http://rfdesign.com.au/

Richards, F. (1959). A flexible growth function for empirical use. *Journal of experimental Botany, 10*(2), 290-301.

Road, H. (2015). ADELAIDE HILLS AUSTRALIA BUSHFIRE JAN 2015. Retrieved from https://www.humanityroad.org/situation-reports/australia/adelaide-hills-australia-bushfire-jan-2015

Road, H. (2017a). Cyclone Debbie Queesland. Retrieved from https://www.humanityroad.org/situation-reports/australia/cyclone-debbie-queensland

Road, H. (2017b). HURRICANE IRMA - FLORIDA. Retrieved from https://www.humanityroad.org/situation-reports/usa/hurricane-irma-florida

Road, H. (2017c). M7.1 EARTHQUAKE, PUEBLA, MEXICO. Retrieved from https://www.humanityroad.org/situation-reports/mexico/m71-earthquake-puebla-mexico

Road, H. (2017d). PERU FLOODING MARCH 2017. Retrieved from https://www.humanityroad.org/situation-reports/peru/peru-flooding-march-2017

Rosas-Casals, M. (2010, 22-24 Feb. 2010). *Power Grids as Complex Networks: Topology and Fragility.* Paper presented at the 2010 Complexity in Engineering.

Ross, N. (2009). Black Saturday survivors point to lack of communications. Retrieved from https://www.news.com.au/news/phone-coverage-failed-in-fire-towns/news-story/7680d7c750f87fc2513debd9e3ddeb2f?sv=2ad38449d344b35de187c1df2da7e7b4

Rubinstein, M., Moraes, I., Campista, M., Costa, L. K., & Duarte, O. B. (2006). A Survey on Wireless Ad Hoc Networks. In G. Pujolle (Ed.), *Mobile and Wireless Communication Networks* (Vol. 211, pp. 1-33): Springer US.

Rubinstein, M. G., Moraes, I. M., Campista, M. E. M., Costa, L. H. M. K., & Duarte, O. C. M. B. (2006). A Survey on Wireless Ad Hoc Networks. In G. Pujolle (Ed.), *Mobile and Wireless Communication Networks: IFIP 19th World Computer Congress, TC-6, 8th IFIP/IEEE Conference on Mobile and Wireless Communications Networks, August 20–25, 2006, Santiago, Chile* (pp. 1-33). Boston, MA: Springer US.

Rutherford, W. H., & de Boer, J. (1983). The definition and classification of disasters. *Injury, 15*(1), 10-12. doi:10.1016/0020-1383(83)90154-7

SA_Power_Networks. (2016). Customers interrupted during 2010 to 2011 information. Retrieved from https://www.sapowernetworks.com.au/centric/home.jsp

SafeWorkAustralia. (2009). Some examples of state statutes defining emergency for this purpose. Retrieved from www.safeworkaustralia.gov.au

Samar, P., Pearlman, M. R., & Haas, Z. J. (2004). Independent zone routing: an adaptive hybrid routing framework for ad hoc wireless networks. *IEEE/ACM Transactions on Networking, 12*(4), 595-608. doi:10.1109/TNET.2004.833153

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for business students* (Fifth Edition ed.): Pearson Education Limited.

Schober, P., Boer, C., & Schwarte, L. A. (2018). Correlation coefficients: appropriate use and interpretation. *Anesthesia & Analgesia, 126*(5), 1763-1768.

Shankar, K. (2008). Wind, Water, and Wi-Fi: New Trends in Community Informatics and Disaster Management. *The Information Society, 24*(2), 116-120. doi:10.1080/01972240701883963

Sharma, A., & Kar, S. K. (2015). *Energy Sustainability Through Green Energy*: Springer India.

Shearer, F. (2008). *Power management in mobile phone devices*: Elsevier Inc. All rights reserved.

Silicon_Labs. (2017). EFM32™ Zero Gecko Starter Kit. Retrieved from http://www.silabs.com/products/development-tools/mcu/32-bit/efm32-zero-gecko-starter-kit

Silva, D. (2018). Mobile phones help transform disaster relief. Retrieved from https://phys.org/news/2018-03-mobile-disaster-relief.html

Sinadinovski, C., Greenhalgh, S., & Love, D. (2006). Historical earthquakes: a case study for Adelaide 1954 earthquake.

Singh, S., & Raghavendra, C. S. (1998). PAMAS—power aware multi-access protocol with signalling for ad hoc networks. *SIGCOMM Comput. Commun. Rev., 28*(3), 5-26. doi:10.1145/293927.293928

Skylis, M. B. (2019). THE WORLD'S MOST ENERGY-EFFICIENT STOVE: BIOLITE REVIEW. Retrieved from https://www.thebrokebackpacker.com/biolite-camping-stove-review/

Solar_Facts. (2016). Charging and Discharging Lead Acid Batteries. Retrieved from http://www.solar-facts.com/batteries/battery-charging.php

South_Australian_Country_Fire_Service. (2015). South Australian Country Fire Service (CFS). Retrieved from http://www.cfs.sa.gov.au/site/home.jsp

Spendelow, N. (2019). Best phone battery life 2019: The longest-lasting smartphones ranked. Retrieved from https://www.expertreviews.co.uk/mobile-phones/1402071/best-phone-battery-life

Spoonauer, M. (2015). Smartphones with the Longest Battery Life. Retrieved from http://blog.laptopmag.com/smartphones-best-battery-life

Stokes, N. (2016). What's Draining Your Android Battery? Retrieved from http://www.techlicious.com/tip/whats-draining-your-android-battery/

Stori, V. (2011). Power Outages and Natural Disasters: Which Ones are Avoidable? Retrieved from http://www.cleanegroup.org/power-outages-and-natural-disasters-which-ones-are-avoidable/

Sung, S. J. (2011). *How can we use mobile apps for disaster communications in Taiwan: Problems and possible practice.* Retrieved from

Suppasri, A., Leelawat, N., Latcharote, P., Roeber, V., Yamashita, K., Hayashi, A., . . . Imamura, F. (2017). The 2016 Fukushima earthquake and tsunami: Local tsunami behavior and recommendations for tsunami disaster risk reduction. *International Journal of Disaster Risk Reduction, 21*(Supplement C), 323-330. doi:https://doi.org/10.1016/j.ijdrr.2016.12.016

Takeno, K., Ichimura, M., Takano, K., & Yamaki, J. (2005). Influence of cycle capacity deterioration and storage capacity deterioration on Li-ion batteries used in mobile phones. *Journal of Power Sources, 142*(1), 298-305. doi:https://doi.org/10.1016/j.jpowsour.2004.10.007

Tanenbaum, A. S., & Wetherall, D. J. (2011). *Computer Networks* (Fifth ed.): Pearson.

Tapim, F. (2017). Cyclone Debbie likely to cost Queensland budget $1.5 billion. Retrieved from http://www.abc.net.au/news/2017-04-24/cyclone-debbie-cost-repair-bill-curits-pitt-state-budget/8466192

Tawalbeh, M., & Eardley, A. (2016). Studying the energy consumption in mobile devices. *Procedia Computer Science, 94*, 183-189.

Technologies, A. C. (2017). Power management. Retrieved from https://source.android.com/devices/tech/power/mgmt

Technopedia. (2015). Mobile phone. Retrieved from http://www.techopedia.com/definition/2955/mobile-phone

Telco, V. (2011). Village Telco. Retrieved from http://villagetelco.org/

The_Serval_Project_Team. (2013). Serval Maps. Retrieved from http://developer.servalproject.org/dokuwiki/doku.php?id=content:servalmaps:main_page

The_Serval_Project_Team. (2014a). Serval Mesh Extender. Retrieved from http://developer.servalproject.org/dokuwiki/doku.php?id=content:meshextender:main_page

The_Serval_Project_Team. (2014b). Supported devices for Serval Mesh. Retrieved from http://developer.servalproject.org/dokuwiki/doku.php?id=content:servalmesh:supported_devices

The_Serval_Project_Team. (2015a). MeshMS. Retrieved from http://developer.servalproject.org/dokuwiki/doku.php?id=content:tech:meshms

The_Serval_Project_Team. (2015b). Serval Mesh. Retrieved from http://developer.servalproject.org/dokuwiki/doku.php?id=content:servalmesh:main_page

The_Serval_Project_Team. (2017a). Serval Chat. Retrieved from http://developer.servalproject.org/dokuwiki/doku.php?id=content:servalchat:main_page

The_Serval_Project_Team. (2017b). Serval Mesh Extender. Retrieved from http://developer.servalproject.org/dokuwiki/doku.php?id=content:meshextender:main_page

The_Straits_Times. (2016). Taiwan rescuers race to search for victims as 72-hour 'golden window' closes. Retrieved from http://www.straitstimes.com/asia/east-asia/taiwan-rescuers-race-to-search-for-victims-as-72-hour-golden-window-closes

Thiagarajan, N., Aggarwal, G., Nicoara, A., Boneh, D., & Singh, J. P. (2012). *Who killed my battery?: analyzing mobile browser energy consumption*. Paper presented at the Proceedings of the 21st international conference on World Wide Web, Lyon, France.

Tingsanchali, T. (2012). Urban flood disaster management. *Procedia Engineering, 32*(Supplement C), 25-37. doi:https://doi.org/10.1016/j.proeng.2012.01.1233

Townsend, A. M., & Moss, M. L. (2005). TELECOMMUNICATIONS INFRASTRUCTURE IN DISASTERS: Preparing Cities for Crisis Communications. Retrieved from https://www.nyu.edu/ccpr/pubs/NYU-DisasterCommunications1-Final.pdf

Twitter. (2017). Twitter. Retrieved from https://twitter.com/

UK_Government. (2004). Civil Contingencies Act 2004: a short guide. Retrieved from https://web.archive.org/web/20070606230917/http://www.ukresilience.info/upload/assets/www.ukresilience.info/15mayshortguide.pdf

Universal_Serial_Bus_Organisation. (2017). USB Specification. Retrieved from http://www.usb.org/developers/docs/

Vallina-Rodriguez, N., Hui, P., Crowcroft, J., & Rice, A. (2010). *Exhausting battery statistics: understanding the energy demands on mobile handsets*. Paper presented at the Proceedings of the second ACM SIGCOMM workshop on Networking, systems, and applications on mobile handhelds, New Delhi, India.

Verkasalo, H. (2010, 13-15 June 2010). *Analysis of Smartphone User Behavior.* Paper presented at the Mobile Business and 2010 Ninth Global Mobility Roundtable (ICMB-GMR), 2010 Ninth International Conference on.

Villas-Boas, A. (2015). The companies that make your smartphone batteries say they should barely last a year. Retrieved from http://www.businessinsider.com/smartphone-batteries-are-only-meant-to-last-a-year-2015-10

VILLAS-BOAS, A. (2019). Here's How to Charge Your Phone to Save The Battery, According to Science. Retrieved from https://www.sciencealert.com/how-to-charge-phone-battery-to-last-longer-advice-science

Vincent, J. (2017). 99.6 percent of new smartphones run Android or iOS. Retrieved from https://www.theverge.com/2017/2/16/14634656/android-ios-market-share-blackberry-2016

Wang, C. X., Haider, F., Gao, X., You, X. H., Yang, Y., Yuan, D., . . . Hepsaydir, E. (2014). Cellular architecture and key technologies for 5G wireless communication networks. *IEEE Communications Magazine, 52*(2), 122-130. doi:10.1109/MCOM.2014.6736752

Warudkar, V. (2015). Wind Energy Technology and Environment Sustainability. In A. Sharma & S. K. Kar (Eds.), *Energy Sustainability Through Green Energy* (pp. 115-143). New Delhi: Springer India.

Wattenhofer, R., Li, L., Bahl, P., & Wang, Y. M. (2001, 2001). *Distributed topology control for power efficient operation in multihop wireless ad hoc networks.* Paper presented at the INFOCOM 2001. Twentieth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE.

Wei, Y., Heidemann, J., & Estrin, D. (2002, 2002). *An energy-efficient MAC protocol for wireless sensor networks.* Paper presented at the Proceedings.Twenty-First Annual Joint Conference of the IEEE Computer and Communications Societies.

Werner, P. (2013). The PowerPot Review. Retrieved from http://sectionhiker.com/powerpot-review/

West, J. G. (2011). Changing patterns of shark attacks in Australian waters. *Marine and Freshwater Research, 62*(6), 744-754.

Williams, Y. (2017). What Is Descriptive Statistics? - Examples & Concept. Retrieved from http://study.com/academy/lesson/what-is-descriptive-statistics-examples-lesson-quiz.html

Woollaston, V. (2015). Charging gadgets using THIN AIR: Freevolt captures radio waves to wirelessly power small devices. Retrieved from http://www.dailymail.co.uk/sciencetech/article-3256272/Charging-phones-using-AIR-Freevolt-captures-radio-waves-wirelessly-power-small-devices.html

Wordtheque. (2016). 4 New Developments and Trends in Mobile Phones. Retrieved from http://www.wordtheque.com/4-new-developments-and-trends-in-mobile-phones/

Wu, X., Zhang, S., Wu, Y., Li, Z., Ke, W., Fu, L., & Hao, J. (2015). on–road measurement of gaseous emissions and fuel consumption for two hybrid electric vehicles in Macao. *Atmospheric Pollution Research, 6*(5), 858-866. doi:http://dx.doi.org/10.5094/APR.2015.095

Wyche, S. P., & Murphy, L. L. (2012). *Dead China-make phones off the grid: investigating and designing for mobile phone use in rural Africa.* Paper presented at the Proceedings of the Designing Interactive Systems Conference.

Xiangyu, L., Xiao, Z., Kongyang, C., & Shengzhong, F. (2014, 26-28 April 2014). *Measurement and analysis of energy consumption on Android smartphones.* Paper presented at the Information Science and Technology (ICIST), 2014 4th IEEE International Conference on.

Xu, Y., Heidemann, J., & Estrin, D. (2001). *Geography-informed energy conservation for Ad Hoc routing*. Paper presented at the Proceedings of the 7th annual international conference on Mobile computing and networking, Rome, Italy.

Yam, M. (2016). Micro Wind Turbine is light, efficient, and can charge 24/7. Retrieved from http://www.digitaltrends.com/outdoors/micro-wind-turbine-usb-charger/

Yang, J., Hou, H., Han, L., & Zhang, D. (2016, 24-27 July 2016). *Study on China's rapid rescue system of natural disasters emergency logistics.* Paper presented at the 2016 International Conference on Logistics, Informatics and Service Sciences (LISS).

Yick, J., Mukherjee, B., & Ghosal, D. (2008). Wireless sensor network survey. *Computer Networks, 52*(12), 2292-2330. doi:http://dx.doi.org/10.1016/j.comnet.2008.04.002

Yoshio, M., Brodd, R. J., & Kozawa, A. *Lithium-ion batteries* (Vol. 1): Springer.

YouTube. (2017). YouTube. Retrieved from https://www.youtube.com/

Zaré, M., & Afrouz, S. G. (2012). Crisis Management of Tohoku; Japan Earthquake and Tsunami, 11 March 2011. *Iranian Journal of Public Health, 41*(6), 12-20.

ZDNet. (2013). 10 tips for better battery life for Android phones. Retrieved from http://www.zdnet.com/pictures/10-tips-for-better-battery-life-for-android-phones/

Zhang, X., Kuchinke, L., Woud, M. L., & Velten, J., & Margraf, J. Survey method matters: Online/offline questionnaires and face-to-face or telephone interviews differ. *Computers in Human Behavior, 71*, 172-180.

Zheng, P., & Ni, L. (2006). 1 - Introduction to Smart Phone and Mobile Computing *Smart Phone and Next Generation Mobile Computing* (pp. 1-21). Burlington: Morgan Kaufmann.

Zhuang, Z., Kim, K.-H., & Singh, J. P. (2010). *Improving energy efficiency of location sensing on smartphones.* Paper presented at the Proceedings of the 8th international conference on Mobile systems, applications, and services.

Zimmerman, A. H. (2004). Self-discharge losses in lithium-ion cells. *IEEE Aerospace and Electronic Systems Magazine, 19*(2), 19-24. doi:10.1109/MAES.2004.1269687

APPENDIX A: CLAIMED MOBILE PHONE BATTERY LIFE FROM MANUFACTURERS

These data are cited using the information on February 2017.

A1. Mobile phone battery life by talk time

Talk time is the time that a battery can last while a mobile phone user constantly talks on the phone (GSMArena, 2017d). The table below shows examples of battery life determined by talk time:

Table A.1: Mobile phone battery life by talk time (GSMArena, 2017a)

Mobile phone model	Talk time (hours)	Battery capacity (mAh)
Lenovo P2	34.49	5,100
Xiaomi Redmi 3 Pro	34.40	4,100
Google Pixel XL	33.21	3,450
Hauwei Ascend Mate 2 4G	33.19	4,050
Samsung Galaxy A9 (2016)	32.54	5,000
OnePlus 3	32.48	3,000
Samsung Galaxy S6 edge+	30.29	3,000
Motorola Moto Z Play	30.26	3,510
Microsoft Lumia 640 XL	29.46	3,000
Samsung Galaxy S7 active	29.17	4,000
Nokia Lumia 1520	28.34	3,400
Samsung Galaxy Note 5	28.34	3,000
HTC One M8 for windows	28.34	2,600
Samsung Galaxy Note 4	28.31	3,220
Sony Xperia Z5 Compact	28.23	2,700
Asus Zenfone Max ZC550KL	27.47	5,000
Samsung Galaxy S5	27.37	2,800
Sony Xperia Z1	26.53	3,000
Samsung Galaxy S6 active	26.29	3,500
Samsung Galaxy A7	26.01	3,600
LG G3	25.38	3,000
Motorola Nexus 6	25.03	3,220
Iphone 6 Plus	23.49	1,915
Samsung Galaxy Note 7	23.45	3,500
Sony Xperia XZ	23.39	2,900

A.2 Mobile phone battery life by web browsing time

Web browsing time is the time that a battery can last when a user constantly use web browsers on a mobile phone. The table below shows examples of battery life indicated by web browsing time:

Table A.2: Mobile phone battery life by web browsing time (GSMArena, 2017a)

Mobile phone model	**Web browsing time (hours)**	**Battery capacity (mAh)**
Asus Zenfone Max ZC550KL	20.22	5,000
Samsung Galaxy S6 active	16.25	3,500
Motorola Moto Z Play	15.39	3,510
Samsung Galaxy S7 edge	13.32	3,600
Iphone 7 Plus	13.31	2,900
Samsung Galaxy A9 (2016)	13.26	5,000
Samsung Galaxy S5 Mini	13.14	2,100
Iphone SE	12.55	1,624
Nokia Lumia 1520	12.40	3,400
HTC One (M8) for windows	12.31	2,600
HTC One M8	12.29	2,600
Iphone 6S	12.27	1,715
Iphone 7	11.48	1,960
Samsung Galaxy Note 7	11.08	3,500
Sansung Galaxy Note 4	11.01	3,220
Samsung Galaxy S6 edge	10.56	2,600
Samsung Galaxy S6	10.56	2,550
Samsung Galaxy Note 5	10.43	3,000

A.3 Mobile phone battery life by video playback time

Video playback time is the time that a battery can last when a user constantly run video playback on a mobile phone. The table below presents examples of battery life by video playback time.

Table A.3: Mobile phone battery life by video playback time (GSMArena, 2017a)

Mobile phone model	**Video playback time (hours)**	**Battery capacity (mAh)**
Lenovo P2	23.11	5,100
Samsung Galaxy S7 active	20.54	4,000
Samsung Galaxy S7 edge	20.08	3,600
Samsung Galaxy A9 (2016)	18.36	5,000
Motorola Moto Z Play	18.26	3,510
Samsung Galaxy S6 active	18.03	3,500
Huawei Ascend Maid 2 4G	18.01	4,050
Samsung Galaxy Note 4	17.52	3,220
Samsung Galaxy Note 7	16.46	3,500
Azus Zenfone Max ZC550KL	15.40	5,000
Samsung Galaxy S7	14.50	3,000
Iphone SE	14.17	1,624
Iphone 6s plus	13.57	1,915
Samsung Galaxy Note 5	13.51	3,000
Samsung Galaxy Note 3	13.32	3,200
OnePlus 3	13.15	3,000
Nokia Lumia 1520	12.31	3,400
Samsung Galaxy S6 edge	12.12	2,600
Samsung Galaxy S6	12.12	2,550
Sony Xperia Z3	11.47	3,100
Xiaomi Redmi 3 Pro	11.33	4,100
Google Pixel	11.27	2,770
Iphone 6 Plus	11.15	1,915
Google Pixel XL	11.09	3,450
Iphone 6S	10.46	1,715

A.4 Mobile phone battery life by Wi-Fi time

Wi-Fi time is the time that a battery can last while a user constantly connects with Wi-Fi via access point on a mobile phone. The table below shows some example of current flagship mobile phone battery life by Wi-Fi time:

Table A.4: Mobile phone battery life by Wi-Fi time (Gikas, 2017)

Mobile phone model	Wi-Fi time (hours)	Battery capacity (mAh)
Samsung Galaxy S7 edge	12.79	3,600
Google Pixel XL	12.09	3,450
Samsung Galaxy S7	11.10	3,000
LG V20	10.70	3,200
HTC 10	10.23	3,000

A.5 Battery capacity on mobile phone

In this section, a battery capacity is classified by popular mobile phone models. It mainly focuses on popular flagship brands including Apple iPhone, Google Phone, LG, Samsung, Windows phone, and HTC which are presented in table A.5, table A.6, table A.7, table A.8, table A.9 and table A.10 respectively.

Table A.5: Battery capacity of Apple Iphone brand (GSMArena, 2017c)

Mobile phone model	Capacity (mAh)
Iphone 7 plus	2,900
Iphone 7	1,960
Iphone 6S plus	2,750
Iphone 6S	1,715
Iphone 6 plus	1,915
Iphone 6	1,810
Iphone SE	1,624
Iphone 5S	1,570
Iphone 5C	1,507
Iphone 5	1,440
Iphone 4S	1,432
Iphone 4	1,420

Table A.6: Battery capacity of Google phone brand (GSMArena, 2017c)

Mobile phone model	Capacity (mAh)
Google Pixel XL	3,450
Google Pixel	2,770
Nexus 6P	3,450
Nexus 5x	2,700
Nexus 6	3,220
Nexus 5	2,300
Nexus 4	2,100
Galaxy Nexus	1,750
Nexus S	1,500
Nexus One	1,400

Table A.7: Battery capacity of LG brand (GSMArena, 2017c)

Mobile phone model	Capacity (mAh)
LG G6	3,330
LG G5	2,800
LG G4	3,000
LG G3	3,000
LG G2	3,000

Table A.8: Battery capacity of Samsung brand (GSMArena, 2017c)

Mobile phone model	Capacity (mAh)
Samsung Galaxy Note 7	3,500
Samsung Galaxy Note 5	3,000
Samsung Galaxy Note 4	3,220
Samsung Galaxy Note 3	3,200
Samsung Galaxy Note 2	3,100
Samsung Galaxy Note	2,500
Samsung Galaxy S7	3,000
Samsung Galaxy S7 edge	3,600
Samsung Galaxy S6	2,550
Samsung Galaxy S6 edge	2,600
Samsung Galaxy S5	2,800
Samsung Galaxy S4	2,600
Samsung Galaxy S3	2,100
Samsung Galaxy S2	1,650
Samsung Galaxy S	1,500

Table A.9: Battery capacity of Microsoft phone and Nokia brand (GSMArena, 2017c)

Mobile phone model	Capacity (mAh)
Microsoft Lumia 950	2,000
Microsoft Lumia 650	2,000
Microsoft Lumia 550	2,100
Nokia Lumia 830	2,200
Nokia Lumia 730 Dual sim	2,200
Nokia Lumia 635	1,830
Nokia Lumia 630	1,830
Nokia Lumia 625	2,000
Nokia Lumia 530	1,430
Nokia Lumia 520	1,430

Table A.10: Battery capacity of HTC brand (GSMArena, 2017c)

Mobile phone model	Capacity (mAh)
HTC EVO	3,200
HTC 10	3,000
HTC One Desire Pro	3,000
HTC One X9	3,000
HTC One M9	2,840
HTC One M8	2,600
HTC One	2,300
HTC One A9	2,150

APPENDIX B: EXAMPLE OF MASSIVE DISASTER EVENTS FROM MODEL ANALYSIS

The figures B.1 to B.17 cited in Chapter 6 have been shown in this appendix

Number of customers without electricity supply due to disaster events since 1 July 2005 to 30 June 2016

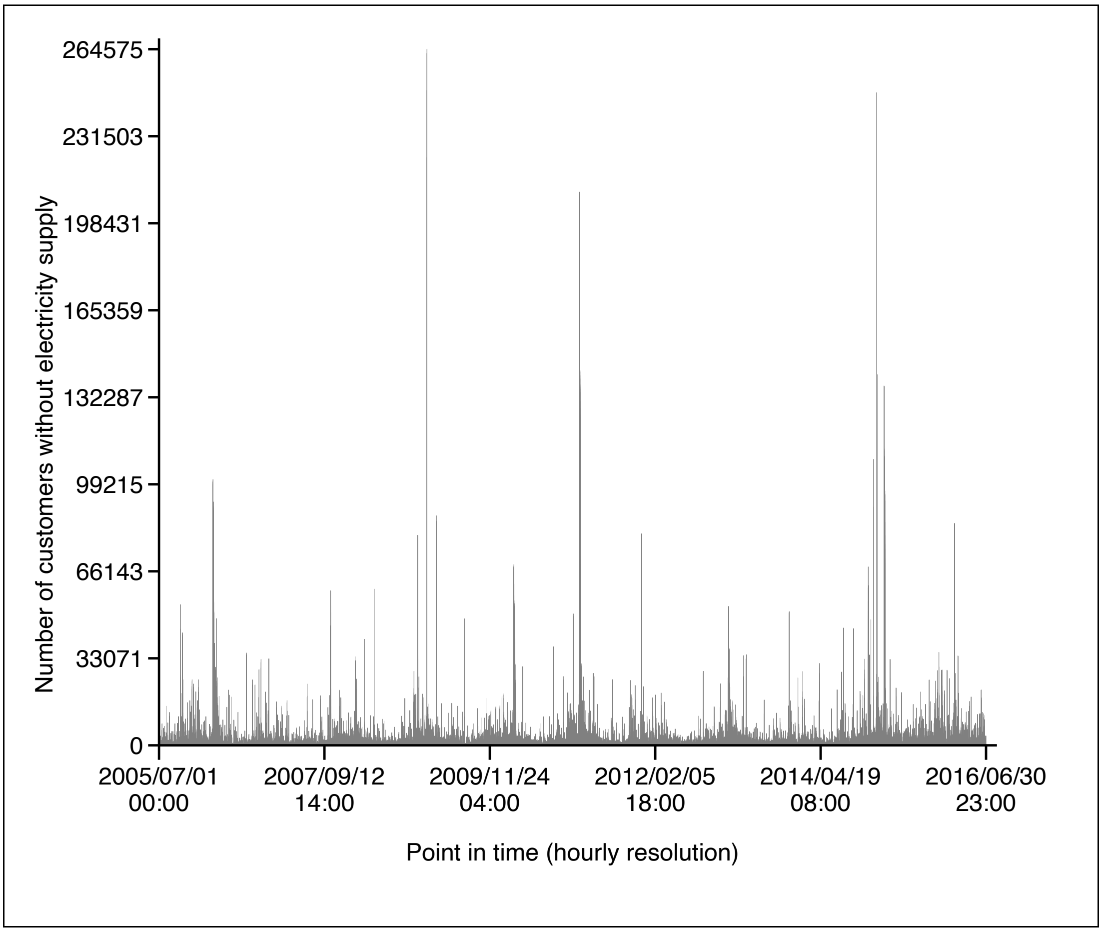


Figure B.1: Number of customers without electricity supply since 1 July 2005 to 30 June 2016

Number of customers without electricity supply with three major disaster events label during 1 July 2005 to 30 June 2016

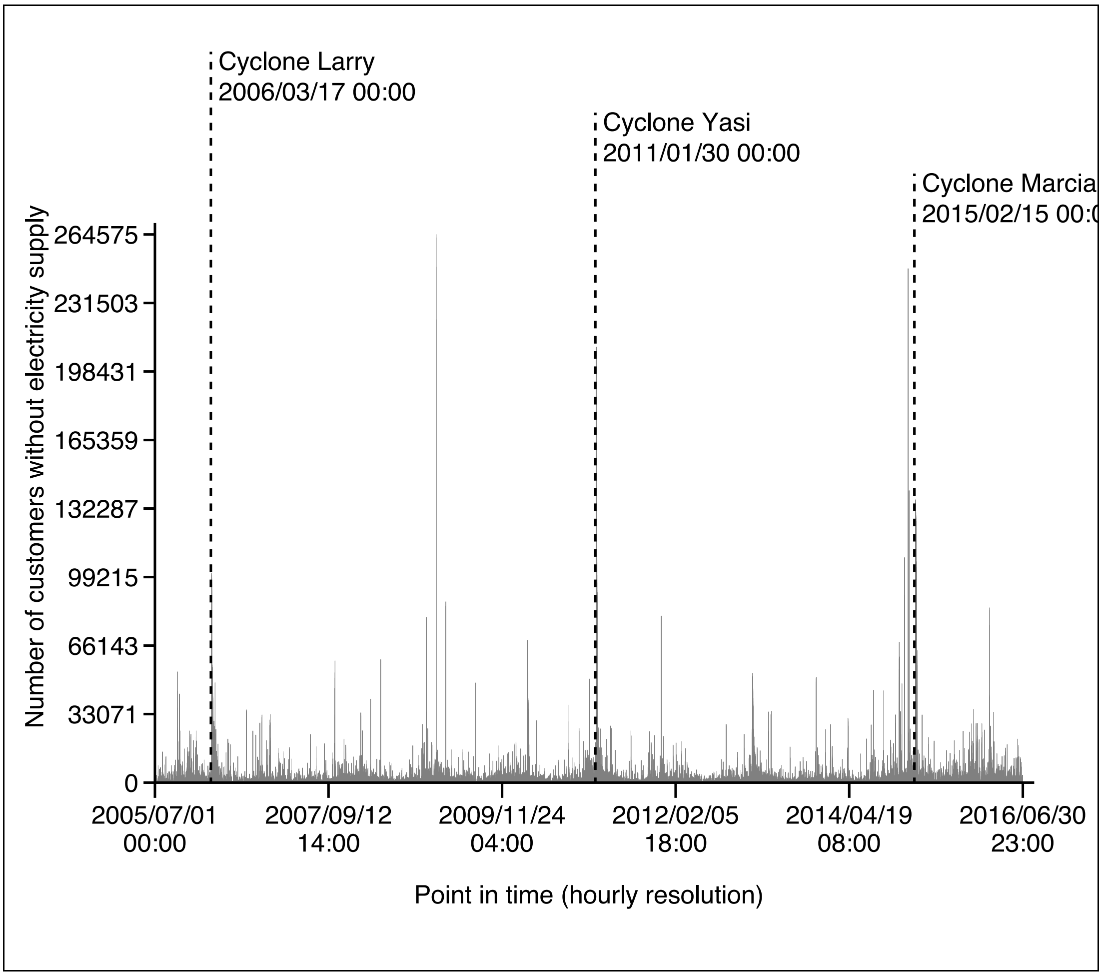


Figure B.2: Number of customers without electricity supply with three major disaster events during 1 July 2005 to 30 June 2016

Severe Tropical Cyclone Larry Level 5, 17 – 20 March 2006

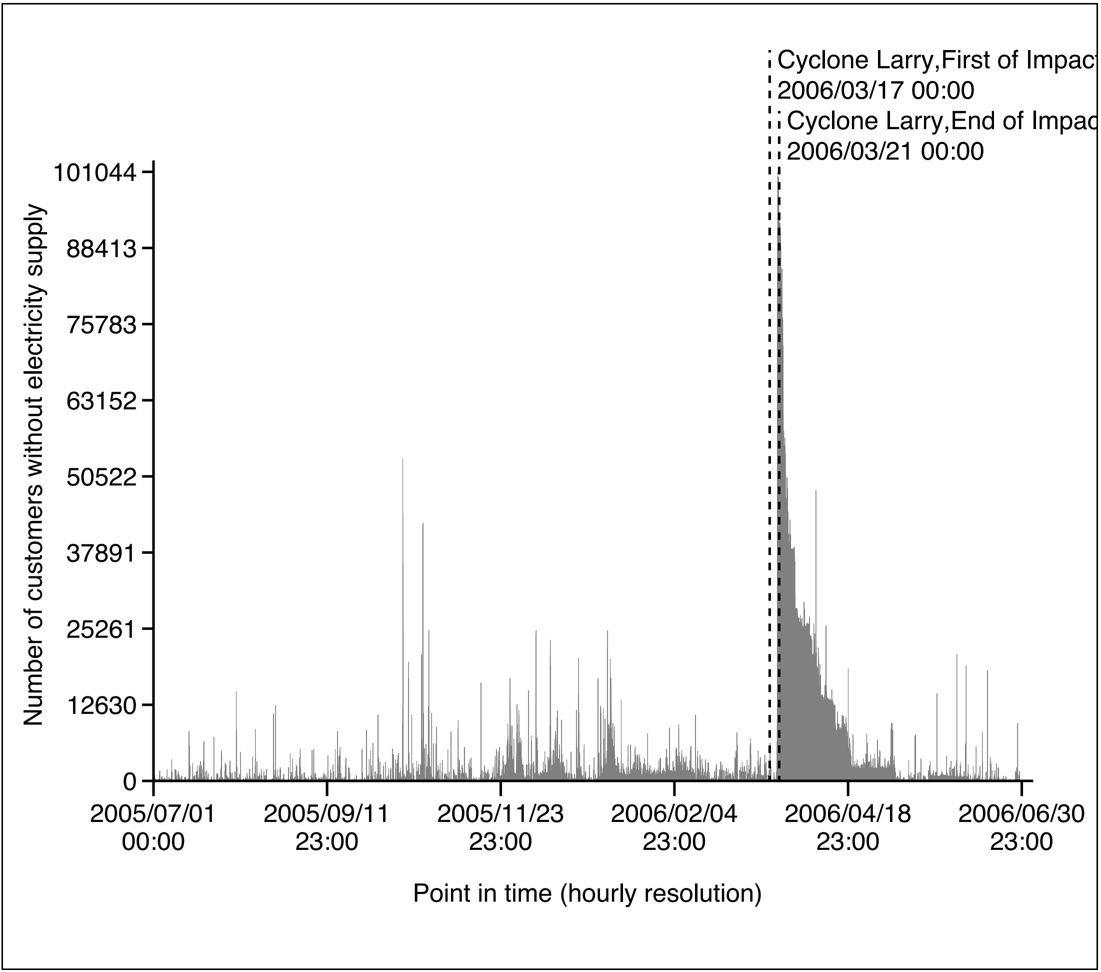


Figure B.3: Number of customers without electricity supply during 1 July 2005 to 30 June 2006

Severe Tropical Cyclone Larry Level 5, 17 – 20 March 2006 (Phone battery life = 0 hour)

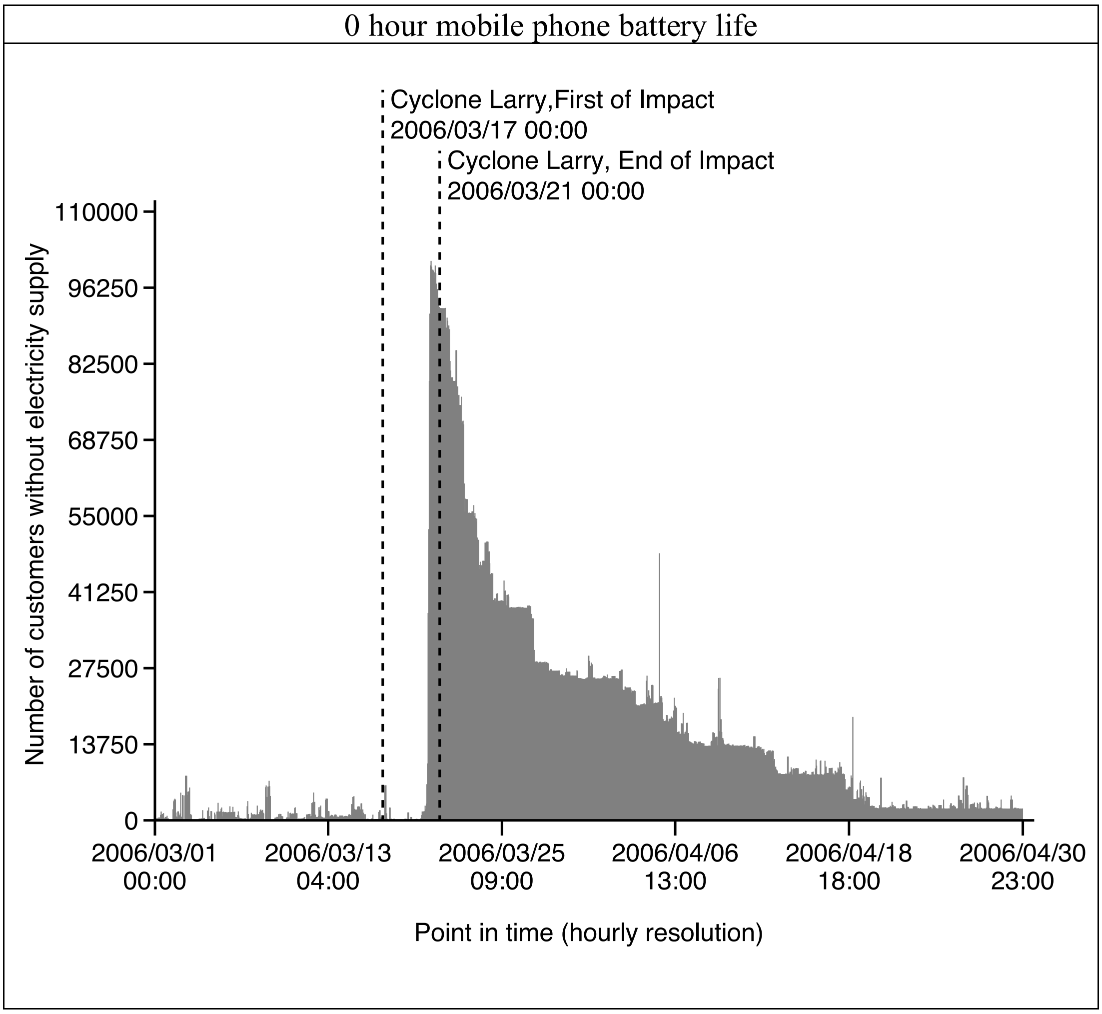


Figure B.4: Number of customers without electricity supply or flat phone battery according to model at battery life 0 hour during 1 March 2006 to 30 April 2006

Severe Tropical Cyclone Larry Level 5, 17 – 20 March 2006 (Phone battery life = 24 hours)

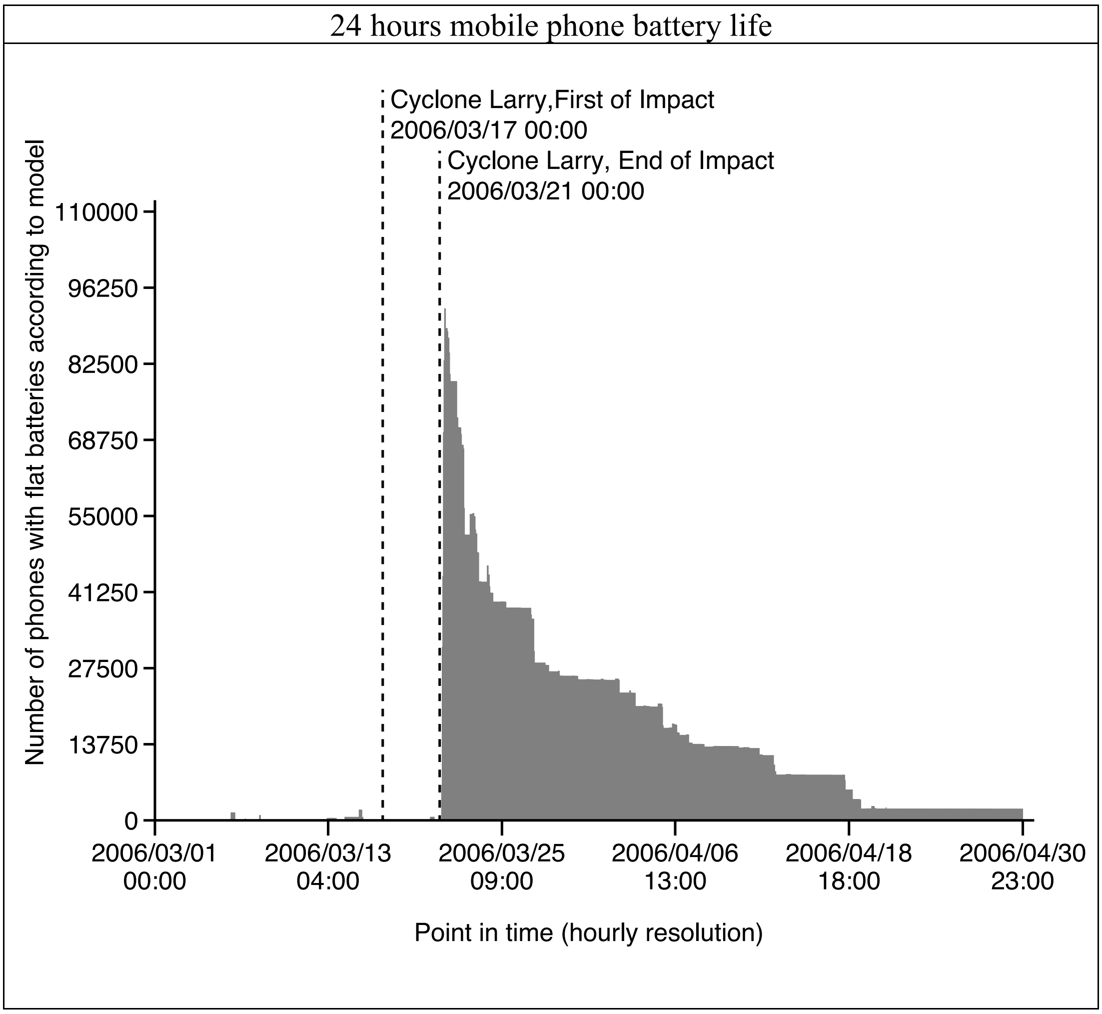


Figure B.5: Number of flat phone battery according to model at battery life 24 hours during 1 March 2006 to 30 April 2006

Severe Tropical Cyclone Larry Level 5, 17 – 20 March 2006 (Phone battery life = 72 hours)

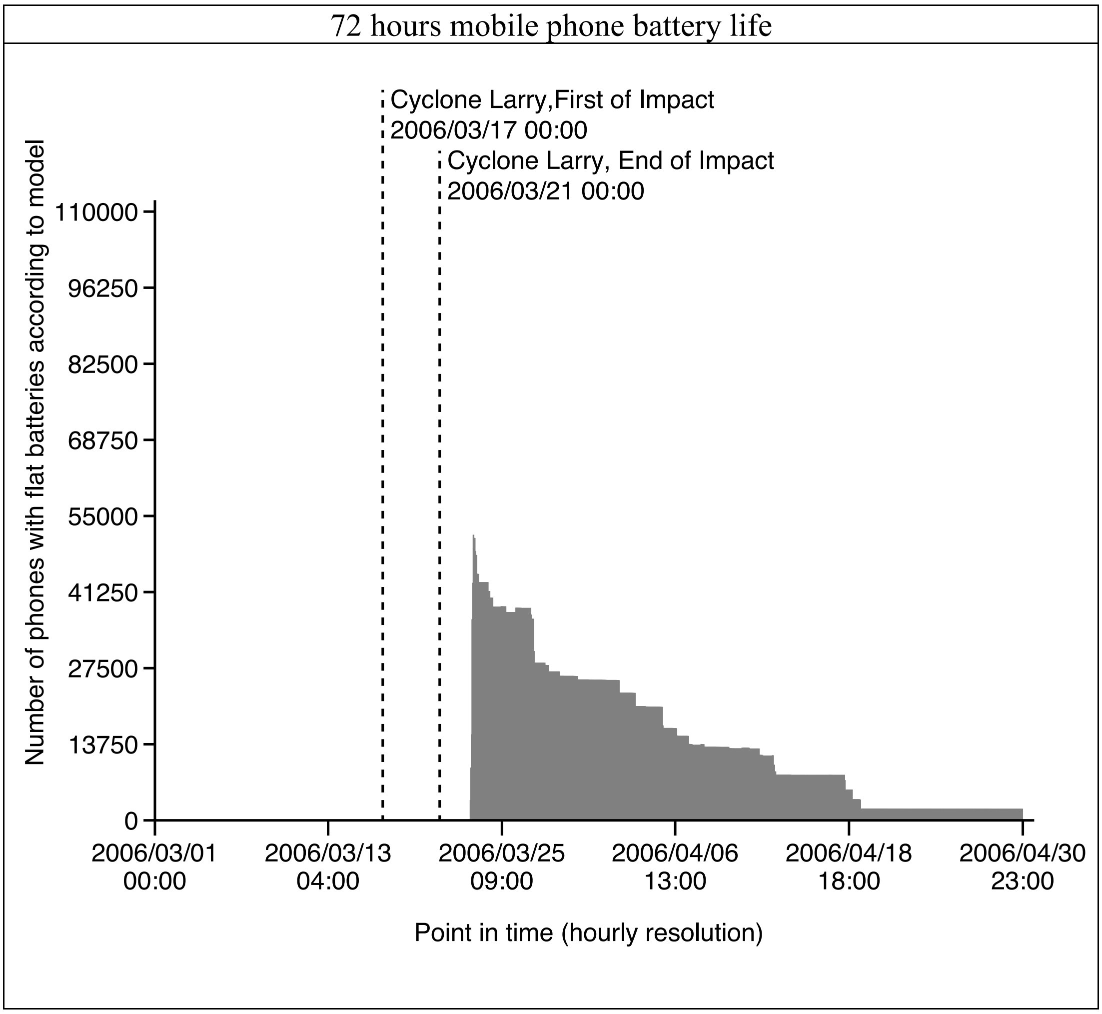


Figure B.6: Number of flat phone battery according to model at battery life 72 hours during 1 March 2006 to 30 April 2006

Severe Tropical Cyclone Larry Level 5, 17 – 20 March 2006 (Phone battery life = 120 hours)

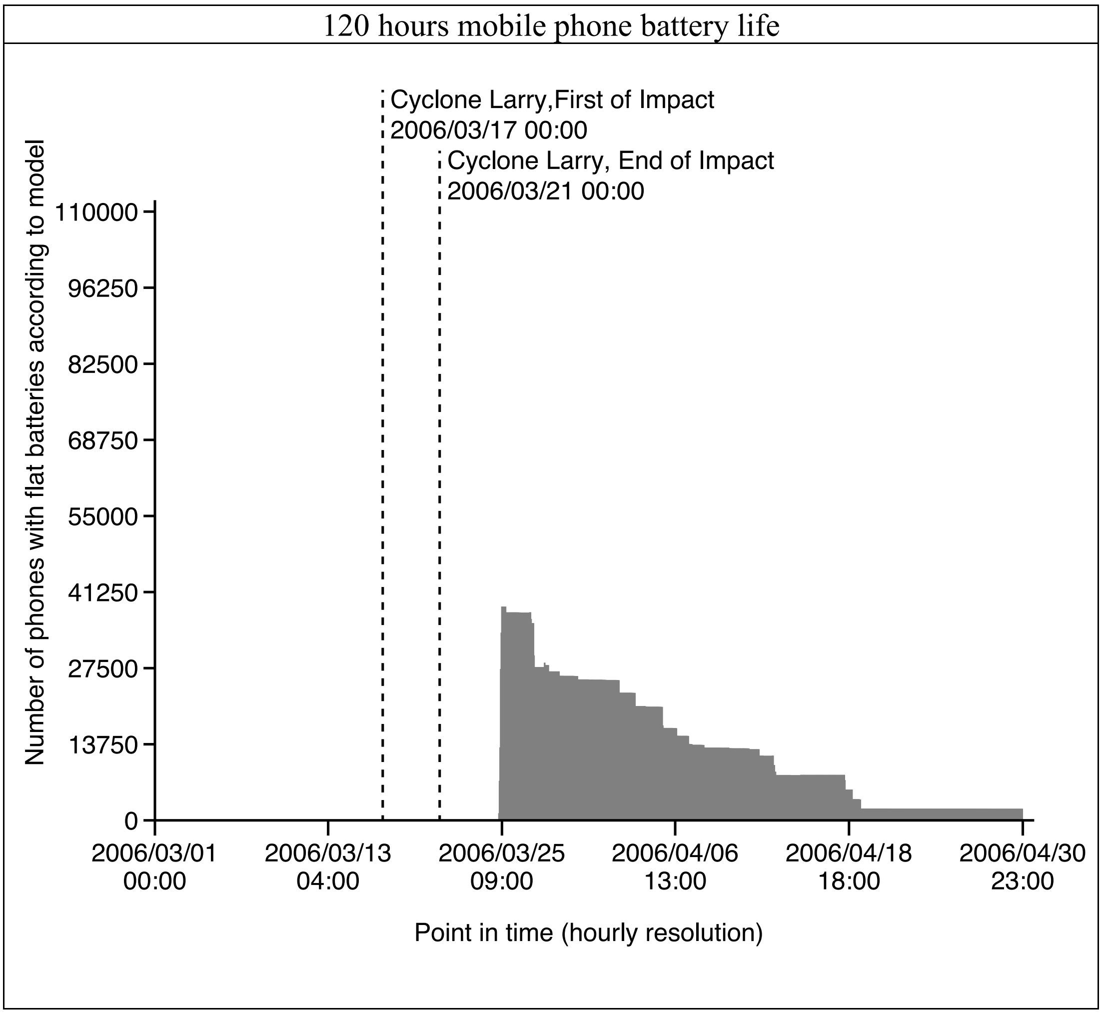


Figure B.7: Number of flat phone battery according to model at battery life 120 hours during 1 March 2006 to 30 April 2006

Severe Tropical Cyclone Yasi Level 5, 30 January – 3 February 2011

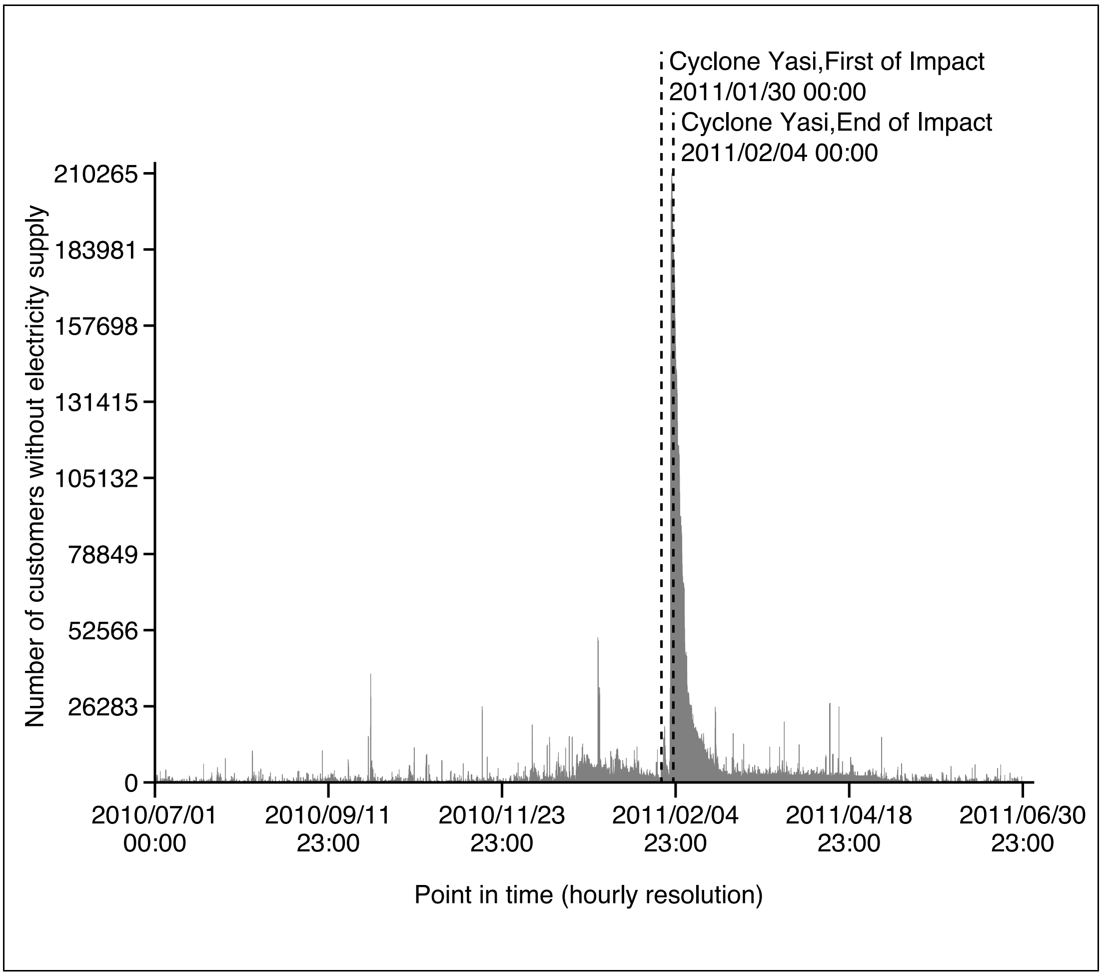


Figure B.8: Number of customers without electricity supply during 1 July 2010 to 30 June 2011

Severe Tropical Cyclone Yasi Level 5, 30 January – 3 February 2011 (Phone battery life = 0 hour)

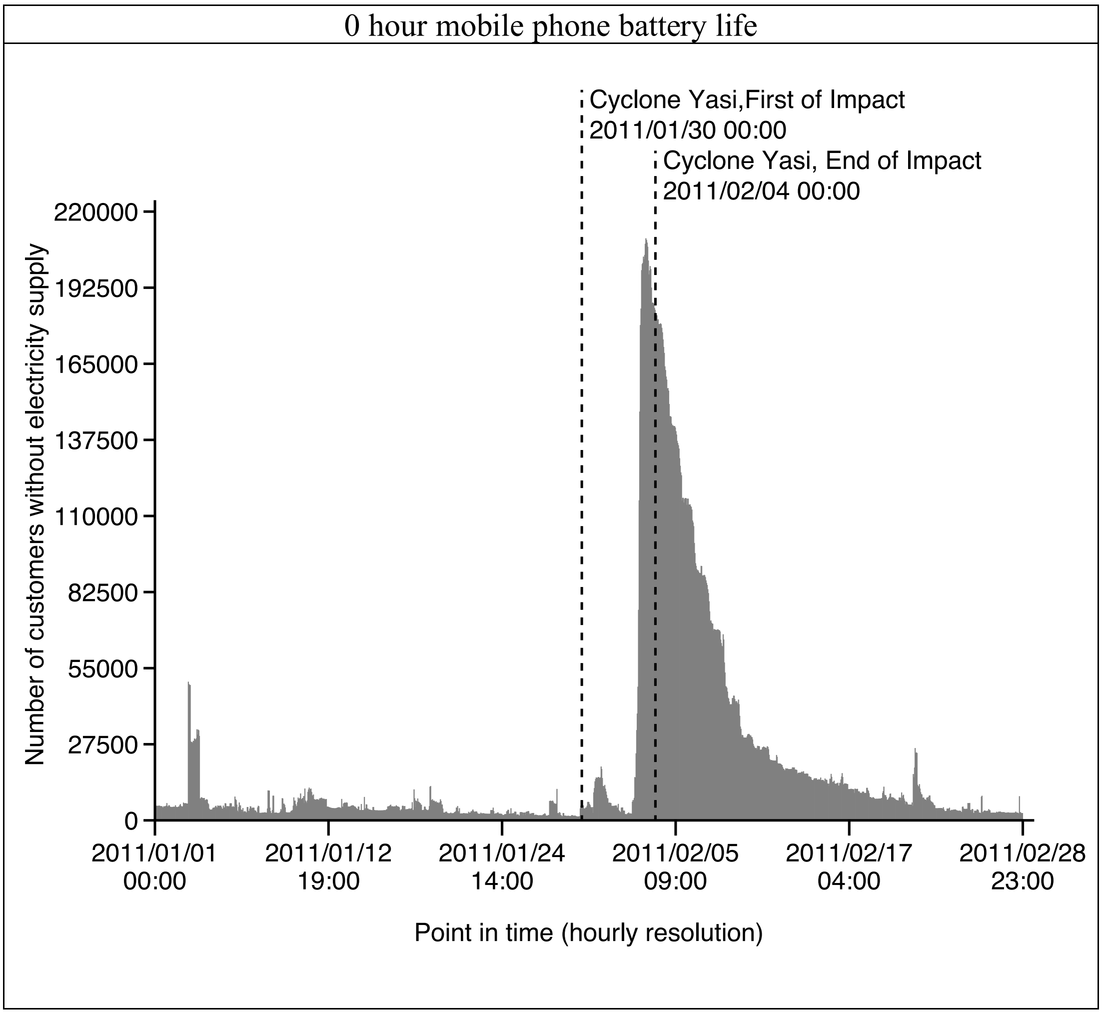


Figure B.9: Number of customers without electricity supply or flat phone battery according to model at battery life 0 hour during 1 January 2011 to 28 February 2011

Severe Tropical Cyclone Yasi Level 5, 30 January – 3 February 2011 (Phone battery life = 24 hours)

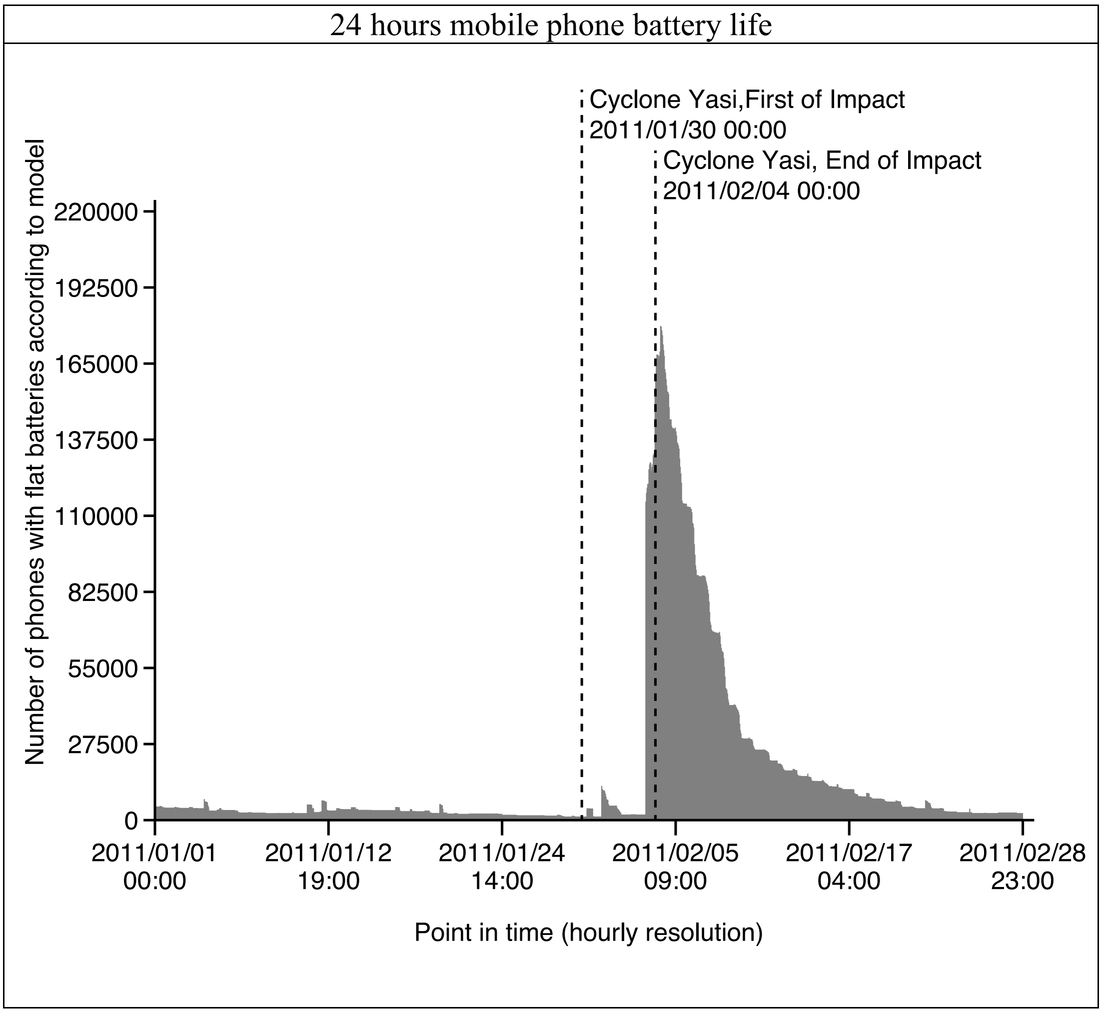


Figure B.10: Number of flat phone battery according to model at battery life 24 hours during 1 January 2011 to 28 February 2011

Severe Tropical Cyclone Yasi Level 5, 30 January – 3 February 2011 (Phone battery life = 72 hours)

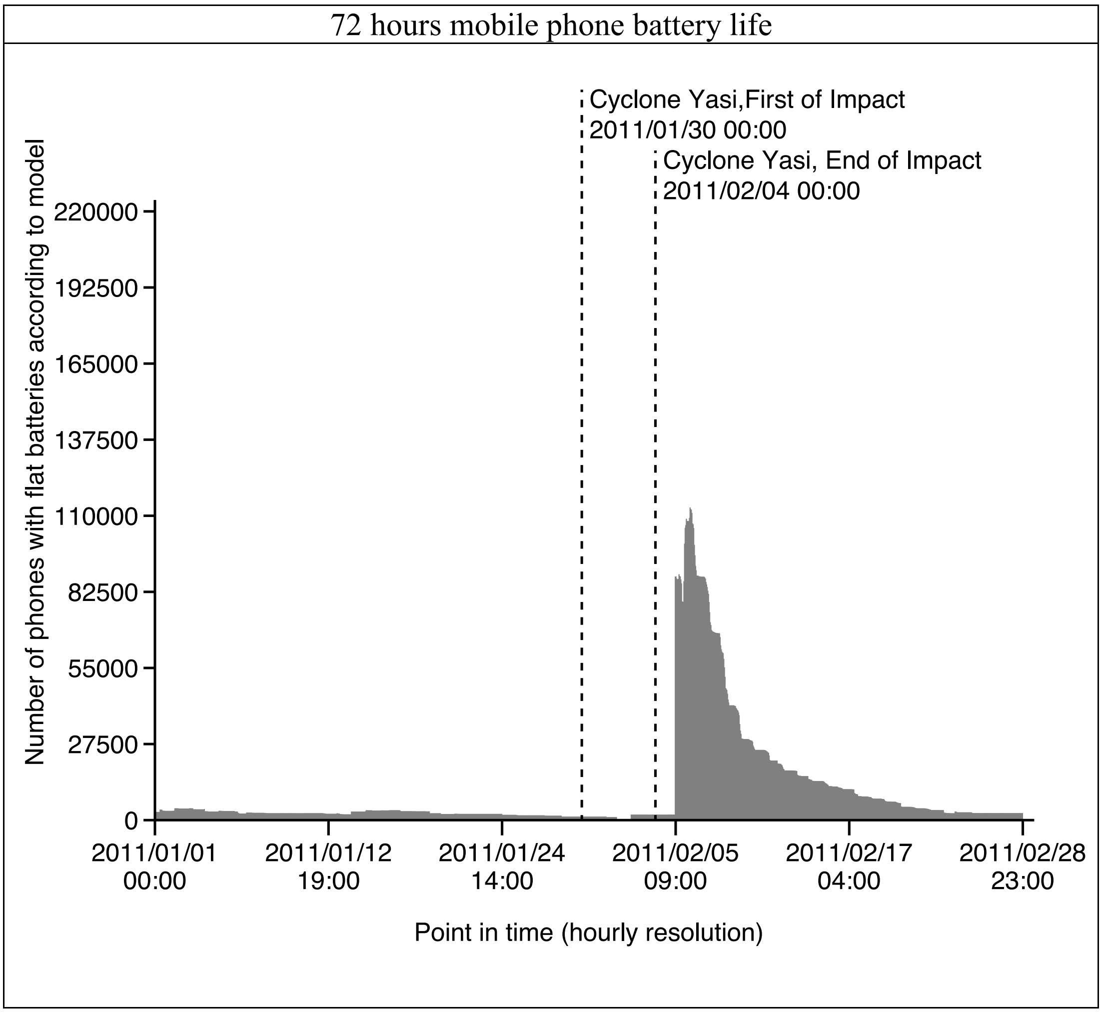


Figure B.11: Number of flat phone battery according to model at battery life 72 hours during 1 January 2011 to 28 February 2011

Severe Tropical Cyclone Yasi Level 5, 30 January – 3 February 2011 (Phone battery life = 120 hours)

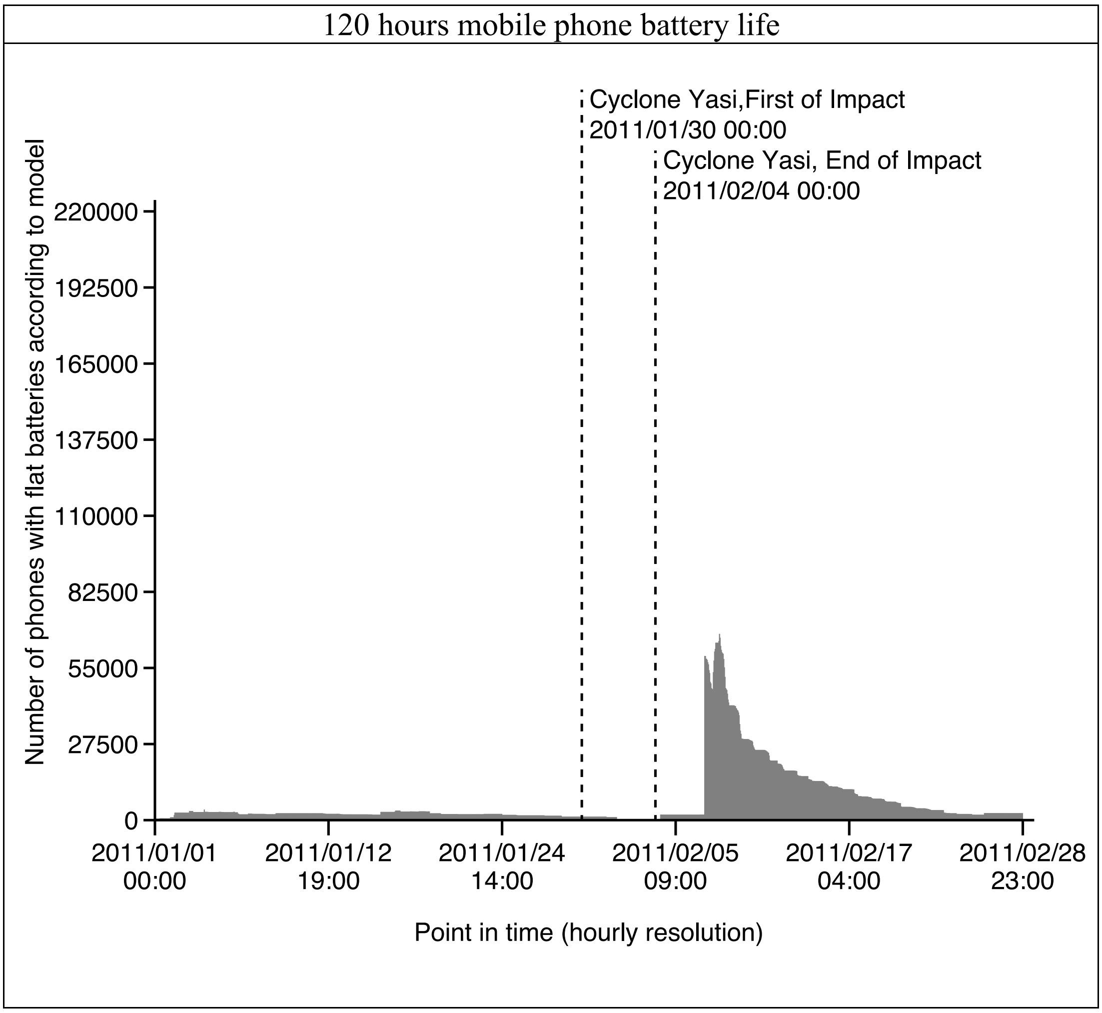


Figure B.12: Number of flat phone battery according to model at battery life 120 hours during 1 January 2011 to 28 February 2011

Severe Tropical Cyclone Marcia Level 5, 15 – 21 February 2015

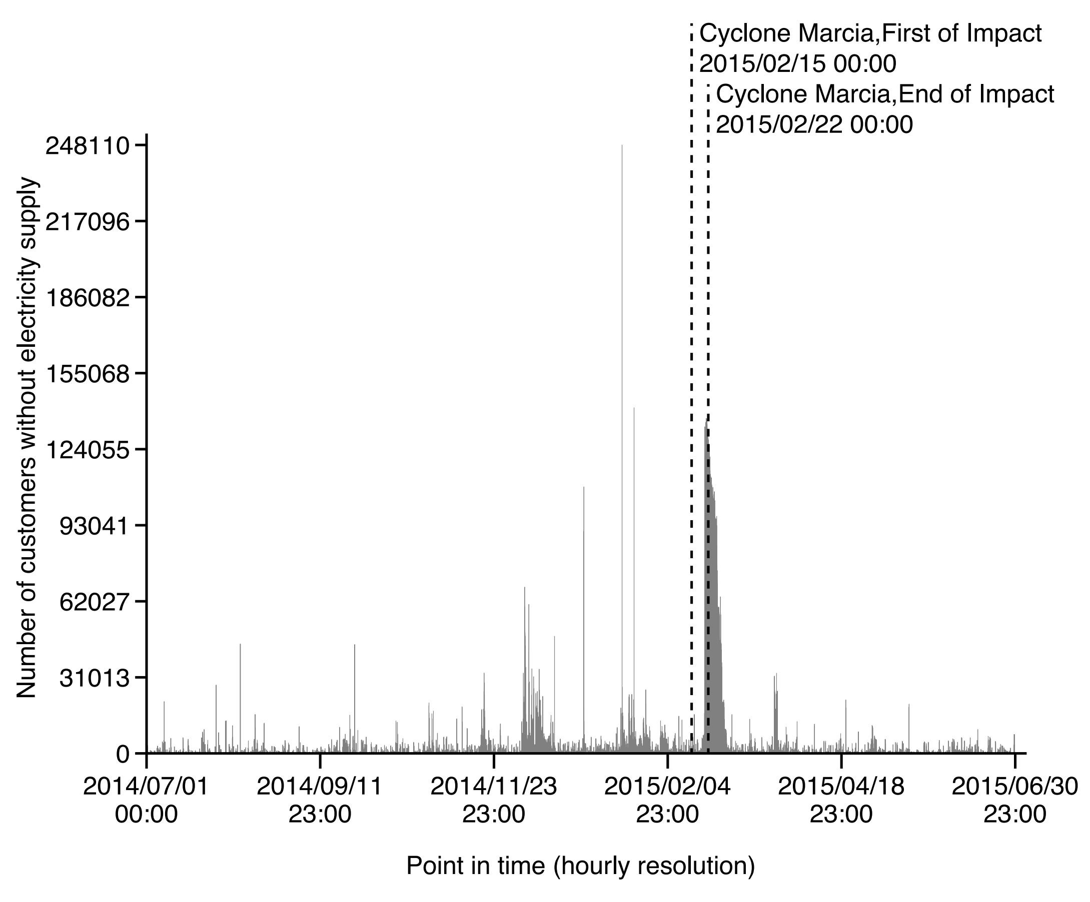


Figure B.13: Number of customers without electricity supply during 1 July 2010 to 30 June 2011

Severe Tropical Cyclone Marcia Level 5, 15 – 21 February 2015 (Phone battery life = 0 hour)

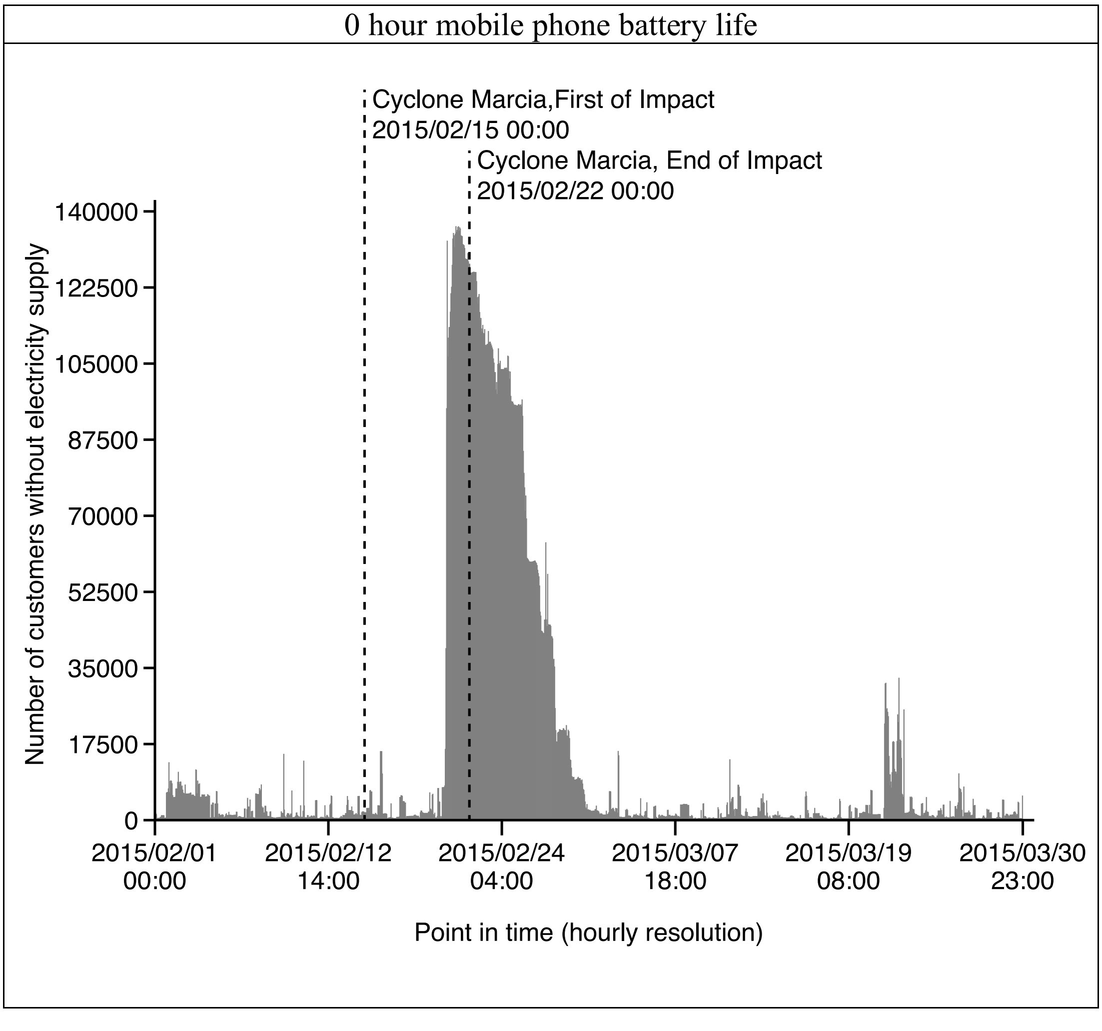


Figure B.14: Number of customers without electricity supply or flat phone battery according to model at battery life at 0 hour during 1 February 2015 to 30 March 2015

Severe Tropical Cyclone Marcia Level 5, 15 – 21 February 2015 (Phone battery life = 24 hours)

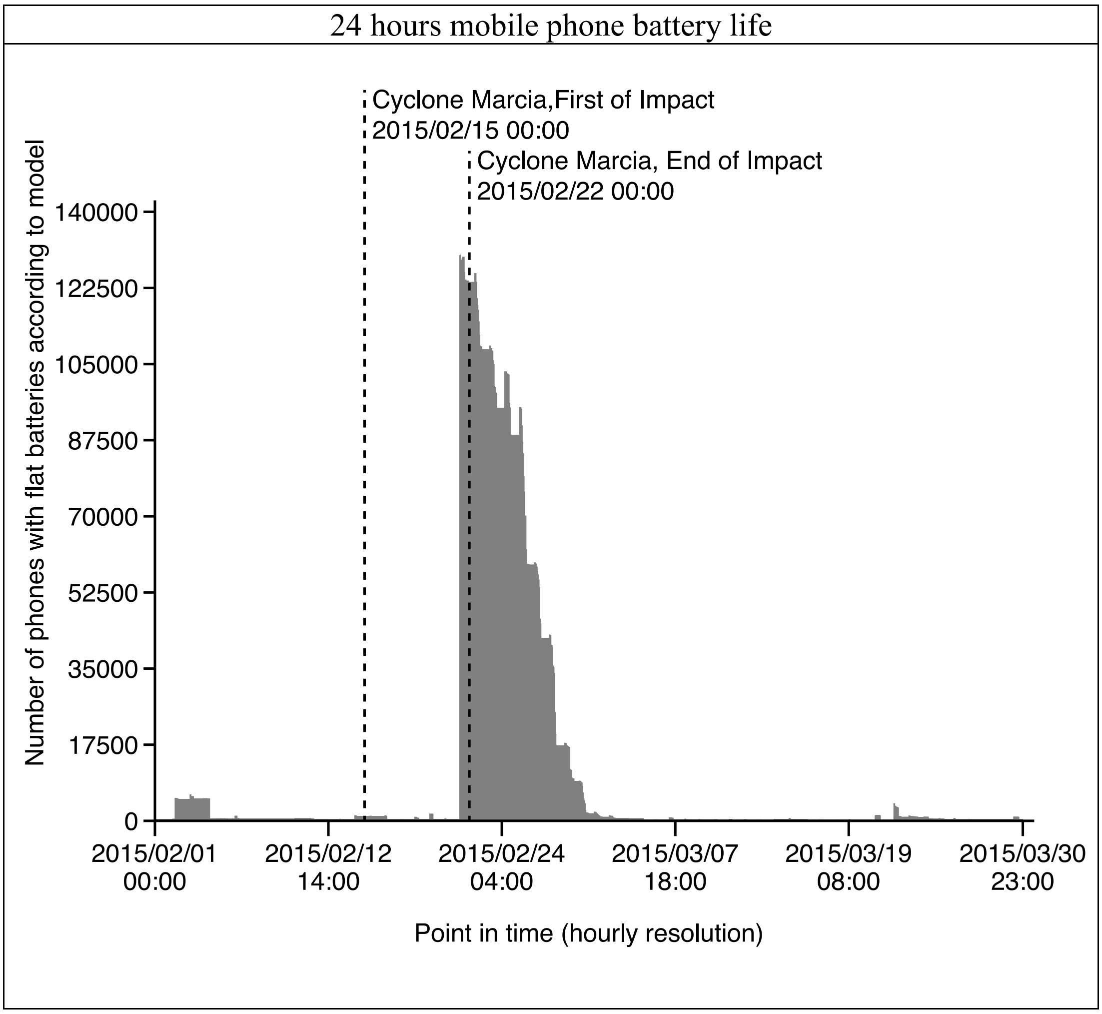


Figure B.15: Number of flat phone battery according to model at battery life at 24 hours during 1 February 2015 to 30 March 2015

Severe Tropical Cyclone Marcia Level 5, 15 – 21 February 2015 (Phone battery life = 72 hours)

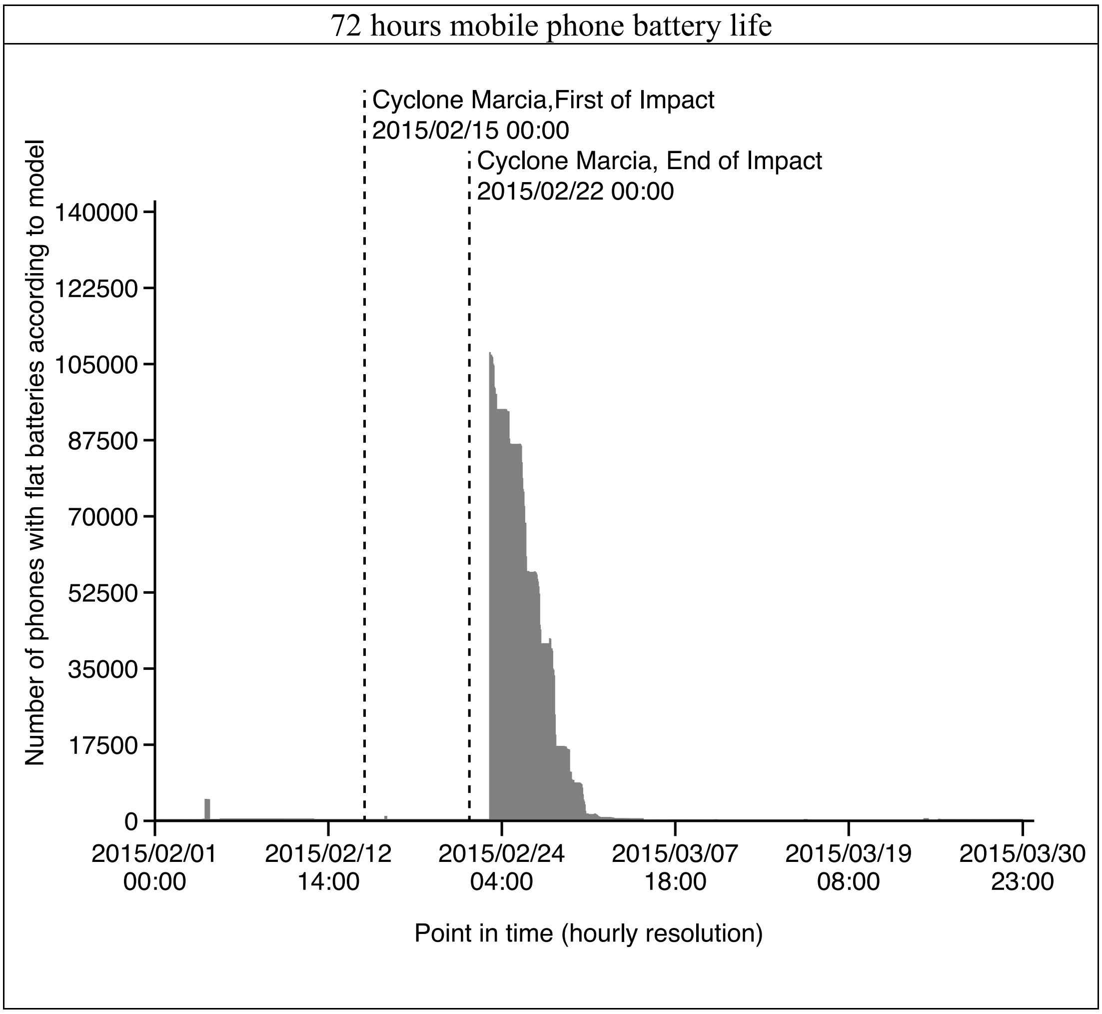


Figure B.16: Number of flat phone battery according to model at battery life 72 hours during 1 February 2015 to 30 March 2015

Severe Tropical Cyclone Marcia Level 5, 15 – 21 February 2015 (Phone battery life = 120 hours)

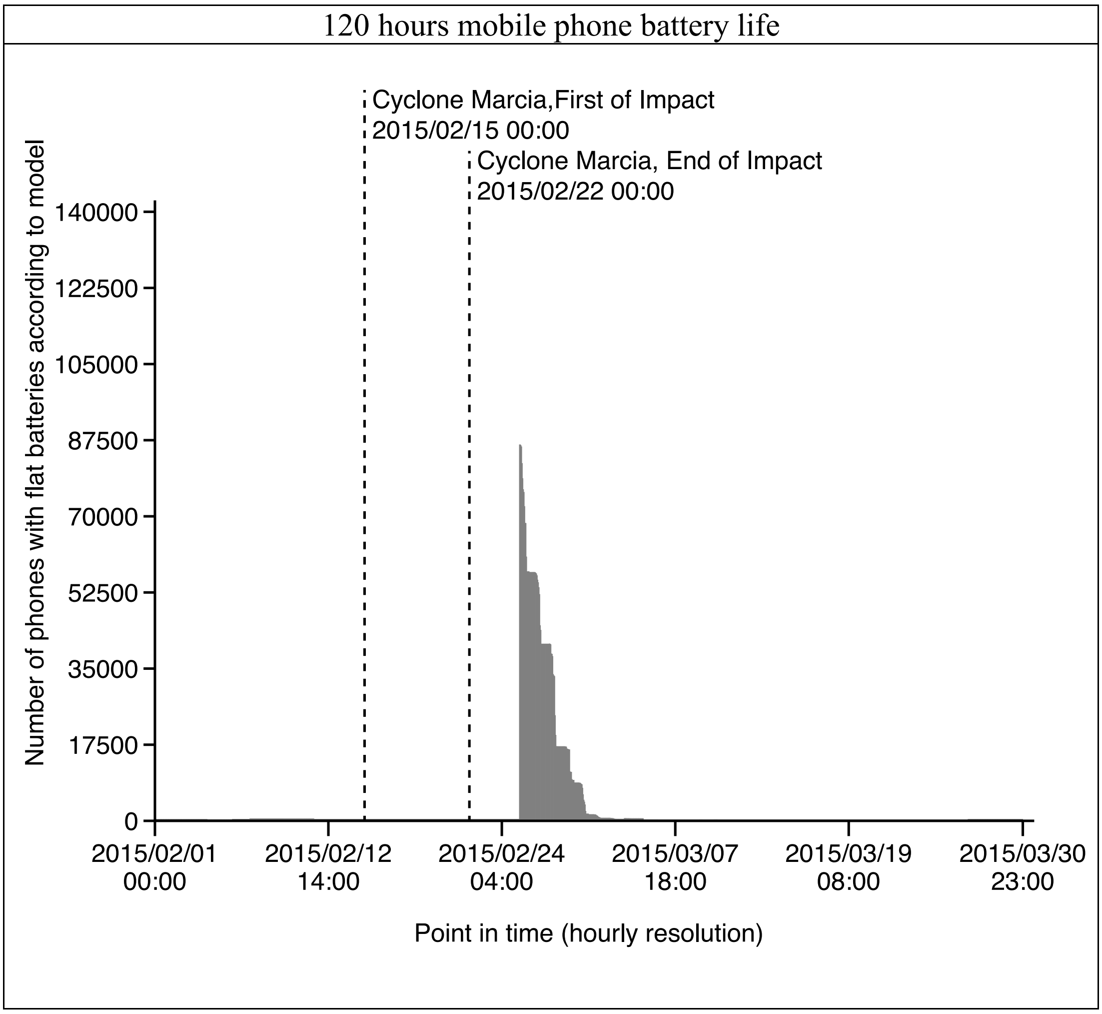

120 hours mobile phone battery life

Figure B.17: Number of flat phone battery according to model at battery life 120 hours during 1 February 2015 to 30 March 201

APPENDIX C: THE QUESTIONNAIRE SURVEY

The Questionnaire regarding Human Factors in Mobile Phone Battery Life

Section A: Research Information

The objective

The questionnaire is to survey human factors in relation to mobile phone battery life for people who use their phone daily and/or have experienced any emergency/disaster contexts. You will be asked about your phone recharging and usage behaviour in general usage and emergency/disaster contexts. Data from this survey will be analysed to determine alternative approaches to reduce energy usage and extend mobile phone battery life using human factors.

Questionnaire instruction

We would be grateful if you could spend 15 – 20 minutes of your time to complete the following short questionnaire about mobile phone human factors. These include battery recharging, usage habits and related issues. The four questions are an example of how to complete the questions in the next section.

Example:

Question: What is your gender?

Male

Female

Example:

Question: What percentage of your mobile phone usage is for entertainment?

Please estimate the percentage of use of your mobile phone that is for entertainment, first by time spent usage it, and secondly by the percentage of battery life used.

By time:____________70 %		By battery use:____________30 %

Example:

Question: How often do you use these features on your mobile phone?

Please indicate the frequency with which you use each feature. Tick one box per row.

Feature	Never	Less than	Weekly	A Few	Most days	Every day	Several
Voice Call				√			
SMS		√					
Voice Mail	√						

Example:

Question: What are your communication needs in an emergency/disaster situation?

Please specify the total should be 100 % communication service percentage that you need to use in an emergency/disaster situation.

Service	Percentage (100%)
Voice Communication	40
SMS (Short Message Service)	20
Voice Mail	5
Maps & Location Service	30
File sharing	5
Other____	

Section B: Personal Details

Please answer the following questions by ticking the relevant checkbox or writing down your answer in the provided space.

Question 1: What is your gender?

Male
Female

Question 2: In which age group are you?

19 and under
20 – 29
30 – 39
40 – 49
50 – 59
60 +

Question 3: Which country, state and area do you currently live?

Country:____________________________

State:________________________________

Town:________________________________

Postcode:_____________________________

Question 4: Do you use a mobile phone in daily life?

Yes, I do. **Please go to question 5**

No, I don't use a mobile phone.

If you select No, please stop completing this questionnaire and thank you for your cooperation.

Section C: Your Mobile Phone Details

Please answer the following questions by ticking the relevant checkbox or writing down your answer in the provided space.

Thinking about the mobile phone you must frequently use:

Question 5: Please tell us the model of your mobile phone

Which of the following is your regular mobile phone model?

IPhone 3	Samsung Galaxy S	Galaxy Nexus	LG Otimus G
IPhone 3GS	Samsung Galaxy S II	HTC One	Nokia Lumia 920
IPhone 4	Samsung Galaxy SIII	HTC Desire	Sony Xperia Z
IPhone 4S	Samsung Galaxy SIV	HTC Nexus One	Huawei U8220
IPhone 5	Samsung Nexus S	LG Nexus 4	Huawei IDEOS

Other____

OR

Model number of your phone___________________

OR

I don't know

Section D: Mobile phone recharging and usage habits

Please answer the following questions by ticking the relevant checkbox or writing down your answer in the provided space.

Question 6: How long does your mobile phone usually last before the battery goes flat needs recharging?

< 1 hour, please specify the amount of minutes: __________minutes
1 – 3 hours
4 – 6 hours
7 – 9 hours
10 – 12 hours
13 – 15 hours
16 – 18 hours
19 – 21 hours
22 – 24 hours
> 24 hours Please specify the number of hours or days that your mobile phone usually run before the battery goes flat: ___________hours or ___________ days

Question 7: How long does your mobile phone need to last before the battery goes flat so that it does not greatly inconvenience you?

< 1 hour, please specify the amount of minutes: __________minutes
1 – 3 hours
4 – 6 hours
7 – 9 hours
10 – 12 hours
13 – 15 hours
16 – 18 hours
19 – 21 hours
22 – 24 hours
> 24 hours. Please specify the number of hours or days that you think your mobile phone should operate before the battery goes flat: ___________ hours or ___________ days

Question 8: On average, how often do you recharge your mobile phone?

Which of the following most accurately describes how often you recharge your mobile phone?

Three or more times per day. Indicate the number of times per day you typically recharge your mobile phone: ___________times
Twice per day
Once per day
Twice in a three day period
Once in two days
Twice in five days
Once in three days
Every days

Question 9: How often does your mobile phone go flat before you have an opportunity to recharge it?

Which of the following indicates the frequency of your mobile phone going flat before recharging?

Once per day
More than once per day
A few times per week
Once or twice per week
Once a week
A couple of times a month
Once a month
Rarely
Never

Question 10: What percentage of remaining charge does your mobile phone usually have left before you recharge it?

Which of the following indicates the percentage of charge when you decide to recharge your mobile phone?

Over 50 % Please indicate the percentage at which you recharge your phone:_____%
50 %
40 %
30 %
20 %
10 %
Below 10 % Please indicate the percentage at which you recharge your phone:____%
When mobile phone goes flat (0 %)
When system shows the alarm message to recharge the mobile phone

Question 11: How do you usually decide to unplug your mobile phone?

Which of the following indicates your preference to disconnect from recharging your mobile phone?

When _____% charged
After ________mins / hours
Fully charged
When I get up in the morning
When I have to go somewhere away from charging
I don't look at the percentage to decide when to unplug

Question 12: How long does your mobile phone usually take to fully charge (100%)? (amount of time the phone must remain plugged in)

Which of the following shows the total duration of your mobile phone recharging?

< 1 hour. Please specify the number of minutes needed recharging your mobile phone until fully charged: ___________minutes
1 hour
2 hours
3 hours
4 hours
5 hours
> 5 hours. Please specify the number of hours needed recharging your mobile phone until fully charged: ___________hours
I don't know how long does my mobile phone usually take to fully charged

Question 13: For what length of time do you usually charge your mobile phone each time you recharge it?

Which of the following shows the duration of your charging of your mobile phone for each recharge?

< 1 hour. Please specify the time in minutes spent recharging your mobile phone for each recharge: ___________minutes
1 hour
2 hours
3 hours
4 hours
5 hours
> 5 hours. Please specify the time in hours spent recharging your mobile phone for each recharge: ___________hours
Overnight

Question 14: Do you use any alternative source of power to increase the time before you need recharge your mobile phone at a mains plug?

You can tick more than one check box.

Laptop USB port Solar, wind or similar independent power source
Solar, wind or similar independent power source
Accessory power outlet from car, or similar
Oversize battery or external backup battery for mobile phone
    Small (1,000 – 3,000 mAh)   Medium (3,001 – 6,000 mAh)
    Large (Over 6,000 mAh)   Other______________________
    I don't know its' capacity
Other___________________________________
No, never

Question 14: Do you use any alternative source of power to increase the time before you need recharge your mobile phone at a mains plug?

You can tick more than one check box.

Laptop USB port Solar, wind or similar independent power source
Solar, wind or similar independent power source
Accessory power outlet from car, or similar
Oversize battery or external backup battery for mobile phone
Small (1,000 – 3,000 mAh) Medium (3,001 – 6,000 mAh)
Large (Over 6,000 mAh) Other______________________
I don't know its' capacity
Other___________________________________
No, never

Question 15: How often do you use these features on your mobile phone?

Please indicates the frequency with which you often use each feature. Tick one box per row.

Feature	Never	Less than	Weekly	A few	Most days	Every day	Several
Voice Call							
SMS							
Voice Mail							
Web browsing							
Chat application (e.g., What's App, Line, and etc.)							
Voice & Video call application (e.g., Skype, FaceTime, and etc.)							
Email							
Maps & GPS							
Social network application (e.g., Facebook, Instagram, Twitter, etc.)							
Camera							
Games							
Audio & Video player							
Audio & Video streaming (Internet radio, Youtube, and etc.)							
Other____							

Question 16: On average, how much time do you spend using these features over a day?											
Please indicate the time for each feature. Tick one box per row.											
Feature	**Never**	**< 1 min**	**1 min**	**2 – 3 mins**	**30 mins**	**1 hour**	**2 – 3 hours**	**4 – 6 hours**	**7 – 12 hours**	**13 – 18 hours**	**19 – 24 hours**
Voice Call											
SMS											
Voice Mail											
Web browsing											
Chat application (e.g., What's App, Line, and etc.)											
Voice & Video call application (e.g., Skype, FaceTime, and etc.)											
Email											
Maps & GPS											
Social network application (e.g., Facebook, Instagram, Twitter, etc.)											
Camera											
Games											
Audio & Video player											
Audio & Video streaming (Internet radio, Youtube, and etc.)											
Other_______________________________											

Question 17: What percentage of your mobile phone usage is for entertainment?

Please estimate the percentage of use of your mobile phone that is for entertainment, first by time spent usage it, and secondly by the percentage of battery life used.

By time:________________% By battery use:_______________%

Question 18: What percentage of your mobile phone usage is for vital communication?

Please estimate the percentage of use of your mobile phone that is for vital communication, first by time spent usage it, and secondly by the percentage of battery life used.

By time:________________% By battery use:_______________%

Section E: Mobile Phone Recharging and Usage Habits in an Emergency/Disaster Situation

This section investigates your mobile phone usage in an emergency/disaster situation. Complete this section if you have experienced, worked or volunteered in an emergency/disaster situation.

The definition of an emergency is a situation that is out of control and requires immediate attention [1]. Examples of an emergency include a car accident, a child is unwell and needs to be taken to a doctor/hospital, and a house fire.

The definition of a disaster is a serious disruption to community life causing damage to property which is beyond the day-to-day capacity of the authorities and which requires outside help and resources [2]. Examples of disasters include floods, volcanic eruptions, earthquakes, tsunamis, and bush fires [3]. It also includes any situation caused by human activity and technological hazards including stampedes, fires, war, unrest, oil&chemical spills transport accidents, industrial accidents, and nuclear radiation/explosions [4].

An emergency is a lesser event and can be attended to locally while a disaster overwhelms the community resources and requires outside help [2].

Please answer the following questions by ticking the relevant checkbox or writing down your answer in the provided space.

Question 19: Have you had any experience/work/volunteer involve in an emergency/disaster environment?

Please select all appropriate answers:

I work or volunteer in an emergency/disaster environment

I have experienced an emergency/disaster in the past 5 years

None of the above.

If you select None of the above. please stop completing this questionnaire and thank you for your cooperation.

References:

[1] Prehosp Diasast Med Vol 17, Supplement 3, 2003

[2] Associate Professor Lidia Mayner, Deputy Director of Disaster Research Centre, Flinders University

[3] G. Bankoff, G. Frerks, D. Hilhorst (*eds.*) (2003). Mapping Vulnerability: Disasters, Development and People ISBN ISBN 1-85383-964-7

[4] Technological Hazard, United Nations Office for Disaster Risk Reduction (UNISDR), 15 Jan 2009, http://www.preventionweb.net/english/professional/terminology/v.php?id=507

Question 20: How long does your mobile phone need to last before the battery goes flat so that it does not greatly inconvenience you in an emergency/disaster situation?

Which of the following indicates the run time needed before the battery dies?

< 1 hour, please specify the amount of minutes: __________minutes
1 – 3 hours
4 – 6 hours
7 – 9 hours
10 – 12 hours
13 – 15 hours
16 – 18 hours
19 – 21 hours
22 – 24 hours
> 24 hours. Please specify the number of hours or days that the mobile phone should operate before the battery goes flat: ___________ hours or___________days

Question 21: On average, how often would you like to recharge your mobile phone in an emergency/disaster situation?

Which of the following most accurately describes how often you would be willing to recharge your mobile phone?

Three or more times per day. Indicate the number of times per day you need to recharge your mobile phone: ___________
Twice per day
Once per day
Twice in a three day period
Once in two days
Twice in five days
Once in three days
Every ______ days

Question 22: What percentage of remaining charge does your mobile phone battery have left before you want to recharge it in an emergency/disaster deployment?

Which of the following indicates the percentage charge when you would like to recharge your mobile phone?

Over 50 % Please indicate the percentage at which you recharge your phone:_____%
50 %
40 %
30 %
20 %
10 %
Below 10 % Please indicate the percentage at which you recharge your phone:____%
When mobile phone goes flat (0 %)
When system shows the alarm message to recharge the mobile phone

Question 23: How do you decide when to unplug your mobile phone while charging during on an emergency/disaster deployment?

Which of the following indicates your preference to disconnect from recharging your mobile phone?

When _____% charged
Fully charged
After ________Mins / Hours
When there is no power
When there is not any supplementary power available for recharging
When I have to go somewhere away from charging
I don't look at the percentage to decide when to unplug

Question 24: What is the maximum acceptable time for your mobile phone to recharge in an emergency/disaster situation?

Which of the following shows the acceptable time to recharge your mobile phone? That is, if your mobile phone took more time to recharge, it would be unacceptable.

< 1 hour. Please specify the number of minutes taken to recharge your mobile phone until fully charged: ___________minutes
1 hour
2 hours
3 hours
4 hours
5 hours
> 5 hours. Please specify the number of hours taken to recharge your mobile phone until fully charged: ___________ hours

Question 25: In an emergency/disaster setting, what is the minimum time you think a mobile phone should be able to operate before needing recharging?

Which of the following indicates run time of mobile phone should be able to operate during an emergency/disaster situation?

< 1 hour, please specify the amount of minutes: __________minutes
1 – 3 hours
4 – 6 hours
7 – 9 hours
10 – 12 hours
13 – 15 hours
16 – 18 hours
19 – 21 hours
22 – 24 hours
> 24 hours, please specify the amount of hours or days: __________hours or _________days

Question 26: On average, how often do you use your mobile phone when deployed during an emergency/disaster?

Which of the following indicates the frequency of using your mobile phone in an emergency/disaster?

Every minute
Every few minutes
Every half an hour
Every hour
Every 6 hours
Every 12 hours
Every 18 hours
Every 24 hours
Other_________________________

Question 27: How often would you like to use your mobile phone in an emergency/disaster situation?

Which of the following indicates your preferred frequency of using a mobile phone during an emergency/disaster situation?

Every minute
Every few minutes
Every half an hour
Every hour
Every 6 hours
Every 12 hours
Every 18 hours
Every 24 hours
Other________________________

Question 28: What are your communication needs in an emergency/disaster situation?

Please specify the total should be 100% communication service percentage that you need to use in an emergency/disaster situation.

Service	Percentage (100%)
Voice Communication	
SMS (Short Message Service)	
Voice Mail	
Maps & Location Service	
File sharing	
Other____	

Question 29: Does the battery life of your existing mobile phone prevent or impede its use by you in an emergency/disaster deployment?

Yes, **Please go to question 30**

No

If you select No. please stop completing this questionnaire and thank you for your cooperation.

Question 30: What factor(s) prevent or impede use of your mobile phone in an emergency/disaster deployment?

Please select all appropriate answers:

Goes flat too quickly
Takes to long to recharge
limited charging options make recharging difficult
Other______________________________________

Thank you very much for your cooperation in completing this questionnaire.