Optimisation in Multi-Objective Mobile User Satisfaction

by

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any tertiary institution, and that, to my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the text of the thesis.

Signed

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Hobart, November 2012

Abstract

Mobile devices have become more and more popular, and the services have grown in number and range. Ready access to the Internet is one of the characteristics of mobile devices which delivers significant value for their users. However, the users are also concerned about costs and other factors related to this access. This research tries to explore the trade-off between the desirable and the undesirable outcomes of data access to find out if it is possible to maintain the mobile user's satisfaction derived from the connectivity attributes for a single data-transfer task while lowering the concerns that come from the other issues, including cost of the access and battery life of the device. A simulation study is used in this research to determine if it is feasible to conduct such a trade-off.

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Chapter 1

Introduction

1.1 Background

Nowadays, mobile devices have become more and more popular, and the services have grown in number and range. BBC News reports that at the moment (October 2012) there are around six billion mobile phone subscriptions in the world (BBC 2012). CNET News also reports that recently, Google Play Store reached their 25 billionth download (CNET 2012). In the context of Australian mobile users, there is an interesting report which mentions that the mobile Internet usage in Australia is increasing rapidly and people are concerned about the higher Internet costs that they might have to pay (The Age 2012).

A mobile device is a Personal Communication Device (PCD), which means, in general a mobile device belongs to only one person and it is personally identifiable. The person who owns the device will carry it almost all the time or for a significant portion of time. As a communication tool, a mobile device can connect to a communication network in various ways to send and receive different forms of messages. A mobile device is also a handheld device. The device can be operated using a single hand, two hands, or a hand with a surface. In addition, mobile devices can provide an 'always on' experience to the users. A mobile device can be awakened quickly by a single touch of the user or by the communication network. A mobile device can receive a new text message any time, even when the device is in the sleep or standby mode (Ballard 2007).

Mobile Internet access is also popular among the mobile users because it requires lower engagement compared to the stationary Internet access. The user can get access to the

Internet without necessarily interrupting their current activity. By using mobile Internet access, the users can get Internet access while they are having dinner at a restaurant, watching TV in the living room, or lying in their bedroom (Cui & Roto 2008).

1.2 Motivation

Ready access to the Internet is one of the characteristics of mobile devices which delivers significant value for their users. However, the users are also concerned about the costs and other factors related to this access. This research tries to explore the trade-off between the desirables and the undesirables to find out if it is possible to maintain mobile user satisfaction derived from the connectivity attributes for a single data-transfer task while lowering the concerns that come from other issues including the access cost and battery usage. A simulation study is used in this research to determine if it is feasible to conduct such a trade-off.

1.3 Problem Description

There are many factors that can influence the users' satisfaction in terms of the usage of the mobile devices for data transfer; for example, how much money users have to spend to transfer the data through the mobile Internet connection using the available data carrier, how critical or how valuable the data which is required to be transmitted is in terms of time span, the battery power consumption to make a mobile Internet connection using the available network carrier and how it will affect the remaining battery life, and finally, how the remaining battery life will affect the future opportunity value for the user of being able to utilise the mobile device without having any issue as a result of a flat battery. Moreover, the optimum level of mobile user satisfaction cannot be achieved by only focusing on optimising a single satisfaction factor and ignoring the rest. The problem in optimising the mobile Internet user satisfaction can be studied as a multi-objective optimisation problem, since there are several conflicting objectives required to be optimised simultaneously (Bui et al. 2008; Deb 2009; Coello et al. 2007; Jones 1998; Goldberg 1989). Each satisfaction factor can be treated as an objective that needs to be optimised. Since it is nearly impossible to have a single solution that can optimise all the objectives, the focus in multi-objective optimisation is in searching for a set of optimum solutions.

As described previously in this section, user satisfaction has many origins in terms of access to a range of quality features and functions available on the mobile device. The user's ability to use the features economically and effectively is essential and it will support the use of the device more often and to a higher degree/level.

The actual use of the mobile device is also limited by the data connectivity and power source availability. The mobile device becomes less useful without data connectivity and is rendered completely useless without the battery power.

1.4 Hypothesis

In order to provide a clear direction for this study, a hypothesis is introduced:

> "It is possible to improve mobile user's satisfaction for a single data-transfer task by controlling transmission related decisions"

The hypothesis is based on an assumption that for a typical mobile device, other factors, apart from the connectivity attributes, are less amenable to change as they are often fixed by the choice of the hardware and related software platform. Some example of connectivity factors are:

1. Mobile Internet technology such as Wireless Local Area Network (WLAN) and cellular data networks
2. Cost of mobile data usage
3. Data rate or speed of access
4. Network availability
5. The utility value of data transfer
6. Battery life and access to power source

1.5 Plan to Prove the Hypothesis

In order to prove the hypothesis, first a mathematical model is constructed to formalise the mobile user's concerns and benefits related to the data connectivity features. Afterward, this model is used to provide support for the mobile user in decision making related to the data transfer in an optimised way.

1.6 Significance of the Study

A successful execution of this study may produce a computation support system that could be able to assist the users when they are making a decision related to the data transfer from their mobile device. Users can make an effective and economical decision about the data transfer based on the list of possible decision-outcome tuples produced with the assistance of the computation support system. The users' concern related to access cost can be lowered without sacrificing some other connectivity attributes that may also influence the satisfaction of the users such as battery life and network availability. The results also have applications in other areas and problems.

1.7 Structure

This thesis is organised as follows:

- Chapter 2 presents a review of the literature which is used to provide a solid basis for this study. There are five areas covered in this chapter, which are mobile device characteristics, mobile Internet characteristics, mobile users' characteristics including their behaviours, the multi-objective optimisation problems, and the evolutionary algorithms in multi-objective optimisations problems.
- Chapter 3 provides an in-depth explanation of the methodology which is used in this study. This chapter covers several key points such as the need of multiple objectives in this research, related studies that have been conducted, the multi-objective optimisation problem, several possible approaches for satisfaction

comparison, the simulation model which is used in this study, evolutionary algorithms for multi-objective optimisation problem, and jMetal framework as the building blocks to construct the simulation model.

- Chapter 4 describes several details of the experiment as the main part of the simulation study including its findings. In this chapter several scenarios and cases of data transmission will be presented. In total, there are four different scenarios and four different cases within each scenario. These scenarios and cases are built in order to understand how the selection of decision variables in data transmission influences the overall user satisfaction.
- Finally, chapter 5 concludes this thesis and presents several possible future directions related to this study.

1.8 Chapter Summary

A brief introduction to my Master thesis proposal is presented in this chapter in order to give a general idea to the readers about the research. This chapter is started with the background section which describes the current trends of mobile devices followed by an overview of mobile device characteristics and mobile Internet user. In the motivation section, a general idea of this study is clearly stated followed by the problem description section. In this section, a brief description of the problem which is going to be solved in this study is presented. A clear statement of the hypothesis which is used as the main guidance in this study is also provided in the hypothesis section followed by a general plan to prove the hypothesis. An overview of the structure in this thesis is described in the structure section in order to give a general idea about how the paper is organised.

An in-depth review of the literature which is used as a basis for this study is presented in the following chapter.

Chapter 2

Literature Review

2.1 Introduction

In order to get a firm foundation for this research, a literature review has been conducted. There are five areas covered in this literature review chapter and they will be presented in five different sections, namely mobile devices, mobile Internet, mobile users, multi-objective optimisation problems, and evolutionary algorithms in multi-objective optimisations problems.

The first two sections are focused on mobile technology. These sections are motivated to find the nature of mobile devices and several communication technologies which are available in mobile environment including their cost and speed implications. In the mobile devices section, several key characteristics of mobile devices will be presented. This section is followed by the mobile Internet section where several key characteristics of mobile Internet will be identified. In this section, two main technologies in mobile Internet will also be presented.

The mobile users section will examine key characteristics of mobile users including their behaviours. Several factors that might influence their satisfaction when they are using their devices will also be identified.

The last two sections are related to the optimisation techniques especially in relation to the multi-objective situations. In the multi-objective optimisation problems section, several key concepts related to the problems in multiple objectives optimisation are introduced, and finally, in the last section, evolutionary algorithm as an approach to address the multi-objective optimisation problem is explored. Some examples of evolutionary algorithms which are commonly used in multi-objective optimisation problems are also presented in this section.

2.2 Mobile Devices

Dictionary.com (2012) defines a mobile device as a portable, wireless computing device that is small enough to be used while held in the hand; a hand-held: a large selection of smartphones, PDAs, and other mobile devices. Moreover, Reference.com (2012) provides a more specific definition of a mobile device: A mobile device (also known as cellphone device, handheld device, handheld computer, "Palmtop" or simply handheld) is a pocket-sized computing device, typically having a display screen with touch input or a miniature keyboard. In the case of the Personal Digital Assistant (PDA) the input and output are combined into a touchscreen interface. Smartphones and PDAs are popular amongst those who require the assistance and convenience of a conventional computer, in environments where carrying one would not be practical. Defining mobile devices based on size factors might introduce ambiguity. For example, by defining mobile device as a handheld and pocket sized computer, a tablet PC will not be able to be classified as a mobile device since in general it cannot be fit into any pocket. In order to solve the problem of definition in mobile devices, Ballard (2007) argues that fundamentally, the attribute "mobile" in mobile device refers to the user, and not to the device or the application. Mobile devices can be defined as computing devices that can be used to support the user's mobility.

Ballard (2007), in her book Designing the Mobile User Experience, describes four main characteristics of mobile devices, which are personal, communicative, handheld, and *wakable*. He also defining a mobile device as a Personal Communication Device (PCD). In general, a mobile device belongs to only one person and it is personally identifiable. In many cases, the mobile devices are used for more personal purposes than televisions or even personal computers; therefore the devices are more likely to be used by just a single person only. Moreover, the person who owns the device will carry it almost all the time or for a significant portion of time. The 'always with you' experience which is provided by the mobile device is something which cannot be found in desktop computers or any other stationary devices. As a communication device, a mobile device can connect to a communication network in various ways to send and receive various forms of messages. Most communications in mobile devices are text based messaging such as Short Message Service (SMS), instant messaging, and email. However, this may not always be the case. A mobile device is also a handheld device. The device can be operated using a single hand, two hands, or a hand with a surface. As a *wakable* device, a mobile device can be awakened quickly by a single touch of the user or by the communication network. A mobile device can receive a new text message any time, even when the device is in the sleep or standby mode. Mobile devices can provide an 'always on' experience to the user which cannot be found in personal computers. In general, personal computers cannot communicate through the communication network when they are in the sleep mode. These characteristics of mobile device make the device indispensable and the users tend to carry it with them almost all the time.

Apart from several capabilities offered by mobile devices, Chen (2008), states that compared to stationary computing devices, mobile devices in general have several limitations such as screen size, computational power, battery capacity, input interface, and network access. Based on the technology point of view, the limitations in mobile devices can be broadly classified into two categories, which are communication related limitations and device related limitations (Subramanya & Byung 2006). Communication related limitations in mobile devices include higher error rates, higher disconnection rates, more noise, and lower bandwidth. In addition, limited processing power, smaller memory capacity, smaller screen size, limited battery power and limited input interfaces are most common device related limitations. Apparently, these device related limitations in mobile devices are mainly introduced by the requirements for mobile devices to be small, light, and fairly affordable for the users.

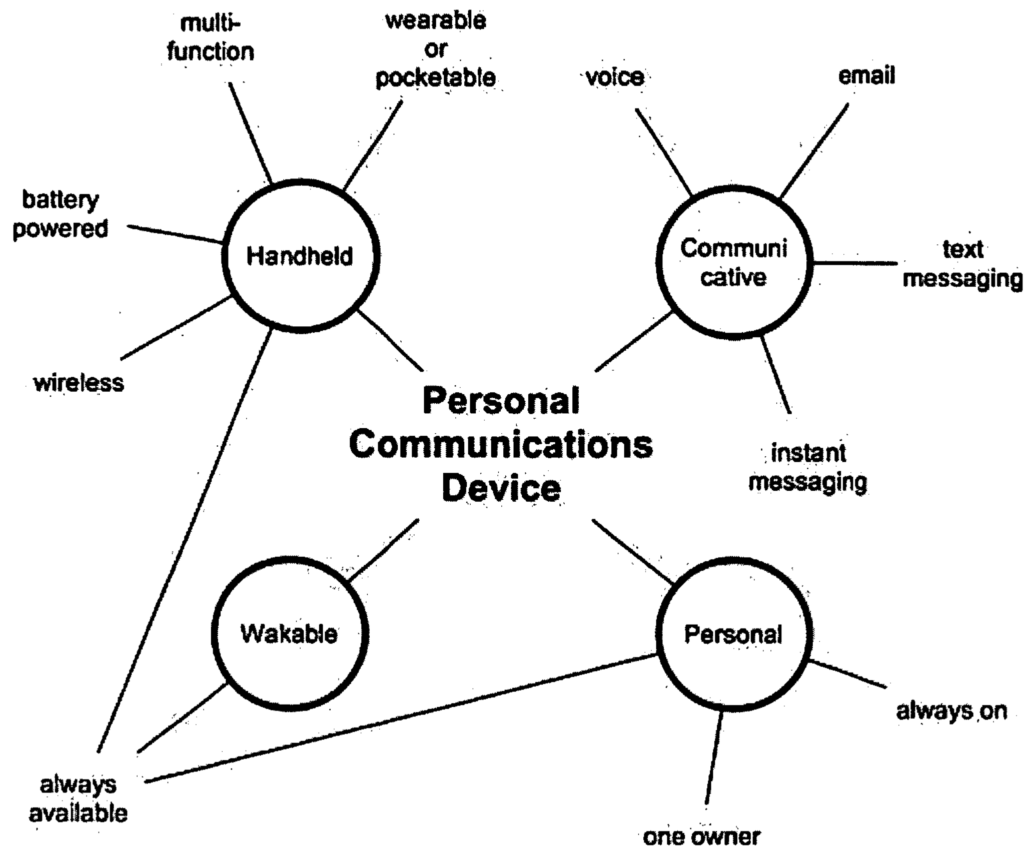


Figure 2.1 Personal communication-device/mobile-device characteristics (Ballard 2007)

2.3 Mobile Internet

Mobile Internet can be defined as the wireless access to the digitised contents available on the Internet using mobile devices (Chae, M. et al 2002; Francis, L. 1997; Kim, H. et al 2002; Kim, J. et al. 2006). There are two main differences between the mobile Internet and stationary Internet. The first difference is, mobile Internet can be used in diverse contexts, in contrast to the stationary Internet which is mainly used in a predetermined environment. Basically, mobile Internet can be readily used in any place, such as on the bus, at the train station, and many others. On the other hand, the stationary Internet is only used in relatively limited and predefined contexts, such as at home, in an office, or in a meeting room. The second difference is, mobile Internet in general has limited extent of system resources compared to the stationary Internet. For example, mobile Internet has slower speed, and less convenience for both input and output device interfaces compared to the stationary Internet (Kim et al. 2002).

Mobile Internet can be categorised into two major network technologies, which are Wireless Local Area Network (WLAN) and cellular data network. WLAN is known for Internet access with high bandwidth and hot spot local coverage, meanwhile, cellular data network is known for wide area coverage Internet access with a relatively lower bandwidth, compared to WLAN (Honkasalo et al. 2002; Jaseemuddin 2003; Manku et al. 2004).

2.3.1 Wireless Local Area Network (WLAN)

There are two main components in Wireless Local Area Network (WLAN) communication which are Wireless Terminals (WT) and WLAN Access Points (AP). A wireless terminal can be a desktop computer, a laptop, a smartphone, a tablet, or any other mobile devices that comes with WLAN capabilities. Every wireless terminal will communicate with a WLAN access point through radio links (Ghetie 2008).

There are two organisations that regulate and provide the standardisations and specifications for WLAN technology. The first one is the Institute of Electrical and Electronics Engineers (IEEE) which provides the WLAN specifications in the US, and the second one is the European Telecommunications Standard Institute (ETSI) which is based in Europe and responsible for regulating and providing the WLAN specifications in Europe. Currently, there are three main specifications for WLAN, which are IEEE 802.11a, IEEE 802.11b, and IEEE 802.11g (Ghetie 2008).

The IEEE 802.11a is the first WLAN specifications promoted by the IEEE and it has adopted in 1999. The IEEE 802.11a is designed to operate in the 5 GHz Unlicensed National Information Infrastructure (UNII) spectrum and using two different bands, which are the 200 MHz band from frequency 5.15 GHz to 5.35 GHz, and the 100 MHz band from frequency 5.725 GHz to 5.825 GHz. For the encoding mechanism, the IEEE 802.11a implements the Orthogonal Frequency Division Multiplexing (OFDM). By using the OFDM, the data carrier is divided into several sub-carriers and transmitted in parallel. By implementing this technique, the differences in delay of signals arriving at the receiver end point can be minimised and the interference issues, which are mainly caused by signal delay differences, can be overcome. In the IEEE 802.11a, the lower 200 MHz band is divided into 8 independent clear channels. Each of them has 20 MHz width. Furthermore, each of the independent clear channels is divided into 52 sub-channels (carriers), with the width of 300 KHz for each sub-channel. These 8 channels are assigned for indoor WLAN. Moreover, the next 100 MHz band in IEEE802.11a is divided into 4 independent clear channels and assigned for point-to-point outdoor WLAN communications. In 802.11a, there are three power domains, which are divided based on the 100 MHz band. The maximum power output which is allowed for the first 100 MHz band is 50 mWatt. The second 100 MHz band is restricted to the maximum of 250 mWatt power output. The third 100 MHz, which is used for point-to-point outdoor communications, is allowed up to 1 Watt power output. Moreover, since IEEE 802.11a uses different frequency than the IEEE 802.11b and the 802.11g, the IEE802.11a is not compatible with them (Ghetie 2008; Zhu et al. 2004).

The IEEE 802.11b is another WLAN specification provided by the IEEE. This WLAN specification operates in the 2.4 GHz Industrial Scientific Medical (ISM) spectrum. The IEEE 802.11b is more popular compared to IEEE 802.11a. The popularity of the IEEE 802.11b WLAN standard is promoted by the Wireless Ethernet Compatibility Alliance (WECA), which is also known as the Wi-Fi Alliance. This organisation is responsible for interoperability testing across many IEEE 802.11b devices produced by many different manufacturers. For each product that passes the interoperability testing conducted by the Wi-Fi Alliance can put the label of "Wi-Fi certified" on the product. Initially, the data rate for IEEE 802.11b is only 1 Mbps and 2 Mbps, later on the data rate is extended to 5.5 Mbps, and finally it can reach the 11 Mbps. For the accessing scheme, the IEEE 802.11b can use either the Direct Sequence Spread Spectrum (DSSS) or the Frequency Hopping Spread Spectrum (FHSS). By using DSSS, the available bandwidth in the IEEE 802.11b is divided into 14 independent sub-channels with the width of 22 MHz for each sub-channel. In order to provide the error detection and correction scheme, the DSSS implement a redundant bit pattern mechanism. On the other hand, the FHSS divides the available bandwidth into 75 sub-channels with 1 MHz width for each sub-channel. The FHSS treats these 75 sub-channels as shared sub-channels which are used by multiple transmitters and receivers. In order to provide a good noise reduction, the FHSS implements a hopping pattern mechanism which is agreed by the communication parties in the beginning of the communication session. Regarding the output power regulation, in the US, the IEEE 802.11b output power is allowed up to 1 Watt. However, most manufacturers limit the devices to produce output power around 30 mWatt only. This is to minimise the heat which is produced by the devices and also to conserve the battery power of the devices.

Following the IEEE 802.11b, the IEEE 802.11g specifications also operate in the 2.4 GHz Industrial Scientific Medical (ISM) spectrum. The IEEE 802.11g WLAN specification was adopted in the third quarter of 2003. Similar to the IEEE 802.11b, the access scheme for the IEEE 802.11g can use either the DSSS or the FHSS. This is to ensure that the IEEE 802.11g is fully compatible with the IEEE 802.11b, therefore it can promote an easy migration process from the previous predominated IEEE 802.11b standard to the new IEEE 802.11g standard. Moreover, the IEEE 802.11g provides a high data rate up to 54 Mbps, which is higher compared to the data rate provided by the IEEE 802.11b. The Wi-Fi Alliance also takes part in providing the interoperability testing and the Wi-Fi certification for the IEEE 802.11g devices (Ghetie 2008; Zhu et al. 2004).

The HiperLAN2 is the WLAN specification promoted by ETSI which is implemented as the alternative to the IEEE 802.11a specification in Europe. This is because in the beginning, the IEEE 802.11a specification was not accepted in Europe. The HiperLAN2 operates in the 5 GHz unlicensed spectrum which is the shared spectrum used by the military and civilians in Europe for satellite communications and ground tracking stations. In order to avoid interferences with other applications that operate in the same spectrum, HiperLAN2 implements Dynamic Frequency Selection (DFS) and Transmit Power Control (TPC). Similar to the IEEE 802.11a, the HiperLAN2 also implements Orthogonal Frequency Division Multiplexing (OFDM) as the encoding scheme. However, compared to the IEEE 802.11 WLAN specifications family, the HiperLAN2 implements a different data link layer which makes it closer to the ATM network than to the Ethernet network. The different implementation of data link layer in the HiperLAN2 compared to the IEEE 802.11a brings differences in the MAC address implementation and the Quality of Service (QoS) mechanism. In contrast to the popularity of the HiperLAN2, the popularity of the IEEE 802.11 WLAN family increased significantly and the WLAN implementations are dominated by the IEEE 802.11 specifications family. Recently, the IEEE 802.11 family has been accepted in Europe and the attraction of HiperLAN2 is fading (Ghetie 2008).

The IEEE 802.11n provides high speed data rates up to 300 Mbps and 600 Mbps within 20 MHz and 40 MHz bandwidth, respectively. The significant improvement in the data rate of the IEEE 802.11n primary through the implementation of spatial multiplexing using Multiple Input Multiple Output (MIMO) and also the use of 40 MHz bandwidth. Moreover, the implementation of multiple antenna, Space Time Block Coding (STBC), and Low Density Parity Check (LDPC) in the IEEE 802.11n bring enhancement for the robustness factor. Dual band mode also introduced in the IEEE 802.11n, which makes it possible to operate in both 2.4 GHz and 5 GHz (Perahia & Stacey 2008).

Table 2.1 Comparisons of the IEEE 802.11 family (Perahia & Stacey 2008)

	802.11b	802.11a	802.11g	802.11n
PHY technology	DSSS	OFDM	OFDM DSSS	SDM/OFDM
Data rates	5.5, 11 Mbps	6–54 Mbps	1–54 Mbps	6–600 Mbps
Frequency band	2.4 GHz	5 GHz	2.4 GHz	2.4 and 5 GHz
Channel spacing	25 MHz	20 MHz	25 MHz	20 and 40 MHz

2.3.2 Cellular Data Network

In mobile cellular networks, the wireless links are established between the Mobile Station (MS) and the Basic Transmission Station (BTS). The Mobile Station can be a smart phone or any other mobile device. In the beginning, the mobile radio transmissions use the same approach as radio or television broadcasting. The BTS is placed on higher ground to cover a particular area. However, when the number of users increases and because of the limitation of the available spectrum, congestion occurs. This situation forces the mobile cellular network to evolve and start using the individual micro cellular radio system. This system introduces the reusability of frequencies across geographical regions. The micro cellular radio is generated either by on-earth radio transmitters or by satellite radio transmitters (Ghetie 2008).

The mobile communication networks have kept evolving in the last thirty years since their first implementation in 1980s. They have evolved to increase efficiency in both access methods and migration paths in order to provide higher data transmission rate capabilities (Ghetie 2008). The first generation (1G) of mobile communication networks is the analog and voice-oriented technologies. The Advanced Mobile Phone Service (AMPS) is the first generation (1G) of mobile analog networks technology and it operates in 900 MHz band. In the USA, AMPS is implemented as Narrowband AMPS (NAMPS). Similar technology is implemented in the UK known as Totals Access Communication System (TACS) and in Japan known as Japanese TACS (JTACS). Furthermore, the second generation of mobile cellular networks technology (2G) is based on digital technologies with low data transmission rate capabilities. This second generation technology was introduced in the 1990s and operates in the 800 MHz and 1.5 GHz bands. It comes with data transmission rate capabilities up to 9.6 Kbps. There are four well known implementations of 2G, which are Global System for Mobile Communications or Groupe Speciale Mobile (GSM), Code Division Multiple Access (CDMA one), Digital AMPS (D-AMPS), and Personal Digital Cellular (PDC). Since then, the data transmission service in GSM has evolved to provide a dedicated data communication network with Internet connection capability. This service is known as the GSM Packet Radio Service (GPRS). There is an intermediary generation between the second and the third generation which is known as 2.5G or 2.75G. This intermediary generation implements new architecture and radio interface which is known as Personal Communication System (PCS). Moreover, it also operates in a new spectrum band and provides higher data rate capabilities compared to the data rate offered by 2G. In the intermediary generation, the GSM operates in 1,800 MHz and 1,900 MHz. Furthermore, its GPRS service has evolved to a new form of data service known as the Enhanced Data rates for GSM Evolution (EDGE). EDGE provides a higher data rate up to 144 Kbps. The third generation (3G) of mobile cellular data network focuses on broadband data services and dealing with more sophisticated data services such as multimedia data services. In the third generation, the data rate capabilities in the mobile cellular data network increased up to 2 Mbps and it implements a new architecture known as Universal Mobile Telecommunications System/ International Mobile Telecommunications (UMTS/IMT-2000). Several well known implementations in the third generation of mobile cellular data networks are CDMA 2000 which is implemented in the USA, and Wideband Code Division Multiple Access (W-CDMA) which is implemented in Europe and Japan (Dahlman et al. 2011; Ghetie 2008).

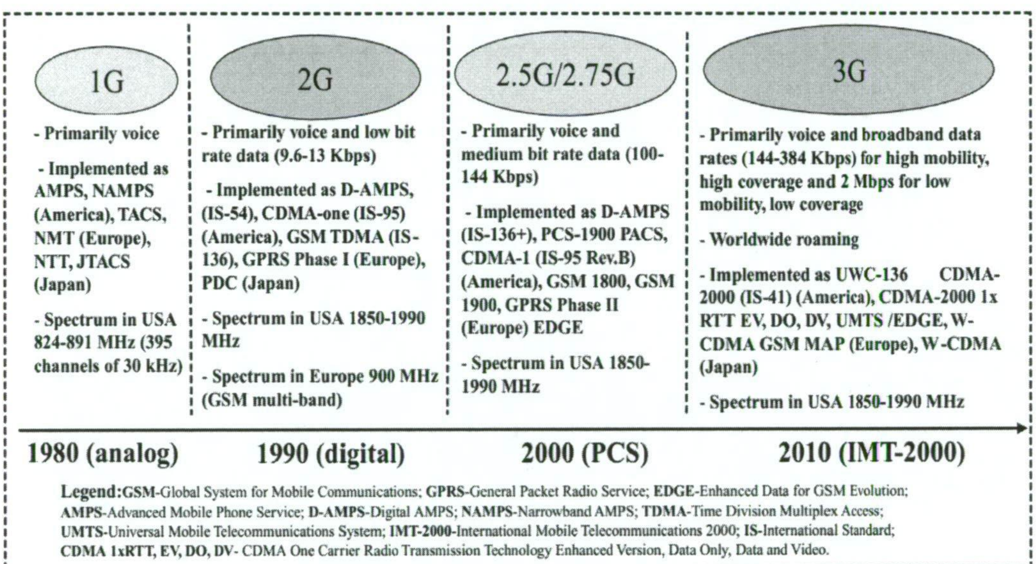


Figure 2.2 Cellular mobile networks evolution (Ghetie 2008)

The creation and development of new services for mobile devices and also the advancement in mobile system technology have contributed to the evolution of 3G to 4G. The fourth generation of cellular data networks (4G) refers to a standard called the Long Term Evolution (LTE), which is defined by the 3rd Generation Partnership Project (3GPP) as a continuing work of W-CDMA for 3G system. Orthogonal Frequency Division Multiplexing (OFDM) is used as downlink transmission scheme in LTE. OFDM offers robustness against time dispersion on the radio channel without introducing any complex channel equalization on the receiver side. By using OFDM, the terminal cost and power consumption can also be reduced, since it simplifies the processing of receiver baseband. Similar to the downlink transmission scheme, the uplink transmission scheme in LTE also based on OFDM. However, due to the lower transmission power for the uplink, compared to the downlink, LTE implements a different mechanism of OFDM for the uplink. Single carrier transmission based on Discrete Fourier Transform (DST) precoded OFDM is used for the LTE uplink transmission. It has a smaller peak to average power ratio compared to the regular OFDM which is used for the downlink transmission. By implementing DST precoded OFDM, the power consumption at the transmitter can be reduced and the coverage can be improved (Astely et al. 2009; Dahlman et al. 2011). Within 20 MHz bandwidth, the downlink peak data rates in LTE can reach up to 173 Mbps and 326 Mbps for 2x2 and 4x4 Multiple Input Multiple Output (MIMO), respectively. On the other hand, the uplink peak data rates in LTE are limited up to 86 Mbps within 20 MHz bandwidth (Khan 2009).

2.3.3 Pricing

A pricing comparison for mobile Internet access is provided in this section. The sources for the data are from several Internet service providers in Australia.

Table 2.2 Comparison of the Internet access cost in Australia (Data collected in May 2012)

Network Type	Provider	Quota (GB)	Price (AUD)
WLAN / ADSL	BigPond	50	$49.95
		200	$69.95
		500	$89.95
	Optus	120	$59.99
		150	$69.99
		500	$79.99
	iinet	100	$59.95
		200	$79.95
		400	$99.95
Cellular Data Networks	BigPond	1	$19.95
		4	$29.95
		8	$39.95
		15	$79.95
	Optus	1	$20.00
		5	$40.00
		6	$50.00
		8	$80.00
		15	$130.00
	Vodafone	2	$10.00
		4	$15.00
		8	$25.00
	Virgin Mobile	1	$10.00
		2	$20.00
		3	$30.00

It clearly can be seen from the comparison table that in general the mobile Internet pricing using cellular data networks is relatively more expensive compared to the one that using WLAN.

2.4 Mobile User

The Webster's online dictionary (2012) defines mobile user as: "The user is the individual or entity designated by the customer, individually or by class, as having access to the mobile service and having such authorization, individually or by class, as may be required by the public land mobile network (PLMN) operator or an authorized agent concerned". According to Ballard (2007), there are six mobile user characteristics that can be identified, which are mobile, interruptible and easily distracted, available, sociable, contextual, and identifiable. Mobile is the main characteristic of mobile users. Being mobile means that the users' location, including their physical and social context, are changing frequently. The user may be in rush-hour traffic, in a conference, in class, on a bus, walking down the street, at a restaurant, at the library, or in a restroom. Their location keeps changing in an unlimited range of shifting environments.

A mobile user is highly interruptible since he/she has all the sources of interruption from the physical environment compared to what a desktop user had before (Ballard 2007). A mobile user is not stationary sitting in an office room, working on a particular task in front of a desktop computer. Moreover, the mobile user can be in a plethora of places and situations with many possibilities of interruption. For example, for a mobile user writing an email or having an instant messaging conversation while he/she is waiting for a train in the station; the arrival of the train can distract his/her current activity with his/her mobile device. The train will not wait for the user to finish his/her task or conversation. The user has just lost his/her opportunity to just complete his/her sentence when the train arrived. The user's presence in a public or social space indicates that he/she is interruptible. Furthermore, even the mobile device itself can be the source of interruption for the user. For example, when there is an incoming call or a new incoming message, the user tends to be easily distracted from their current activity with the mobile device.

Availability is the other side of interruptibility. Most mobile users keep their mobile devices with them almost all the time. Therefore, mobile users are highly available to be reached by their distant friends, family, colleagues, and clients (Ballard 2007). Some users even feel uncomfortable when they are apart from their mobile devices because the devices enable them to feel more connected with others. Being present and readily available is the characteristic of mobile users. Moreover, they also tend to keep and look at the devices frequently even though they are with others.

2.4.1 Mobile User Behaviour: Device-Network Interaction Pattern

Related to mobile user behaviour, there are several interesting studies that have been conducted. One of the studies is about how the pricing of mobile services affects the users behaviour in mobile Internet usage. According to Blechar et al. (2006), when both the stationary Internet access and mobile Internet access are available, it has been found that the users prefer to access the Internet services via stationary Internet access over the mobile Internet access. In this context, the mobile Internet access refers to the mobile Internet access via cellular telecommunication network such as EDGE, GPRS, 3G, or 4G. The users perceive the cost of mobile Internet access as too expensive. This is because the mobile service users often make reference to the existing stationary Internet access pricing, which they are already familiar with, when making their mobile Internet access decision. Their mobile Internet access usage tends to be influenced by their past experiences with similar Internet service provided via stationary Internet access. Furthermore, several users also have their stationary Internet access at their office or at the school which they do not directly pay for. This condition makes some users perceive the stationary Internet access as a free of charge service. Therefore when they start to compare the pricing between the stationary Internet access and the mobile Internet access, they believe that the mobile Internet access is far more expensive. Blechar et al. (2006) also mentions that most mobile users use mobile Internet access in the evening, which is the time period when the users are away from their desktop computers and their laptops to access a stationary Internet connection.

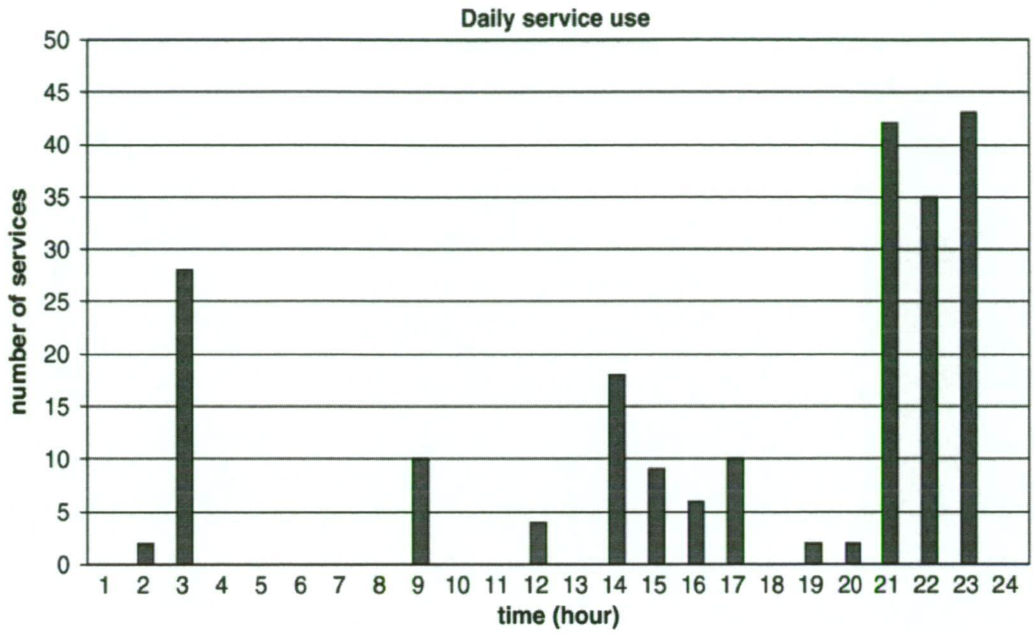


Figure 2.3 Time of mobile Internet access daily usage (Blechar et al. 2006)

The mobile Internet usage is very suitable for accessing information unilaterally, such as reading emails, checking stock quotes and news headlines, in order to fill the users' time slot when they are in the waiting state, for example during the short bus ride or while waiting in a line. Some users tend to use mobile Internet access to keep themselves engaged or entertained in their free time. Bilateral use of data services via mobile Internet, such as instant messaging and other text messaging services, is also effective under many circumstances. Some mobile Internet users associate the mobility of Internet with efficiency. The expectation of continuous availability of data and information services naturally fits with the fast-paced society that rely their decision making on information in many aspects of their life (Sarker & Wells 2003).

Cui & Roto (2008), based on their field exploration using four different context factors of mobile Internet access usage, show several interesting findings related to mobile user behaviour. The four contextual factors that they use are spatial factors, temporal factors, social factors, and access factors. From the spatial factors, Cui & Roto (2008) found that in some cases Internet users tend to choose mobile Internet access because it requires lower engagement compared to the stationary Internet access. Therefore they can get the

Internet access without necessarily interrupting their current activity. By accessing Internet via mobile Internet access, the users can have Internet access while they are having dinner at a restaurant, watching TV in the living room, or lying in their bedroom. Based on the temporal factors, Cui & Roto (2008) uncovered a similar users behavior as what Sarker & Wells (2003) found. They found that the users tend to use mobile Internet access for short breaks or the moments between planned activities, for example waiting for a bus to arrive or friends to show up, and even when waiting for a traffic light to change. Furthermore, based on social factors, Cui & Roto (2008) found that users also use mobile Internet access as a conversation enhancer. They occasionally use it for starting a new discussion topic, participating in ongoing discussion, and sometimes they also get involved in a dispute. From access factors, Cui & Roto (2008) try to identify mobile users behavior based on their usage of two main mobile Internet access types, which are via Wireless Local Area Network (WLAN) and cellular data network. The users tend to use WLAN more often than cellular data network, even though cellular data network offers a higher mobility level compared to WLAN. The main reason for this behavior is also similar to what Blechar et al. (2006) mentioned before, that the users are concerned about the higher data traffic expenses in cellular data network. Moreover, WLAN offers not only cheaper but also faster mobile Internet access. Therefore the mobile users prefer to use WLAN than cellular data network to access heavy content such as video, music, and others multimedia content.

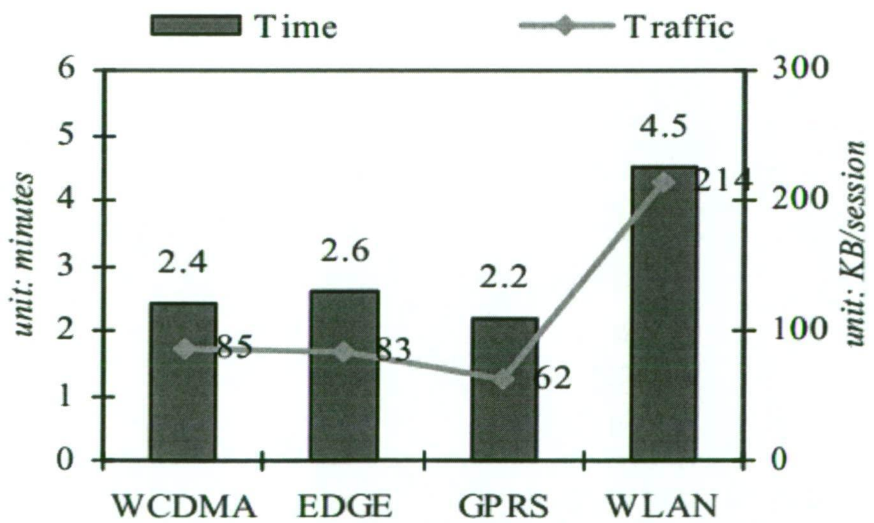


Figure 2.4 The effect of network types on mobile Internet usage (Cui & Roto 2008)

Furthermore, Cui & Roto (2008) also categorise the mobile user activities into three main groups, which are information seeking, communication, and content object handling. Information seeking is the activity to gain more knowledge or entertainment and it can be fact finding, information gathering, or casual browsing activity. In fact finding activity, the mobile users use the mobile Internet access to seek a piece of small and specific information such as today's weather forecast, an address of a restaurant, or list of new movies. Mobile users also use the mobile Internet access for information gathering activity where the they collect information from multiple sources and use it for decision making purposes or to collect knowledge related to a particular topic. Some mobile users use mobile Internet access to get more detailed information about a particular product and they even start to compare it with some other products or other shops to support their purchase decision. Another common activity among the mobile users related to information seeking is casual browsing, where the users are accessing general information without any specific goal, for example reading an online newspaper.

Most communication activities through mobile Internet access are text based communication such as email and instant messaging. Nowadays, most mobile email clients are built with a push mail feature which will enable a mobile device to get new email messages automatically and notify the user about the new incoming messages. In this case, the mobile users do not have to check incoming email messages regularly because the mobile device already handles this task for the users. This allows mobile email communication to become a nearly synchronous communication channel. However, most mobile users use their mobile device to read their email but not to send or to reply to email messages. They only reply to the urgent incoming email messages and tend to postpone replying to other regular email messages until they get to a proper keyboard (Cui & Roto 2008).

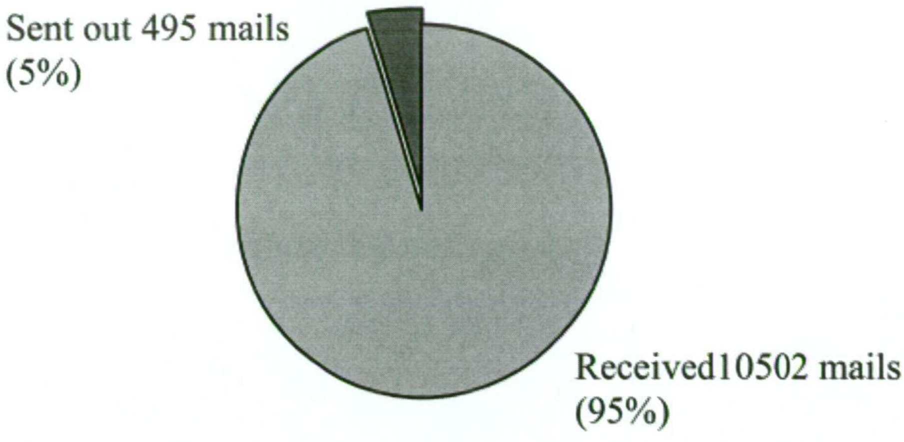


Figure 2.5 Low response on platform mobile mail (Cui & Roto 2008)

2.4.2 Mobile Internet User Satisfaction Factors

In order to identify mobile Internet user satisfaction factors, several studies have been conducted (El-Kiki & Lawrence 2006; Scheepers et al. 2006). In addition, Büyüközkan (2009) provides an analytic framework to identify mobile user requirements, specifically in the context of mobile commerce. Even though the focus of the study is mainly the mobile commerce context, however, it is still relevant to be used in the broader context such as to identify the mobile user requirements in general. Mobile user satisfaction would eventually be affected by the fulfillment of these requirements. In other words, these mobile user requirements can also be treated as mobile user satisfaction factors.

In the top level, Büyüközkan (2009) classifies these mobile user satisfaction factors into three main categories, which are functionality, profitability, and credibility. Functionality covers the interface related issues between the mobile technologies and the user. The mobile platform should be as easy as possible to access by the user. Portability, as the second category, covers both concrete and conceptual benefits that can be offered to the user. The concrete benefits can also be represented in financial terms. The last category, credibility, covers several issues that would attract the user to keep using the mobile services. There are two aspects that would influence the credibility, the first one is credibility issues produced by the system and the second one is those perceived by the user. Furthermore, each category can be divided into more specific factors in order to address the mobile user satisfaction. There are six specific factors that can be derived from functionality, which are simplicity, usability, flexibility, interface, speed, and accessibility. Similar to functionality, the profitability category can also be divided into four derived factors, which are added value, options of payment, price, and individualization. Moreover, there are three specific factors derived from the credibility category, which are reliability, safety, and correction of the system. A further study is also conducted by Büyüközkan (2009) by implementing the fuzzy number technique in order to produce weight based composite priority among those identified mobile user satisfaction factors.

Table 2.3 Composite priority weights for mobile user requirements – satisfaction factors (Büyüközkan 2009)

Main requirements	Local weights	Sub-requirements	Local weights	Global weights
		Simplicity	0.28	0.0924
Functionality	0.33	Usability	0.22	0.0726
		Flexibility	0.10	0.033
		Interface	0.15	0.0495
		Speed	0.15	0.0495
		Accessibility	0.10	0.033
Profitability		Added value	0.33	0.1221
	0.37	Options of payment	0.22	0.0814
		Price	0.39	0.1443
		Individualization	0.07	0.0259
		Reliability	0.38	0.114
Credibility	0.30	Safety	0.38	0.114
		Correction of the system	0.24	0.072

2.5 Multi-Objective Optimisation Problems

Optimisation can be defined as the task of finding one or more feasible solutions which can produce desired or useful values of one or more objectives. Optimisation itself can be single-objective optimisation or multi-objective optimisation. If there is only one objective function that needs to be satisfied, the task of finding the optimal solution is called single-objective optimisation. It follows then that if there is more than one objective function that needs to be satisfied, the task of finding one or more optimum solutions is called multi-objective optimisation (Deb 2009).

Most problems in real world applications have multiple objectives which are possibly conflicting each other. By optimising one objective, it may be sacrificing the other objectives (Bui & Alam 2008). A simple example can be found in computing equipment purchase decisions. People in general want to have computing equipment with high performance. However, people also want to save their money and spend less in every purchasing activity, including purchasing their computing equipment. In this case, the objective of having the computing equipment with the best performance cannot be achieved without abandoning the objective of spending less money in purchasing. On the other hand the objective of spending less cannot be achieved without sacrificing the objective of having computer equipment with the best performance. Both objectives in the purchasing decision are conflicting each other. In formal study, the problems that deal with more than one objective, which need to be satisfied or optimised simultaneously, are known as Multi-Objective Optimisation Problems (Coello 2006).

In order to conduct further study in multi-objective optimisation problems, Coello (2007) provides a clear definition of these phenomena as:

> the problem of finding a vector of decision variables which satisfies constraints and optimises a vector function whose elements represent the objective functions. These functions form a mathematical description of performance criteria which are usually in conflict with each other. Hence, the term 'optimise' means finding such a solution which would give the values of all the objective functions acceptable to the decision maker.

The decision variables in multi-objective optimisation problems are the numerical values which are chosen in such a problem. In mathematical notation, the variables can be represented as:

$$x_j \ , \ j \in \{1, \ldots, n\}$$

Decision Variables (Coello 2001)

And the vector x of n decision variables will be represented as:

$$\overline{x} = [x_1, ..., x_n]$$

Vector x of n Decision Variables (Coello, C. 2001)

A vector of n decision variables in a multi-objective optimisation problem is called a solution (Deb 2009).

Constraints in optimisation problems are the restrictions or limitations introduced by the environment or resources, such as physical limitations, time restrictions, processing power limitations, and several other kind of limitations. Certain solutions can be considered acceptable when these solutions can satisfy all the available constraints (Coello 2001). In mathematical notation, the constraints can be represented in mathematical inequalities:

$$g_i(\overline{x}) \geq 0 \ , \ i \in \{1, ..., p\}$$

Constraints Inequalities (Coello 2007)

and equalities:

$$h_j(\overline{x}) = 0 \ , \ j \in \{1, ..., m\}$$

Constraints Equalities (Coello 2001)

The number of inequality constraints p cannot be greater than or equal to the number of decision variables n. In other word, p must be less than n or in mathematical notation can be represented as $p < n$. The optimisation problem with $p \geq n$ is considered to be over constrained and there is no more flexibility or any degrees of freedom for optimising. The value of degree of freedom is given by n - p (Coello 2007).

In addition to constraints, Deb (2009) also mentions the decision variable bounds as a part of the constraints set. In mathematical notation, the variable bounds can be represented as:

$$x_j^{(L)} \leq x_j \leq x_j^{(U)}$$

Decision Variables Bounds (Deb 2009)

These variable bounds restricting each decision variable x_j to take a value only in the range between the lower value $x_j^{(L)}$ and the upper value $x_j^{(U)}$. These variable bounds represent a decision variable space D also known as decision space.

A solution x that satisfies all of the constraints and the variable bounds is known as a feasible solution. On the other hand, if any solution x does not satisfy all the constraints and the variable bounds, it is known as an infeasible solution. Clearly, not all solutions in the entire decision variable space D are feasible solutions. The set of all feasible solutions is known as feasible region S (Deb 2009).

According to Coello (2001), objective functions are the computable functions of the decision variables that are used as criteria to evaluate a certain solution in order to know how good the solution is. In real world optimisation problems, some functions are required to be minimised while other functions are required to be maximised. Moreover, in multi-objective optimisation problems, these functions in many cases are conflicting each other. Optimising a particular objective function may sacrifice the other objective functions. These objective functions may be measured using the same measurement units, which are known as commensurable, or the functions may also be measured using different measurement units, known as non-commensurable. In mathematical notation, the objective functions can be represented as:

$$f_1(\overline{x}), \ldots, f_k(\overline{x})$$

Objective Functions (Coello 2007)

where k represents the number of objective functions being solved in the multi-objective optimisation problem.

The objective functions will form a vector function which can be represented in mathematical notation as:

$$\overline{f(\overline{x})} = [f_1(\overline{x}), \ldots, f_k(\overline{x})]$$

Vector Function (Coello 2007)

Using this notation, the goal in multi-objective optimisation problems can clearly be seen as optimisation of all k objective functions simultaneously. The optimisation process itself can be done by maximizing the values of all k objective functions, or by minimizing the values of all k objective functions, or even in some cases by combining the maximisation and the minimisation values of these k objective functions (Coello, C. 2007). Since the task in multi-objective optimisation problems is about optimising a vector of objectives instead of a single-objective, multi-objective optimisation is also known as vector optimisation (Deb 2009).

Deb (2009) notes that many optimisation algorithms have been developed to deal with only one type of optimisation problem which is either minimisation or maximisation. In order to simplify the task dealing with mixed types of optimisation problems, the duality principle can be applied. In the context of optimisation, the duality principle suggest that a maximisation problem can be converted into minimisation problem by multiplying the objective function by -1. The same thing works vice versa.

2.5.1 Concept of Domination

Deb (2009) states that the concept of domination is applied in most multi-objective optimisation problems. Two solutions are compared to see whether one of the solutions dominates the other solution or not.

In the case of comparing two solutions, solution x_1 and solution x_2, solution x_1 is said to dominate the other solution x_2 if it complies with the two domination conditions, which are:

1. The solution x_1 is no worse than x_2 in all objectives
2. The solution x_1 is strictly better than x_2 in at least one objective

Or in mathematical notation can be represented as:

$$\forall j : \neg(f_j(x_1) \quad \rhd \; f_j(x_2)) \;\; , \;\; j \in \{1, \ldots, k\}$$

and

$$\exists j : \; f_j(x_1) \;\; \lhd \; f_j(x_2) \;\; , \;\; j \in \{1, \ldots, k\}$$

Concept of Domination (Deb 2009)

In this case, k represents the number of objective functions being solved in the multi-objectives optimisation problem.

Operator $\lhd$ is used to represent "better than" relationship between two solutions. For example, a $\lhd$ b means a is better than b. Operator $\lhd$ is commonly used to describe optimisation problems since it can produce a better understanding compared to operator < and > which often produce ambiguity. For example, if an objective function in optimisation problems is to be minimised then the $\lhd$ operator would express the same meaning with operator < since in minimisation problem, the solution that can produce a lower value is better compared to the one that produce a higher value. The same thing works vice versa when an objective function in optimisation problems is to be maximised (Deb 2009).

If all the two domination conditions are true, then it can be said that solution x dominates solution y or in mathematical notation can be represented as:

$$x \preceq y$$

Dominance Notation (Deb 2009)

Furthermore, in the context of minimisation as an optimisation problem, the concept of domination between two solutions, x and y, can be represented in mathematical notation as:

$$\overline{x} = [x_1, \ldots, x_k]$$
$$\overline{y} = [y_1, \ldots, y_k]$$
$$\overline{x} \preceq \overline{y} \Leftrightarrow \forall i \in \{1, \ldots, k\} : \ x_i \leq y_i \ \wedge \ \exists i \in \{1, \ldots, k\} : x_i < y_i$$

Concept of Domination in Minimisation (Coello 2007)

According to Deb (2009), apart from representing solution x dominating solution y, this mathematical notation also implies that:

- solution y is dominated by solution x
- solution x is non dominated by solution y
- solution x is non inferior to solution y

Deb (2009) also states that there are three possible outcomes that can be produced from a dominance check between two solutions x and y, which are:

- solution x dominates solution y
- solution x gets dominated by solution y
- solution x and solution y do not dominate each other

In addition to the concept of domination, Bui & Alam (2008) describes the four properties of dominance relation which are:

1. Irreflexive

   The dominance relation is irreflexive, since a solution does not dominate itself.

2. Asymmetric

   The dominance relation is asymmetric, since x $\preceq$ y does not imply y $\preceq$ x.

3. Not Antisymmetric

   The dominance relation is not antisymmetric, since the dominance relation is asymmetric. The antisymmetric property requires that if x $\preceq$ y and y $\preceq$ x, then x = y.

4. Transitive

The dominance relation is transitive since if x $\preceq$ y and y $\preceq$ z, then x $\preceq$ z.

2.5.2 Pareto Optimal

It is nearly impossible to have a single solution that can optimise all the objective functions. Therefore in multi-objective optimisation problems the focus is looking for a trade-off among the objective functions instead of looking for a single solution (Coello 2007). In single-objective optimisation, when there is only one objective function to be optimised, the notion of optimality can be clearly identified. The optimum solution can be found by simply looking for the best value of the predefined objective function, which can be the highest value in the case of maximisation or the lowest value in the case of minimisation. However, in multi-objective optimisation, the notion of optimality has become harder to identify, since there are more objective functions that need to be optimised. The notion of optimality needs to be redefined to guarantee that it can respect the integrity of each objective function. The concept of Pareto optimality can be applied in order to find a set of optimum solutions (Goldberg 1988).

According to Deb (2009), all possible pairwise comparisons can be performed for a given finite set of solutions in order to find which solutions are non-dominated with respect to each other. The set of non-dominated solutions that is left has the property of dominating all other solutions apart from the solutions which belong to this set. In other words, the set of non-dominated solutions is simply better compared to all other solutions. Moreover, Deb (2009) explains that if P is a set of solutions and P* is a set of non-dominated solutions, the P* are those that are not dominated by any member of P. Furthermore, if P is the entire search space of solutions, or P = D, then P* is called the Pareto Optimal Set. In mathematical notation, Pareto optimality can be represented as:

$$P^* := \{\overline{x} \in D \mid \neg\exists\, \overline{x}^* \in D : f(\overline{x}^*) \preceq f(\overline{x})\}$$

Pareto Optimal Set Notation (Coello 2007)

where D is the entire space of solutions or decision variables.

The global Pareto Optimal Set can be defined as the non-dominated set of the entire feasible search space S. Often the globally Pareto Optimal Set is simply referred to as Pareto Optimal Set (Deb 2009). Moreover, by plotting the Pareto Optimal Set in objective space, the non-dominated vectors are collectively known as the Pareto Front (Coello 2007). In mathematical notation, Pareto Front can be represented as:

$$PF^* := \{u = f(\overline{x}) \mid \overline{x} \in P^*\}$$

Pareto Front Set Notation (Coello 2007)

2.6 Evolutionary algorithms in Multi-Objective Optimisation Problem

In order to solve multi-objective optimisation problems, the Operations Research community has developed several approaches based on a variety of mathematical programming techniques since the 1950s. However, there are several limitations in mathematical programming techniques when dealing with multi-objective optimisation problems. Most of them only produce a single solution for each run, therefore in order to produce a Pareto Optimal Set, several runs are required. Moreover, mathematical programming techniques in general are susceptible to the shape and continuity of the Pareto Front. In contrast, evolutionary algorithms can find several members of the Pareto Optimal Set in a single run. Evolutionary algorithms are also less susceptible to the shape or continuity of the Pareto Front (Coello 2006).

According to Jones (1998) and Deb (2009), evolutionary algorithms are computer programs that mimic natural evolutionary principles, which are inspired by Charles Darwin, in order to solve complex searching and optimisation problems. In evolutionary algorithms there would be a number of artificial creatures, known as individuals, which are generated to search over a particular problem space. Individuals continually compete against each other in order to discover the optimal areas from the predefined search space. Gradually, over some periods of time , the most successful individuals evolve to discover the optimal solution.

The individuals in evolutionary algorithms are commonly represented by strings or vectors that have a fixed length. Every individual encodes a unique possible solution to address a particular problem. In an evolutionary algorithm, a set of individuals is known as a population. The evolutionary algorithm is started with an initial population consisting of a particular number of randomly generated individuals. String values in every individual are generated randomly by a random number generator. Furthermore, a fitness value is assigned to each individual. In order to generate the fitness value, each individual is decoded to produce a possible solution to the problem. The fitness function will calculate the solution value to produce a fitness value for the corresponding individual. The individuals with higher fitness values represent better solutions to address the problem, compared to the ones with lower fitness values. This initial process is followed by the main iterative cycle which consists of two main operations, mutation and recombination. In every iteration, the individuals in the current population produce a new set of individuals called children. After the fitness value is assigned to every child, a new population is created. The current individuals and the children are allocated to become members of the new population. This new population will be treated as the current population in the next iteration cycle. In order to control the growth of the population, the similar approach to the natural evolutionary strategy, the survival of the fittest, is applied and the individuals start competing against each other. This kind of approach in evolutionary algorithms is known as the selection process. The fitness value is used as the basis for the selection process. The individuals with better fitness values have more chance of being selected as parents, in order to be able to produce children, and also to be selected to form a new population (Jones 1998).

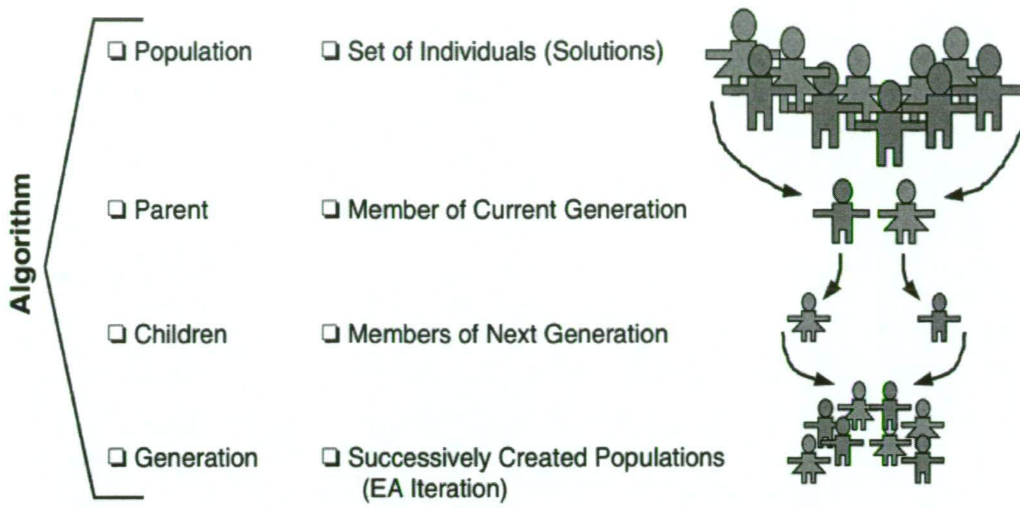


Figure 2.6 Key components in Evolutionary Algorithms (EA) (Coello 2007)

Coello (2007) identifies four main primary goals of evolutionary algorithms in order to solve multi-objective optimisation problems:

1. Maintain the non-dominated points in the objective space and associated solution points in the decision space
2. Continually make algorithmic progress towards the Pareto Front in the objective function space
3. Maintain diversity on the Pareto Front and the Pareto Optimal Set
4. Provide a sufficient number of Pareto Optimal Set for the decision maker

2.6.1 NSGA

NSGA or Non-dominated Sorting Genetic Algorithm is one example of evolutionary algorithm in multi-objective optimisation problem. NSGA is proposed by Srinivas and Deb as another variation of Goldberg's approach (Goldberg 1988; Srinivas & Deb 1994; Coello 2007). The algorithm is based on a non-dominated sorting procedure and it differs from a simple genetic algorithm in the selection operation. The population is ranked based on an individual's non-domination before the selection operation is performed. Ranking selection method and niche selection method are implemented in NSGA. A ranking selection method is implemented in order to emphasise good points and a niche selection method is implemented to maintain stable subpopulations of good points.

The first non-dominated individuals which are identified from the current population will be classified as the first non-dominated front in the population. A large dummy fitness value is assigned to these non-dominated individuals. In order to give an equal reproductive potential to all these non-dominated individuals, these individuals are assigned with the same fitness value. These classified individuals are then shared with their dummy fitness values in order to maintain the diversity in the population. This causes multiple optimal points to co-exist in the population. Furthermore, the rest unclassified individuals in the population will be processed in the same way in order to identify individuals for the second non-dominated front. These newly identified non-dominated individuals are then assigned with a new dummy fitness value which is kept smaller than the minimum shared dummy fitness value of the previous front. The process is continued until the entire population is classified into several fronts of non-dominated individuals. Later on, the population is reproduced according to the dummy fitness values. Individuals in the first front always get more copies than the rest of the population since they have the highest fitness value. The reproduction or crossover process is aimed to search for non-dominated regions or Pareto Optimal Front. The computational efficiency in NSGA is achieved using a non-dominated sorting method where multiple objectives are reduced to a dummy fitness function (Srinivas & Deb 1994).

```
Initialize Population P
Evaluate Objective Values
Assign Rank Based on Pareto dominance in Each Wave
Compute Niche Count
Assign Shared Fitness
For i=1 to number of generation Do
  Selection via Stochastic Universal Sampling
  Single Point Crossover
  Mutation
  Evaluate Objective Values
  Assign Rank Based on Pareto dominance in Each Wave
  Compute Niche Count
  Assign Shared Fitness
End Loop
```

Figure 2.7 NSGA Pseudocode (Srinivas & Deb 1994; Coello 2007)

2.6.2 NSGA II

NSGA II or Non-dominated Sorting Genetic Algorithm version two is the new version of NSGA proposed by Kalyanmoy Deb, Samir Agrawal, Amrit Pratap, and T. Meyarivan. It is proposed in order to address several critics on NSGA such as high computational complexity of non-dominated sorting, lack of elitism, and need for specifying the sharing parameter. Compared to the first version of NSGA, NSGA II is more efficient in term of computational process (Deb et al. 2000; Coello 2007). NSGA II uses elitism and a crowded comparison operator to maintain diversity of the population. Elitism is implemented in NSGA II in order to help achieving better convergence. In term of converging near the Pareto Front and in term of maintaining diversity among obtained solutions, NSGA II in general is better than PAES (Pareto Archived Evolution Strategy) and SPEA (Strength Pareto Evolutionary Algorithm), the two other elitist multi-objective evolutionary algorithm (Knowles & Corne 1999; Zitzler & Thiele 1999; Deb et al. 2000).

```
Initialize Population P
Generate random population - size N
Evaluate Objective Values
Assign Rank (level) Based on Pareto dominance - sort
Generate Child Population
Binary Tournament Selection
Recombination and Mutation
For i = 1 to number of generation do
  For each Parent and Child in Population do
    Assign Rank (level) based on Pareto - sort
    Generate sets of nondominated vectors along PFknown
    Loop (inside) by adding solutions to next generation
    starting from the first front until N individuals found
    determine crowding distance between points on each front
  End Loop
  Select points (elitist) on the lower front (with lower rank)
  and are outside a crowding distance
  Create next generation
  Binary Tournament Selection
  Recombination and Mutation
End Loop
```

Figure 2.8 NSGA II Pseudocode (Deb et al. 2000; Coello 2007)

2.7 Chapter Summary

In order to provide a solid basis for this research, a literature review has been conducted and presented in this chapter. The five areas covered in this literature review chapter are mobile device characteristics, mobile Internet characteristics, mobile users' characteristics including their behaviours, the multi-objective optimisation problems, and the evolutionary algorithms in multi-objective optimisations problems.

An in-depth explanation related to the methodology which is used to conduct this study is presented in the following chapter.

Chapter 3

Methodology

3.1 Need for Multiple Objectives

There are many factors that can influence the users' satisfaction in terms of the usage of the mobile devices for data transfer; for example, how much money the users have to spend to transfer the data through the mobile Internet connection using the available data carrier, how critical or how valuable the data which is required to be transmitted is in terms of time span, the battery power consumption to make a mobile Internet connection using the available network carrier and how it will affect the remaining battery life, and how the remaining battery life will affect the future opportunity value for the user of being able to utilise the mobile device without having any issue as a result of a flat battery. Moreover, the optimum level of mobile user satisfaction cannot be achieved by only focusing on optimising a single satisfaction factor and ignoring the rest of the factors.

3.2 Related Study

Several studies have been conducted to identify and analyse the users' satisfaction factors while they are using their mobile devices (El-Kiki & Lawrence 2006; Scheepers et al. 2006; Büyüközkan 2009). However, there is no study that addresses the problem in optimising the user satisfaction while they are using their mobile devices for a single act of data transfer. This research tries to fill this gap by proposing a simulation study to analyse the multi-objective optimisation problem in mobile user satisfaction.

3.3 Multi-Objective Optimisation Problem

The problem in optimising mobile user satisfaction can be classified as a multi-objective optimisation problem since there is more than one satisfaction factor required to be optimised and these satisfaction factors are conflicting with each other. Optimising one factor may sacrifice some other factors.

The main idea of the multi-objective optimisation problem is to find a set of decision variables that can produce an optimum value for all available objective functions without violating any prespecified constraint functions. In mathematical notation, a set of decision variables can be represented as:

$$\bar{x} = [x_1, \ldots, x_n]$$

Decision Variables (Coello 2001; Deb 2009)

where n represents the number of decision variables.

In multi-objective optimisation there are two main categories of function, namely objective functions and constraint functions. In general, the term optimisation in multi-objective optimisation problem is related to the case of minimisation (Coello 2001; Deb 2009). Since not all of the objective functions can be optimised by minimisation, some objective functions have to be converted to minimisation functions simply by multiplying them by -1. In mathematical notation, objective functions can be represented as:

$$minimise\ f_i(\bar{x}),\ i \in \{1, \ldots, k\}$$

Objective Functions (Coello 2001; Deb 2009)

where k represents the number of objective functions.

Constraint functions in mathematical notation can be either inequalities or equalities which will be used to reduce the search space into a feasible solution region. Mathematical inequalities for constraint functions can be represented as:

$$g_i(\bar{x}) \geq 0,\ i \in \{1, \ldots, t\}$$

Constraint Inequalities (Coello 2001; Deb 2009)

where t represents the number of inequality constraint functions.

Mathematical equality for constraint functions can be represented as:

$$h_i(\bar{x}) = 0,\ i \in \{1, \ldots, u\}$$

Constraint Equalities (Coello 2001; Deb 2009)

where u represents the number of equality constraint functions.

3.4 Approaches for Satisfaction Comparison

There are several approaches used to address the multi-objective optimisation problem, such as the aggregating approach, lexicographic ordering approach, and Pareto based approach. Each of them has its own strengths and weaknesses.

3.4.1 Aggregating Approach

The main idea in aggregating approaches is to combine all objective functions into a single objective function by using addition, multiplication, or any other combination of arithmetic operations. These kinds of approaches are also known as naive approaches due to their simplicity. In many cases, the aggregating approaches produce relatively successful results when the behaviour of the objective functions is more or less well known. For some applications, the aggregating approaches can be the simplest and the most efficient approaches, since no further interaction with the decision maker is required (Coello 2000).

Despite the simplicity of these methods, there are also several problems in the aggregating approaches. The aggregating approaches require accurate scalar information on all of the objectives in order to prevent one of the objectives dominating the others, meaning that sound understanding of the behaviour of each of the objective functions is required. However, in most real world applications, knowing the exact or nearly exact behaviour of each objective function can be very expensive in term of computational process. In these cases, the cost of computational process might be unaffordable (Coello 2000).

One example of the aggregating approach is the weighted sum approach. This was the first method developed for generating non-inferior solutions for multi-objective optimisation based on the seminal work of Kuhn and Tucker on numerical optimisation (Khun & Tucker 1951). In this approach, all the objective functions are added together using different weighting coefficients for each objective function. The main idea of the weighted sum approach is to transform the multi-objective optimisation problem into a scalar optimisation problem. In mathematical notation, the scalar optimisation can be formed as:

$$minimize \sum_{i=1}^{k} w_i f_i(\overline{x})$$

subject to constraints:

$$g_j(\overline{x}) \leq 0, \ j \in \{1, \ldots, m\}$$

where

$$0 \leq w_i \leq 1$$

and

$$\sum_{i=1}^{k} w_i = 1$$

Weighted Sum Approach (Coello 2000)

w_i are the weighting coefficients representing the relative importance of the objectives. However, in real world application, the weighting coefficients do not proportionally reflect the relative importance of the objectives. The difficulty with this approach is in determining the appropriate weights for each objective function especially when there is not enough information about the problem or the behaviour of the objective functions (Coello 2000).

3.4.2 Lexicographic Ordering Approach

Using lexicographic ordering approach, the objective functions are ranked based on the order of importance. The optimum solution $\bar{x}^*$ is obtained by minimising (optimising) all of the objective functions from the most important objective function to the least important one (Coello 2000). In the case of k objective functions to be optimised, $f_1(\bar{x})$ has the highest importance rank and $f_k(\bar{x})$ has the lowest importance rank.

The first problem is formulated as:

$$minimise\ f_1(\bar{x})$$

subject to constraints:

$$g_j(\bar{x}) \leq 0,\ j \in \{1, \ldots, m\}$$

and its solution $\bar{x}_1^*$ is obtained based on the $f_1^*(\bar{x}_1^*)$ as the most minimum (optimum) result. Then the second problem is formulated as:

$$minimise\ f_2(\bar{x})$$

Subject to constraints:

$$g_j(\bar{x}) \leq 0,\ j \in \{1, \ldots, m\}$$

$$f_1(\bar{x}) = f_1^*(\bar{x}_1^*)$$

and the solution $\bar{x}_2^*$ is obtained based on the $f_2^*(\bar{x}_2^*)$ as the most minimum (optimum) result.

This process is repeated until all k objective functions have been considered.

The i^{th} problem is formulated as:

$$minimise\ f_i(\overline{x})$$

subject to constraints:

$$g_j(\overline{x}) \leq 0,\ j \in \{1, \ldots, m\}$$

$$f_n(\overline{x}) = f_n^*(\overline{x}_n^*),\ n \in \{1, \ldots, i-1\}$$

At the end, solution $\overline{x}_k^*$ is obtained and is taken as the desired solution $\overline{x}^*$ of the problem.

The difficulty with this approach is in determining the appropriate order for each objective function, especially when there is not enough information about the problem. It is crucial to have a sound understanding of the behaviour of each objective function in relation to the other objective functions. Randomly ordering the objective functions may lead to favouring certain objectives over others when many are present (Coello 1996).

3.4.3 Pareto Based Approach

The main idea of the Pareto based approaches is using the non-domination ranking and selection to drive a population of solutions toward the Pareto Front in a multi-objective optimisation problem. In the initial iteration, the first Pareto non-dominated population is identified. This population is assigned with the highest rank and eliminated from the rest of the population to avoid further contention. In the next iteration, another Pareto non-dominated population is identified from the remaining population. Similar to the previous one, this new Pareto non-dominated population is assigned with the next highest rank and eliminated from the remaining population. This process continues until the population is suitably ranked. The idea of using Pareto based approach for fitness assignment was first proposed by Goldberg (Goldberg 1989; Coello 2000).

In a Pareto based approach, the non-dominated solutions in each set has the property of dominating all other solutions apart from the solutions which belong to this set. In other words, the set of non-dominated solutions is simply better compared to all other solutions. Moreover, Deb (2009) explains that if P is a set of feasible solutions and P^* is a set of non-dominated solutions, then P^* are those that are not dominated by any member of P. Furthermore, if P is the entire search space of solutions, or P = D, then P^* is called the Pareto Optimal Set. In mathematical notation, Pareto optimality can be represented as:

$$P^* := \{\bar{x} \in D \mid \neg\exists\, \bar{x}^* \in D : f(\bar{x}^*) \preceq f(\bar{x})\}$$

Pareto Optimal Set Notation (Coello 2007)

where D is the entire space of solutions or decision variables.

The global Pareto Optimal Set can be defined as the non-dominated set of the entire feasible search space S. Often the global Pareto Optimal Set is simply referred to as Pareto Optimal Set (Deb 2009). Moreover, by plotting the Pareto Optimal Set in objective space, the non-dominated vectors are collectively known as the Pareto Front (Coello 2007).
In mathematical notation, Pareto Front can be represented as:

$$PF^* := \{u = f(\bar{x}) \mid \bar{x} \in P^*\}$$

Pareto Front Notation (Coello 2007)

In contrast to the two previous approaches, in Pareto based approach, a complete understanding of each objective function behaviour is not essential, since in this approach the objective functions are not going to be ranked. Therefore, an objective function is no longer required to be compared with the other objective functions.

The main issue in the Pareto based approach is to find an efficient algorithm to check non-dominance in a set of feasible solutions. The increase in the size of the population and the number of objective functions introduces a serious degradation in the performance (Coello 1996, 2000).

In order to conduct a simulation study in this research, the Pareto based approach is the one which is going to be used to find a set of optimum solutions for mobile user satisfaction. The main reason for this decision to use the Pareto based approach is that the result of an objective function will only be compared with the other results from the same objective function produced by another solution set. This condition can bring a fair comparison among the solution set in the population.

3.5 Simulation Model

For the purposes of this research, in order to run the simulation study for optimising the multi-objective of mobile user satisfaction, construction of a simulation model is required. The simulation model will be divided into three major parts, which are decision variables, objective functions, and constraints.

3.5.1 Decision Variables

The decision variables in this case will represent variable values which can be chosen by the user as a decision maker in order to produce a particular sequence of activities, leading to a level of satisfaction for each satisfaction factor. In this simulation study, there will be two decision variables, which are the postpone interval and the resource type.

3.5.1.1 Postpone Interval

The postpone interval as the first decision variable will represent the length of the delay interval or the postpone interval before making a data transfer. In presenting the simulation result in this report, multiples of minutes are used to represent the postpone intervals. However, all computations in this simulation study were done to the accuracy of a single second.

3.5.1.2 Resource Type

The resource type, as the second decision variable, will represent the combination of network type and network provider which is going to be used to make a mobile Internet connection. The network type in this case can be WiFi or cellular data network, and the network provider can be any network provider which is available in Australia such as Telstra or Optus. Each network provider will offer a different pricing scheme and network quality for every network type that they provide to their customers.

These decisions will affect the user satisfaction factors that will take the form of objective functions. Since there are two decision variables in this simulation study, in mathematical notation they can be represented as:

$$\bar{x} = [x_1, x_2]$$

Decision Variables

where x_1 represents the postpone interval and x_2 represents the resource type

3.5.2 Objective Functions

In this simulation study, each user satisfaction or concern factor which is required to be optimised is going to be represented by an objective function. The value of the decision variable will be used as the input value for each objective function, therefore the value which is going to be produced by each objective function is dependent on the value of the decision variable. In this particular study there are five objective functions which require optimisation: minimising the cost of mobile Internet access, maximising the utility level, maximising the remaining battery life, minimising the liability level, and minimising the access interval/duration.

3.5.2.1 Cost Objective Function

Mobile Internet access pricing is one of the users' main concerns while they are accessing the Internet using their mobile device. A high cost of mobile Internet access might prevent the users from accessing the Internet from their mobile device (Blechar et al. 2006; Büyüközkan 2009).

In this study, the cost is modeled and used as an important objective function to determine user's satisfaction. The cost of mobile Internet access is dependent on the available resource type. Each resource type has its own pricing scheme. Since the cost of mobile Internet access varies across many different network providers, the lower cost of mobile Internet access can be achieved by postponing the Internet access for a particular interval of time in order to get a cheaper available connection from the provider. In mathematical notation the cost objective function can be represented as:

$$minimise\ f_1(\bar{x})$$

where

$$f_1(\bar{x}) = price(x_2) * EDS$$

Cost Objective Function

$price(x_2)$ represents the cost for transferring the data using resource type x_2, and EDS is the estimated data size which is going to be transmitted.

In presenting the simulation result in this report, Megabytes (MB) are used as the measurement unit to represent the estimated data size. However, all computation in this simulation study was done to the accuracy of a bit.

3.5.2.2 Utility Level Objective Function

Mobile users and applications put a significant premium on immediate data transfer and interaction. In this respect, the data communication needs to have features of a real time system. A user may wish to upload his/her latest photo on a social media site such as Facebook or Twitter soon after it was taken to share with his/her friends. Thus, the user may assign a full 100% utility benefit if the data can be transferred in (say) the first 15 minutes after the photo was taken. The perceived utility value would be modeled as a linear function declining to zero if it misses the initial full-value period.

One main reason that motivates the users to transfer a particular data is the utility value which is offered by transferring the data. Data as a critical resource is required to be processed or in this case is required to be transmitted within a specified period of time in order to get a maximum utility value from it. There is a time constraint involved in this case and it will affect the utility level of the data being transferred. The utility level would decrease if the data transmission could not meet the time constraint (Williams 2006; Laplante 2004). A solution that can maintain a high level of utility is necessary for the users, and it is one of the factors that can influence their satisfaction while they are using their mobile device.

Considering the importance of the utility level for the mobile users' satisfaction, the utility level function is implemented as the second objective function in this simulation study. The utility level represents the value of the data which is required to be transmitted in terms of time span. The range of the utility level is between 0 as the minimum utility level and 100 as the maximum. There will be two additional variables which are taking part in the utility level calculation: the maximum utility level interval and the zero utility level interval. The maximum utility level interval defines the maximum postpone interval for the data which is going to be transmitted in order to be able to get the maximum utility level from it. The zero utility level interval is the minimum postpone interval for the data being transmitted to start having a zero utility level, or in other words for the data to become meaningless. In the time interval between the maximum utility level interval and the zero utility level interval, the utility level of the data decreases gradually from its maximum utility level to finally reach its lowest utility level (zero utility level).

In mathematical notation the utility objective function can be represented as:

$$maximise\ f_2(\bar{x})$$

where

$$f_2(\bar{x}) = (x_1 \leq a) \rightarrow 100$$

$$f_2(\bar{x}) = (x_1 \geq b) \rightarrow 0$$

$$f_2(\bar{x}) = (a < x_1 < b) \rightarrow 100 - \frac{100 * (x_1 - a)}{(b - a)}$$

Utility Objective Function

a represents the maximum utility level interval and b represents the zero utility level interval.

3.5.2.3 Remaining Battery Life Objective Function

Battery life is one fundamental limitation of mobile devices which is mainly introduced by the requirements for mobile devices to be small and light. The battery is required not only to keep the mobile device alive but also to enable the device to do several important task including transmitting data. Therefore, a sufficient amount of remaining battery life is essential (Ballard 2007; Subramanya & Byung 2006). A solution for mobile data access that maintains the remaining battery life of the mobile device is necessary for the users. This is one of the important factors that influences users' satisfaction while they are using their mobile device.

The remaining battery life is best measured by the "charge" or power measured in mili Ampere hours (mAh). Each data transfer connection drains the battery and thus lowers the remaining charge in the battery. Typically, the charge is drained at a slow constant rate to keep the device connected and alive. However, data transfer requires significantly larger power to radiate signals and to perform related computation activities. The power demand for a data transfer task is determined by a number of factors including the communication mode, duration and noise characteristics of the channel. However, drained battery charge is not a permanent liability. The battery levels are frequently restored by regular recharges of the battery.

Considering the importance of the remaining battery life for the mobile users' satisfaction therefore, an objective function related to the remaining battery life is implemented as the third objective function in this simulation study. To calculate the remaining battery life there are several variables involved in the calculation process. The first variable is the duration of the Internet connection usage in order to transmit the data. The connection duration itself relies on two other variables, which are the estimated data size and also the network speed. For calculation purposes, the measurement unit for the network speed is in bps (bit per second), however, the user will perceive it in Mbps (megabit per second). The network speed also varies for each resource type (network type and network provider), as does the battery consumption. Moreover, the mobile device itself will consume a constant amount of battery life for each particular time interval in order to keep its life.

In mathematical notation, the battery life objective function can be represented as:

$$maximise\ f_3(\bar{x})$$

where

$$f_3(\bar{x}) = BL - deviceBattUse(x_1) - transmitBattUse(EDS, x_2)$$

Remaining Battery Life Objective Function

BL represents the initial remaining battery life before the data transmission, $deviceBattUse(x_1)$ represents the constant battery consumption to power up the mobile device for the duration of x_1, and $transmitBattUse(EDS, x_2)$ represents the battery consumption in in order to transmit the data with the estimated size of EDS using resource type x_2.

3.5.2.4 Liability Objective Function

In economics, if a resource is used for a purpose, it is not available for alternate usages. This is referred to as an opportunity cost. A similar dilemma is also faced by the users of mobile devices. Battery life is an important resource and devices become un-usable once the battery has run out.

In this study, the liability is also modeled and used as an important objective function to determine user's satisfaction. The liability level represents the liability that will be produced as a consequence of the usage of some amount of the battery power in order to transmit the data with respect to the current remaining battery life. The liability level will reduce the future opportunity involved with the usage of the mobile device due to the insufficient remaining battery life. In mathematical notation, the liability objective function can be represented as:

$$minimise\ f_4(\overline{x})$$

where

$$f_4(\overline{x}) = (RBL = max) \rightarrow 0$$

$$f_4(\overline{x}) = \neg(RBL = max) \rightarrow \frac{transmitBattUse(EDS, x_2) * powerAvailInterval(x_1)}{BL}$$

Liability Objective Function

RBL represents the remaining battery life after transmitting the data, max represents the maximum battery life, $transmitBattUse(EDS,$ $x_2)$ represents the battery consumption in order to transmit the data with the EDS amount of estimated data size using resource type x_2, BL represents the remaining battery life before transmitting the data, and $pwrAvailIntval(x_1)$ represents the time interval to reach the closest available power outlet in order to recharge the battery based on x_1 postpone interval. The optimum value for the liability level is 0.

3.5.2.5 Access Interval Objective Function

It is typical for mobile devices to be not fully available when they are busy transmitting data. This limitation is often the result of their available computational power as well as limited wireless bandwidth. A relatively low bandwidth and slow data rate are part of the limitations in mobile Internet access that lead to a longer access interval when a user is transferring data to the Internet using their mobile device. However, if the access time is too long it will require the user to wait longer for the data to be completely transferred, and it might also impact the user satisfaction level (Büyüközkan 2009; Fogelgren-Pedersen 2005). Moreover, longer access interval will also affect the battery consumption. The longer the access interval, the more it consumes the battery life (Chen et al. 1999).

Considering the importance of the mobile Internet access interval for the mobile users' satisfaction, an objective function related to the access interval is implemented as the last objective function in this simulation study. The access interval represents the time interval which is required in order to successfully transmit a particular amount of data using the available resource type. Each resource type has a different data rate (speed) in each particular time interval. Since the access interval depends on the data rate of the available resource type, the minimum access interval can be achieved by postponing the Internet access for a particular interval of time in order to get the fastest available network from a particular provider. In mathematical notation the access interval objective function can be represented as:

$$minimise\ f_5(\bar{x})$$

where

$$f_5(\bar{x}) = \frac{EDS}{speed(x_2)}$$

Access Interval Objective Function

$speed(x_2)$ represents the data rate (speed) of resource type x_2, and EDS represents the estimated size of the data being transmitted.

3.5.3 Constraints

The constraints in this case represent the environmental conditions that will restrict the value selection for each decision variable. In this model, constraints are also related to a mechanism to prevent a user from choosing decision variables which may lead to a failure in data transfer. There are two main constraints in this simulation study, which are: the minimum remaining battery life and the resource availability.

3.5.3.1 Minimum Remaining Battery Life

The minimum remaining battery life constraint is a prevention mechanism from producing a set of decision variables that will bring a negative value to the remaining battery life after the data transmission. In other words, this constraint will assure that there will be sufficient battery power in order to transmit the data based on the selected values of the decision variables. In mathematical notation, the battery constraint can be represented as:

$$g(\overline{x}) \geq 0$$

where

$$g(\overline{x}) = BL - deviceBattUse(x_1) - transmitBattUse(EDS, x_2)$$

Remaining Battery Life Constraint

BL represents the initial remaining battery life before the data transmission, $deviceBattUse(x_1)$ represents the constant battery consumption to power up the mobile device for the duration of x_1, and $transmitBattUse(EDS, x_2)$ represents the battery consumption in in order to transmit the data with the estimated size of EDS using resource type x_2.

3.5.3.2 Resource Type Availability

Since the resources, such as a particular network type provided by a particular network provider, are not available all the time but only available for some particular period of time, the resource availability constraint will restrict the usage of the resources based on the resources availability schedule. In other words, the resource availability constraint is used to prevent a user from choosing a set of decision variables that leads to a data transmission failure due to the unavailability of transmission media.

In mathematical notation, the resource type availability constraint can be represented as:

$$h(\overline{x}) = available$$

where

$$h(\overline{x}) = resourceAvailability(EDS, x_1, x_2)$$

Resource Availability Constraint

$resourceAvailability(EDS, x_1, x_2)$ represents the detection mechanism to check the availability of resource x_2 in order to successfully transmit the data with the estimated size of EDS while postponing with the interval of x_1 .

3.6 Evolutionary Algorithms: NSGA II

There are several evolutionary algorithms available to implement the Pareto based approach in order to solve the problem in multi-objective optimisation. In this research, NSGA II is the algorithm which has been chosen to run the simulation study. NSGA II or Non-dominated Sorting Genetic Algorithm version two is the new version of NSGA proposed by Kalyanmoy Deb, Samir Agrawal, Amrit Pratap, and T. Meyarivan. It is proposed in order to address several criticisms on the first version of NSGA such as high computational complexity of non-dominated sorting, lack of elitism, and need for specifying the sharing parameter. Compared to the first version of NSGA, NSGA II is more efficient in terms of computational process (Deb et al. 2000; Coello 2007). NSGA II uses elitism and a crowded comparison operator to maintain diversity of the population. Elitism is implemented in NSGA II in order to help achieve better convergence. In terms of converging near the Pareto Front and in terms of maintaining diversity among obtained solutions, NSGA II in general is better than PAES (Pareto Archived Evolution Strategy) and SPEA (Strength Pareto Evolutionary Algorithm), the two other elitist multi-objective evolutionary algorithms (Knowles & Corne 1999; Zitzler & Thiele 1999; Deb et al. 2000).

```
Initialize Population P
Generate random population - size N
Evaluate Objective Values
Assign Rank (level) Based on Pareto dominance - sort
Generate Child Population
Binary Tournament Selection
Recombination and Mutation
For i = 1 to number of generation do
  For each Parent and Child in Population do
    Assign Rank (level) based on Pareto - sort
    Generate sets of nondominated vectors along PFknown
    Loop (inside) by adding solutions to next generation
    starting from the first front until N individuals found
    determine crowding distance between points on each front
  End Loop
  Select points (elitist) on the lower front (with lower rank)
  and are outside a crowding distance
  Create next generation
  Binary Tournament Selection
  Recombination and Mutation
End Loop
```

Figure 3.1 NSGA II Pseudocode (Deb et al. 2000; Coello 2007)

3.7 jMetal Framework

In this research, jMetal framework is going to be used as the building blocks to construct the simulation model. jMetal stands for Metaheuristic Algorithms in Java, and it is a framework for constructing and solving the multi-objective optimisation problem using evolutionary algorithms. The framework is based on Java programming language and has been used in a wide range of applications since it was built as an easy to use, flexible, and extendable software package. This ease of use, flexibility, and extendibility can be achieved by jMetal since it takes full advantage of the capabilities that Java offers and is structured in a way that a problem can be developed as an independent class from the algorithm that solves it. A wide range of core classes which can be used as the building blocks of multi-objective metaheuristics are provided by this framework in order to take advantage of code-reusing (Durillo & Nebro 2011; Jmetal.sourceforge.net 2012).

The main reason for using jMetal as a development framework to construct the simulation model in this research is the fact that the evolutionary multi-objective algorithms in this framework are tested for their performance with standard multi-objective optimisation problems (Vergidis 2008; Durillo & Nebro 2011). Moreover, jMetal also support several Genetic Algorithms to solve multi-objective optimisation problem including NSGA II.

3.8 Simulation Scenario

In order to apply the methodology, in the next chapter, a few examples of current Internet services available in Australia for the mobile device usage will be presented. Various schedules which are used to represent the user behaviour with respect to the resource availability will be provided. These schedules will be used as the main part for the simulation scenario. The parameters which are going to be used in the simulation such as the data rate (speed) for each network type, the pricing scheme for each network provider, and the battery consumption for each network type will use realistic values in order to provide a nearly real life simulation study.

In the remaining part of this chapter, a great deal of data related to the pricing scheme of different network types which are offered by several network providers in Australia are presented.

Table 3.1 Price comparison of the Internet access in Australia (Data collected in May 2012)

Network Type	Provider	Quota (GB)	Price (AUD)
WLAN / ADSL	BigPond	50	$49.95
		200	$69.95
		500	$89.95
	Optus	120	$59.99
		150	$69.99
		500	$79.99
	iinet	100	$59.95
		200	$79.95
		400	$99.95
Cellular Data Networks	BigPond	1	$19.95
		4	$29.95
		8	$39.95
		15	$79.95
	Optus	1	$20.00
		5	$40.00
		6	$50.00
		8	$80.00
		15	$130.00
	Vodafone	2	$10.00
		4	$15.00
		8	$25.00
	Virgin Mobile	1	$10.00
		2	$20.00
		3	$30.00

3.9 Chapter Summary

An in-depth explanation of the methodology which is used in this study is presented in this chapter in a systematical order. This chapter covers several key points such as the need for multiple objectives in this research, related studies that have been conducted, the multi-objective optimisation problem, several possible approaches for satisfaction comparison, simulation model which is used in this study, evolutionary algorithms for the multi-objective optimisation problem, and jMetal framework as the building blocks to construct the simulation model. The simulation model has a significant role in this study and it also makes up the greatest part of this chapter. There are three major parts in the simulation models, which are: decision variables, constraints, and objective functions. Decision variables are related to the variable values which are a user can choose when he/she makes a decision to transfer data. Constraints represent the limitations in the operational environment. In this model, constraints are also related to a mechanism to prevent a user from choosing decision variables which may lead to a failure in data transfer. Objective functions in this model are related to the factors that are required to be optimised in order to produce a better satisfaction for the user.

Several scenarios and cases of data transmission will be simulated and presented in the following chapter.

Chapter 4

Experimental Evaluation

4. 1. Introduction

As part of this study, a simulation has been arranged/created. In this chapter, several details of the experiment as the main part of the simulation study will be examined/illustrated. For the purposes of simulating the multi-objective optimisation problem in mobile user satisfaction, several scenarios and cases will be introduced in the experiment. There are four different scenarios which are going to be constructed, and there will be four different cases of data transfer in each scenario. In this simulation study, the term 'scenario' refers to the several experimental data such as the list of available resource types, the resource availability schedule, and the power outlet availability schedule. Furthermore, the term 'case' in this simulation study will be used to represent several situations of data transfer requirements. Each case refers to different information such as the access time, the estimated size of the data which is required to be transmitted, the amount of remaining battery life, and also the maximum and the minimum or the zero utility interval of the data.

In this experiment, the term 'resource type' refers to the combination of network type and network provider. There are two different types of network used in the experiment, which are WiFi and cellular data network. In some scenarios, these network types will be provided by some specific network providers. However, in some other scenarios, these network types will be treated as general network types without any information about a particular network provider.

Successful execution of simulations based on the realistic data transfer needs and communication parameters provides a proof of the concept for the model in this simulation study. These experiments also provide another benefit, the results of these experiments would offer a clear and measurable indication of the range of objective function values which a mobile device user can observe when using their device. The objective functions that do not show significant variation in the Pareto Front across the experiments are unlikely to affect the user's decisions to any great degree.

As indicated earlier, the study is based on four scenarios, each with multiple cases representing different data transfer needs. In order to support the aim of understanding the relationships between the decisions and their effects on the outcomes, these scenarios are organised in order of increasing complexity. The first scenario is simple and does not involve any overlapping in the resource availability -- there is only one available resource at each point in time. Progressively, the later scenarios include more options and opportunities to be selected from a range of alternatives.

4. 2. Scenario 1

In the first scenario, there will be two available resource types, which are WiFi and cellular data network. These resource types will be treated as general network types without any specific information about network providers. In terms of the pricing scheme, WiFi will cost $0.999 for every 1 Gigabyte of data transfer, and cellular data network will cost $19.95 for every 1 Gigabyte data transfer.

Table 4.1 Resource Types for Scenario 1

Resource Detail		
Resource Type	Cost ($/GB)	Power Use (mAh/sec)
WiFi	0.999	0.08
CELLULAR	19.95	0.03

In terms or power consumption, for the purposes of this simulation study, WiFi will consume 0.08mAh of battery life for every second of utilisation and cellular data network will consume 0.03mAh of battery life. The mobile device itself has a constant consumption of 0.008mAh from battery life in order to keep its life, and the maximum battery life capacity when the mobile device is fully charged is 1,300mAh.

The resource availability schedule in this scenario is designed to be free from any resource overlapping; or in other words, there will be only one available resource type in a particular time. Each resource type also has a constant data rate or speed. For WiFi, the data rate is fixed at 50 Mbps and for cellular data network the data rate is fixed at 5 Mbps. There are two periods in this scenario where there is no resource available to be used. These periods of time are used in this experiment to simulate the dead zone. The detail information about the resource availability for this scenario is presented in Table 4.2.

Table 4.2 Resource Availability Schedule for Scenario 1

Resource Availability Schedule			
Start	**End**	**Resource Type**	**Speed (Mbps)**
00:00:00	05:59:59	WiFi	50
06:00:00	07:59:59	CELLULAR	5
08:00:00	09:59:59	WiFi	50
10:00:00	11:59:59	CELLULAR	5
12:00:00	12:59:59	N/A	0
13:00:00	14:59:59	CELLULAR	5
15:00:00	16:59:59	WiFi	50
17:00:00	17:59:59	N/A	0
18:00:00	19:59:59	WiFi	50
20:00:00	21:59:59	CELLULAR	5
22:00:00	23:59:59	WiFi	50

There are four occurrences of power outlet availability in this scenario. These period of time are introduced in the experiment in order to simulate the period for a user to recharge his/her mobile device. The detailed information about the power outlet availability for this scenario is presented in Table 4.3.

Table 4.3 Power Outlet Availability for Scenario 1

Power Outlet Availability Schedule	
Start	**End**
11:30:00	11:44:59
14:30:00	14:44:59
17:30:00	17:44:59
21:30:00	21:44:59

Four cases will be simulated in this scenario. Each case is varied in terms of access time, data size, remaining battery life, and the intervals of maximum and minimum (zero) utility level. A brief overview of the experiment case for this scenario is presented in Table 4.4 and further information for each case will be provided in the following section.

Table 4.4 Experiment Cases for Scenario 1

Experiment Case				
Input Variable	**case 1**	**case 2**	**case 3**	**case 4**
Access Time (hh:mm:ss)	06:30:00	13:15:00	14:15:00	19:45:00
Data Size (MB)	300	500	800	1000
Remining Battery Life (mAh)	800	200	300	100
Max Utility Value Interval (minutes)	30	60	30	15
Min Utility Value Interval (minutes)	360	240	60	240

4.2.1 Case 1

The first case of this experiment will simulate the condition where a user is going to transfer particular data using his/her mobile device. The intended user's data transfer is at 6:30 and the estimated size of the data which is going to be transmitted is 300 Megabytes. The data can produce a maximum utility level for the user if data is transferred within the maximum postpone interval of 30 minutes, and its utility level will drop to zero if it is transferred after 6 hours (360 minutes). In this case, the mobile device which is going to be used to transmit the data has 800mAh of remaining battery life.This information is going to be used as the input parameters in order to find the set of solutions that can produce the optimum level of satisfaction for the user.

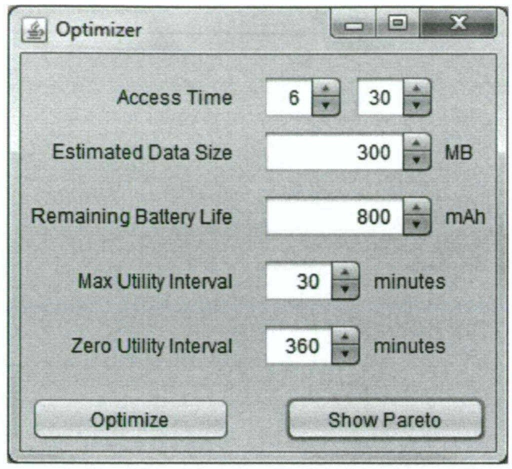


Figure 4.1 Access Parameters for Scenario 1 Case 1

Based on these input parameters, a set of non-dominated/optimum solutions is produced and presented in Figure 4.2.

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
0.0012	CELLULAR	5.8447	100.0	784.8999	5.6623	8.3886
82.0036	CELLULAR	5.5875	84.2413	746.0517	5.7533	8.0389
84.2548	CELLULAR	4.0983	83.5592	747.9412	4.5884	6.0139
85.0784	CELLULAR	3.5578	83.3096	748.6238	4.1648	5.2789
86.0247	CELLULAR	2.9291	83.0228	749.4236	3.6714	4.4239
86.0787	CELLULAR	2.8849	83.0065	749.4857	3.6365	4.3639
89.2893	CELLULAR	0.767	82.0336	752.1686	1.9704	1.4839
89.4281	CELLULAR	0.6788	81.9915	752.278	1.9008	1.3639
89.6448	CELLULAR	0.5354	81.9258	752.46	1.7877	1.1689
90.6895	WiFi	0.2927	81.6092	752.4425	1.5968	0.8389
292.4601	CELLULAR	5.8447	20.4666	1300.0	0.0	8.3886
510.1527	WiFi	0.2927	0.0	1202.2935	1.0014	0.8389

Figure 4.2 Pareto Set and Pareto Front for Scenario 1 Case 1

Figure 4.2 shows the Pareto Set and Pareto Front produced by the NGSA II Algorithm based on the input parameters in case 1. The Pareto Set in this experiment represents the optimum or the non-dominated set of solutions and the Pareto Front represents the optimum or the non-dominated set of user satisfaction factors. The solution in this experiment refers to the combination of postpone interval and resource type which are chosen to transmit the data.

As shown in Figure 4.2, the maximum utility level can be achieved by postponing the data transfer for 0.0012 minutes and based on the resource availability schedule, the available resource that can be used to transmit the data is the cellular data network. This non-dominated/optimum solution produces a relatively high level in access cost and access interval since all of the data is transferred using the cellular data network.

By postponing the data transfer in the interval between 82.0036 minutes and 90.6895 minutes, the user can get a lower access cost and a faster data rate since in this period of time there is a transition of the available resource from cellular data network to WiFi. In this period, some part of the data will be transmitted using the cellular data network and the rest will be transmitted using WiFi. These solutions are still able to maintain the utility level in the level between 81.6092 and 84.2413.

The other non-dominated/optimum satisfaction level is produced by postponing the data transfer for 292.4601 minutes. By using this solution, the highest battery life and the lowest liability level can be achieved since the power outlet is available at the end of data transmission. However, this solution produces a relatively high level of access cost and access interval since all data is transmitted using cellular data network.

The last non-dominated/optimum solution offered by the algorithm for this case is by postponing the data transmission for 510.1527 minutes. By using this solution, the user will get the lowest access cost and the shortest access interval since all of the data is transmitted using WiFi. The high amount of battery life can also be achieved since the data is transmitted after a battery recharging period. However, since the postpone interval is longer than the zero utility level interval, the user will not be able to get any utility value from the transferred data.

4.2.2 Case 2

In the second case of this experiment, the intended user access time is 13:15 and the estimated size of the data which is going to be transmitted is 500 Megabytes. The data can produce a maximum utility level for the user if it is transferred within the maximum postpone interval of an hour (60 minutes), and its utility level will drop to zero if it is transmitted with a postpone interval longer than 4 hours (240 minutes). In this case, the mobile device which is going to be used to transmit the data has 200mAh of remaining battery life. This information will be used as the input parameters in order to find the set of solutions that can produce the optimum level of satisfaction for the user.

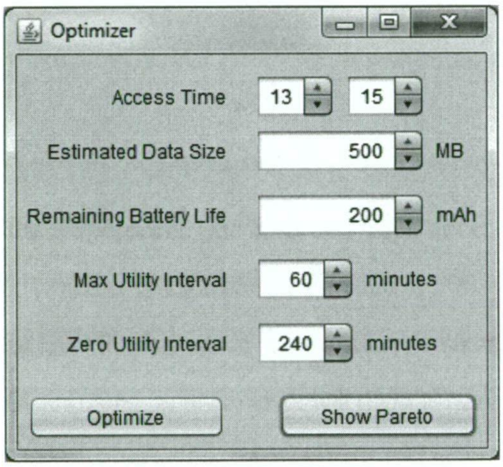


Figure 4.3 Access Parameters for Scenario 1 Case 2

Based on these input parameters, a set of non-dominated/optimum solutions is produced and presented in Figure 4.4.

Pareto Set & Pareto Front

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
0.0269	CELLULAR	9.7412	100.0	174.8213	9.4399	13.981
0.0677	CELLULAR	9.7412	100.0	174.8017	9.4387	13.981
61.5374	CELLULAR	9.7412	99.1459	1300.0	0.0	13.981
92.651	CELLULAR	8.6507	81.8605	1275.7211	1.3277	12.4981
93.2389	CELLULAR	8.2756	81.534	1276.1971	1.2848	11.9881
93.5598	CELLULAR	8.055	81.3557	1276.4771	1.2595	11.6881
97.1761	CELLULAR	5.6723	79.3466	1279.5011	0.9865	8.4481
97.7432	CELLULAR	5.2862	79.0316	1279.9911	0.942	7.9231
99.9019	CELLULAR	3.8522	77.8323	1281.8111	0.7771	5.9731
102.2882	CELLULAR	2.2858	76.5066	1283.7991	0.5969	3.8431
104.6071	CELLULAR	0.7525	75.2183	1285.7451	0.42	1.7581
105.1657	WiFi	0.4878	74.9079	1286.0011	0.3893	1.3981

Figure 4.4 Pareto Set and Pareto Front for Scenario 1 Case 2

Figure 4.4 shows the Pareto Set and Pareto Front produced by the NGSA II Algorithm based on the input parameters in case 2.

As shown in Figure 4.4, the maximum utility level can be achieved by postponing the data transmission between 0.0269 and 0.0677 minutes. However, these non-dominated/optimum solutions involve a relatively high access cost and access interval since the entire data is fully transmitted using the cellular data network.

By postponing the data transmission for 61.5374 minutes, the user can get the most optimum battery life and liability level since the power outlet is available at the end of data transmission. However, the access cost and the access interval are still relatively high as this data completely transferred using the cellular data network

The other non-dominated/optimum satisfaction levels are produced by postponing the data transmission in the interval between 92.651 and 105.1657 minutes. By using these solutions, the user can get a lower access cost and a faster data rate since in this period of time there is a transition of the available resource from cellular data network to WiFi. In this period, some part of the data will be transmitted using cellular data network and the rest will be transferred using WiFi. These solutions are still able to maintain the utility level in the range of 74.9079 to 81.8605. Moreover, since the data is transferred just after the battery recharging period, the user can also get a relatively high amount of remaining battery life and low liability level.

4.2.3 Case 3

In the third case of this experiment, the intended user access time is 14:15 and the estimated size of the data to be transferred is 800 Megabytes. The maximum utility level for the user can be achieved if it is transmitted within the maximum postpone interval of half an hour (30 minutes), and its utility level will drop to zero if it is transmitted within a postpone interval longer than one hour (60 minutes). Compared to the previous two cases, the size of the data in this case is bigger and the interval for both the maximum and the minimum utility level is much shorter. In this case, the mobile device which is going to be used to transfer the data has 300mAh of remaining battery life. This information is to be used as the input parameters in order to find the set of solutions that can produce the optimum level of user satisfaction.

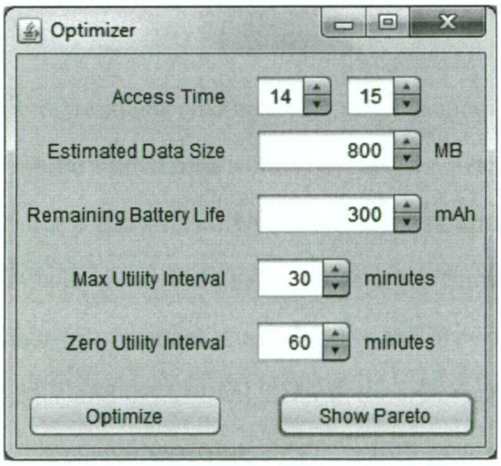


Figure 4.5 Access Parameters for Scenario 1 Case 3

Based on these input parameters, a set of non-dominated/optimum solutions is produced and presented in Figure 4.6.

Pareto Set & Pareto Front

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
2.2824	CELLULAR	15.5859	100.0	1300.0	0.0	22.3696
4.2014	CELLULAR	15.5859	100.0	1300.0	0.0	22.3696
31.1821	CELLULAR	9.9251	96.0598	1270.4486	0.3345	14.672
31.408	CELLULAR	9.7707	95.3065	1270.6446	0.331	14.462
31.5758	CELLULAR	9.6604	94.7473	1270.7846	0.3284	14.312
31.7087	CELLULAR	9.5721	94.3043	1270.8966	0.3264	14.192
32.5397	CELLULAR	9.0206	91.5342	1271.5966	0.3138	13.442
33.0395	CELLULAR	8.6896	89.8685	1272.0166	0.3062	12.992
33.1488	CELLULAR	8.6235	89.5041	1272.1006	0.3047	12.902
45.0234	WiFi	0.7805	49.9218	1282.0466	0.1247	2.237
45.2577	WiFi	0.7805	49.1411	1281.9266	0.1246	2.237

Figure 4.6 Pareto Set and Pareto Front for Scenario 1 Case 3

Figure 4.6 shows the Pareto Set and Pareto Front that are produced by the NGSA II Algorithm based on the input parameters in case 3.

As shown in Figure 4.6, by postponing the data transmission in the interval between 2.2824 and 4.2014 minutes, the user can get not only the highest value for utility level, but also the maximum amount of battery life and the lowest level of liability. This condition can be achieved because the data transmission ends in the period of time while battery recharging is possible.

Some other non-dominated/optimum satisfaction levels are produced by postponing the data transmission in the interval between 31.1821 and 33.1488 minutes. By using these solutions, the access costs gradually decrease from $9.9251 to $8.6235. This happens because in this period of time there is a transition of the available resource type from cellular data network to WiFi. Therefore, one part of the data will be transferred using cellular data network and the rest will be transmitted using WiFi. Moreover, these solutions can still maintain a utility level of 89.5041 to 96.0598.

The final set of non-dominated/optimum solutions offered by the algorithm for this case is to postpone the data transmission in the interval between 45.0234 and 45.2577 minutes. By using this set of solutions, the user will get the lowest access cost and the lowest access interval because the data is completely transmitted using WiFi. The utility level that can be maintained is at the level between 49.9218 and 49.1411.

4.2.4 Case 4

In the fourth case, the intended user access time is 19:45 and the estimated size of the data to be transferred is 1,000 Megabytes. The data can produce a maximum utility level for the user if it is transmitted within the maximum postpone interval of a quarter of an hour (15 minutes), and its utility level will drop to zero if it is transmitted within a postpone interval longer than 3 hours (180 minutes). In this case, the mobile device which is going to be used to transfer the data has 100mAh of remaining battery life. Compared to the other cases in this first scenario, this case has the biggest estimated data size and the lowest remaining battery life. This information is going to be used as the input parameters in order to find the set of solutions that can produce the optimum level of satisfaction for the user.

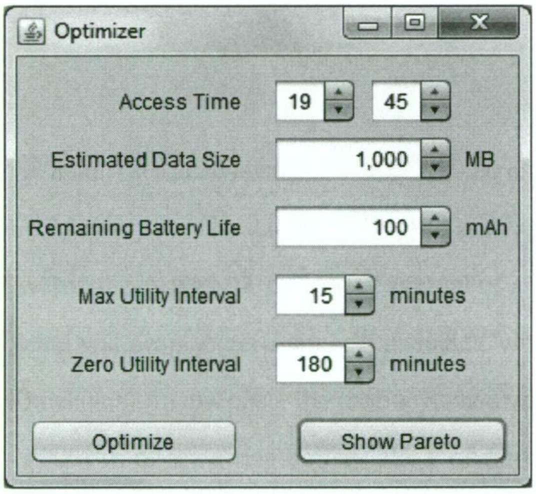


Figure 4.7 Access Parameters for Scenario 1 Case 4

Based on these input parameters, a set of non-dominated/optimum solutions is produced and presented in Figure 4.8.

Pareto Set & Pareto Front

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
0.0071	WiFi	0.9756	100.0	86.5748	14.0933	2.7962
77.4734	CELLULAR	19.4824	72.234	1300.0	0.0	27.962
108.0679	CELLULAR	18.7905	58.6365	1251.0482	3.9538	27.0212
108.1086	CELLULAR	18.7685	58.6184	1251.0922	3.9502	26.9912
113.6312	CELLULAR	15.1172	56.1639	1258.3742	3.3621	22.0262
116.095	CELLULAR	13.4847	55.0689	1261.6302	3.0991	19.8062
118.1371	CELLULAR	12.1279	54.1613	1264.3362	2.8805	17.9612
119.3838	CELLULAR	11.3005	53.6072	1265.9862	2.7473	16.8362
121.6422	CELLULAR	9.8114	52.6035	1268.1562	2.5089	14.8112
124.5339	CELLULAR	7.892	51.3183	1270.5922	2.2019	12.2012
125.0175	CELLULAR	7.5721	51.1033	1270.9982	2.1507	11.7662
125.1218	CELLULAR	7.5059	51.057	1271.0822	2.1401	11.6762
126.0663	CELLULAR	6.8882	50.6372	1271.8662	2.0411	10.8362
126.663	CELLULAR	6.5021	50.372	1272.3562	1.9795	10.3112
130.821	CELLULAR	3.7333	48.524	1275.8702	1.5344	6.5462
135.1431	WiFi	0.9756	46.6031	1279.2982	1.0902	2.7962

Figure 4.8 Pareto Set and Pareto Front for Scenario 1 Case 4

As shown in Figure 4.8, the maximum utility level can be achieved by postponing the data transmission for 0.0071 minutes. By using this solution, the user can also get the lowest access cost and access interval. This condition can be achieved since in this period of time all of the data can be transmitted using WiFi. However, compared to the other non-dominated/optimum solutions offered by the algorithm, this solution produces the lowest amount of remaining battery life and the highest level of liability.

By postponing the data transmission for 77.4734 minutes, the highest battery life and the lowest liability level can be achieved since the power outlet is available at the end of data transmission. This solution can also maintain the utility at the level of 72.234.

The other non-dominated/optimum satisfaction levels can be produced by postponing the data transmission in the interval between 108.0679 minutes and 130.821 minutes. By using these solutions, the user can get a lower access cost and a faster data rate since in this period of time there is a transition between the cellular data network and WiFi. Therefore, the first part of the data will be transferred using the cellular data network and the rest using WiFi. Since the data is transmitted after the battery recharging period, a high amount of battery life can also be achieved by using these solutions. However, these solutions can only maintain a utility level between 48.524 and 58.6365.

The last non-dominated/optimum solution offered by the algorithm for this case is to postpone the data transmission for 135.1431 minutes. By using this solution, the user will get the lowest access cost and the lowest access interval because the entirely of the data is transferred using WiFi. A high amount of battery life can also be achieved since the data is transmitted after the battery recharging period.

4.3 Scenario 2

As in scenario 1, in the second scenario, there will be two available resource types, namely WiFi and cellular data network. These resource types will be treated as general network types without any specific information about network providers. In terms of pricing schemes, WiFi will cost $0.999 for every 1 Gigabyte of data transmission, and cellular data network will cost $19.95 for every 1 Gigabyte data transmission.

Table 4.5 Resource Types for Scenario 2

Resource Detail		
Resource Type	Cost ($/GB)	Power Use (mAh/sec)
WiFi	0.999	0.08
CELLULAR	19.95	0.03

In terms or power consumption, for the purposes of this simulation study, WiFi will consume 0.08mAh of battery life for every second of utilisation and cellular data network will consume 0.03mAh of battery life. The mobile device itself has a constant consumption of 0.008mAh from battery life in order to keep its life, and the maximum battery life capacity when the mobile device is fully charged is 1,300mAh.

The resource availability schedule in this scenario is designed to introduce resource overlapping or in other words, there will be more than one available resource types at one particular time. Each resource type also has a constant data rate or speed. For WiFi, the data rate is fixed at 50 Mbps and for cellular data network the data rate is fixed at 5 Mbps. There are two periods in this scenario where there is no resource available to be used. These periods of time represent the dead zone. The detailed information about the resource availability for this scenario is presented in Table 4.6.

Table 4.6 Resource Availability Schedule for Scenario 2

Resource Availability Schedule			
Start	End	Resource Type	Speed (Mbps)
00:00:00	05:59:59	WiFi	50
05:30:00	07:59:59	CELLULAR	5
07:30:00	09:59:59	WiFi	50
09:30:00	11:59:59	CELLULAR	5
12:00:00	12:59:59	N/A	0
13:00:00	14:59:59	CELLULAR	5
14:30:00	16:59:59	WiFi	50
17:00:00	17:59:59	N/A	0
18:00:00	19:59:59	WiFi	50
19:30:00	21:59:59	CELLULAR	5
21:30:00	23:59:59	WiFi	50

There are four occurrences of power outlet availability in this scenario. These period of time are introduced in the experiment in order to simulate the period for a user to recharge his/her mobile device. The detail information about the power outlet availability for this scenario is presented in Table 4.7.

Table 4.7 Power Outlet Availability for Scenario 2

Power Outlet Availability Schedule	
Start	End
11:30:00	11:44:59
14:30:00	14:44:59
17:30:00	17:44:59
21:30:00	21:44:59

There are four cases will be simulated in this scenario. Each case is varied in term of access time, data size, remaining battery life, and the interval of maximum and minimum (zero) utility level. A brief information about the experiment case for this scenario is presented in Table 4.8 and the detail information for each case will be provided in the following section.

Table 4.8 Experiment Cases for Scenario 2

Experiment Case				
Input Variable	**case 1**	**case 2**	**case 3**	**case 4**
Access Time (hh:mm:ss)	06:15:00	13:30:00	14:15:00	19:45:00
Data Size (MB)	300	500	800	1000
Remining Battery Life (mAh)	800	200	50	100
Max Utility Value Interval (minutes)	15	30	30	60
Min Utility Value Interval (minutes)	330	180	120	180

4.3.1 Case 1

In the first case of this experiment, the user access time is happen at 6:15 and the estimated size of the data which is going to be transferred is 300 Megabytes. The data can produce a maximum utility level for the user if it is transmitted within the maximum postpone interval of 15 minutes, and this utility level will drop to zero if it is transferred within a postpone interval longer than 5.5 hours (330 minutes). In this case, the mobile device which will be used to transfer the data has 800mAh of remaining battery life. These will form the parameters be used as the input parameters in order to find the set of solutions that can produce the optimum level of satisfaction for the user.

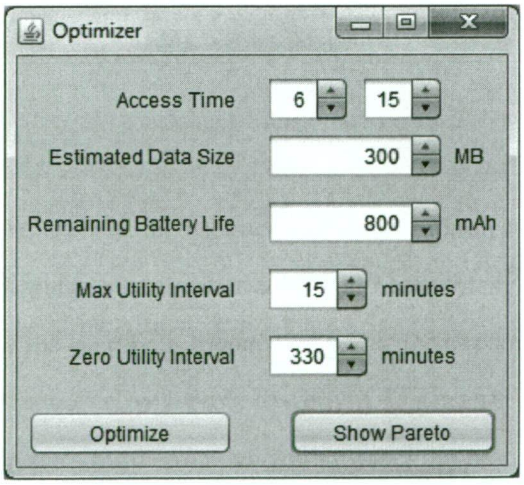


Figure 4.9 Access Parameters for Scenario 2 Case 1

Based on these input parameters, a set of non-dominated/optimum solutions is produced and presented in Figure 4.10.

Pareto Set & Pareto Front

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
0.0089	CELLULAR	5.8447	100.0	784.8962	5.9455	8.3886
75.0053	WiFi	0.2927	80.9507	759.9709	1.6602	0.8389
307.6061	CELLULAR	5.8447	7.1092	1300.0	0.0	8.3886
498.1298	WiFi	0.2927	0.0	1300.0	0.0	0.8389
499.1362	WiFi	0.2927	0.0	1300.0	0.0	0.8389
499.6762	WiFi	0.2927	0.0	1300.0	0.0	0.8389
500.9491	WiFi	0.2927	0.0	1300.0	0.0	0.8389
504.6094	WiFi	0.2927	0.0	1300.0	0.0	0.8389
505.2825	WiFi	0.2927	0.0	1300.0	0.0	0.8389
505.8763	WiFi	0.2927	0.0	1300.0	0.0	0.8389
506.5608	WiFi	0.2927	0.0	1300.0	0.0	0.8389
508.6314	WiFi	0.2927	0.0	1300.0	0.0	0.8389
508.7222	WiFi	0.2927	0.0	1300.0	0.0	0.8389

Figure 4.10 Pareto Set and Pareto Front for Scenario 2 Case 1

As shown in Figure 4.10, the maximum utility level can be achieved by postponing the data transmission for 0.0089 minutes and based on the resource availability schedule, the only available resource type which can be used to transfer the data is cellular data network. Compared to the other optimum solutions, This solution produces the highest access cost and access interval since the data is transmitted using cellular data network in its entirety.

By postponing the data transmission for 75.0053 minutes, the user can get a lower access cost and a shorter access interval since in this period of time there are two available resource types and the algorithm chose to use WiFi which is cheaper in terms of access cost and faster in terms of data rate. By using this solution, the utility can also be maintained at the level of 80.9507.

The other optimum satisfaction level is produced by postponing the data transmission for 307.6061 minutes. By using this solution, the highest battery life and the lowest liability level can be achieved since recharging is available at the end of data transmission. However, this solution produces a relatively high access cost and access interval since the only available resource that can be used to transfer the data is cellular data network and the entire data has to be transferred using this network.

The last set of optimum solutions offered by the algorithm for this case is to postpone the data transmission in the interval between 498.1298 and 508.7222 minutes. By using this set of solutions, the user will get the lowest access cost and the lowest access interval since all of the data is transmitted using WiFi. The maximum amount of battery life can also be achieved since a power outlet is available at the end of data transmission. However, since the postpone interval is longer than the zero utility level interval, the user will not be able to get any utility value from the data.

4.3.2 Case 2

In the second case of this experiment, the intended user access time is 13:30 and the estimated size of the transferred data is 500 Megabytes. A maximum utility level can be produced for the user if the data is transmitted within the maximum postpone interval of half an hour (30 minutes), and its utility level will drop to zero if it is transmitted within a postpone interval longer than 3 hours (180 minutes). In this case, the mobile device which is going to be used to transfer the data has 200mAh of remaining battery life.This information will form input parameters in order to find the set of solutions that can produce optimum level of user satisfaction.

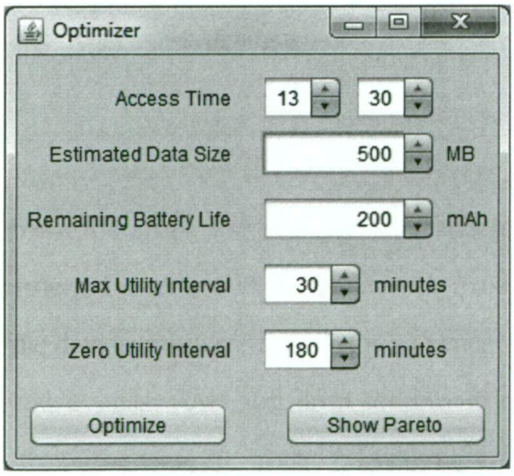


Figure 4.11 Access Parameters for Scenario 2 Case 2

Figure 4.12 shows a set of non-dominated/optimum solutions produced using the input parameters.

Pareto Set & Pareto Front

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
0.0051	CELLULAR	9.7412	100.0	174.8317	7.5498	13.981
46.059	CELLULAR	9.7412	89.294	1300.0	0.0	13.981
60.0961	WiFi	0.4878	79.9359	1300.0	0.0	1.3981

Figure 4.12 Pareto Set and Pareto Front for Scenario 2 Case 2

As shown in Figure 4.12, the maximum utility level can be achieved by postponing the data transmission for 0.0051 minutes and based on the resource availability schedule, the only available resource type that can be used to transfer the data is cellular data network. This solution produces a relatively high access cost and access interval as the data is entirely transmitted using cellular data network.

By postponing the data transmission for 46.059 minutes, the user can get a maximum amount of battery life and the lowest liability level since recharging is possible at the end of data transfer. This solution can also maintain a utility level of 89.294. However, since cellular data network is the only available resource type in this period, this solution also produces a relatively high access cost and access interval.

The other optimum solution offered by the algorithm for this case is to postpone the data transfer for 60.0961 minutes. Compared to the other non-dominated solutions, this solution can produce the lowest access cost and the shortest access interval since there are two resources available in this period and the algorithm chose to transmit the data using WiFi instead of cellular data network. Moreover, the maximum battery life and the lowest liability level can also be achieved since a power outlet is available after the data is transmitted. However, compared to the other optimum solutions, this solution produces the lowest utility level.

4.3.3 Case 3

In the third case of this experiment, the intended user access time is 14:15 and the estimated size of the data which is going to be transferred is 800 Megabytes. The data can produce a maximum utility level for the user if it is transferred within the maximum postpone interval of half an hour (30 minutes), and its utility level will decrease to zero if it is transmitted within a postpone interval longer than 2 hours (120 minutes). In this case, the mobile device which is going to be used to transfer the data has only 50mAh of remaining battery life. In this scenario, this case is the one which uses the least battery life. The set of solutions that leads to the highest level of user satisfaction will be found by using this information as the input parameters.

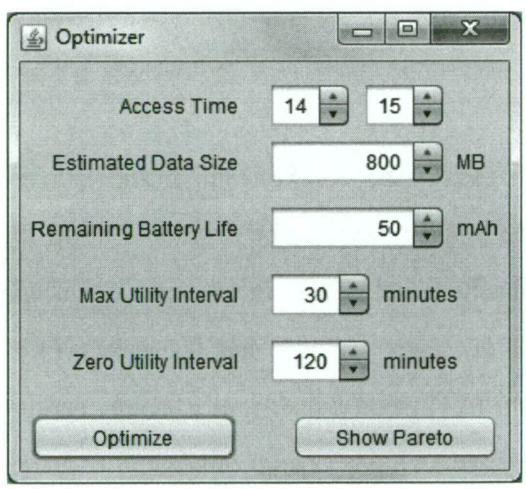


Figure 4.13 Access Parameters for Scenario 2 Case 3

Based on these input parameters, a set of non-dominated/optimum solutions is produced and presented in Figure 4.14.

Pareto Set & Pareto Front

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
15.3596	WiFi	0.7805	100.0	1300.0	0.0	2.237
15.398	WiFi	0.7805	100.0	1300.0	0.0	2.237
15.6383	WiFi	0.7805	100.0	1300.0	0.0	2.237
15.6588	WiFi	0.7805	100.0	1300.0	0.0	2.237
16.1546	WiFi	0.7805	100.0	1300.0	0.0	2.237
16.5737	WiFi	0.7805	100.0	1300.0	0.0	2.237
16.7023	WiFi	0.7805	100.0	1300.0	0.0	2.237
16.7131	WiFi	0.7805	100.0	1300.0	0.0	2.237
16.7429	WiFi	0.7805	100.0	1300.0	0.0	2.237
16.7828	WiFi	0.7805	100.0	1300.0	0.0	2.237
16.9967	WiFi	0.7805	100.0	1300.0	0.0	2.237
17.0385	WiFi	0.7805	100.0	1300.0	0.0	2.237
17.2988	WiFi	0.7805	100.0	1300.0	0.0	2.237
17.9429	WiFi	0.7805	100.0	1300.0	0.0	2.237
17.9846	WiFi	0.7805	100.0	1300.0	0.0	2.237
18.036	WiFi	0.7805	100.0	1300.0	0.0	2.237
18.0544	WiFi	0.7805	100.0	1300.0	0.0	2.237
18.0801	WiFi	0.7805	100.0	1300.0	0.0	2.237
18.6506	WiFi	0.7805	100.0	1300.0	0.0	2.237
18.8362	WiFi	0.7805	100.0	1300.0	0.0	2.237
19.2858	WiFi	0.7805	100.0	1300.0	0.0	2.237
19.794	WiFi	0.7805	100.0	1300.0	0.0	2.237
21.0589	WiFi	0.7805	100.0	1300.0	0.0	2.237
21.3776	WiFi	0.7805	100.0	1300.0	0.0	2.237
21.4245	WiFi	0.7805	100.0	1300.0	0.0	2.237
21.4547	WiFi	0.7805	100.0	1300.0	0.0	2.237
21.4768	WiFi	0.7805	100.0	1300.0	0.0	2.237
21.4845	WiFi	0.7805	100.0	1300.0	0.0	2.237
21.5022	WiFi	0.7805	100.0	1300.0	0.0	2.237
21.5321	WiFi	0.7805	100.0	1300.0	0.0	2.237
22.1074	WiFi	0.7805	100.0	1300.0	0.0	2.237
22.1646	WiFi	0.7805	100.0	1300.0	0.0	2.237
22.1685	WiFi	0.7805	100.0	1300.0	0.0	2.237
23.0445	WiFi	0.7805	100.0	1300.0	0.0	2.237
23.0622	WiFi	0.7805	100.0	1300.0	0.0	2.237
23.1688	WiFi	0.7805	100.0	1300.0	0.0	2.237
23.466	WiFi	0.7805	100.0	1300.0	0.0	2.237
23.7593	WiFi	0.7805	100.0	1300.0	0.0	2.237
23.7824	WiFi	0.7805	100.0	1300.0	0.0	2.237
23.8164	WiFi	0.7805	100.0	1300.0	0.0	2.237
23.8375	WiFi	0.7805	100.0	1300.0	0.0	2.237
23.8744	WiFi	0.7805	100.0	1300.0	0.0	2.237
25.6557	WiFi	0.7805	100.0	1300.0	0.0	2.237
25.6675	WiFi	0.7805	100.0	1300.0	0.0	2.237
25.6898	WiFi	0.7805	100.0	1300.0	0.0	2.237
25.7011	WiFi	0.7805	100.0	1300.0	0.0	2.237
26.566	WiFi	0.7805	100.0	1300.0	0.0	2.237
26.574	WiFi	0.7805	100.0	1300.0	0.0	2.237
26.6195	WiFi	0.7805	100.0	1300.0	0.0	2.237
27.4204	WiFi	0.7805	100.0	1300.0	0.0	2.237

Figure 4.14 Pareto Set and Pareto Front for Scenario 2 Case 3

As shown in Figure 4.14, the set of optimum solutions which is produced by the algorithm is in the range of 15.3596 to 27.4204 minutes for the postpone interval. This set of solutions can produce a maximum level of utility for the user and also a maximum amount of battery life since the data transmission ends in the period while the power outlet is available. Moreover, both WiFi and cellular data network are available in this period, therefore the algorithm can choose to use WiFi in order to be able to produce the lowest access cost and the shortest access interval for the user.

4.3.4 Case 4

In the fourth case of this experiment, the intended user access time is 19:45 and the estimated size of the data transmitted is 1,000 Megabytes. A maximum utility level is achievable if the data is transferred within the maximum postpone interval of an hour (60 minutes), and its utility level will drop to zero if it is transmitted within a postpone interval longer than 3 hours (180 minutes). In this case, the mobile device which will be used to transmit the data has 100mAh of remaining battery life. This information is going to be used as the input parameters in order to find the set of solutions that can produce the optimum level of satisfaction for the user.

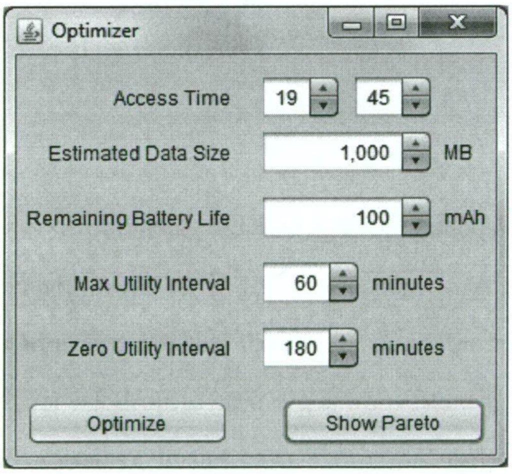


Figure 4.15 Access Parameters for Scenario 2 Case 4

Based on these input parameters, a set of non-dominated/optimum solutions is produced and presented in Figure 4.16.

Pareto Set & Pareto Front

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
0.0013	WiFi	0.9756	100.0	86.5776	14.0952	2.7962
0.0024	WiFi	0.9756	100.0	86.5771	14.093	2.7962
79.9148	CELLULAR	19.4824	83.4043	1300.0	0.0	27.962
105.096	WiFi	0.9756	62.42	1300.0	0.0	2.7962

Figure 4.16 Pareto Set and Pareto Front for Scenario 2 Case 4

As shown in Figure 4.16, the maximum utility level can be achieved by postponing the data transmission in the interval between 0.0013 and 0.0024 minutes. Moreover, based on the resource availability schedule, both WiFi and the cellular data network are available in this period. Therefore the algorithm chose to use WiFi to gain the lowest access cost and the shortest access interval. However, compared to the other optimum solutions, these solutions produce the lowest amount of battery life since there is no power outlet available for recharging in this period.

By postponing the data transfer for 79.9148 minutes, the user can get a maximum amount of battery life since a power outlet is available at the end of the data transmission. This solution can also maintain utility at the level of 83.4043. However, since the cellular data network is the only available resource in this period, this solution produces the highest access cost and the longest access interval compared to the other optimum solutions.

The other maximum satisfaction level is produced by postponing the data transmission for 105.096 minutes. By using this solution, the highest battery life and the lowest liability level can be achieved as a power outlet is available at end of the data transfer. Both WiFi and cellular data network are also available in this period. The algorithm chose to use WiFi in order to gain the lowest access cost and the shortest access interval. However, this solution produces the lowest level of utility since it has the longest postpone interval compared to the other solutions.

4.4 Scenario 3

In the third scenario, there will be two available resource types, which are WiFi and cellular data network. These resource types will no longer be treated as general network types, however; Telstra will act as the service provider for both the WiFi and the cellular data network in this scenario. In terms of pricing scheme, Telstra WiFi will cost $0.999 for every 1 Gigabyte of data transfer, and Telstra cellular data network will cost $19.95 for every 1 Gigabyte data transfer.

Table 4.9 Resource Types for Scenario 3

Resource Detail		
Resource Type	Cost ($/GB)	Power Use (mAh/sec)
WiFi TELSTRA	0.999	0.08
CELLULAR TELSTRA	19.95	0.03

In terms or power consumption, for the purposes of this simulation study, WiFi will consume 0.08mAh of battery life for every second of utilisation and cellular data network will consume 0.03mAh of battery life. The mobile device itself has a constant consumption of 0.008mAh from battery life in order to keep its life, and the maximum battery life capacity when the mobile device is fully charged is 1,300mAh.

The resource availability schedule in this scenario is designed to be free from any resource overlapping or in other words, there will be only one available resource type in a particular time. Moreover, each resource type also varies in data rate or speed. For Telstra WiFi, the data rate can be in 30 Mbps, 40 Mbps, or 50 Mbps depending on the resource availability schedule. Similar to Telstra WiFi, the data rate for Telstra cellular data transmission also varies according to the resource availability schedule, it can be in 5 Mbps, 10 Mbps, or 15 Mbps. In this scenario, there are two periods of time where there is no resource available to be used. These periods of time are implemented in this experiment to simulate the dead zone. The detailed information about the resource availability for this scenario is presented in Table 4.10.

Table 4.10 Resource Availability Schedule for Scenario 3

Resource Availability Schedule			
Start	End	Resource Type	Speed (Mbps)
00:00:00	02:59:59	WiFi TELSTRA	30
03:00:00	05:59:59	WiFi TELSTRA	50
06:00:00	06:59:59	CELLULAR TELSTRA	15
07:00:00	07:59:59	CELLULAR TELSTRA	5
08:00:00	08:59:59	WiFi TELSTRA	30
09:00:00	09:59:59	WiFi TELSTRA	40
10:00:00	10:59:59	CELLULAR TELSTRA	10
11:00:00	11:59:59	CELLULAR TELSTRA	5
12:00:00	12:59:59	N/A	0
13:00:00	13:59:59	CELLULAR TELSTRA	15
14:00:00	14:59:59	CELLULAR TELSTRA	10
15:00:00	15:59:59	WiFi TELSTRA	50
16:00:00	16:59:59	WiFi TELSTRA	40
17:00:00	17:59:59	N/A	0
18:00:00	18:59:59	WiFi TELSTRA	30
19:00:00	19:59:59	WiFi TELSTRA	40
20:00:00	20:59:59	CELLULAR TELSTRA	10
21:00:00	21:59:59	CELLULAR TELSTRA	15
22:00:00	22:59:59	WiFi TELSTRA	30
23:00:00	23:59:59	WiFi TELSTRA	50

There are two occurrences of power outlet availability in this scenario. These periods of time are introduced in the experiment in order to simulate the period for a user to recharge his/her mobile device. The detailed information about the power outlet availability for this scenario is presented in Table 4.11.

Table 4.11 Power Outlet Availability for Scenario 3

Power Outlet Availability Schedule	
Start	End
13:30:00	13:44:59
17:30:00	17:44:59
21:30:00	21:44:59

There are four cases that will be simulated in this scenario. Each case is varied in terms of access time, data size, remaining battery life, and the interval of maximum and minimum (zero) utility level. A brief information about the experiment case for this scenario is presented in Table 4.12 and the detailed information for each case will be provided in the following section.

Table 4.12 Experiment Cases for Scenario 3

Experiment Case				
Input Variable	**case 1**	**case 2**	**case 3**	**case 4**
Access Time (hh:mm:ss)	07:30:00	13:45:00	15:15:00	19:30:00
Data Size (MB)	500	300	800	1000
Remining Battery Life (mAh)	200	500	1000	100
Max Utility Value Interval (minutes)	60	30	30	60
Min Utility Value Interval (minutes)	360	150	240	240

4.4.1 Case 1

In the first case of this scenario, the intended user access time is 7:30 and the estimated size of the data which is going to be transferred is 500 Megabytes. The data can produce a maximum utility level for the user if it is transferred within a maximum postpone interval of one hour (60 minutes), and its utility level will fall to zero if it is transmitted with postpone interval longer than 6 hours (360 minutes). In this case, the mobile device which is going to be used to transmit the data has 200mAh of remaining battery life.This information is to be used as the input parameters in order to find the set of solutions that can produce optimum level of satisfaction for the user.

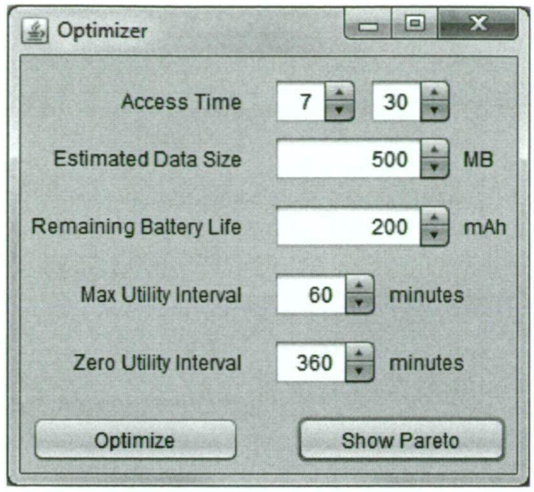
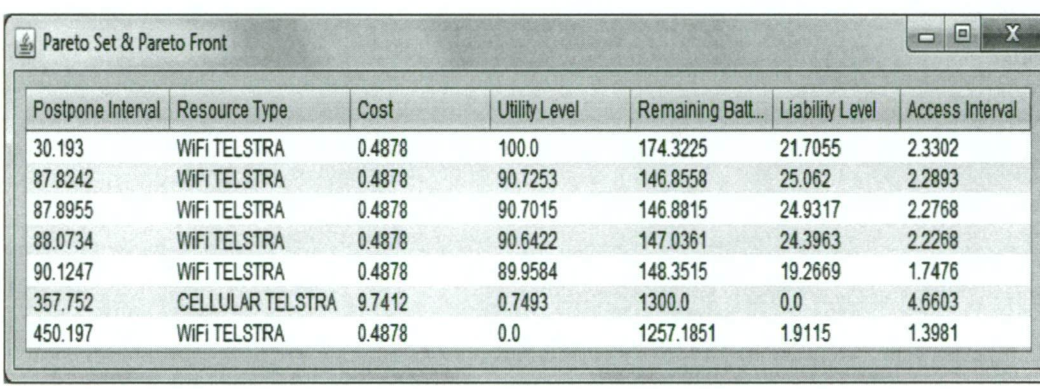


Figure 4.17 Access Parameters for Scenario 3 Case 1

Based on these input parameters, a set of non-dominated/optimum solutions is produced and presented in Figure 4.18.



Pareto Set & Pareto Front

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
30.193	WiFi TELSTRA	0.4878	100.0	174.3225	21.7055	2.3302
87.8242	WiFi TELSTRA	0.4878	90.7253	146.8558	25.062	2.2893
87.8955	WiFi TELSTRA	0.4878	90.7015	146.8815	24.9317	2.2768
88.0734	WiFi TELSTRA	0.4878	90.6422	147.0361	24.3963	2.2268
90.1247	WiFi TELSTRA	0.4878	89.9584	148.3515	19.2669	1.7476
357.752	CELLULAR TELSTRA	9.7412	0.7493	1300.0	0.0	4.6603
450.197	WiFi TELSTRA	0.4878	0.0	1257.1851	1.9115	1.3981

Figure 4.18 Pareto Set and Pareto Front for Scenario 3 Case 1

Figure 4.18 shows the optimum solutions produced by the NGSA II Algorithm based on the input parameters in case 1. The maximum utility level can be achieved by postponing the data transmission for 30.193 minutes and based on the resource availability schedule, the available resource type that can be used to transmit the data is Telstra WiFi with data rate of 30 Mbps. This optimum solution also produces the lowest access cost since the data is transferred using Telstra WiFi which has the lowest access cost in this scenario.

By postponing the data transfer in the interval between 87.8242 minutes and 88.0734 minutes, the user can get a faster data rate since in this period of time there is a transition in data rate for Telstra WiFi from 30 Mbps to 40 Mbps. Using these solutions, some part of the data will be transmitted using Telstra WiFi with data rate of 30 Mbps and the rest of the data will be transmitted using Telstra WiFi with data rate of 40 Mbps. These solutions still be able to maintain the utility level in the level between 90.7253 and 90.6422.

The other optimum satisfaction level is produced by postponing the data transmission for 90.1247 minutes. By using this solution, a shorter access interval can be achieved since in this period the available Telstra WiFi has a data rate of 40 Mbps and the entirety of the data can be transmitted using this available resource. Moreover, the utility of the data is still able to be maintained at the level of 89.9584.

A maximum amount of battery life can be achieved by postponing the data transmission for 357.752 minutes. However, this solution can only produce data utility in the level of 0.7493. Moreover, even though this solution can offer the lowest level of liability, this solution also has the highest access cost and the longest access interval compared to the other optimum solutions since the only available resource type in this period is Telstra cellular data network and therefore it is the only resource used to transmit the whole amount of data.

The last optimum solution offered by the algorithm for this case is to postpone the data transmission for 450.197 minutes. By using this solution, the user will get a low access cost and the shortest access interval since the entire data is transferred using Telstra WiFi with 50 Mbps of data rate. A high amount of battery life can also be achieved since the data is transmitted after the battery recharging period. However, since the postpone interval is longer than the zero utility level interval, the user will not be able to get any utility value from the data.

4.4.2 Case 2

For the second case, the user intends to transfer the data at 13:45 and the estimated size of the data is 300 Megabytes. The data can produce a maximum utility level for the user if it is transmitted within the maximum postpone interval of half an hour (30 minutes), and its utility level will drop to zero if it is transferred with postpone interval longer than 2.5 hours (150 minutes). In this case, the mobile device that will be used to transfer the data has 500mAh of remaining battery life.This information is going to be used as the input parameters to find the set of solutions that can produce the optimum level of user satisfaction.

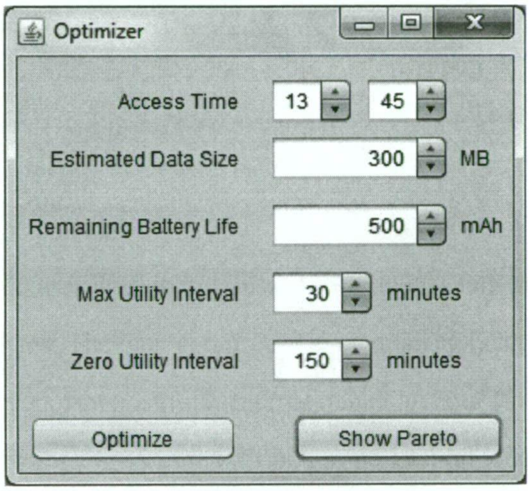


Figure 4.19 Access Parameters for Scenario 3 Case 2

Based on these input parameters, a set of non-dominated/optimum solutions is produced and presented in Figure 4.20.

Pareto Set & Pareto Front

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Ba...	Liability Level	Access Interval
0.0221	CELLULAR TELSTRA	5.8447	100.0	494.9562	4.6811	2.7962
72.0569	CELLULAR TELSTRA	4.1976	64.9526	458.9081	6.499	3.1989
73.8046	CELLULAR TELSTRA	1.8811	63.4961	459.5392	5.0393	1.7989
74.3316	CELLULAR TELSTRA	1.1972	63.057	459.7203	4.6074	1.3855
74.4389	CELLULAR TELSTRA	1.0428	62.9676	459.7668	4.5098	1.2922
74.4773	CELLULAR TELSTRA	0.9987	62.9356	459.7763	4.4819	1.2655
74.9032	CELLULAR TELSTRA	0.425	62.5807	459.9359	4.1191	0.9189
75.035	WiFi TELSTRA	0.2927	62.4708	459.9567	4.0355	0.8389
464.4378	CELLULAR TELSTRA	5.8447	0.0	1300.0	0.0	2.7962
474.4983	CELLULAR TELSTRA	5.8447	0.0	1300.0	0.0	2.7962
475.515	CELLULAR TELSTRA	5.8447	0.0	1300.0	0.0	2.7962
475.5385	CELLULAR TELSTRA	5.8447	0.0	1300.0	0.0	2.7962
500.9337	WiFi TELSTRA	0.2927	0.0	1283.2251	2.4192	1.3981
554.9037	WiFi TELSTRA	0.2927	0.0	1259.8215	1.5519	0.8789
555.3199	WiFi TELSTRA	0.2927	0.0	1259.8055	1.4815	0.8389

Figure 4.20 Pareto Set and Pareto Front for Scenario 3 Case 2

As shown in Figure 4.20, the maximum utility level can be achieved by postponing the data transfer for 0.0221 minutes. However, this solution introduces a relatively high access cost since Telstra cellular data network is the only available resource type in this period and the entire data is transmitted using this resource type.

The next optimum satisfaction levels are achieved by postponing the data transmission for an interval between 72.0569 minutes and 74.9032 minutes. By using these solutions, users can get a cheaper access cost and shorter access interval compared to the previous solution since in this period there is a transition in resource availability from Telstra cellular data network to Telstra WiFi, meaning that some of the data will be transferred through the former, and the remainder will be transferred through the latter.

By postponing the data transmission for 75.035 minutes, the user can get the cheapest access cost and the shortest access interval since in this period of time Telstra WiFi is available with the data rate of 50 Mbps. The utility of the data that can be maintained by using this solution is at the level of 62.4708.

A maximum amount of battery life can be achieved by postponing the data transmission for a period between 464.4378 minutes and 475.5385 minutes. However, these optimum solutions also produce the highest access cost compared to the other optimum solutions since the only available resource type in this period is Telstra cellular data network and the entire data is transmitted using this resource type. Moreover, by using these solutions, the user only gets a zero utility level from the data being transferred since the postpone interval is longer than the zero utility level interval.

The last optimum solutions offered by the algorithm for this case are by postponing the data transfer in the interval between 500.9337 minutes and 555.3199 minutes. By using these solutions, the user will get the lowest access cost and the shortest access interval since the entire data is transmitted using Telstra WiFi with 50 Mbps of data rate. A high amount of battery life can also be achieved since the data is transferred after the battery recharging period. However, since the postpone interval is longer than the zero utility level interval, the user will not be able to get any utility value from the data.

4.4.3 Case 3

In the third case of this scenario, the intended user access time is happen at 15:15 and the estimated size of the data which is going to be transferred is 800 Megabytes. The data can produce a maximum utility level for the user if it is transmitted within the maximum postpone interval of half an hour (30 minutes), and its utility level will drop to zero if it is transferred with postpone interval longer than 4 hours (240 minutes). In this case, the mobile device used to transmit the data has 1,000mAh of remaining battery life.This information is going to be used as the input parameters in order to find the set of solutions that can produce the optimum user satisfaction.

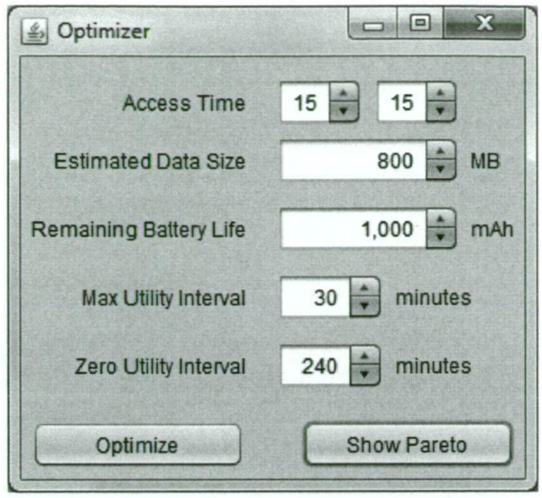


Figure 4.21 Access Parameters for Scenario 3 Case 3

Based on these input parameters, a set of non-dominated/optimum solutions is produced and presented in Figure 4.22.

Pareto Set & Pareto Front

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
8.0E-4	WiFi TELSTRA	0.7805	100.0	989.2622	4.0265	2.237
372.0141	CELLULAR TELSTRA	15.5859	0.0	1300.0	0.0	7.4565
399.8729	CELLULAR TELSTRA	10.94	0.0	1280.4223	4.2923	6.2866
405.8727	WiFi TELSTRA	0.7805	0.0	1274.4723	5.1927	3.7283
465.3833	WiFi TELSTRA	0.7805	0.0	1253.0786	3.1862	2.237

Figure 4.22 Pareto Set and Pareto Front for Scenario 3 Case 3

Figure 4.22 shows the optimum solutions produced by the NGSA II Algorithm based on the input parameters in case 3. The maximum utility level can be achieved by postponing the data transfer for 0.0008 minutes. Moreover, based on the resource availability schedule, the available resource type which can be used to transmit the data in this period is Telstra WiFi with a data rate of 50 Mbps. This condition can offer lowest access cost and the shortest access interval for the user.

A maximum amount of battery life can be achieved by postponing the data transmission for 372.0141 minutes. However, this solution produces the highest access cost and the longest access interval compared to the other optimum solutions since in this period, the only available resource type is Telstra cellular data network and the entire data is transferred using this resource type. Moreover, this solution can only offer a zero utility level for the user.

The last optimum solutions offered by the algorithm for this case are by postponing the data transfer for 405.8727 minutes and 465.3833 minutes. By using these solutions, the user will get relatively low access cost and short access interval since the data is transmitted using only Telstra WiFi. A high amount of battery life can also be achieved since the data is transmitted after the battery recharging period. However, since the postpone interval is longer than the zero utility level interval, the user will not be able to get any utility value from the data.

4.4.4 Case 4

In the last case of this scenario, the intended user access time is happen at 19:30 and the estimated size of the data which is going to be transmitted is 1,000 Megabytes. The data can produce a maximum utility level for the user if it is transferred within the maximum postpone interval of an hour (60 minutes), and its utility level will fall to zero if it is transmitted with postpone interval longer than 4 hours (240 minutes). In this case, the mobile device which will be used to transmit the data has 100mAh of remaining battery life.This information is going to be used as the input parameters in order to find the set of solutions that results in the optimum level of user satisfaction.

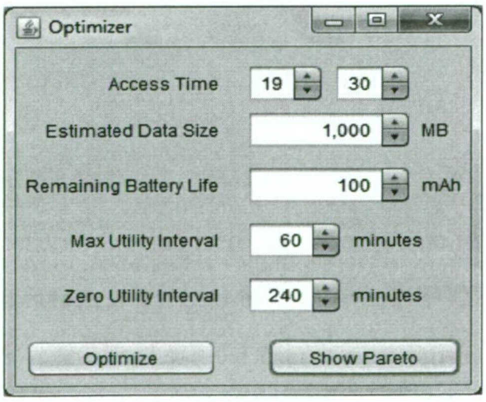
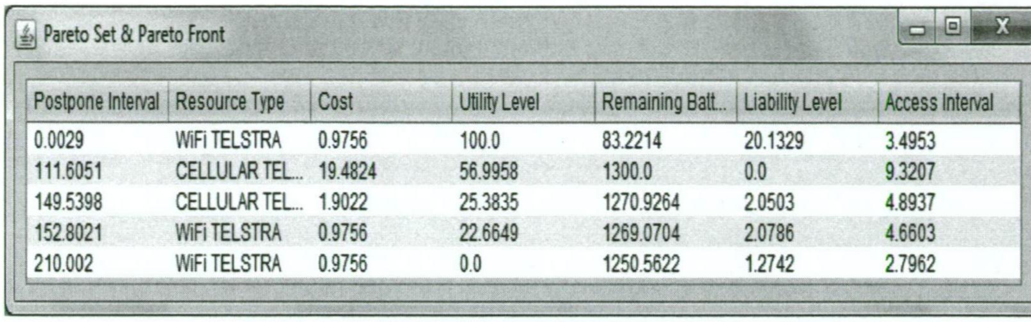


Figure 4.23 Access Parameters for Scenario 3 Case 4

Based on these input parameters, a set of non-dominated/optimum solutions is produced and presented in Figure 4.24.



Pareto Set & Pareto Front

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
0.0029	WiFi TELSTRA	0.9756	100.0	83.2214	20.1329	3.4953
111.6051	CELLULAR TEL...	19.4824	56.9958	1300.0	0.0	9.3207
149.5398	CELLULAR TEL...	1.9022	25.3835	1270.9264	2.0503	4.8937
152.8021	WiFi TELSTRA	0.9756	22.6649	1269.0704	2.0786	4.6603
210.002	WiFi TELSTRA	0.9756	0.0	1250.5622	1.2742	2.7962

Figure 4.24 Pareto Set and Pareto Front for Scenario 3 Case 4

As shown in Figure 4.24, the maximum utility level can be achieved by postponing the data transfer for 0.0029 minutes. By using this solution, the user can also get the lowest access cost and a relatively short access interval compared to the other optimum solutions offered by the algorithm for this case. The reason for this is that in this period, the available resource type that can be used to transfer the data is Telstra WiFi with the data rate of 40 Mbps. However, this solution produces the lowest amount of remaining battery power and the highest liability level compared to the other optimum solutions.

The user can get a maximum amount of battery life by postponing the data transmission for 111.6051 minutes. However, this solution produces the highest access cost and the longest access interval compared to the other optimum solutions since the only available resource type in this period is Telstra cellular data network and the entire data is transmitted using this resource type.

The other optimum satisfaction level is produced by postponing the data transmission for 152.8021 minutes. By using this solution, the cheapest access cost and a relatively short access interval can be achieved since in this period Telstra WiFi is existed as the available resource type and the entire data can be transferred using this available resource type. However, the utility of the data can only be maintained in the level of 22.6649.

The last optimum solution offered by the algorithm for this case is by postponing the data transfer for 210.002 minutes. By using this solution, the user will get the lowest access cost and the shortest access interval since the entire data is transmitted using Telstra WiFi with the highest data rate (50 Mbps). A relatively high amount of battery life can also be achieved since the data is transmitted after the battery recharging period. However, since the postpone interval is longer than the zero utility level interval, the user will not be able to get any utility value from the data.

4.5 Scenario 4

Similar to the previous scenario, in the fourth scenario there will be two available resource types, which are WiFi and cellular data network. In this scenario, these resource types will again not be treated as general network types, a detail information about the service providers will be presented. In contrast to the previous scenario which only introduces one providers, there are two providers will be presented in this scenario, which are Telstra and Optus. Both of them will provide WiFi and cellular data network with a different pricing scheme and availability schedule. In terms of pricing scheme, Telstra commands a slightly higher access cost for both WiFi and cellular data network compared to Optus. For WiFi, Telstra charges \$0.999 for every 1 Gigabyte of data transfer. In contrast Optus offers \$0.777 for every 1 Gigabyte of data transfer. For cellular data network, Telstra charges \$19.95 for every 1 Gigabyte of data transfer and Optus asks \$17.75 for every 1 Gigabyte of data transfer.

Table 4.13 Resource Types for Scenario 4

Resource Detail		
Resource Type	Cost ($/GB)	Power Use (mAh/sec)
WiFi TELSTRA	0.999	0.08
CELLULAR TELSTRA	19.95	0.03
WiFi OPTUS	0.777	0.08
CELLULAR OPTUS	17.75	0.03

In terms or power consumption, for the purposes of this simulation study, WiFi will consume 0.08mAh of battery life for every second of utilisation and cellular data network will consume 0.03mAh of battery life. The mobile device itself has a constant consumption of 0.008mAh from battery life in order to keep its life, and the maximum battery life capacity when the mobile device is fully charged is 1,300mAh.

The resource availability schedule in this scenario is designed to introduce resource overlapping or in other words, there are more than one available resource types at one particular time. Moreover, each resource type also varies in data rate or speed. For Telstra WiFi, the data rate can be in 30 Mbps, 40 Mbps, or 50 Mbps depending on the resource availability schedule. Similar to Telstra WiFi, the data rate for Optus WiFi also varies according to the resource availability schedule, it can be in 25 Mbps, 35 Mbps, or 45 Mbps. For cellular data network, Telstra offers the data rate in the range of 5 mbps, 10 Mbps, or 15 Mbps. Optus cellular data network also offers a varied data rate depend on the resource availability schedule. For Optus cellular data network, the data rates are in the range of 4 Mbps, 8 Mbps, or 12 Mbps. In this scenario, there are two periods of time where there is no resource available to be used. These periods of time are implemented in this experiment to simulate the dead zone. The detailed information about the resource availability for this scenario is presented in Table 4.14.

Table 4.14 Resource Availability Schedule for Scenario 4

Resource Availability Schedule			
Start	End	Resource Type	Speed (Mbps)
00:00:00	02:59:59	WiFi TELSTRA	30
03:00:00	05:59:59	WiFi TELSTRA	50
01:30:00	03:29:59	WiFi OPTUS	45
03:30:00	06:29:59	CELLULAR OPTUS	12
06:00:00	06:59:59	CELLULAR TELSTRA	15
07:00:00	07:59:59	CELLULAR TELSTRA	5
06:30:00	07:29:59	WiFi OPTUS	25
07:30:00	08:29:59	CELLULAR OPTUS	8
08:00:00	08:59:59	WiFi TELSTRA	30
09:00:00	09:59:59	WiFi TELSTRA	40
08:30:00	09:29:59	WiFi OPTUS	25
09:30:00	10:29:59	CELLULAR OPTUS	12
10:00:00	10:59:59	CELLULAR TELSTRA	10
11:00:00	11:59:59	CELLULAR TELSTRA	5
10:30:00	11:29:59	WiFi OPTUS	35
11:30:00	11:59:59	CELLULAR OPTUS	8
12:00:00	12:59:59	N/A	0
13:00:00	13:59:59	CELLULAR TELSTRA	15
14:00:00	14:59:59	CELLULAR TELSTRA	10
13:30:00	14:29:00	WiFi OPTUS	25
14:30:00	15:29:59	CELLULAR OPTUS	4
15:00:00	15:59:59	WiFi TELSTRA	50
16:00:00	16:59:59	WiFi TELSTRA	40
15:30:00	16:29:59	WiFi OPTUS	45
16:30:00	16:59:59	CELLULAR OPTUS	12
17:00:00	17:59:59	N/A	0
18:00:00	18:59:59	WiFi TELSTRA	30
19:00:00	19:59:59	WiFi TELSTRA	40
18:30:00	19:29:59	WiFi OPTUS	45
19:30:00	20:29:59	CELLULAR OPTUS	8
20:00:00	20:59:59	CELLULAR TELSTRA	10
21:00:00	21:59:59	CELLULAR TELSTRA	15
20:30:59	21:29:59	WiFi OPTUS	25
21:30:00	22:29:59	CELLULAR OPTUS	12
22:00:00	22:59:59	WiFi TELSTRA	30
23:00:00	23:59:59	WiFi TELSTRA	50
22:30:00	23:29:59	WiFi OPTUS	35
23:30:00	23:59:59	CELLULAR OPTUS	8

There are two occurrences of power outlet availability in this scenario. These periods of time are introduced in the experiment in order to simulate the period for a user to recharge his/her mobile device. The detailed information about the power outlet availability for this scenario is presented in Table 4.15.

Table 4.15 Power Outlet Availability for Scenario 4

Power Outlet Availability Schedule	
Start	End
13:30:00	13:44:59
17:30:00	17:44:59
21:30:00	21:44:59

Four cases will be simulated in this scenario. Each case is varied regarding access time, data size, remaining battery life, and the interval of maximum and minimum (zero) utility level. A brief overview of the experiment case for this scenario is presented in Table 4.16 and the detail information for each case will be provided in the following section.

Table 4.16 Experiment Cases for Scenario 4

Experiment Case				
Input Variable	case 1	case 2	case 3	case 4
Access Time (hh:mm:ss)	07:45:00	13:15:00	15:45:00	21:10:00
Data Size (MB)	800	500	300	200
Remining Battery Life (mAh)	700	100	300	50
Max Utility Value Interval (minutes)	60	20	15	30
Min Utility Value Interval (minutes)	360	180	240	60

4.5.1 Case 1

In the first case for scenario 4, the intended user access time is 07:45 and the estimated size of the data which is going to be transferred is 800 Megabytes. The data can produce a maximum utility level for the user if it is transmitted within the maximum postpone interval of an hour (60 minutes), and its utility level will drop to zero if it is transferred within a postpone interval longer than 6 hours (360 minutes). In this case, the mobile device has 700mAh of remaining battery life.This information is going to be used as the input parameters in order to find the set of solutions that can produce optimum level of satisfaction for the user.

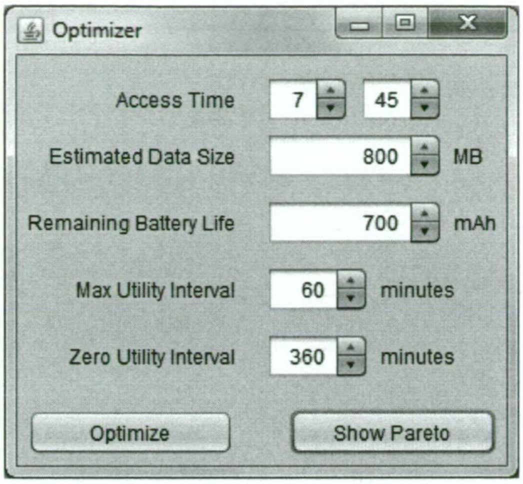
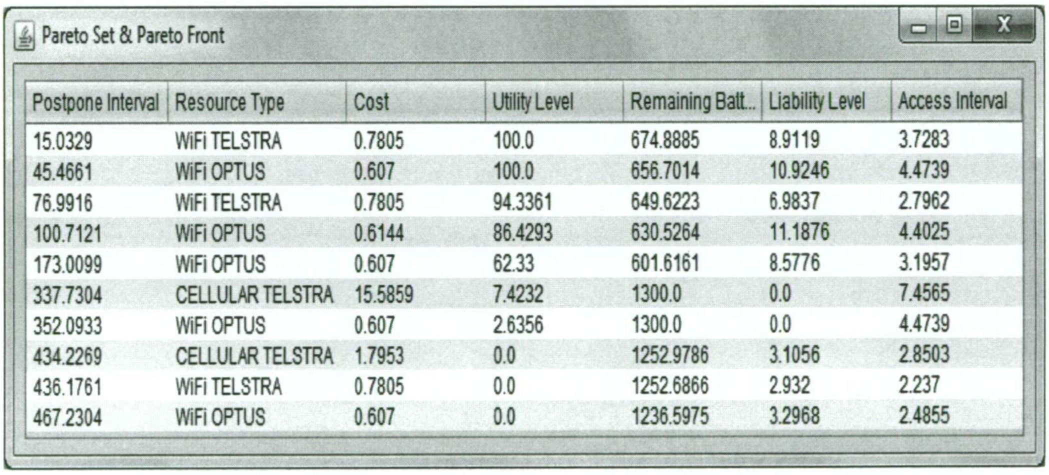


Figure 4.25 Access Parameters for Scenario 4 Case 1

Based on these input parameters, a set of non-dominated/optimum solutions is produced and presented in Figure 4.26.


Pareto Set & Pareto Front

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
15.0329	WiFi TELSTRA	0.7805	100.0	674.8885	8.9119	3.7283
45.4661	WiFi OPTUS	0.607	100.0	656.7014	10.9246	4.4739
76.9916	WiFi TELSTRA	0.7805	94.3361	649.6223	6.9837	2.7962
100.7121	WiFi OPTUS	0.6144	86.4293	630.5264	11.1876	4.4025
173.0099	WiFi OPTUS	0.607	62.33	601.6161	8.5776	3.1957
337.7304	CELLULAR TELSTRA	15.5859	7.4232	1300.0	0.0	7.4565
352.0933	WiFi OPTUS	0.607	2.6356	1300.0	0.0	4.4739
434.2269	CELLULAR TELSTRA	1.7953	0.0	1252.9786	3.1056	2.8503
436.1761	WiFi TELSTRA	0.7805	0.0	1252.6866	2.932	2.237
467.2304	WiFi OPTUS	0.607	0.0	1236.5975	3.2968	2.4855

Figure 4.26 Pareto Set and Pareto Front for Scenario 4 Case 1

Figure 4.26 shows the optimum solutions produced by the NGSA II Algorithm based on the input parameters in case 1. There are two solutions offered to achieve the maximum utility level. The first solution is to postpone the access interval for 15.0329 minutes. In this period, there are two available resources, which are Optus cellular data network with the data rate of 8 Mbps and Telstra WiFi with the data rate of 30 Mbps. In order to produce an optimum solution for this period, Telstra WiFi is selected by the algorithm to transfer the data instead of Optus cellular data network since it has cheaper access cost and produces shorter access interval.

The second optimum solution to achieve the maximum utility level is by postponing the data transfer for 45.4661 minutes. In this period, there are two available resources, namely, Optus WiFi with the data rate of 25 Mbps and Telstra WiFi with the data rate of 30 Mbps. In order to produce an optimum solution for this period, Optus WiFi is selected by the algorithm to transfer the data instead of Telstra WiFi since it has cheaper access cost, even though it offers a slightly longer access interval.

As shown in Figure 4.26, there are two optimum solutions offered by the algorithm that can achieve the maximum amount of remaining battery life and the lowest level of liability. The first solution is to postpone the access interval for 337.7304 minutes. However, this solution offers the highest access cost and the longest access interval since the only available resource type in this period is Telstra cellular data network. Using this solution, the utility level can also only be maintained in the level of 7.4232.

The second optimum solution offered by the algorithm to achieve the maximum amount of battery life is by postponing the data transfer for 352.0933 minutes. This solution can also produce the cheapest access cost and a relatively short access interval since Optus WiFi is available in this period and this is the resource type which is chosen by the algorithm to transmit the data for this solution. However, this solution can only maintain the utility in the level of 2.6356.

The minimum access cost and the short access interval can be achieved by using WiFi to transfer the entirety of the data. In this case, there are two optimum solutions offered by the algorithm in order to achieve a minimum access cost and short access interval. The first option is to postpone the data transmission for 436.1761 minutes. In this period, the Telstra WiFi is available with the data rate of 50 Mbps and can be used to transfer the entire data. Therefore this solution can reduce the access cost to $0.7805 and decrease the access interval to 2.237 minutes. However, since the postpone interval is longer than the zero utility level interval, the user will not be able to get any utility value from the data.

The second optimum solution offered by the algorithm to achieve a minimum access cost and short access interval in this case is by postponing the access interval for 467.2304 minutes. Since Optus WiFi is available in this period with its highest data rate (45 Mbps), the algorithm chooses this resource type to transfer the whole of the data. This solution can reduce the access cost to $0.607 and decrease the access interval to 2.4855 minutes. However, since the postpone interval is longer than the zero utility level interval, the user will not be able to get any utility value from the data.

4.5.2 Case 2

In the second case of this scenario, the user access time is 13:15 and the estimated size of the data to be transferred is 500 Megabytes. The data can produce a maximum utility level for the user if it is transmitted within the maximum postpone interval of 20 minutes, and its utility level drops to zero if it is transferred with postpone interval longer than 3 hours (180 minutes). In this case, the mobile device used to transfer the data has 100mAh of remaining battery life.This information is going to be used as the input parameters in order to find the set of solutions that can produce optimum level of satisfaction for the user.

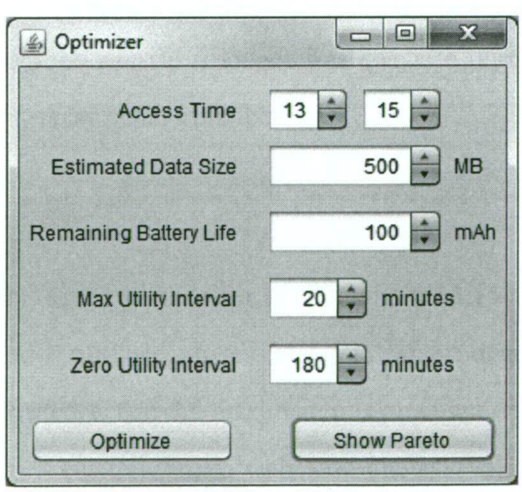


Figure 4.27 Access Parameters for Scenario 4 Case 2

Based on these input parameters, a set of non-dominated/optimum solutions is produced and presented in Figure 4.28.

Pareto Set & Pareto Front

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
15.1497	WiFi OPTUS	0.3794	100.0	1300.0	0.0	2.7962
17.0986	WiFi OPTUS	0.3794	100.0	1300.0	0.0	2.7962
17.0995	WiFi OPTUS	0.3794	100.0	1300.0	0.0	2.7962
17.3049	WiFi OPTUS	0.3794	100.0	1300.0	0.0	2.7962
19.836	WiFi OPTUS	0.3794	100.0	1300.0	0.0	2.7962
19.8982	WiFi OPTUS	0.3794	100.0	1300.0	0.0	2.7962
105.6252	WiFi TELSTRA	0.4878	46.4842	1256.9771	0.0797	1.3981
135.566	WiFi OPTUS	0.3794	27.7712	1241.8635	0.0895	1.5534
164.7048	WiFi TELSTRA	0.4027	9.5595	1228.0395	0.0887	1.5201

Figure 4.28 Pareto Set and Pareto Front for Scenario 4 Case 2

As shown in the Figure 4.28, the maximum utility level can be achieved by postponing the data transmission for an interval between 15.1497 minutes and 19.8982 minutes. in this period, Optus WiFi is available and the algorithm chooses to use this resource type in order to produce the optimum satisfaction level for the user in this case. Moreover, these optimum solutions also offer a maximum amount of battery life since the data transmission ends in the period where the power outlet is available.

The next optimum satisfaction levels are achieved by postponing the data transfer for 105.6252 minutes. This solution offers the shortest access interval, the entire data is transmitted using Telstra WiFi which is in this period it has the highest data rate (50 Mbps). The utility is maintained by this solution at a level of 46.4842.

Another optimum solution offered by the algorithm is found by postponing the data transmission for 135.566 minutes. By using this solution, the lowest access cost can be achieved since in this period, the data is transferred using Optus WiFi which has the lowest access charges. In terms of access interval, this solution can produce a slightly shorter access interval compared to the previous solutions that also using Optus WiFi. This is possible because the Optus WiFi in this period has a higher data rate compared to the previous ones. However, this solution can only maintain the utility in the level of 27.7712.

The last optimum solution offered by the algorithm is by postponing the access interval for 164.7048 minutes. Using this solution, the first part of the data is transmitted using Telstra WiFi and the rest of it is transferred using Optus WiFi. Therefore this solution can offers a cheaper access cost compared to the previous solution which also using Telstra WiFi. However, since the rest of the data is transferred using Optus WiFi, the access interval is longer compared to the previous one. With regard to utility level, this solution can only maintain the utility in the level of 9.5595.

4.5.3 Case 3

In the third case for this scenario, the data transmission time is 15:45 and the estimated size is 300 Megabytes. The data can produce a maximum utility level for the user if it is transmitted within the maximum postpone interval of a quarter of an hour (15 minutes), and its utility level will drop to zero if it is transmitted with a postpone interval longer than 4 hours (240 minutes). In this case, the mobile device which is going to be used to transfer the data has 300mAh of remaining battery life.This information will be used as the input parameters in order to find the set of solutions that can produce optimum level of satisfaction for the user.

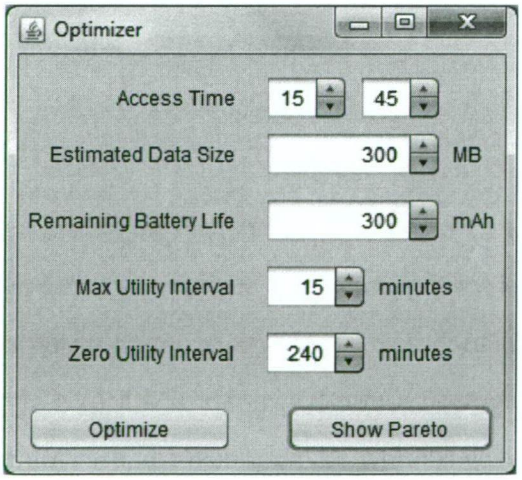


Figure 4.29 Access Parameters for Scenario 4 Case 3

Figure 4.30 shows the set of non-dominated/optimum solutions produced using the previous input parameters.

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
0.0015	WiFi OPTUS	0.2276	100.0	295.5253	1.5659	0.9321
0.004	WiFi TELSTRA	0.2927	100.0	295.9716	1.4093	0.8389
135.9863	WiFi TELSTRA	0.2927	46.2283	1285.6011	0.5453	1.3981
188.5098	WiFi OPTUS	0.2276	22.8846	1262.6301	0.3707	0.9321
343.8015	WiFi OPTUS	1.8829	0.0	1300.0	0.0	2.0073
437.2156	WiFi TELSTRA	0.2927	0.0	1143.7015	0.3684	0.8389

Figure 4.30 Pareto Set and Pareto Front for Scenario 4 Case 3

As shown in the Figure 4.30, there are two optimum solutions offered by the algorithm in order to achieve the maximum utility level. The first optimum solution can be found by postponing the data transmission for 0.0015 minutes and using Optus WiFi to transfer the data. This solution also produces the lowest access cost for this case since in this period, the entire data can be transferred using Optus WiFi which has the lowest access cost compared to the other resource types.

The second optimum solution that can produce a maximum utility level is to delay the access interval by 0.004 minutes and using Telstra WiFi to transfer the data. This solution also produces the shortest access interval since in this period, Telstra WiFi offers its highest data rate (50 Mbps) which is also the highest data rate compared to the other resource types in this scenario.

Similar to the previous two optimum solutions, the next two options also offer a relatively low access cost and a short access time. Moreover, these two solutions also offer a higher amount of battery life since by using these two solutions the data is transmitted after the battery recharging period. The first solution is by postponing the data transfer for 135.9863 minutes and using Telstra WiFi to transfer the data. The second solution is to postpone the data transmission for 188.5098 minutes and use Optus WiFi to transfer the data. However, compared to the previous two optimum solutions, these two solutions offer a significantly lower level of utility level since they require a relatively longer postpone interval compared to the maximum utility interval which is implemented in this case.

A maximum amount of battery life can be achieved by postponing the data transfer for 343.8015 minutes. However, these optimum solutions also produce the highest access cost and the longest access interval compared to the other optimum solutions in this case since in this period even though the data is transmitted using optus WiFi, only some part of the data can be transferred using this resource type. The rest of the data has to be transferred using another resource type due to the availability schedule. Moreover, by using this solution, the user gets a zero utility level from the data being transmitted since the postpone interval is longer than the zero utility level interval.

The last optimum solution offered by the algorithm for this case is shown by postponing the data transfer for 437.2156 minutes and using Telstra WiFi to transfer the data. Similar to the previous solutions, by using this option, the user can also get the lowest access cost and the shortest access interval since the entire data is transmitted using Telstra WiFi with 50 Mbps data rate. Moreover, a maximum amount of battery life can also be achieved since the data transmission extends into the period when the power outlet is available. However, since the postpone interval is longer than the zero utility level interval, the user will not be able to get any utility value from the data.

4.5.4 Case 4

In the last case of this scenario, the user intends to transfer the data at 21:10 and the estimated size of the data is 200 Megabytes. The data can produce a maximum utility level for the user if it is transmitted within the maximum postpone interval of half an hour (30 minutes), and its utility level will drop to zero if it is transferred with a postpone interval longer than an hours (60 minutes). In this case, the mobile device which is going to be used to transfer the data has 50mAh of remaining battery life.This information will be used as the input parameters in order to find the set of solutions that can produce optimum level of user satisfaction.

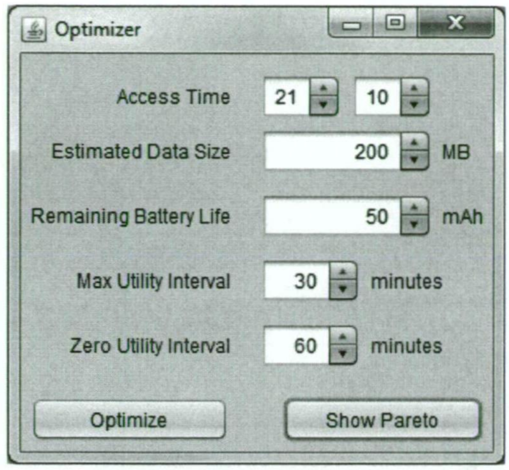


Figure 4.31 Access Parameters for Scenario 4 Case 4

Based on these input parameters, a set of non-dominated/optimum solutions is produced and presented in Figure 4.32.

Postpone Interval	Resource Type	Cost	Utility Level	Remaining Batt...	Liability Level	Access Interval
0.0	WiFi OPTUS	0.1518	100.0	44.6313	2.1475	1.1185
18.8851	WiFi OPTUS	0.2136	100.0	1300.0	0.0	1.1308
49.6772	CELLULAR TELSTRA	0.8239	34.4095	1288.6601	0.0663	1.0904
49.8295	CELLULAR TELSTRA	0.526	33.9016	1288.4981	0.0677	1.0154
49.8888	CELLULAR TELSTRA	0.3937	33.704	1288.4261	0.0683	0.9821
50.1278	WiFi TELSTRA	0.1951	32.9073	1288.2541	0.0692	0.9321
80.0151	WiFi OPTUS	0.1518	0.0	1274.5492	0.06	0.7989
109.9937	WiFi TELSTRA	0.1951	0.0	1261.3076	0.0425	0.5592
109.9947	WiFi TELSTRA	0.1951	0.0	1261.3076	0.0425	0.5592
109.9978	WiFi TELSTRA	0.1951	0.0	1261.3076	0.0425	0.5592
109.9982	WiFi TELSTRA	0.1951	0.0	1261.3076	0.0425	0.5592
139.8538	WiFi OPTUS	0.1879	0.0	1246.7796	0.046	0.5992

Figure 4.32 Pareto Set and Pareto Front for Scenario 4 Case 4

As shown in the Figure 4.32, the algorithm offers two optimum solutions that can achieve a maximum utility level. The first solution is to delay the data transfer for 0.0 minutes or in other word by transmitting the data immediately. Since Optus WiFi is the resource type which is used to transmit the entire data in this solution, this solution also produces the lowest access cost. The second optimum solution that offers a maximum utility level is by postponing the data transfer for 18.8851 minutes. Using this solution, the first part of the data is transmitted using Optus WiFi and the rest part of it is transferred using Optus cellular data network, which has higher access cost and slower data rate. Therefore this solution produces a slightly higher access cost and slightly longer access interval compared to the previous one. However, this solution offers a maximum amount of battery life since the data transmission ends within the period where power outlet is available.

The next optimum satisfaction levels are achieved by postponing the data transfer in the interval between 49.6772 minutes and 49.8888 minutes. Telstra cellular data network is the resource type which is used in these solutions. By using these options, user can get a relatively high amount of battery life since the data is transmitted after the battery recharging period. Moreover, even though the data is transferred using Telstra cellular data network which has the highest access cost in this scenario, it is only used to transmit the first part of the data and the rest of it is transmitted using Telstra WiFi which has a lower access cost and the highest data rate in this scenario. However, these solutions can only maintain utility in the level between 34.4095 and 33.704.

The rest of the optimum solutions offered by the algorithm for this case are using either Telstra WiFi of Optus WiFi as the main resource type to transfer the data. These resource types are chosen in order to achieve a relatively low access cost and short access interval. Moreover, since in these solutions the data is transmitted after the device recharging period, these solutions also offer a relatively high amount of remaining battery life. However, this solution can only offer a zero utility level for the user since the postpone interval in these solutions are longer than the zero utility level interval.

4.6 Chapter Summary

In this chapter several scenarios and cases of data transmission have been presented as a part of the simulation study. In total, there are four different scenarios and four different cases of data transfer within each scenario have been constructed. These scenarios and cases are built in order to understand how the selection of decision variables in data transmission influences the overall user satisfaction. These scenarios are organised in order of increasing complexity. The first scenario is simple and does not involve any overlapping in resource availability. Progressively, the later scenarios include more options and opportunities to be selected from a range of alternatives. A successful execution of simulations based on the realistic data transfer needs and communication parameters provides proof of the concept for the model in this simulation study. Moreover, the results of these experiments would offer a clear and measurable indication of the range of objective function values which a mobile device user can observe when they are using their device.

Conclusions and several possibilities of future works/actions for this study will be presented in the following chapter.

Chapter 5

Summary, Conclusions and Future Works

5.1 Summary

This study began by presenting the hypothesis stating: "It is possible to improve the mobile user's satisfaction for a single data-transfer task by controlling transmission related decisions". The hypothesis is based on an assumption that for a typical mobile device, other factors, apart from the connectivity attributes, are less amenable to change as they are often fixed by the choice of the hardware and the related software platform.

A review of the literature was then conducted in order to provide a firm basis for this work. There are five broad areas covered in the literature review, which are mobile device characteristics, mobile Internet characteristics, mobile users' characteristics including their behaviours, the multi-objective optimisation problems, and the evolutionary algorithms in multi-objective optimisations problems.

An in-depth explanation of the methodology which is used in this study is also provided. The methodology covers several key points such as the need for multiple objectives in this research, related studies that have been conducted, the multi-objective optimisation problem, several possible approaches for comparing users' satisfaction, the simulation model which is used in this study, evolutionary algorithms for the multi-objective optimisation problem, and the jMetal framework as the building blocks to perform the simulation model.

In order to provide proof of the concept for the model in this study, an execution of the simulation model based on the realistic data transfer needs and communication parameters is conducted. Several scenarios and cases of data transmission are presented as a part of the experiments. These scenarios are organised in order of increasing complexity. The first scenario is simple and does not involve any overlapping in the resource availability. Progressively, the later scenarios include more options and opportunities to be selected from a range of alternative decisions. These experiments provide a deeper understanding of the relationships among decisions and satisfaction outcomes for mobile device users.

5.2 Conclusions

After several experiments have been conducted, the main Hypothesis of this research can be verified; it is possible to improve the mobile user's satisfaction for a single data-transfer task by controlling transmission related decisions. In addition, the successful execution of this study has also produced a computation support system which can assist the users when they are making a decision related to the data transfer from their mobile device. Users can make an effective and economical decision about the data transfer from the list of possible decision-outcome tuples produced with the assistance of the computation support system. The users' concern related to access cost can be lowered without sacrificing some other benefits that may also influence the satisfaction of the users such as the remaining battery life and the network availability.

5.3 Future Works

For the future works of this research, there are several possibilities that can and need to be explored.

The simulation model in this research can be augmented in order to handle multiple transfers and multiple data access. The enhanced model may be used to schedule the data transfer in an optimised way. Alternatively one may propose an algorithm to prioritise the transfers and choose a subset of them for actual transfer consistent with the expected cost and benefit outcomes.

A machine learning capability can be integrated into this model to predict the mobile user's daily activity in order to generate a more accurate resource availability schedule/table. A simulator tool may also be of value to monitor the device and its usage to provide accurate and precise estimates of various parameters used in the model.

Sensor devices are often deployed in remote locations without 24x7 access to resources. Their data transfer operations may be subject to natural and unpredictable activities. For example long periods of cloudy weather may reduce the charge in the battery. Data communication may be subject to the availability of a base station. The model can be extended to optimise data collection activity for remote sensors.

Cloud computing resources also have access patterns that are subject to interruption quality variations similar to the issues modelled in this research. The model can be extended to optimise and streamline access to cloud resources for cost, reliability, security and availability benefits.

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Appendices

This sections present the list of resources and tools which are used to conduct the experiment in this study. These resources and tools can be located on the attached DVD under the "EXPERIMENT" directory.

- Experimental Source Code (/EXPERIMENT/SOURCE_CODE/)
- Scenarios and Cases Data (/EXPERIMENT/SCENARIOS_CASES/)
- Java Libraries (/EXPERIMENT/LIBRARIES/)
- Netbeans IDE (/EXPERIMENT/NetBeansIDE/)
- MySQL Database Server (/EXPERIMENT/MySQLServer/)