Scheduling Data Communication based Services on the Personal Mobile Devices

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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 the mobile devices that deliver significant value for their users. However, the users are also concerned about costs and other factors related to this access. This paper describes a multi-objective model to optimally schedule a service on a mobile device that requires data communication with the external data repositories. These objectives are incomparable with each other and represent different personal and temporal needs and preferences. Thus, the objectives cannot be assigned unanimously accepted fixed weights to generate a single outcome metric. Pareto optimal solutions are used to provide the best option for determining efficient schedules.

1 INTRODUCTION

Mobile device usage is growing as is their ability to provide sophisticated services. The primary reason for the growing popularity of the mobile devices is their ability to support relationships among the peers through the connectivity and communication anywhere and anytime mantra (Constantiou, 2007; Cui and Roto, 2008; Sarker and Wells, 2003). However, the mobile devices have noticeable resource constraints and users are often concerned about the communication costs, battery life and device busy periods. The paper describes a model that aids in finding Pareto optimal schedules for the data communication dependent services available through the mobile devices.

To explain the reader about the scheduling problem, we present the following made-up story: A mobile device user accidently meets the President holidaying on a remote island and is invited for a breakfast with the first family. The user has a number of pictures that she is eager to share them with her social groups. What is the best schedule to upload these pictures to match the urgency to upload tempered with limited access to the bandwidth and perhaps desire to conserve the device battery? Though the story is a bit unrealistic, everyday mobile device users face the similar sentiments when using their devices.

The rest of the paper is organized as follows. Section 2 presents the Multi-objective Model for Mobile Data Communication. Each objective functions including related constraints are presented in Section 2.1 to Section 2.5. In Section 3, a brief description of the experimental evaluation for our model is presented. We conclude the paper in Section 4.

2 MULTI-OBJECTIVE MODEL FOR MOBILE DATA COMMUNICATION

Several studies have been conducted to identify and understand the satisfaction factors of the mobile device users (Büyüközkan, 2009; Cui and Roto, 2008; Sarker and Wells, 2003). However, these studies do not explain how the mobile device users can optimize the access to a service by scheduling it for better outcomes. The problem of optimizing the access to a service through a mobile device can be set as a multi-objective optimization problem since there are more than one satisfaction factors required to be optimized and these satisfaction factors are conflicting with each other.

Two primary decision variables controlling the access to mobile services are: the postpone interval

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(*delay*) and the communication mode to use for the data communication (*mode*). The postpone interval, *delay*, represents the length of the period by which the data communication is delayed after the need for the data communication outside the mobile device is first noted; in this paper, the time at which the data communication need is first noted is marked as time 0. The communication mode, *mode*, as the second decision variable represents the use of a wired, Wi-Fi or a cellular data network to contact the data repository. In this paper, we will use the following identifiers and functions in the equations:

size(data)	Size of the data to be communicated by the mobile service.
speed(mode)	Communication speed for communication mode *mode*.
batteryCharge(delay)	MilliAmpere hours (mAh) of the electric charge stored in the mobile device battery at time *delay*.
dischargeRate(mode)	Battery discharge rate mAh/s in communication mode *mode*.
qdr	Quiescent discharge rate for the device battery to keep the device active.
nextRechargeTime(delay)	Time to the next battery recharge opportunity after delay interval *delay*.
accessTime(delay)	Time to start transmitting the data at or after time *delay*.
schedule(mode)	Availability schedule to utilize communication mode *mode*.
available(delay,mode)	Boolean function; true if the mobile user can use communication mode *mode* at delay interval *delay*. A mobile user may avoid a live communication mode if it is considered unsecure. Thus, the function captures security needs.
fixedCosts(delay,mode)	Fixed costs to utilize the communication mode *mode* at delay interval *delay*.
varCosts(delay,mode)	Variable costs to utilize the communication mode *mode* at delay interval *delay*.

When accessing a service requiring data communication from a mobile device, the device owner seeks to choose values for the decision variables *delay* and *mode* to use the best data communication outcomes for the service. The proposed model defines five objectives to find the Pareto-optimal solutions: data access cost, service efficacy, battery charge depletion, depleted battery charge encumbrance, and device unavailable duration.

2.1 Minimizing Data Access Cost

A high cost for the mobile Internet access discourages the users from accessing the Internet from their mobile device (Büyüközkan, 2009; Blechar, 2006). The cost of the mobile Internet access is determined by the amount of data communicated and is dependent on the available communication modes and the time of the access. Since the cost of communication varies across many different network providers, a lower data communication cost can be achieved by delaying the communication for a particular interval of time in order to get a cheaper available connection. In mathematical notation the cost objective goal can be represented as:

$$minimize\ cost(delay, mode)$$

where

$$\begin{aligned} &cost(delay, mode) \\ &= fixedCosts(delay, mode) \\ &+ varCosts(delay, mode) * size(data) \end{aligned} \qquad (1)$$

2.2 Maximizing Service Efficacy

Mobile users and applications place a significant

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premium on the immediacy of the data interaction and servicing. In this respect, the data communication requirements have the characteristics similar to the real-time applications. The full benefits of the service are derived if the data can be transferred before a user or service specific deadline; titled festive deadline. However, if the service is delayed past a later deadline, titled obsolesce deadline, the mobile user derives little benefit from the service. Basic real-time schedulers approximate the benefits from a service completed between these two deadlines using a linearly decaying service efficacy function (Laplante, 2004; Williams, 2006). Thus, the service efficacy objective is expressed as:

$$maximize\ efficacy(delay, mode)$$

where

$$efficacy(delay, mode) = \begin{cases} 100, & delay < festive \\ \frac{obsolesce - delay}{obsolesce - festive}, & delay > obolesce \\ 0, & delay > obolesce \end{cases} \tag{2}$$

2.3 Minimize Battery Charge Depletion

Battery status is a fundamental constraint of the mobile devices resulting from the requirements for the mobile devices to be small and light. The battery power is required not only to run the mobile device to perform user started operations but also to keep the device functioning and continuing its quiescent services. Therefore, an adequate amount of remaining battery life is essential for the satisfied device owners.

The battery charges drain at a slow constant rate (*qdr*) to keep the device active and functioning. However, each data communication episode uses significantly larger amount of battery power to radiate signals and to perform the related computational activities. This demand is determined by a number of factors including the communication mode, duration and the noise characteristics of the communication channel. However, drained battery charge is not a permanent liability. The battery levels are restored by recharge of the device batteries. Considering the importance of the remaining battery charge for the mobile device, a number of objectives exist in the model.

The remaining electric charge in the battery after a data communication episode is a function of three arguments: the state of the battery before the communication episode, the communication mode used for the data communication, and the duration of communication. The communication duration is primarily determined by the amount of data transfer and the transmission speed for the communication mode. However, transmission speed is also affected by the environmental conditions such as the channel noise and congestion. Smaller battery discharge in completing the data communication needs of a service leaves more charge for other services; thus

$$minimize\ batteryDischarge(delay, mode)$$

where

$$batteryDischarge(delay, mode) = dischargeRate(mode) * \frac{size(date)}{speed(mode)} \tag{3}$$

Closely related to this objective are the constraints that determine the feasibility of the communication episode. Firstly, the communication mode should be available over the period *delay* to *delay + size(data) / speed(mode)* for the data to be communicated. Secondly, the battery should have enough charge to complete the data communication. These requirements are expressed in the two constraints below:

$$available(t, \mathrm{mode}) == true$$

$$for\ all\ t, accessTime(delay) \le t \le accessTime(delay) + \frac{size(data)}{speed(mode)} \tag{4}$$

and,

$$batteryCharge\big(accessTime(delay)\big) \ge dischargeRate(mode) * \frac{size(data)}{speed(mode)} \tag{5}$$

2.4 Minimize Depleted Battery Charge Encumbrance

If a resource is used for a purpose, it is not available for the alternate purposes. Economists describe the idea as an opportunity cost. A similar dilemma is also faced by the user of a mobile device. Battery life is an important resource and a mobile device becomes inoperative once the battery has run down below a low charge threshold. The savvy mobile users take significant care to preserve the battery life. It is not uncommon to notice the mobile users minimizing the device usage to preserve the battery charges to the time when the device battery can be recharged.

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This objective is modelled by the area under the battery charge line plotted against the time. Each data communication episode reduces the area; and, this reduction in the area defines the depleted battery charge encumbrance for the mobile user. The encumbrance reduces the future opportunities to use the mobile device due to the reduced remaining battery charges. As the common mobile devices use rechargeable batteries, the encumbrance is cleared at the next battery recharge.

$$minimize\ encumbrance(delay, mode)$$

where

$$\begin{aligned} &encumbrance(delay, mode) \\ &= nextRechargeTime(delay) \\ &* dischargeRate(mode) * \frac{size(data)}{speed(mode)} \end{aligned} \tag{6}$$

2.5 Minimizing Device Unavailable Duration

A mobile device is not fully available to its user when it is busy in a data communication based service. This limitation is a consequence of the constraints on the computational resources as well as the limited communication bandwidths available to the mobile devices.

A long access time is annoying and lowers user satisfaction (Büyüközkan, 2009; Fogelgren-Pedersen, 2005). A longer access period also drains more battery charges (Chen, 1999).

The device busy interval is the time interval required to successfully transmit the data using the available communication modes – this also is a period of significantly restricted availability of the mobile device. Thus, the objective:

$$minimize\ deviceUnavailable(delay, mode)$$

where

$$deviceUnavailable(delay, mode) = \frac{size(data)}{speed(mode)} \tag{7}$$

The constraints listed earlier in Equation 5 with the objective function battery charge depletion apply to this objective too. However, there is another cause leading to a potential device unavailable situation. The events leading to this situation are described as follows: if the battery charge is depleted by a data communication episode, the remaining charges on the battery may not sustain the device in the active mode till the next recharge time. In this case a period may occur, before the next recharge, where the device is unavailable because the device battery charges have drained to their low threshold level. The situation may be cared for in the model by augmenting the constraints on the feasible solutions. Each feasible decision must ensure:

$$\begin{aligned} &batteryCharge(delay) \\ &\geq dischargeRate(mode) * \frac{size(date)}{speed(mode)} \\ &+ (nextRechargeTime(delay) - delay) \\ &* qdr \end{aligned} \tag{8}$$

If the inequality is not satisfied, the device battery will discharge to a level below the minimum threshold and cause the device to become unavailable. Thus, the function to be minimized when the condition is not met is:

$$minimize\ deviceUnavailable(delay, mode)$$

where

$$\begin{aligned} &deviceUnavailable(delay, mode) \\ &= size(data)/speed(mode) \\ &+ (nextRechargeTime(delay) \\ &- (batteryCharge(delay) \\ &- dischargeRate(mode) \\ &* size(data)/speed(mode)\ )/qdr) \end{aligned} \tag{9}$$

3 EXPERIMENTAL EVALUATION

A number of simulation experiments were performed to determine the affects of various operational conditions on the communication outcomes. Each experimental set-up may be viewed as consisting of two components -- scenario and case. The term scenario refers to the general environmental data such as the list of available communication modes, the communication mode availability schedules, and the battery recharge schedule. These describe operational environment in which the mobile device is operating irrespective of specific user activity. The term case is used to represent individual data transfer requirement. A case refers to specific activity and is described by the access time, the estimated size of the data which is required to be transmitted, the state of battery charge, and also the festive and the obsolesce interval of the activity. In order to support the aim of understanding the relationships between the decisions and their effects on the outcomes, these scenarios were organized in order of increasing complexity. The earlier scenarios were simple and did not involve any overlapping in the communication mode availability -- there is only one

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available communication mode at each point in time. Progressively, the later scenarios included more options and opportunities to be selected from a range of alternatives.

Successful execution of simulations based on the realistic data transfer needs and communication parameters provide a proof of the concept for our model. The results of the experiment 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.

Here we only present one experiment consisting of a single scenario containing one case. The set-up data and the outcome results are presented in detail to give clear view to the reader.

Table 1: Communication mode.

Communication Mode	Cost ($/GB)	Power Use (mAh/sec)
Wi-Fi Provider X	0.999	0.08
CELLULAR Provider X	19.95	0.03
Wi-Fi Provider Y	0.777	0.08
CELLULAR Provider Y	17.75	0.03

Table 1 presents the communication modes which are available in this sample scenario. As presented, there are two service providers in this scenario, which are Provider X and Provider Y. Both of them provide Wi-Fi and cellular data network with a different pricing scheme and availability schedule. In terms of pricing scheme, Provider X commands a slightly higher access cost for both Wi-Fi and cellular data network compared to Provider Y. Moreover, in this scenario, the power consumption for each communication mode to transmit the data is also varying (0.08mAh/sec for Wi-Fi and 0.03mAh/sec for cellular data network).

The availability schedule for each communication mode in this scenario is presented in Table 2. This table represents not only the availability of each communication mode provided by the service provider but also the quality of the communication mode in each particular period of time (represented by speed fluctuation for each communication mode). As presented, there are two periods of time where there is no communication available to be used. These periods of time are implemented in this experiment to simulate the dead zone or the period without any mobile communication reception.

Table 2: Communication mode availability schedule.

Start	End	Communication Mode	Speed (Mbps)
0:00	2:59	Wi-Fi Provider X	30
3:00	5:59	Wi-Fi Provider X	50
1:30	3:29	Wi-Fi Provider Y	45
3:30	6:29	CELLULAR Provider Y	12
6:00	6:59	CELLULAR Provider X	15
7:00	7:59	CELLULAR Provider X	5
6:30	7:29	Wi-Fi Provider Y	25
7:30	8:29	CELLULAR Provider Y	8
8:00	8:59	Wi-Fi Provider X	30
9:00	9:59	Wi-Fi Provider X	40
8:30	9:29	Wi-Fi Provider Y	25
9:30	10:29	CELLULAR Provider Y	12
10:00	10:59	CELLULAR Provider X	10
11:00	11:59	CELLULAR Provider X	5
10:30	11:29	Wi-Fi Provider Y	35
11:30	11:59	CELLULAR Provider Y	8
12:00	12:59	N/A	0
13:00	13:59	CELLULAR Provider X	15
14:00	14:59	CELLULAR Provider X	10
13:30	14:29	Wi-Fi Provider Y	25
14:30	15:29	CELLULAR Provider Y	4
15:00	15:59	Wi-Fi Provider X	50
16:00	16:59	Wi-Fi Provider X	40
15:30	16:29	Wi-Fi Provider Y	45
16:30	16:59	CELLULAR Provider Y	12
17:00	17:59	N/A	0
18:00	18:59	Wi-Fi Provider X	30
19:00	19:59	Wi-Fi Provider X	40
18:30	19:29	Wi-Fi Provider Y	45
19:30	20:29	CELLULAR Provider Y	8
20:00	20:59	CELLULAR Provider X	10
21:00	21:59	CELLULAR Provider X	15
20:30	21:29	Wi-Fi Provider Y	25
21:30	22:29	CELLULAR Provider Y	12
22:00	22:59	Wi-Fi Provider X	30
23:00	23:59	Wi-Fi Provider X	50
22:30	23:29	Wi-Fi Provider Y	35
23:30	23:59	CELLULAR Provider Y	8

There are three battery recharge periods in this scenario as presented in Table 3. These periods of time are introduced in the experiment in order to simulate the period for a user to recharge his/her mobile device.

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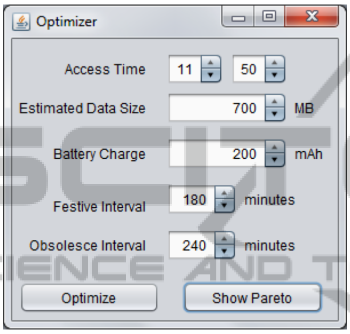
Table 3: Battery recharge schedule.

Start	End
13:30	13:44
17:30	17:44
21:30	21:44

A sample case is presented in this paper in order to run the simulation based on the sample scenario described earlier. As mentioned before, the parameters in a case is used to represent the situation of data transfer. In this case, the parameters are presented in Figure 1.



Access Time 11 50
Estimated Data Size 700 MB
Battery Charge 200 mAh
Festive Interval 180 minutes
Obsolesce Interval 240 minutes

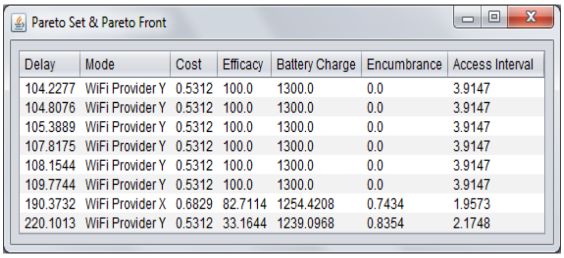
Figure 1: Data transmission parameters.

As presented, the intended user's data transfer in this case is at 11:50 and the estimated size of the data which is going to be transmitted is 700MB. The data has a festive interval of 180 minutes (3 hours) and an obsolesce interval of 240 minutes (4 hours). In this case, the mobile device which is going to be used to transmit the data has 200mAh of battery charge. 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.

In order to solve the problem in multi-objective optimization, there are several evolutionary algorithms available and can be implemented. For our model, Non-dominated Sorted Genetic Algorithm version 2 (NSGA II) is the one which chosen to run the simulation. Compared to the first version of NSGA, the NSGA II is more efficient in terms of computational process. 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 (Deb, 2002; Deb, 2010; Coello, 2007).

As the building blocks to construct the simulation model, jMetal framework is used. jMetal stands for Meta-heuristic Algorithms in Java, it is a framework for constructing and solving the multi-objective optimization 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. The 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 meta-heuristics are provided by this framework in order to take advantage of code-reusing. In addition, the evolutionary multi-objective algorithms in this framework are tested for their performance with standard multi-objective optimization problems (Durillo and Nebro, 2011.).

Based on these input parameters as presented in Figure 1, a set of non-dominated/optimum solutions is produced and presented in Figure 2. A number of non-dominated solutions that were produced and reported by the simulator and in Figure 2 do not seem to be different from each other especially in Delay period from 100 to 110 minutes. This may be due to close real values for the metrics that exceed the others by only a very small amount. However, we like to stress that these nearly similar outcomes provide assurance that the outcomes are not very sensitive to the delay and mode value in this period -- the user can select delay in a relaxed calm fashion.



Delay	Mode	Cost	Efficacy	Battery Charge	Encumbrance	Access Interval
104.2277	WiFi Provider Y	0.5312	100.0	1300.0	0.0	3.9147
104.8076	WiFi Provider Y	0.5312	100.0	1300.0	0.0	3.9147
105.3889	WiFi Provider Y	0.5312	100.0	1300.0	0.0	3.9147
107.8175	WiFi Provider Y	0.5312	100.0	1300.0	0.0	3.9147
108.1544	WiFi Provider Y	0.5312	100.0	1300.0	0.0	3.9147
109.7744	WiFi Provider Y	0.5312	100.0	1300.0	0.0	3.9147
190.3732	WiFi Provider X	0.6829	82.7114	1254.4208	0.7434	1.9573
220.1013	WiFi Provider Y	0.5312	33.1644	1239.0968	0.8354	2.1748

Figure 2: A set of optimum solutions.

As shown in Figure 2, the optimum solution with the highest efficacy level can be achieved by postponing/delaying the data transmission for 104.2277, 104.8076, 105.3889, 107.8175, 108.1544, or 109.7744 minutes (time period 13:34:13 to 15:48:04) and using Wi-Fi provided by Provider Y as the communication mode to transmit the data. As

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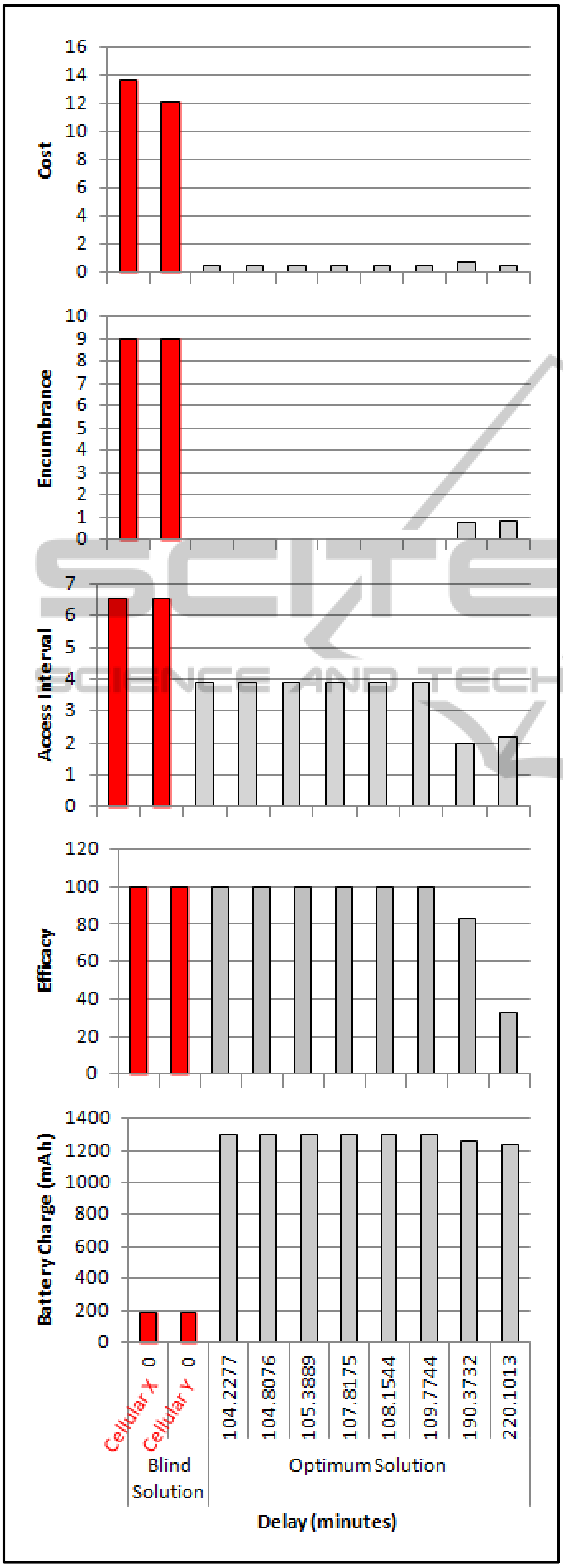

Figure 3: Blind solutions and optimum solutions comparison.

presented in Table 2, in this period of time there are more than one communication modes available, and in order to produce optimum satisfaction level, Wi-Fi provided by Provide Y is chosen.

By postponing the data transfer for 190.3732 minutes and using Wi-Fi provided by Provide X, another optimum satisfaction can be achieved. This optimum solution offers the shortest access interval compared to the others optimum solutions in this case.

As an evaluation, we also compare these optimum solutions with the possible blind solutions which are a user might chose for this case. A blind solution is a solution where the device owner performs the data communication activity immediately. Most mobile device data communication today operates in this mode. Based on Table 2, there are two available communication modes for blind solution in this case: cellular data network provided by Provider X or cellular data network provided by Provider Y. We compare these blind and optimum solutions based on the five objective functions which we have explained earlier. The following figures show the solutions comparison for this case.

As shown in the Figure 3, the optimum solutions can significantly produce better outcomes in order to satisfy the five objective functions which we discussed earlier. Blind solution can only produce a better outcome in terms of efficacy due to immediate data transmission. A mobile device owner can achieve best outcomes for data communication activity by choosing a delay and comparing the various outcomes against those that are achieved at other delays.

4 CONCLUSION AND FUTURE WORK

The paper has presented a multi-objective model for scheduling the data communication based services on the mobile devices. As these objectives are incomparable with each other and represent different needs they cannot be assigned meaningful weights to generate a single outcome. Even if such weights were feasible, each mobiles user will attach different weight of importance to these objectives. Indeed, one would expect the same user to assign different weights to these objectives at the different times. Pareto optimal solutions provide the best option for determining efficient schedules.

Using realistic parameter values and cyclic lifecycle of the mobile users we have run several test

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scenarios. The experiments support the common wisdom of preferring a wired data communication mode over a Wi-Fi mode and preferring the Wi-Fi communication over the cellular communication. This rule receives support as these preferred modes also frequently overlap with the battery recharge opportunities.

The increasing adaption of the cloud computation and resources would make the services on the mobile devices even more dependent on the externally located data. The models for scheduling the data communication would optimize the use of mobile device resources and capabilities.

There are several possibilities that can and need to be explored as future works. Our model 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 optimized way. Alternatively one may propose an algorithm to prioritize 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 communication availability schedule. 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.

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