Powerlet: An Active Battery Interface for Smartphones

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ABSTRACT
A smartphone battery interface should provide energy-related information efficiently with high accuracy because it is the basis for user actions on battery consumption. Previous studies have mainly focused on battery information per se, but the effectiveness of user interaction with the interface has barely been studied. In this paper, we first discuss the results of a survey on different types of energy-related information and features to investigate what users want in terms of battery consumption for smartphones. We then introduce Powerlet, which is a new battery interface that attempts to actively interact with users to provide battery usage information. We validated the efficiency of Powerlet with real users' experiences derived over a seven-week study period. We found that the users actively managed and changed their phone usage based on the energy-related information provided by Powerlet. With the Powerlet active battery interface, participants reduced daily energy consumption by 8.2% on average.

Author Keywords
Battery interface; mobile device; energy; active interface

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
With the diverse use of smartphones and growing user expectations for the devices, battery life has progressively become an important issue [1]. To extend the battery life of mobile device, active research has been conducted to develop a wide spectrum of battery management policy [2-8]. Traditional approaches tried *automatic* policies for battery management without having to consider user intervention. More recently, users are considered as a key factor for aggressive battery control [9-17]. The management scheme now focuses on understanding user's behavior, and subsequently changes the device usage for efficient battery management. Designing such a scheme is indeed challenging, and the battery interface plays an important role. The battery interface includes an indicator of the device's power status and an interface to adjust the power-related variables [9, 10]. The major concerns are then what information should be delivered; how the interface exhibits information; and when the information should be delivered to user. Users may take adequate actions with regard to power consumption based on the energy usage information provided by their battery interface. A conventional battery interface shows the remaining battery capacity as a percentage alongside a battery icon. Many of the latest mobile platforms provide detailed information about the energy consumed by the system components and applications. Smartphone vendors and application developers also distribute various battery interfaces that present additional information [18]. However, we argue that previous work has not fully encouraged users to take the actions necessary to improve battery efficiency.

Active research is being conducted on the development of an efficient battery interface. Recent studies have suggested diverse methods to increase the accuracy of energy estimation [5, 13, 15], as well as to manage the running state of applications [5, 15, 16]. However, with these efforts users have to constantly be aware of their smartphone energy use and take the necessary actions in order for the energy information to be effective. In other words, delivering information to users is as important as ensuring the accuracy or the types of energy-related information in order to solve energy issues. Previous work on battery interfaces has mostly focused on the accuracy and content of information, but how this information is delivered to users has not been investigated in depth. Consequently, this paper focuses on how a battery interface delivers information to users; that is, how interaction has to occur in order to provide information on energy and maximize efficiency.

We first surveyed users to find out what features and information they wanted from a battery interface. Based on the results of the survey, we designed Powerlet, a new battery interface that actively provides energy-related information to users. To validate the efficiency of Powerlet, we deployed Powerlet among 42 users over a period of seven weeks. The results indicate that the participants actively changed their behavior to maximize the efficiency of their batteries based on the information provided by Powerlet. Eventually, our study presents several evidences that the interaction type of battery interface significantly influences the users' energy behavior.

UbiComp '14, September 13 – 17, 2014, Seattle, WA, USA

http://dx.doi.org/10.1145/2632048.2636085

To the best of our knowledge, this study is the first work to systematically investigate *types of interaction* with a smartphone battery interface. The contributions of this work are summarized as follows:

- Based on the user survey results, we review the usability and usefulness of existing battery interfaces in finding the information and interaction types that users want.
- We propose Powerlet, which uses an active interaction type of in-battery interface.
- The impact that the interaction type has on user behavior is observed through our field study and analyzed via various types of quantitative and qualitative data.

RELATED WORK

A wide variety of research has been conducted regarding the power consumption of mobile devices, including smartphones. Indeed, many attempts have been made to discern the relation between users and energy problems, and many new types of battery interfaces have been suggested.

Rahmati et al. [9, 10] looked into the interactions between users and batteries. This was the first significant work that focused on the importance of battery interfaces in the interaction between a user and a battery. They pointed to the problems with conventional battery interfaces, such as low accuracy and the narrow range of information offered, and claimed that a well-designed battery interface would be able to guide users to change their actions and thus improve energy efficiency. Truong et al. [13] proposed the task-centered battery interface (TCBI), which is a battery interface that accurately calculates the remaining battery time on a device. The TCBI offers the estimated remaining battery life on a device for a few predefined cases while taking into account currently activated applications. The interactive battery interface (IBI) proposed by Ferreira et al. [15] also shows the remaining battery life and provides functionality to terminate activated applications. Similarly, Oliner et al. [5] claimed that showing the remaining and extendable battery life when each activated application is terminated encourages users to take action to improve energy efficiency. They also suggested a method to identify problematic applications from an energy perspective via crowdsourcing. They deployed a battery interface, named Carat, to more than 670,000 devices and presented the changes of users' behavior based on the survey results [19]. In summary, previous work on battery interface primarily focused on the content and accuracy of the provided information [5, 13, 15]. Our work is differentiated from the prior art in a way that we mainly consider the *interaction type* of battery interface (i.e., how information is delivered to users) which is rarely conducted in previous work.

Note that the interaction method for energy-related information has been actively studied in home energy management [20, 21]. The key theme of reducing energy consumption based on user's feedback is similar to ours, but we in this work focused on mobile platform that is inherently different from the case in home environments.

PRELIMINARY STUDY

We conducted a survey to assess users' interest, their requirements with respect to battery issues, and their experiences. The survey questions are listed in Table 1. Items SQ3 through SQ12 ask about users' previous experiences with battery interfaces.

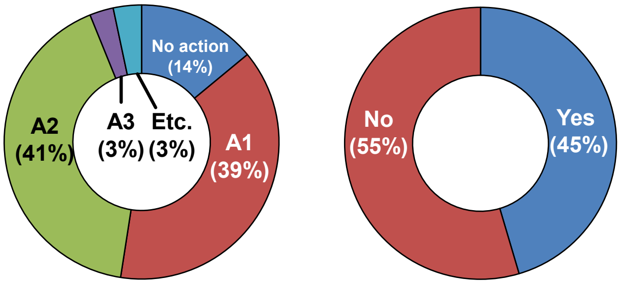
The questions were distributed online through Google Drive and promoted over social networking services. Over a period of one week, 566 valid responses were collected. The respondents ranged in age from teenagers to people in their 60s (17 respondents between ages 10 and 19; 320 between 20 and 29; 167 between 30 and 39; 47 between 40 and 49; 14 between 50 and 59; and one for 60 and above).

User Involvement

A battery interface can be considered as a function intended to help ease energy-related problems via user intervention. What we were most keen to learn from our survey was whether the participants were sensitive to the energy issues of smartphones and whether they were willing to play an active role in addressing them. The results of our survey showed that the participating smartphone users were willing to play a proactive role in lengthening battery life. Figure 1(a)

SQ1	What action do you primarily take to save battery power?
SQ2	Have you previously used a battery interface, such as the battery item in the Settings menu on an Android phone or battery management apps/widgets that are downloaded from an app market?
SQ3	Mark X next to the battery interfaces you have used before.
SQ4	How satisfying has your experience of battery interfaces been on a scale of 1 to 5? (1: very dissatisfied, 2: dissatisfied, 3: neutral, 4: satisfied, 5: very satisfied)
SQ5	Mark X next to the factors that made your experience of battery interfaces inconvenient.
SQ6	Mark X next to the features offered by the battery interfaces that you have used.
SQ7	Mark X next to the types of information provided by the battery interfaces that you have used
SQ8	Mark X next to the features you found convenient.
SQ9	Mark X next to the types of information you found convenient.
SQ10	Mark X next to the types of features you would like to see in a battery interface.
SQ11	Mark X next to the types of information you would like to see in a battery interface.
SQ12	Describe your thoughts with regard to battery interfaces in general.

Table 1. Survey questions. SQ1–SQ2: single choice questions, SQ3 and SQ5–SQ11: multiple choice questions, SQ4: 5-point Likert scale, SQ12: short answer question. Items SQ3 through SQ12 were only asked of the respondents who responded in SQ2 that they had used a battery interface before.



(a) Types of user actions in terms of mobile device energy

(b) Percentage of users with experience of a battery interface

Figure 1: Types of user actions in terms of mobile device energy and the percentage of users with experience of a battery interface. In (a), A1=User checks battery level frequently and reduces use, A2=User always carries a back-up, A3=User uses third-party battery management interfaces.

shows the answers to SQ1: 86% of the respondents answered that they took action with respect to energy issues on their devices. Thus, most of the users were both aware of energy issues and took action to address them. Among the actions we suggested, A1 and A3 were related to battery interfaces. The results indicate that more than 42% of the respondents resolved their energy issues primarily through battery interfaces.

Usability and Usefulness of Battery Interfaces

The usefulness of existing battery interfaces (e.g., the battery item in the Setting menu of Android devices) has not kept pace with user interest in battery issues. Figure 1(b) shows the responses to SQ2, which asks whether the respondent has used a battery interface before. More than half answered they had never used a battery interface. We did not include the battery icon as an example of battery interfaces in SQ2 because it is obvious that most users (maybe all users) have used the battery icon before; items SQ3 through SQ12 were questions for the users who had used battery interfaces other than the battery icon. Android users (71% of respondents) were more exposed to battery interfaces than iPhone users (29% of respondents) since Android provides battery-related information in the basic device setting. However, about half of the Android users (i.e., 48%) had hardly experienced the battery interface. More surprisingly, 63% of Android users did not respond that they had used the battery item in the Settings menu, which is Android's default battery interface. These results indicate that many users do not utilize battery interface features even though the function is provided by the smartphone operating system.

Our respondents indicated that they were not satisfied with the accuracy or types of information provided by either smartphone OS or third-party developers. This was evident in the low score of 2.75 out of 5 on rating how satisfied the respondents were with regard to the battery interfaces they had used. Figure 2 shows the respondents' dissatisfaction with the interfaces they had used (SQ5). It shows that our respondents were least satisfied with the actual battery life

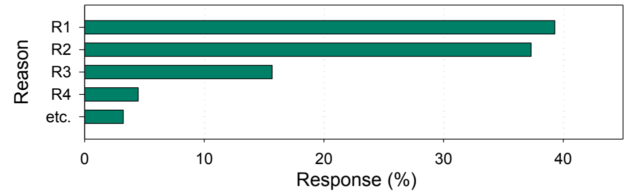


Figure 2: Factors contributing to users' negative experiences of battery interfaces. R1=No significant increase in battery life, R2=Inaccurate battery information and limited types of information offered, R3=Desired types of functions not offered, R4=Interface too complex to use.

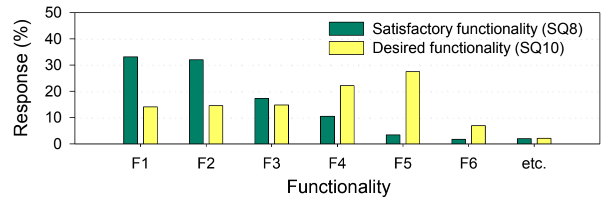


Figure 3: Functionality that satisfies users and the functionality that they expect. F1=Warning (e.g., low-battery warning), F2=Predefined power-saving mode, F3=Hardware configuration (e.g., setting display brightness level), F4=Application configuration (e.g., setting synchronizing duration), F5=Diagnosis of abnormal situation and provision of a solution, F6=Power mode scheduling.

reduction, which is attributable to the discrepancy between what third-party interfaces either explicitly or implicitly claim to be the power-saving effects and what users actually experience. They also indicated very low satisfaction with the types and accuracy of information provided. Our survey result was consistent with the findings of other research [9, 10, 13-15].

Users' Requirements for Battery Interfaces

Our respondents indicated that they were highly satisfied with the alarm features for specific situations, such as an alarm for a low battery status. They were also satisfied with power-saving features that can be switched on with a simple control, such as the power-saving mode.

The survey asked which features were most satisfying (SQ8) and what features the users wanted on their devices (SQ10), for which the available options were selected from what is already available in default battery interfaces, from third-party interfaces [5, 13, 15, 17, 18], and from a few of our own ideas. Figure 3 shows the responses obtained for these two questions, with warning features and power-saving modes ranking highest for satisfaction. While the power-saving mode tangibly reduces power consumption, low battery warning features simply alert users. The latter guides users to take action, which has been suggested as a major feature of battery interfaces by various studies [10, 13, 15]. One special aspect of alarms is that an alarm plays a proactive role with respect to user interaction when dealing with a battery issue, and this has not been given much attention in previous studies.

According to our survey, the most desirable items regarding batteries were the diagnosis of problems and the provision of solutions, as well as application configurations. Users seemed willing to play a proactive role in dealing with battery issues. It was noticeable that the number of requests for application configurations was 50% more than the number of requests for hardware configurations to save energy. Users in general may perceive that not all the applications they use are energy-efficient. The following short answers to a question (SQ12) in the survey support this speculation:

"(The application is) scarcely brought to the foreground, and I'd like to know how much power is consumed while it runs in the background." – SP7

"I want to know the amount of energy used by non-essential applications and stop them easily or automatically." – SP63

In terms of information from default battery interfaces, users were satisfied with the remaining battery capacity expressed as a percentage. However, users wanted to be provided with more in-depth information. In SQ9, the respondents were asked whether they were satisfied with the types of information offered in the battery interfaces they had tried or used; in SQ11, they were asked what types of information they would like to see on a battery interface. Figure 4 illustrates the responses to these two items. For the information with which the respondents were satisfied, an overwhelming majority chose the remaining battery capacity as a percentage. It was interesting that even though I3 is already provided by the default battery interface on the Android platform, only 35% of the Android users answered that they had ever accessed the information (SQ6). That is, a significant proportion of users seemed to be unable to access the information already available in the default battery interface. Each type of information that the users wanted to see in the future was selected at roughly the same rate. Information about energy consumption by different hardware components was not especially favored, probably for the same reason that the demand for application configurations was higher than the demand for hardware configurations. In other words, the users were interested in identifying the applications that waste energy rather than the hardware components. The following response supports this view:

"It might be useful if the battery interface shows the expected energy consumption per hour or per minute for each application upon launching." – SP3

Summary and Implications

The results of the survey can be summarized as follows:

- Users are willing to play an active role in resolving energy issues.
- The current battery interfaces are problematic either in their approaches to delivering information or in their interactions with users. Thus, a significant proportion of users have never accessed even their devices' default battery interfaces.
- Users who have previously accessed this information want various types of information with improved accuracy.

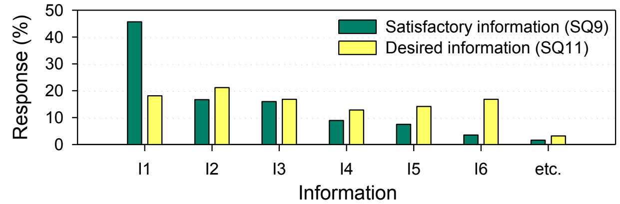


Figure 4: Types of information that users find necessary and satisfying. I1=Current battery level as a percentage, I2=Available time on the device, I3=Energy consumption rate of each app, I4=Energy consumption rate of each hardware component, I5=Available time in a category, I6=Available time for each app.

- Users demand a wider variety of energy-related information, especially the energy consumption levels of each application.

To the best of our knowledge, we are the first to claim that the *interaction type* of current battery interface is problematic to enforce user's change in device usage behavior towards efficient battery use. If the assumption is true that a well-designed battery interface positively influences user actions on battery life [9, 10, 13, 15], then the question of *how* energy-related information is delivered is as important as *what* information is delivered to the user.

The majority of users were not accessing the information offered by even default battery interfaces. The positive responses regarding alarm features provided us with the clue that similar interactions may guide users to take action to enhance battery life. It then seemed necessary to evaluate this through experimentation.

Based on the implications derived from the survey, we designed a battery interface which *aggressively interacts with users* in order to provide *application-related energy information*. In the following, we describe the interface design and the study results acquired with real deployment of the system.

STUDY DESIGN

This section describes how we designed our study to investigate which types of battery interfaces are effective among the different approaches to interaction. The battery interfaces used in the study are discussed in the next section.

Types of Interaction of Battery Interfaces

We, in this paper, categorize the battery interface into either passive or active, defined as follows:

With a *passive interface*, the *user* triggers a set of interactions with the device. The user decides when to interact with the interface and when energy-related information is viewed, and *accesses to* the information in a "pull" manner [22]. The default battery menu in the settings on the Android platform shown in Figure 5(a) is an example of a passive interface; the overwhelming majority of third-party interfaces fit into this category.

With an *active interface*, the *device* initiates a chain of interactions. The device alerts the user at appropriate moments

(a) Passive interface (information access) (b) Active interface (information delivery)

Figure 5: Types of interaction between battery interface and user.

and displays a range of information that the user needs to be aware of; that is, the information is *delivered to* (or notified to) the user in a "push" manner [22]. Figure 5(b) illustrates examples of active interfaces, which include the battery icon in the notification bar of the default interface on the Android platform and the low battery alarm that we noted in the survey.

Study Method

The purpose of our study was to evaluate the usefulness and usability of our proposed interface, which is described in the next section, and also to find answers to the following questions relating to the approaches to interactions on battery interfaces:

- Q1. Are users induced to take action by being offered information about battery consumption?
- Q2. What is the expected range of user actions when the interface is passive?
- Q3. How different will user actions be when the interface is active? (Is an active interface any more effective?)
- Q4. Will users notice changes in how they use their devices to save energy?

In our study, a total of 42 undergraduate students (20 male and 22 female) participated in the experiments. All the participants are the Android users. The participants' major subjects were widely different, ranging from engineering to sociology, and their average age was 23.5 years. We conducted the initial survey used in our preliminary study, and the results were similar to our original findings. In the study, we followed the policy of the National Research Foundation of Korea and thereby carefully examined the study's design prior to obtaining the Foundation's approval, which is equivalent to an IRB in the U.S. The collected data was accessible only to those researchers who were part of the project. The study was conducted by deploying an application with the battery interface described below. This application logged energy-related data and automatically uploaded the following data to our server, which was implemented using a mobile service and Azure SQL of Windows Azure [23]:

- Battery level change: Timestamps and amount of energy used
- Application usage: Energy consumption level, application name, UID, and other relevant information
- Powerlet activity: Alerts and information checked by users

The experiment consisted of three phases; in each phase, a different version of the application was installed on each device. In Phase 1, the data described above were logged to perceive users' energy-related behaviors. We divided the participants into two groups (Group A and Group B) for Phases 2 and 3 based on their gender, age and the battery usage information collected in Phase 1. We sorted friends into the same groups to conceal the different policies we were applying to Groups A and B. In Phase 2, each participant of Group A was offered a passive interface, which was similar to the implementations of other existing studies, while the Group B participants were offered both passive and active interfaces. In Phase 3, Group A was given both the passive and the active interfaces inversely, and Group B only the passive interface. Features of the passive and active interfaces deployed in the study are described further in the following section.

Phase 1 lasted three weeks while the other phases lasted two weeks each, so the entire course of the experiment ran for seven weeks. In order to make the collected data as unbiased as possible, the participants were not notified of the procedure of the experiment and that the application would be updated during the experiment. We conducted a different survey four times at the start and end of each phase, and carried out an online interview at the end of the experiment.

When the experiment had finished, each participant was rewarded with a gift certificate worth $60. Before the start of the experiment, the data to be logged were explicitly explained to the participants. The actual log files were disclosed after Phase 3, and the participants consented to providing the data for research purposes.

POWERLET: AN ACTIVE BATTERY INTERFACE

Powerlet is a battery interface that performs both passive and active interactions with users. We implemented Powerlet as an Android application which runs on Android ver.4.0 (ICS) and later. Powerlet provides energy-related information including power consumption data for each application. Note that, compared to previous approach, Powerlet adopts an active type of interface.

(a) Application energy information (b) Interactive energy warning (c) Elapsed time notification

Figure 6: Main features of Powerlet.

Functionalities

Powerlet interacts with users through three functionalities: (1) application energy information, (2) an interactive energy warning, and (3) an elapsed time notification.

Application Energy Information: A Passive Interface

The application energy information function performs *passive interactions* with the user. When the user explicitly requests information, as in Figure 6(a), the following are provided: the estimated remaining run time of the application in question, the battery consumption rate by the application as a percent per minute, and the application run time per 1 batt%[1]. The interface shows the time taken to consume 10 batt% and the average value over power consumption history, as well as information on the applications. This information is equivalent to that provided by the next two functions explained below. This feature however does not consider user accessibility.

Interactive Energy Warning: An Active Interface

Interactive energy warning is a feature that allows *active interaction* with users. Through this feature, the device triggers a chain of interactions with the user at a point when a specific piece of information is deemed necessary for the user. In the current version, the user is sent an alarm (1) when the user launches an application and (2) whenever the battery level decreases by 1 batt% while running an application continuously. The alarm is displayed for approximately 3.5 seconds, and the battery consumption rate and time taken to consume 1 batt% of the battery life are displayed, as shown in Figure 6(b). Among the information showing energy consumption characteristics, the time to consume 1 batt% of battery life (min/batt%) is analogous to the mileage of an automobile in km/liter or miles/gal. This similarity is expected to be intuitively understood by users. Through this feature, users are offered energy-related information at appropriate moments without explicitly requesting it.

[1] In this paper, we use “batt%” for the unit of battery capacity, in order to distinguish it from the normal percentage notion (“%”).

Elapsed Time Notification: An Active Interface

The third feature of Powerlet is the elapsed time notification, which attempts *active interactions* with the user. Notifications are given at every 10 batt% reduction in battery life. At each notification point, the user is notified of the time taken to consume 10 batt% since the last alert and the average time taken to consume 10 batt% over the history, as illustrated in Figure 6(c). It was expected that this would motivate the users to take action. That is, by comparing the latest energy consumption to the average consumption, the user would be motivated to take appropriate action to ensure efficient power consumption.

Estimating Energy-Related Information

Powerlet estimates the battery consumption rate (BCR) of each application using the battery level provided by Android. BCR is expressed as:

$$BCR_i(batt\%/min) = \frac{BC_i(batt\%)}{Time_i(min)},$$

where BCR_i is the battery consumption rate of application i, $Time_i$ is the usage time of application i, and BC_i is the battery consumption of application i. BCR is the average battery usage of the application per minute, which is the same with the metric used in previous work [15]. Powerlet runs in the background to continuously estimate the usage time and battery consumption of applications. This method provides accurate information when the sample size is sufficient for learning [24]. Thus, we set the training phase (i.e., Phase 1) to three weeks to collect a sufficient amount of learning data. Note that a mechanism to improve the accuracy of the estimation is beyond the scope of this study.

STUDY RESULTS

This section provides the results of the experiment conducted in three phases over seven weeks. We first present the change in energy consumption during the experiment and investigate the user behaviors that led to the changes in energy consumption. We then analyze the users’ interests and knowledge about energy consumption after using each version of Powerlet. We used the *one-way repeated measures analysis of variance* (ANOVA) for statistical analysis across three phases [25]. To compare two phases,

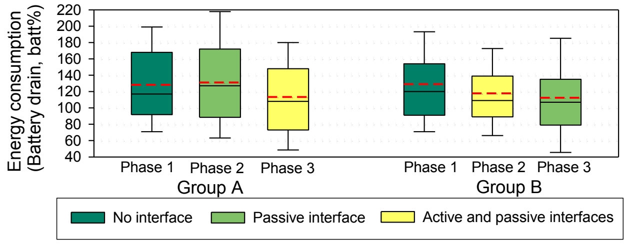


Figure 7: Energy consumption. Each bar includes data for two or three weeks (Phase 1: three weeks, Phases 2 and 3: two weeks). The red dashed-line in the box indicates the mean value, while the black line indicates the median value.

we performed the *adjusted pairwise tests* with Bonferroni correction [25].

Energy Consumption

The energy consumption of the devices changed significantly after the active interface was introduced. Figure 7 shows the average amount of energy used by each user per day during each phase. The difference across three phases of each group is statistically significant (Group A: $F(2, 40)=8.82$), $p < .01$; Group B: $F(1.3, 26.5)=6.43$, $p < .05$ after Greenhouse-Geisser correction). The amount of energy consumed by our participants was reduced after Phase 3 (Group A) and Phase 2 (Group B), at which time the active interface was introduced to the participants. In Phase 3 of Group A, the amount of energy used was reduced from 128.9 batt% (SD=35.1) to 115.4 batt% (SD=36.7) on average compared to Phase 1, and this reduction was statistically significant ($p < .01$ after Bonferroni correction). Similarly, the use of the active interface in Phase 2 reduced energy consumption from 128.3 batt% (SD=40.5) to 118.7 batt% (SD=37.8) on average, which is also statistically significant ($p < .05$ after Bonferroni correction).

However, the use of the passive interface demonstrated a different tendency among the two groups. In comparing the energy usage of Phase 1 with the phase that used the passive interface (i.e., Phase 2 of Group A and Phase 3 of Group B), Group A did not show a significant change, but a change was observed in Group B. That is, compared to Phase 1, the energy consumption of Group B decreased from 128.3 batt% (SD=40.5) to 112.0 batt% (SD=38.8) at Phase 3, and this decrease was statistically significant ($p < .05$ after Bonferroni correction). We surmise that this difference was caused by the learning effect in Phase 2 when the participants used the active interface. In other words, the participants in Group B still utilized the knowledge and information they had learned in Phase 2. We investigate this issue in a later section of this paper.

The survey results after Phase 2 and 3 also support the changes of energy consumption that we described; after Phase 2, only 14.3% of participants in Group A responded that they felt the reduction of battery usage, while 33.3% in Group B gave the positive responses. After Phase 3, 47.6% in Group A and 57.1% in Group B responded that they felt the reduction. The following comment indicates that the participants indeed appreciated the reduction of energy consumption and lessened the burden on battery charge:

"I used to recharge my battery at night time; After I used Powerlet, I noticed that the battery level was higher than usual when I plugged my phone to the charger." – PA17 (After Phase 3)

Consequently, participants reduced their devices' energy usage in the phase with the active interface (i.e., Phase 3 for Group A and Phase 2 for Group B), but the use of the passive interface did not produce a significant change in energy usage. In other words, the results indicate that the active interface clearly induced a change in user behavior towards energy efficiency.

Users' Behavioral Changes

The possible causes of the energy reductions could be (1) a decrease in the time required for device interaction or (2) less battery-drain during the interaction time. In what follows, we investigate this issue in greater detail.

After the end of Phases 2 and 3, we asked the participants *whether they intentionally changed their behavior to ensure efficient battery usage*. In the case of Phase 2, six participants in Group A and 15 participants in Group B responded that they intentionally changed their behavior. In the case of Phase 3, 13 participants in Group A and 13 in Group B responded positively. Given that the active interface was provided in Phase 2 for Group B and Phase 3 for Group A, the participants are considered to have changed their behavior because of the active interface. This result indicates that the users started to be vigilant about battery usage after using the active interface.

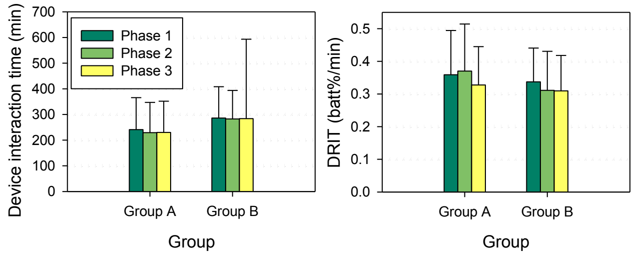
We then asked the participants *what activities they undertook to reduce energy consumption*. Their responses were categorized as the following three actions:

- Action 1: Reduce device interaction time.
- Action 2: Uninstall and/or reduce the usage time of the applications that consume significant energy (using the Powerlet information).
- Action 3: Hardware configuration, such as the control of screen brightness.

Among the three actions, the participants mainly performed Action 2, which was derived from the information provided by the active interface. This is outlined in Table 2. We further investigate the details of each action below.

Group	Action	After Phase 2	After Phase 3
A	Action 1	3	4
	Action 2	0	6
	Action 3	3	4
B	Action 1	4	4
	Action 2	7	7
	Action 3	4	3

Table 2. Participants' actions to reduce energy consumption.



(a) Device interaction time (b) DRIT

Figure 8: Behavioral changes. Error bars show the standard deviation.

Device Interaction Time

The length of time for which the participants used their devices is examined below. The device interaction time was measured as the duration for which the screen was switched on or a few applications were being executed with the screen off, such as a music player.

Figure 8(a) shows the changes in device interaction time. Some participants changed their behaviors to improve energy efficiency by reducing their device interaction time. However, we could not find that reductions in device interaction time were a primary factor in reducing energy consumption; although the device interaction time slightly decreased in the phase when we provided the active interface (i.e., Phase 3 for Group A and Phase 2 for Group B), the changes in reduction time across three phases were not statistically significant (Group A: $F(1.4, 28.19)=0.582$, $p > .05$ after Greenhouse-Geisser correction); Group B: $F(1.1, 21.40)=0.002$, $p > .05$ after Greenhouse-Geisser correction).

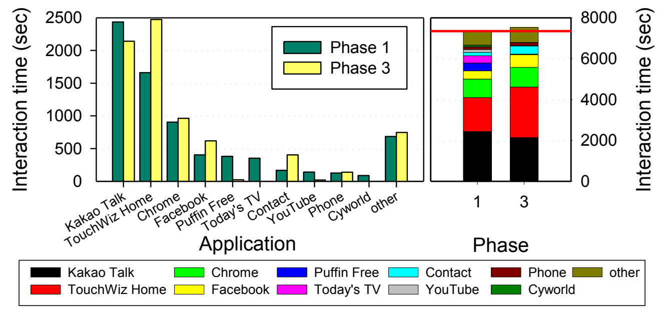
Drain Rate during Interaction Time

Many participants reduced energy consumption during device interaction to enhance device battery life after using the active interface. In order to estimate the change in user behaviors, we measured the drain rate during interaction time (DRIT), which is defined as follows:

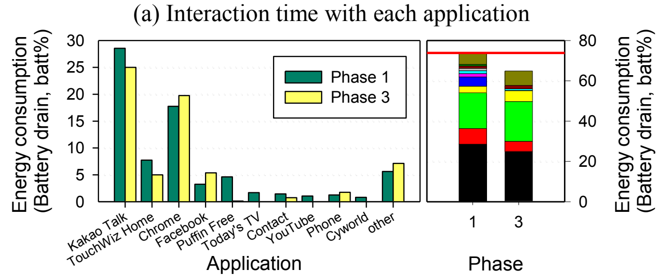
$$DRIT = \frac{Battery\ drain\ during\ device\ interaction\ (batt\%)}{Device\ interaction\ time\ (min)}.$$

A smaller DRIT value indicates that the user used the device more energy-efficiently while interacting with the device. The DRIT is the same with the mertic proposed in [15] except that we used only the interaction time.

The result of the one-way repeated measures ANOVA indicates that the difference of DRIT of each group is statistically significant (Group A: $F(2, 40)=7.35$, $p < .01$; Group B: $F(2, 40)=3.92$, $p < .05$). Figure 8(b) shows that DRIT decreased from 0.36 batt%/min (SD=0.14) to 0.33 batt%/min (SD=0.12) in Group A, and from 0.33 batt%/min (SD=0.10) to 0.31 batt%/min (SD=0.11) in Group B in the phase with the active interface. These changes were statistically significant (Group A: $p < .05$ after Bonferroni correction, Group B: $p < .05$ after Bonferroni correction). Consequently, a change in DRIT was a major factor in reducing energy consumption, and it was enhanced by the use of the active interface. In the following section, we investigate what user behaviors led to a reduced DRIT.



(a) Interaction time with each application



(b) Energy consumption of each application

Figure 9: Example of the behavioral change of a participant (PA3).

Example of Behavioral Change

The change in DRIT could have been caused by changes in the applications used (Action 2) or hardware configurations (Action 3). However, we could not find statistically significant changes in DRIT in Phase 2 for Group A although changes in hardware configuration (e.g., screen brightness) were observed for three participants (c.f., four participants of Group B in Phase 2). The change in the application usage pattern might be a primary reason for the lower DRIT.

The usage pattern of Participant 3 (PA3) in Group A clearly indicates the effect of the active interface. Figure 9 shows the application usage time and battery drain of each application in both Phases 1 and 3. Energy consumption decreased by 12.1% from Phase 1 to Phase 3, and DRIT was reduced by 15%. Considering that the device interaction time was slightly increased (by 2.6%), the result indicates that the user changed his behavior (i.e., less DRIT) to ensure efficient use of the battery. This tendency was commonly observed in Phase 3 across all participants in Group A.

DRIT was decreased due to a change in application usage pattern. In Phase 1, PA3 used 63 applications, and the user spent 90% of his interaction time with 10 major applications, as shown in Figure 9(a). In Phase 3, however, the number of major applications decreased to six although the total number of applications almost did not change (i.e., 62 applications). That is, the user reduced the usage time of several applications significantly in Phase 3 compared to Phase 1. The next question is therefore *why the user reduced the usage time of the applications*. The eliminated applications in Phase 3 were Puffin Free, Today's TV, YouTube, and Cyworld, as shown in Figure 9. The user responded that he chose other applications that provided similar functionalities with better battery consumption rates:

"I tried not to use the applications which consume battery too much…I used a similar one (which consumes less battery) instead" – PA3 (After Phase 3)

As such, the usage time of Puffin Free (a web browser) and Cyworld (a web browser for a specific portal site) considerably decreased, while the other browser (i.e., Chrome), for which the consumption rate (0.46 batt%/min) is relatively better than the others (Puffin Free: 0.77 batt%/min, Cyworld: 0.63 batt%/min), increased slightly.

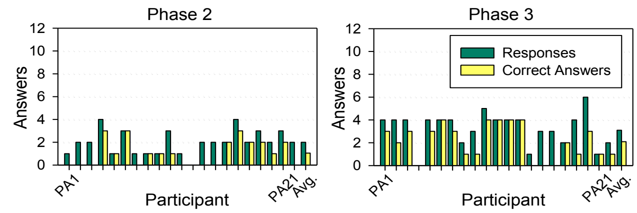
Figure 9 shows that the battery consumption of each application depended on the usage time of the application, but an exception was observed in TouchWiz Home (a launcher application). Although the usage time of this application increased by 13.5 minutes in Phase 3, the battery consumption was, counter-intuitively, reduced by 2.3%. According to the interview after Phase 3, the reason is that PA3 changed the configuration of the widget in the launcher application in order to reduce the battery drain rate. That is, the user intentionally configured the application into an efficient form using the information provided by Powerlet and consequently acquired a drain rate of 23%.

This phenomenon was generally observed across all the participants in both groups. The number of applications that consumed 90% of usage time decreased after the participants used the active interface; the number decreased from 10.8 (SD=2.6) to 8.9 (SD=2.5) in Group A and from 11.0 (SD=3.8) to 9.6 (SD=2.8) in Group B. The eliminated applications were shown to exhibit a relatively high battery consumption rate. The examples typically included (1) applications that could be easily replaced by other applications (e.g., web browsers or instant messengers) and (2) entertainment-related applications (e.g., games or movie players).

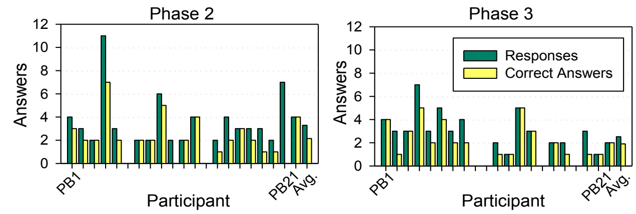
Users' Knowledge of Power Characteristics

Users' knowledge of system power characteristics is a dominant factor driving energy-efficient behavior [9, 10]. The goal of Powerlet was to improve users' knowledge based on the provision of battery-related information. The active interface continuously stimulated the users to gain knowledge of power characteristics. To validate this hypothesis, we asked the participants to record the battery consumption rates of the applications they remembered after Phase 2. The participants in Group B (who used the active interface) recalled a relatively higher number of applications (2.0 in Group A and 3.0 in Group B) with higher correction (1.0 in Group A and 2.1 in Group B), as shown in Figure 10. Here, we rounded their answers to the nearest minute, and the answers were considered correct if the difference was within 10%. After Phase 3, the results, especially the average numbers of correct answers (2.1/3.3 in Group A and 1.9/2.5 in Group B), were similar in the two groups.

In summary, the users' knowledge was greatly improved after they used the active interface, and the acquired knowledge continuously affected the users' behavior even after the active interface had been removed: The difference



(a) Group A



(b) Group B

Figure 10: Users' knowledge of power characteristics.

of Group A users' knowledge between Phase 2 and 3 is statistically significant by the t-test (responses: $t(20)=2.487$, $p < .05$; correct answers: $t(20)=2.482$, $p < .05$). In Group B, the numbers of applications that users remembered regarding their battery usage and correct answer at Phase 2 are not statistically different with Phase 3.

It is also noteworthy that the participants' knowledge after being exposed to active interface might be more accumulated than the abovementioned numerical values in practice. For example, although they do not remember the exact value of energy consumption, the participants could classify the applications in terms of energy consumption. This speculation is supported by the response such as the following:

"Although I don't know the exact number, I remember at least which Apps consume more battery than others." – PB20 (after Phase 2)

Consequently, it was established that the proposed active interface successfully provided battery-related information to drive efficient battery use.

Result Summary

The result of our study can be summarized as follows with regard to the questions we posed in the study design stage:

- The participants used their devices in more energy-efficient ways compared to the time before they started using Powerlet. The degree of effectiveness depended on the type of interface employed.
- The use of the passive interface failed to induce changes in user behaviors. The results of Phase 3 in Group B were caused by the learning that took place in Phase 2 through use of the active interface.
- The participants showed positive changes in behavior in terms of improved energy efficiency when information was delivered to them via the active interface. This is because they recognized the information presented by Powerlet more readily when they were alerted by the active interface.

- Many participants appeared to recognize their own behavioral changes after using the active interface. In particular, they proactively substituted energy-hungry applications with similar applications that had better energy performance based on the information provided by Powerlet.

These observations support the view that users take action towards improved energy efficiency when the relevant information is provided through active interactions rather than passive ones.

DISCUSSION

In this section, we describe the limitations of our study settings, the user experiences of the Powerlet prototype, and the definition of interaction types.

Study Limitations

We set a counterbalanced experiment with two groups, and the results from both groups confirmed that the use of the active interface was effective in positively changing user behavior towards greater energy-efficiency. However, our experiment setting still had a few limitations. First, the population was not particularly diverse since all the participants were undergraduate students. Second, our study was performed with participants who were compensated. Thus, a large-scale study with casual users would be necessary to generalize the results.

User Experience with Powerlet

We now present the user experience of Powerlet during the study. The participants were able to share their views about the Powerlet prototype via an online feedback system. We used a five-point Likert scale to present our questions.

The usefulness of the active interface was relative higher (3.42) than that of the passive one (3.02). User satisfaction with each functionality was 3.09 for the application energy information (passive interface), 3.28 for the interactive energy warning (active interface), and 3.38 for the elapsed time notification (active interface). The results were higher than the satisfaction levels for the existing battery interface that we presented in the preliminary section, which were 2.75. The following response, for example, denotes the poor accessibility of the passive interface:

"I'd rather not access the application energy information list." – PB15

Of the two kinds of active interface, the interactive energy warning received a relatively lower score than the elapsed time notification. The reason was revealed in the responses about user annoyance. The participants responded with respect to the user annoyance levels of the Powerlet interfaces with 2.01 for the passive interface and 3.15 for the active interface (a high score indicates more annoyance). Accordingly, 81% of the participants were not happy with the interactive energy warning due to the frequent notifications of the information window (5% for the application energy information and 14% for the elapsed time notification). The following comments were given about this functionality:

"The information window appeared too frequently on the screen. It hides the content on the screen." – PB13

This result indicates that a better interface is required to reduce the mental overload of users. Several works in HCI focused on this mental problem of the interruption by information notification (i.e., active interface) [26-29]. These works considered the user's state and application usage to appropriately provide information without mental overload. This policy would reduce the annoyance of Powerlet. For example, if a user is likely to remember the information, the application may increase the interval of the notifications and vice versa. Although the current version of Powerlet has a user annoyance issue, our claim is still valid: The proposed type of interaction (i.e., an active interface) is effective in changing user behavior in favor of the efficient use of a smartphone battery.

Definition of Interaction Type

We in our work defined the pull and push type of interaction as the passive and active interface, respectively. However, the active interface can be further categorized into *focus* and *peripheral* type according to the visibility. For example, the low battery warning in Figure 5(b) is the focus type, which has higher visibility than the peripheral type (battery level icon in Figure 5(b)). In other words, the focus type is more aggressive (or more active) than the peripheral one. In this study, we investigated the effectiveness of the passive and active interface, but the differences between the focus and peripheral types of active interface should be further investigated to validate its performance.

CONCLUSIONS

Based on findings from our user survey, in this paper, we proposed a smartphone battery interface to keep track of energy-related data and proactively offer the information that users indicated they want to read. In the field study in which Powerlet was distributed, changes in user behavior were observed when the users were exposed to active interface. We found that the users greatly preferred the active interface, and that this caused user behavior to become more efficient in terms of energy usage. The results of this study demonstrate that it is possible to change user behavior patterns towards improved energy efficiency by altering their type of interaction with the battery interface. Our work is the first to investigate approaches to interaction with battery interfaces (i.e., *interaction types*) and as such inevitably contains limitations. Future studies may explore these in more depth while taking into account a greater number of relevant factors than those presented in this study. We expect that our work would lead to various studies that consider the interaction type as an important factor in battery interface.

ACKNOWLEDGEMENTS

This work was supported by the Microsoft Research and the National Research Foundation of Korea grant funded by the Korean government, Ministry of Education, Science and Technology (No.2013-027363).

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