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Research Article

Daily Life Activities on Smartphones and Their Effect on Battery Life for Better Personal Information Management

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Abstract: The ubiquity of smartphones is evident from the fact that it is present in the pocket of almost every individual. Because of the increasing computing power and the integration of other abundant resources like storage and sensors, smartphones are proving as the most common Personal Information Management (PIM) platform. Smartphones can capture a broad range of users' experiences as compared to a traditional desktop computer which is evident from the numerous smartphone apps available in app markets for the purpose. These applications capture context of a user by utilizing full resources of the smartphone, especially the sensors. However, limited battery power of smartphones has proven to be the most significant bottleneck. Currently, app-based power consumption is estimated which provide only an indication of per app power usage and is of no use to researchers. This research identifies users' common daily life activities on smartphones and critically analyses their effects on battery power. Our approach looks into the problem through the eyes of researchers working in the domain of intelligent and context-aware systems. An Android-based application called Smartphone Task-based Energy Monitoring System (STEMS) is developed for estimating power consumption rates of different daily life activities. The system collects activities and the power consumption data from the participants' smartphones operating on cellular network with GSM/GPRS and Wi-Fi capabilities. It was found that activities requiring internet connectivity are more energy hungry than others. The results so obtained may prove useful to the stakeholders, like app designers and developers, PIM managers, and the end users.

Keywords: Smartphones, power consumption, daily life activities, life logging, battery lifetime

1. INTRODUCTION

Acquiring and keeping of valuable information is a fundamental property of human behavior. However, users' physical and virtual information spaces get overloaded with information accumulated from unfolding their lives. The tremendous increase in information volume generates information overload problem which makes storage, organization, and retrieval of information increasingly difficult. Personal Information Management (PIM) systems are computer-based applications developed to help users in managing their Personal Information (PI) spaces for facilitating their daily tasks and fulfilling their leisure needs [1]. The modern era of PIM started at the end of World War II (1945) when Vannevar Bush proposed an imaginary mechanical device called "Memex" to record an individual's lifetime data (i.e., books, records, and communications etc.) and retrieve them with exceeding speed and flexibility [2]. He assumed

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that extending technology into Memex will not only augment human memory for helping knowledge workers in easing the difficulties of information management but will also facilitate information exchange[3]. Researchers' growing interest in the PIM can be attributed to the advancements in computer technologies. The storage capacity of hard drives is increased significantly and terabytes hard drives are now very common and inexpensive. In addition to storing conventional information, digital storage can store pictures, music, full-motion videos, and photographs, etc. [4]. However, defining meaningful relationships between the information items and ensuring retrieval of right information at the right time is as hard as finding a needle in a haystack. Semantic Desktop approach solves the problem by providing a semantic middleware for integrating desktop applications and data using Semantic Web technologies [5].

Smart phones are modern high-end mobile phones combining the features of pocket sized communication devices with personal computers (PCs) like capabilities [6]. Smartphones have been proven as the highly ubiquitous computing devices with millions of smartphones are in use around the globe. Modern technological advancements (i.e., processor, memory, and operating systems etc.) have enabled smartphone as an ideal tool for future computing. Smartphone provides the same users' experiences as desktop computers with certain additions and improvements. Strong support from the application developers' community has enabled smartphones users to create information in a fashion similar to desktop computers. The available smartphones' applications typically defines users' daily life activities such as audio/video calling, SMS/MMS messaging, web browsing, music listening, videos watching, TV viewing, social networking, e-shopping, gaming, locations visiting, and many more. Smartphones offers numerous characteristics which instigates the need of developing sophisticated PIM systems because sooner or later they will suffer with the same information overload problem. The availability of applications enables users to create thousands of files (i.e., documents, emails, pictures, videos, and audios etc.) signifying the realities and importance of different aspects of their lives. Similarly, smartphone capabilities and features have turned it into ideal lifelogging tool which could use its sensory capabilities to capture contextual cues to annotate users' daily life activities to augment their episodic memories. However, the increasing capabilities of smartphone can be hindered by a number of limitations, importantly power issue which could not be met by the limited power sources. In smartphone, battery size and capacity is severely restricted due to the device size and weight constraints [6]. Smartphone uses rechargeable electrochemical batteries as its power source which is expensive to manufacturer and can run out of charge within a few hours. A modern smartphone featuring with conventional hardware components and applications demands for greater power sources because each one is taking toll on the battery resource [7].

Researchers have investigated energy consumption optimization at different levels (e.g., hardware and software etc.) for extending the battery life. However, smartphone's limited battery power can foster big hurdles and restrictions for using different types of applications. Applications are characterizing users' daily life activities and users have to use a number of applications to execute their daily life activities. Activities via applications creates heavy workloads and requires intensive usage of resources (i.e., processor, network interfaces, sensors, display etc.), that could result into significant energy consumption and could severely affect the capabilities and significances of smartphone such as missing of important mementos etc. Therefore, ranking an individual application for its energy consumption would be an infeasible and dreadful solution. Instead of focusing on accumulation and classification of applications into activities and finding energy consumption rates at activities levels can be of significant importance. This

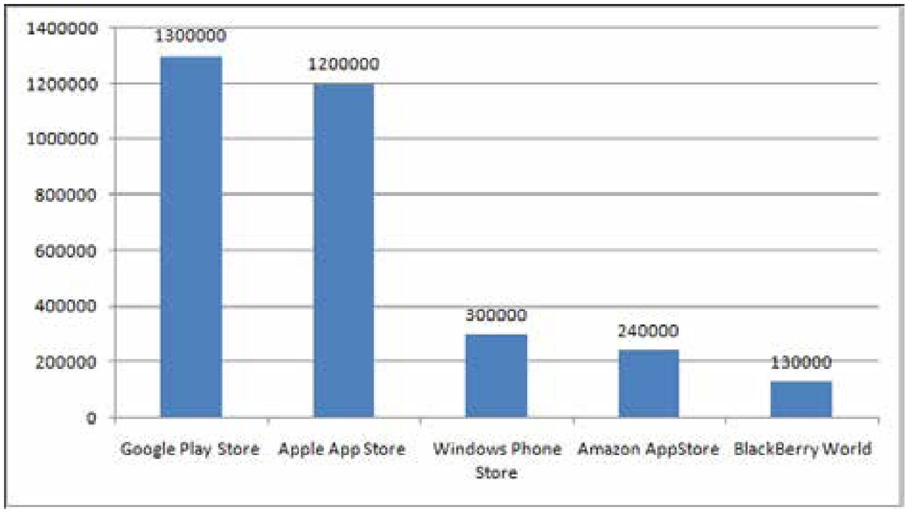

Fig. 1. Number of applications available on different app stores.

investigation will help PIM managers to identify common users' smartphones daily life activities, their power consumption shares, and customize their activity tracking patterns. It will also instigate application developers for developing novel daily life activities energy optimization methods by diagnosing and debugging the highly energy hungry applications used by users' in their daily life activities.

The work reported in this paper is done in the context of our larger project which aims to make a smartphone the most effective Semantic Desktop platform. In this paper, we have presented an approach for analyzing the energy consumption rates of users' smartphones daily life activities. To validate our approach, an Android based application namely Smartphone Task-based Energy Monitoring System (STEMS) is developed which can effectively monitor, record, and analyze the energy consumption rates of the various users' smartphones daily life activities. For representing users' daily life activities, we have divided the available smartphone applications into a number of broad categories such as accessing emails, text messaging, initiating and receiving calls, social networking, watching videos, listening audios, and playing games etc. An exhaustive set of tests have been carried to determine energy consumption rate of each activity explicitly and in conjunction with other activities. Results obtained have been tested, verified, analyzed, and found of significant importance for all of the stack holders: researchers, PIM managers, applications developers, and users.

2. COMMONDAILY LIFE ACTIVITIES ON SMARTPHONE

Smartphone applications shortened "apps" are application software designed to run on smartphones. Initially, apps were aimed for general productivity and information retrieval such as email,calendar, contacts, and stock market and weather information. However, rapid public demands, identification of new application areas, and the availability of sophisticated development tools drove rapid expansion into other categories such asgames,location-based services,e-commerce and e-banking, entertainment, transportation, healthcare and fitness etc. According to statistica[1] that by July 2014 the number of apps available in leading app stores has reached into million as depicted in Fig. 1. In June 2014, Apple had reported of 75 billion apps downloads from its App Store and in July 2013, Google had reported of over 50 billion apps downloads from its app store.

[1] http://www.statista.com/statistics/276623/number-of-apps-available-in-leading-app-stores/

Smartphone has transformed methods of engagements in our everyday lives. The growing penetration of smartphone in our everyday lives has resulted into increased screen time by engaging in numerous activities such as entertainment and social media etc. Now, the time spent using smartphone exceeds the time spent for web usage on computers. Nielson data has shown that today's smartphones users of age 18 and above spend 65% more time each month using apps than they did just two years ago [8]. Similarly, an average smartphone user checks his phone 150 times a day for different tasks and if each interaction lasts for an average of one minute it would mean a user would be using smartphone for more than two hours up to whopping 3.3 hours per day [9, 10]. In a survey, 85% of respondents have concluded smartphones as the central part of their everyday lives and marked them as the major source to remain up to date with loved ones and social events [11].

Over the past few years, the proliferation of smartphones has transformed us into an app-driven society, presenting marketers with new opportunities to connect with consumers by creating more interesting and sophisticated apps to command their attention. However, the number of apps usage varies according to demographics such as in USA the smartphones owners ages 25-44 are found using greatest number of apps with an average of 29 apps per month [8], and South Korea is the top chart country where average smartphones users downloads 40 apps per month [12]. Apps enable users to do more with their smartphones rather than just making phone calls. Thus, makes smartphone as a portal of an ever-growing list of activities. Exact Target survey has indicated that top smartphones users' daily life activities are accessing email (91%), text messaging (90%), getting news alert (62%), watching videos (30%), and getting directions (24%) [10]. Pew Research Center's Internet & American Life Project survey has indicated that most popular smartphones users' activities are taking pictures (82%), test messaging (80%), accessing internet (56%), email (50%), video recording (44%), apps downloading (43%), online health and medical information (31%), and online banking (29%) [11].

Researchers have developed applications to provide reliable data about a user's average smartphone consumption (.i.e. usage time and activities preformed) per day such as Menthal, etc. [13]. To explicitly identify the main users activities on smartphones for this study, an Android based application called Activity Logger is developed. Activity Logger was installed on smartphones of the 50 panelist (i.e., students of the

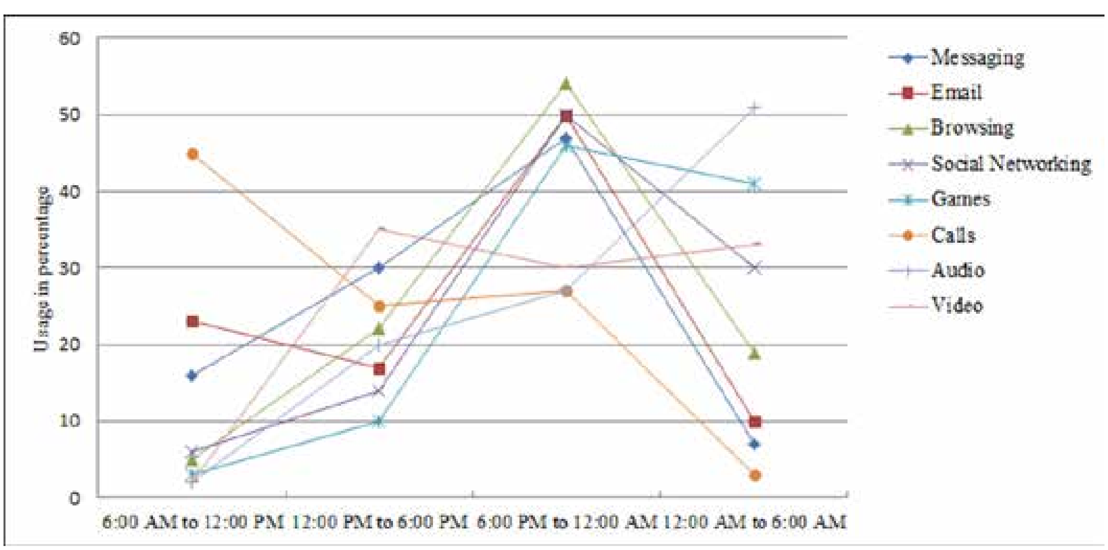

Fig. 2. Users' common daily life activities on smartphone.

University of Peshawar) aging from 18 onward. The sample size is kept fairly small in relation to smartphone owning population due to limitations of time and resources. Activity Logger runs inconspicuously in the background and captures information about applications (i.e., type, name, and usage duration etc.) used by the users while performing different daily life activities in a day. The data is collected on digital tracking of the panelists from March 10, 2014 to March 25, 2014 and stored on the panelists' smartphones. After refining, organizing, and categorizing the collected data, the most common activities performed by the panelists on their smartphones were text messaging, voice calls, entertainment, social networking, web accessing, email accessing, and playing games. The overall results of the survey are shown in the Fig. 2 depicting the most common activities and their execution time in a day.

3. RELATED WORK

A fair amount of research has attempted to investigate that how a smartphone battery power has been consumed. Researchers have concluded the energy consumption as the primary problem and emphasized on smartphone energy management by defining their own ways to save energy. They argued that smartphone energy consumption monitoring is essential and saving energy can increase battery lifetime.

A rich body of research has concluded hardware components as the major source of energy consumption. John et al.[14] have measured and compared the power consumption of several hardware components including CPU, RAM, I/O, memory controller, video, and disk controller under various workloads. CPU and disk controller were found major power consumers. However, under the SPEC CPU suites, RAM can consume more power than CPU due to high memory-bound workloads. Carroll et al.[6]have produced a breakdown power consumption of various hardware components including CPU, RAM, graphics hardware, audio, storage, and various networking interfaces under a number of usage scenarios. They observed non-uniform power consumption by the hardware components in variable scenarios such as GSM in suspended state, and graphics in the idle sate with backlight off etc. Perrucci et al. [15] have compared energy consumption of various components of a smartphone and found that wireless technologies are more energy hungry as compared to others (i.e., display, CPU, and memory etc.). To optimize energy, 2G network is suitable for voice calls and 3G for data connections. Furthermore, Bluetooth has fair applications for small data and Wi-Fi for large data transmission. Abdesslem et al. [16] have described Sense Less which is an automated system for maximizing battery life in mobile sensing applications by leveraging the different energy characteristics of sensors. The system proposed the frequent use of less expensive sensors as compared to energy expensive sensors in location-aware services. Among the sensors, GPS is found more power hungry and accelerometer is less power hungry. Wang et al. [17] have described Energy Efficient Mobile Sensing System (EEMSS) and assumed that continuously capturing contextual information using sensing capabilities of smartphones can consume large amount of battery energy. To significantly improve battery life, they have suggested of empowering only a minimum set of sensors and employing appropriate sensors' duty cycles for recognizing users' daily life activities in real time. Datta et al. [18] have projected that hardware components including sensors and third party applications are the major causes of power consumptions. Display hardware and networking interfaces are found the most energy hungry components. A number of useful tips are suggested for minimizing power consumption by the display hardware, networking interfaces, and CPU etc.

Another group of researchers assumes that smartphones' applications can be the major source of power consumption if not developed with power consumption management as priority. Liu et al. [19] have augmented that sensors-based applications can be the root cause of energy wastage if they use sensors and their data ineffectively. They have developed a system, called Green Droid, for analyzing sensors-based applications to successfully locate real energy inefficiency problems in them. Oliner et al. [20] have advocated that an application's misbehavior (i.e., known as energy bugs) consumes energy by performing activities which are not intrinsic to the application's functions. They classified applications as energy bugs and hogs where energy hog is an application which drains the battery much faster than an average application and energy bug is an application whose running instance can drain the battery much faster than other instances of the same application. A smartphone application called Carat is developed for collecting data for detecting and diagnosing applications' energy problems by looking for their deviations from typical battery usage. Some of the hogs found in Samsung Galaxy S2 are Facebook, WhatsApp, Andro Sensor, and AVG antivirus. Datta et al. [18] have reported in their study that third party applications displaying advertisements are major causes of power consumption. Ding et al. [21] have described Smart Energy Monitoring System (SEMO) for profiling mobile applications with battery consumption information. File download applications are reported as more energy hungry in the study.

All of these efforts provides enough evidences for calling attention of the researchers for the development of efficient battery energy saving and management methods. However, mostly hardware or applications using hardware components exclusively (i.e., sensing applications etc.) are condemned for excessive battery energy usage. Applications used by users in their daily life activities are of vital importance and can produce significant effects on battery life time. Identifying and estimating activity level energy consumption rates are of importance for a number of reasons such as helping PIM managers to customize their activitiestracking patterns to record more and more daily life activities related data etc. The most relevant work is of SEMO [21], but it has focused onindividual application's level energy consumption monitoring and no detailed statistical analysis, case study, and evaluations has been presented. Furthermore, only few of the applications from the wild have been selected for the study. In this paper, we have presented a method for classifying the available smartphone applications into daily life activities and analyzing energy consumption rates using daily life activities levels. To validate our study, an advanced energy monitoring system called STEMS has been developed for collecting activities'battery usage information from a community of users and ranking activities in power consumption list according to their shares.

4. STEMS METHODOLOGY AND ARCHITECTURE

To calculate and analyze the energy consumption rates of the smartphone applications, we have designed and implemented Smartphone Task-based Energy Monitoring System (STEMS) for Android based smartphones. Since the number of applications on Google Play store has reached into millions, therefore, STEMS first enables users to customize their smartphones by categorizing the installed applications into different categories (i.e., representing activities) which are identified from the survey discussed in section 2 (i.e., text messaging, voice calls, entertainment, and social networking etc.). Second, before collecting data, it checks current status of the battery by determining its temperature level and remaining power etc. Third, the energy consumption data is collected for the active applications during an activity in real time for the duration of the activity. Fourth, it analyzes the applications' energy consumption according to the data collected. The collected data consists of time duration, battery power consumed, and names of the applications used in an activity category. Layered architecture of the STEMS is depicted in Fig. 3.

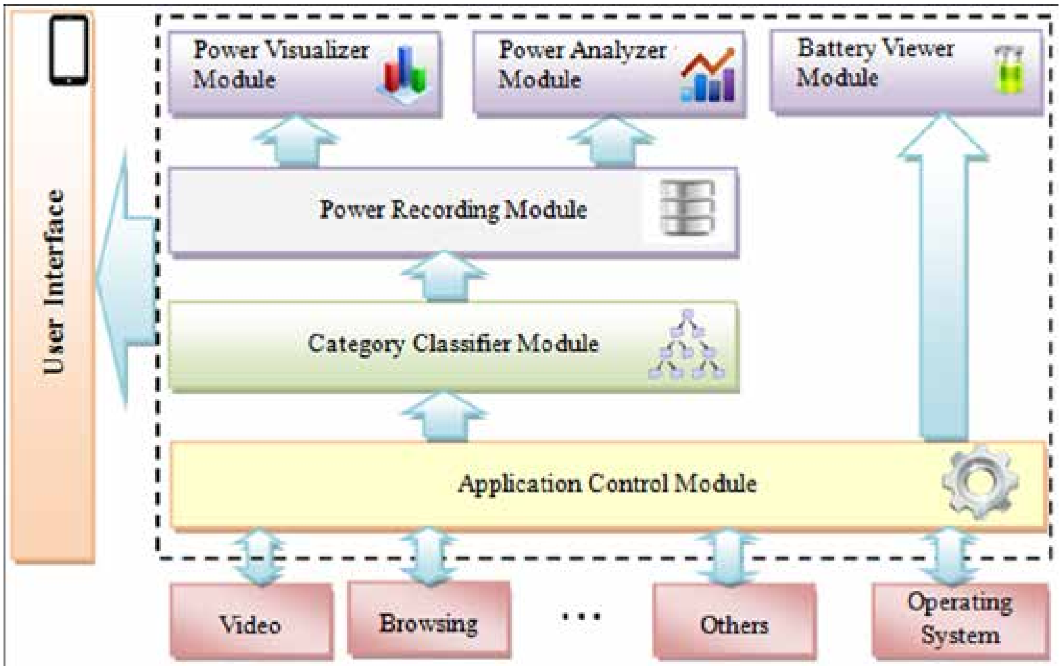

Fig. 3. STEMS architecture showing individual components and their interactions.

Fig. 4. STEMS main user interface.

STEMS is composed of four main components: classifier, investigator, registrar, and decider. Main user interface of the STEMS is shown in Fig. 4. The classifier enrolls the installed applications into different categories. The investigator checks for the information about current state of the battery. The registrar stores numerous information including application name, categories name, time duration, battery information, and battery power consumed in a data store for further processing. The decider analyzes the information stored in data store for determining rates of energy consumption of the activities and ranks the activities according to their consumption rates.

4.1 Classifier

At the present, we have tones of applications developed by the researchers, and professional programmers for answering a number of real world problems. The available applications can be classified into a number of broad categories depending on their functionality. The classifier module checks for the installed applications on a smartphone and enables user to classify them into categories. The overall operation of the module is presented in flowchart in the Fig. 5. Classifier, first, finds the installed applications and retrieves categories information from the database. It enables users to put an application in any existing category or create a new category in real time. It also enables users to switch applications between the categories. Once an application is admitted in a category, it will be treated accordingly.

4.2 Investigator

Investigator is a demon which starts when the application (i.e., STEMS) is started and

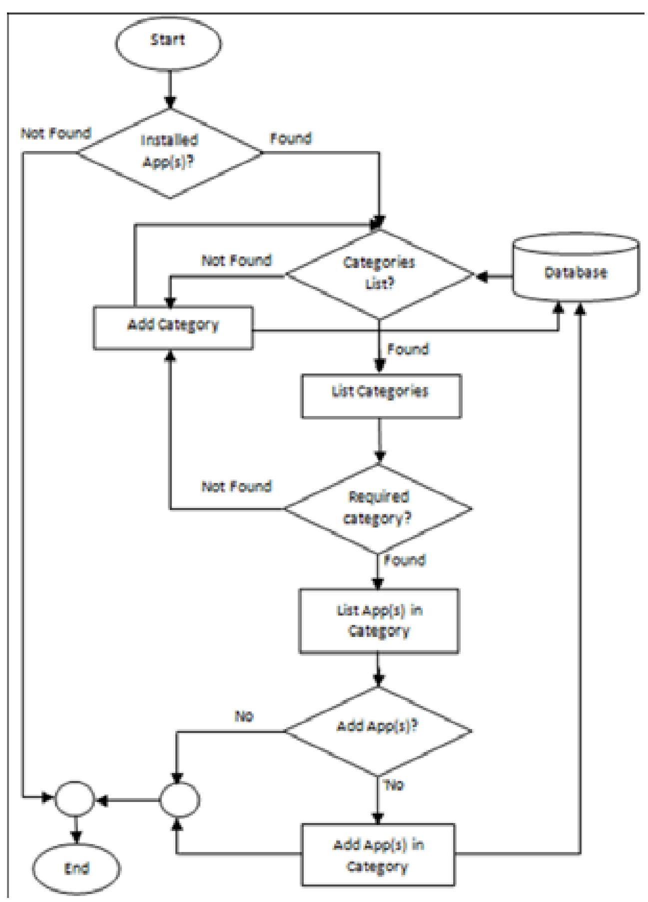

Fig. 5. Flowchart of classifier.

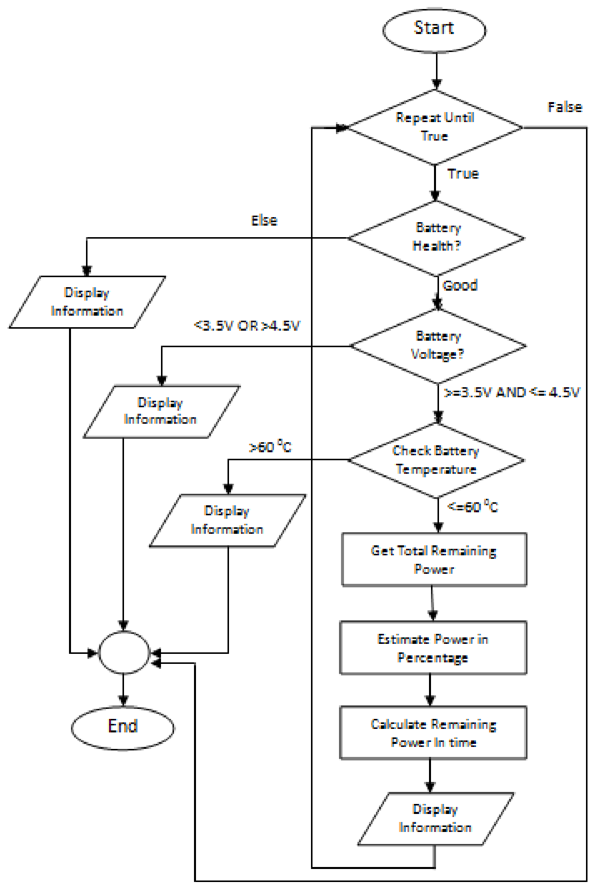

Fig. 6. Flowchart of investigator.

continuously runs in the background inconspicuously for gathering critical information about a smartphone battery. The investigator performs the activities which are essential for any energy monitoring systems and are shown in flowchart in the Fig. 6. First, investigator gets information about vital aspects of a battery including health status, voltage, and temperature. If everything is within the acceptable range, investigator displays information to a user including battery remaining power in percentage, and total remaining power time etc. If any discrepancy is found, investigator will inform user for taking prompt actions. Similarly, investigator remains in the background for continuously monitoring the battery for any critical condition. If any is found, user is informed for taking necessary actions. For example, if battery remaining power is found less than 15%, user will be informed to recharge the battery etc.

4.3 Recorder

Recorder is another important component of STEM which starts with the application and periodically records information about the battery and currently running applications. The overall activities of recorder are shown in Fig. 7. First, recorder store information about applications and their respective categories in the database. Recorder periodically checks for the applications currently running using the information stored in the database. If a new application is found, it will check for its category. If already assigned, recorder will store information related to the applications (.i.e. name and its category etc.), an application startup time, and the battery level at the start time etc. otherwise user will be prompted for assigning application into a category. If a previously active application has been shut down, it will store information related to application end time, the battery level at the end time, the total

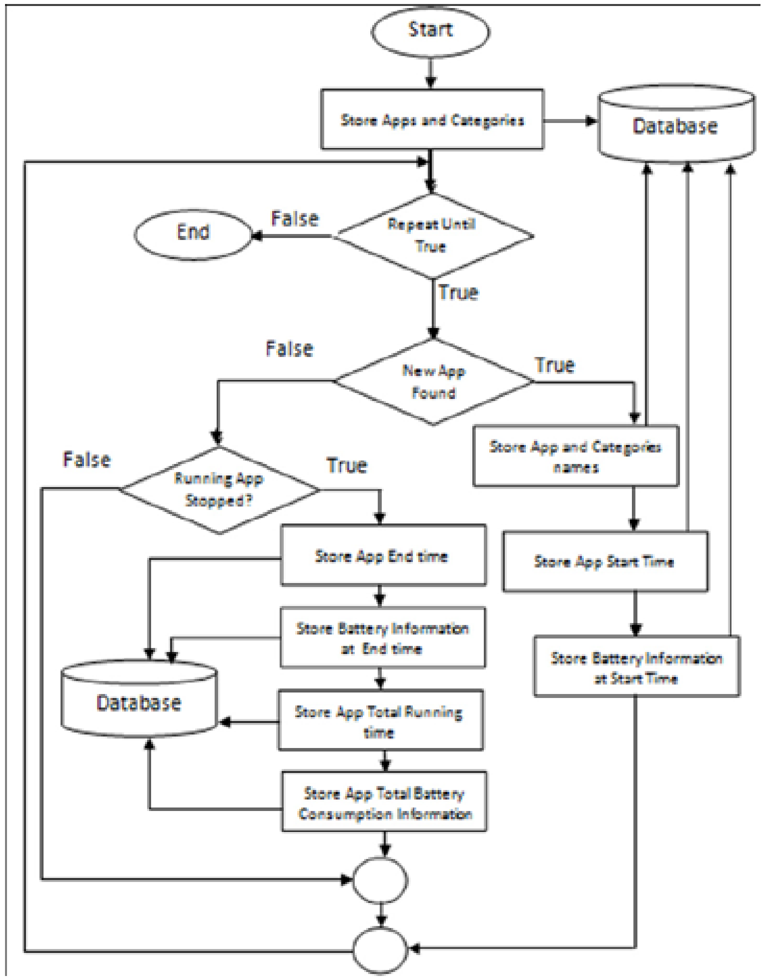

Fig. 7. Flowchart of recorder.

amount of time application has been executed, and the total amount of battery power consumed. This periodic checking can impose excessive burden on a device. Therefore, record interval is defined and set to 2 minutes.

4.4 Analyzer

Analyzer is the decision maker of the STEM which analyzes the information stored by recorder for calculating the energy consumption rates of individual applications in a category, summing them up, and ranking the applications' categories using their energy consumption rates. First, the analyzer retrieves information related to applications, their categories, and their energy consumption from the database. The retrieved information is analyzed and the energy consumption of individual applications in each of the category is estimated. The applications' energy consumption estimations in a category are used for determining the energy consumption rates of the individual categories. The calculated information are used for ranking categories by their energy consumption rates.

5. STEMS IMPLEMENTATION

Using the architecture (i.e., discussed in section 4), STEMS has been developed for the android based smartphones. The system is programmed in Java and developed in Android Studio with Android SDK tools version 5.0 (Lollipop) [2] and others. The popularity of Java programming and the increasing adoptability of Android as operating system by the

[2] https://developer.android.com/sdk/index.html

Fig. 8. Battery information displayed by the investigator.

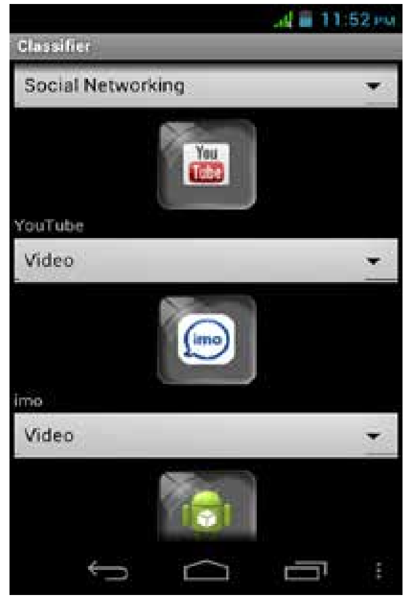

Fig. 9. Applications classification into activities by the classifier.

smartphone vendors ensure the portability and scalability of the STEMS.

5.1 Battery Information Display

STEMS is composed of several activities where each one is designed for performing a specific function. After installing STEMS on a smartphone, the main interface will appear on the screen at its startup time. The main interface consists of several controls including buttons. The investigator will get started once the "Battery Information" button is clicked on the main interface. The investigator is implemented as a service which will remain in the background inconspicuously monitoring various states and behaviors of the battery. However, it will initiate an activity which will display battery information including type, technology, voltage, remaining time, CPU usage, temperature, and health etc. as shown in Fig. 8. The investigator also monitors battery power during the experiment time and intimates users accordingly.

5.2 Categorizing Applications

Clicking "Categorize" button on the main interface starts classifier. The classifier is implemented as tab activity with categories and applications tabs. The category tab contains some pre-defined categories and enables users to create new categories as well. The applications tab reads and lists applications already installed on a smartphone. With each list entry, a pull down list of already created categories would appear for enabling users to enroll application in a category. Similarly, users can also remove an application from a category, and put it into another category.

5.3 Recording Power Information

Clicking "Record" button on the main interface starts recorder. The recorder is implemented as a service for running in the background inconspicuously and storing power consumption information of the applications' category wise in SQLITE database during the experiment time. The stored information includes application id, category id, start time, end time, start time battery power, end time battery power, and total power consumed etc. The database is created in Android's native SQLITE which can be exported to computer for performing advanced analysis using Excel, Navicate Lite, and Origin applications.

5.4 Analysis and Results

Once the data has been collected and recorded by the recorder from the experiments, analyzer can be started by clicking the Analyzer button from the

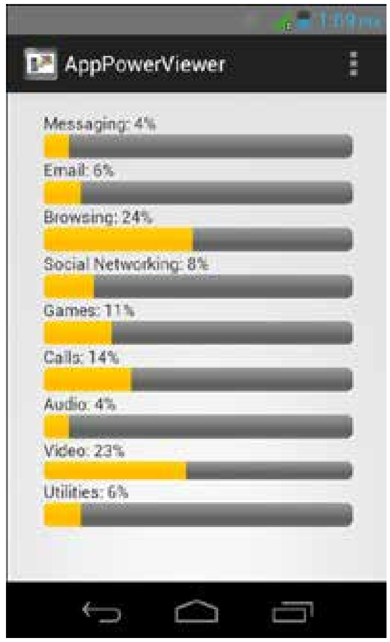

Fig. 10. Activities power consumption results displayed by the analyzer.

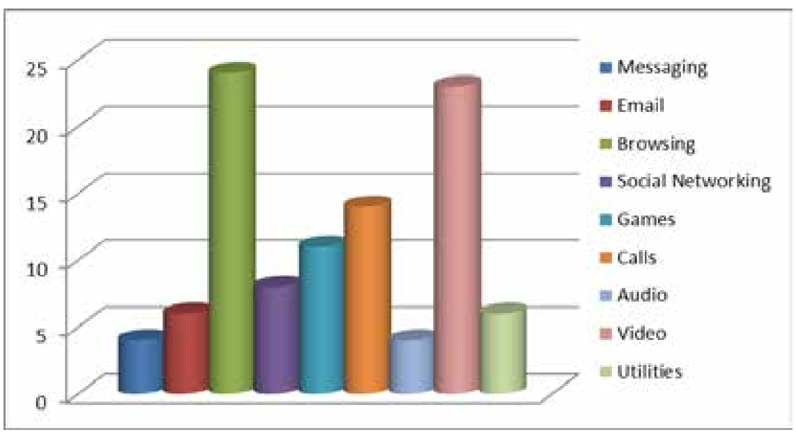

Fig. 11. Analyzer results showing the amount of energy consumed by the activities.

main interface. The analyzer read the data stored in the SQLITE database, compute rate of total power consumption application wise and category wise, and ranks the categories using their energy consumption rates.

6. STEMS TESTING AND EVALUATION

STEMS is tested on QMobile A12 smartphones running on Android Ice Cream Sandwich 4.0.3 and connected to a cellular network with GSM/GPRS capabilities. In order to demonstrate the accuracy of STEMS, the application is tested closely in real world domains. A testing strategy was defined where three participants were given QMobile A12 smartphones installed with STEMS. The participants were instructed to use applications in each of the categories, identified in section 2, for at least 30 minutes each day. Categories were created using the prescribed criteria and applications belonging to the various categories were downloaded and installed from Google's Android Market, the Google Play as shown in Fig. 9. The tests were conducted continuously for a week. The collected data was analyzed, ranked, and displayed by the analyzer as shown in Fig. 10. Analysis of the data collected from each participant after completion of the tests revealed that from the course of users' activities web browsing and watching videos were the most energy hungry activities and can result in significant battery power loss. However, messaging and audio were found the least energy hungry activities. The results remained the same for each participant for the entire testing period.

To validate and ensure the accuracy of the data collected by the STEMS, data stored in the STEMS's database was imported in to MS-Excel and presented in a bar chart as shown in Fig.11. Results depicted by the bar chart in MS-Excel werefound exactly the same which wereprovided by the analyzer.

7. CONCLUSIONS

PIM systems were needed to solve the information overload problems on personal computers (PCs) by enabling users to store, organize, and retrieve their personal information conveniently. The idea of Semantic Desktop was coined as a solution to the problem by leveraging the Semantic Web ideas and technologies. A Semantic Desktop uses ontologies to develop a mental model for defining meaningful relationship between the information items on a PC. However, the paradigm has been shifted and today’s smartphone is proven as sophisticated computing platform having the same communication and technological capabilities as PCs. Over the past few years, the popularity of smartphones has turned us into applications driven society enabling developers to develop applications for almost all walks of life. A vast number of applications are developed for enabling users to execute their routine activities. Furthermore, smartphone capabilities and features has enabled it as de-facto lifelogging device for capturing information related to users' daily life activities and use them for augmenting humans' organic memory. Sooner or later the smartphone will suffer with the same information overload problem because of extensive data created and captured during daily life activities. For developing an effective smartphone PIM system, users' common daily life activities and their effects on battery power are needed to be diagnosed and analyzed. The inefficient execution of activities could result in significant loss of battery power which could severely affect the capabilities and significances of a smartphone such as missing of important mementos.

This research work is a part of our long time efforts to leverage the ideas of Semantic Desktop for solving the PIM problem on smartphones. In this paper, we have presented a profound analysis of the energy bugs introduced by the users while performing their daily life activities on smartphones. We have articulated that how users' smartphones activities can contribute to the overall power consumption and which of them is of the vital nature. First, a survey is conducted for identifying the most common users' smartphones activities in the wild. Second, the design, implementation, and evaluation of testing application called Smartphone Task-based Energy Monitoring System (STEMS) is presented. STEMS is Android based and provide enormous function for monitoring status of the battery, enabling users to classify installed applications into categories for representing users' activities, power consumption data collection during activities, and analyzing data for ranking activities according to their power consumption rates. STEMS is deployed on users' smartphones for power consumption data collection in real world scenarios under a strategy. Results obtained are of significant importance confirming that ineffective use of applications in activities can contribute to greater battery power loss. Results revealed us that web browsing and videos watching are the most energy hungry activities. This investigation will be helpful for all of the stack holders (i.e., researchers, PIM managers, developers, and users etc.) to develop methods for lowering the overall energy consumption rates of the daily life activities for performing more and more activities and capturing enormous amount of data related to them.

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