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Google Play Apps ERM: (Energy Rating Model) Multi-Criteria Evaluation Model to Generate Tentative Energy Ratings for Google Play Store Apps

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Thesis presented to the Fernando Pessoa University as part of the requirements for obtaining a doctorate degree in Information Science, under the guidance of Prof. Doctor Luís Borges Gouveia

Abstract

Google Play Apps ERM: (Energy Rating Model) Multi-Criteria Evaluation Model to Generate Tentative Energy Ratings for Google Play Store Apps

(Under the supervision of Professor Luís Borges Gouveia)

A common issue that is shared among Android smartphones users was and still related to saving their batteries power and to avoid the need of using any recharging resources. The tremendous increase in smartphone usage is clearly accompanied by an increase in the need for more energy. This preoperational relationship between modern technology and energy generates energy-greedy apps, and therefore power-hungry end users. With many apps falling under the same category in an app store, these apps usually share similar functionality. Because developers follow different design and development schools, each app has its own energy-consumption habits. Since apps share similar features, an end-user with limited access to recharging resources would prefer an energy-friendly app rather than a popular energy-greedy app. However, app stores give no indication about the energy behaviour of the apps they offer, which causes users to randomly choose apps without understanding their energy-consumption behaviour. Furthermore, with regard to the research questions about the fact that power saving application consumes a lot of electricity, past studies clearly indicate that there is a lot of battery depletion due to several factors. This problem has become a major concern for smartphone users and manufacturers. The main contribution of our research is to design a tool that can act as an effective decision support factor for end users to have an initial indication of the energy-consumption behaviour of an application before installing it. The core idea of the "before-installation" philosophy is simplified by the contradicting concept of installing the app and then having it monitored and optimized. Since processing requires power, avoiding the consumption of some power in order to conserve a larger amount of power should be our priority. So instead, we propose a preventive strategy that requires no processing on any layer of the smartphone. To address this issue, we propose a star-rating evaluation model (SREM), an approach that generates a tentative energy rating label for each app. To that end, SREM adapts current energy-aware refactoring tools to demonstrate the level of energy consumption of an app and presents it in a star-rating schema similar to the Ecolabels used on electrical home appliances.

The SREM will also inspire developers and app providers to come up with multiple energy-greedy versions of the same app in order to suit the needs of different categories of users and rate their own apps.

We proposed adding SREM to Google Play store in order to generate the energy-efficiency label for each app which will act as a guide for both end users and developers without running any processes on the end-users smartphone. Our research also reviews relevant existing literature specifically those covering various energy-saving techniques and tools proposed by various authors for Android smartphones. A secondary analysis has been done by evaluating the past research papers and surveys that has been done to assess the perception of the users regarding the phone power from their battery. In addition, the research highlights an issue that the notifications regarding the power saving shown on the screen seems to exploit a lot of battery. Therefore, this study has been done to reflect the ways that could help the users to save the phone battery without using any power from the same battery in an efficient manner. The research offers an insight into new ways that could be used to more effectively conserve smartphone energy, proposing a framework that involves end users on the process.

Key Words

Green Computing, Mobile Computing, Energy Saving, Android Applications, Energy efficiency.

RESUMO

Abdullah Mahmoud Almasri: ERM para aplicações no Google Play (Modelo de classificação energética). Modelo de avaliação de critérios múltiplos para a geração de classificações experimentais de energia para aplicações no Google Play

(Sob a orientação do Professor Doutor Luís Borges Gouveia)

Um problema comum entre utilizadores de *smartphones Android* tem sido a necessidade de economizar a energia das baterias, de modo a evitar a utilização de recursos de recarga. O aumento significativo no uso de *smartphones* tem sido acompanhado por um aumento, também significativo, na necessidade de mais energia. Esta relação operacional entre tecnologia moderna e energia gera aplicações muito exigentes no seu consumo de energia e, portanto, perfis de utilizadores que requerem níveis de energia crescentes. Com muitos das aplicações que se enquadram numa mesma categoria da loja de aplicações (*Google Store*), essas aplicações geralmente também partilham funcionalidades semelhantes. Como os criadores destas aplicações seguem abordagens diferentes de diversas escolas de design e desenvolvimento, cada aplicação possui as suas próprias caraterísticas de consumo de energia. Como as aplicações partilham recursos semelhantes, um utilizador final com acesso limitado a recursos de recarga prefere uma aplicação que consome menos energia do que uma aplicação mais exigente em termos de consumo energético, ainda que seja popular. No entanto, as lojas de aplicações não fornecem uma indicação sobre o comportamento energético das aplicações oferecidas, o que faz com que os utilizadores escolham aleatoriamente as suas aplicações sem entenderem o correspondente comportamento de consumo de energia. Adicionalmente, no que diz respeito à questão de investigação, a solução de uma aplicação de economia de energia consume muita eletricidade, o que a torna limitada; estudos anteriores indicam claramente que há muita perda de bateria devido a vários fatores, não constituindo solução para muitos utilizadores e para os fabricantes de *smartphones*. A principal contribuição de nossa pesquisa é projetar uma ferramenta que possa atuar como um fator de suporte à decisão eficaz para que os utilizadores finais tenham uma indicação inicial do comportamento de consumo de energia de uma aplicação, antes de a instalar. A ideia central da filosofia proposta é a de atuar "antes da instalação", evitando assim a situação em se instala uma aplicação para perceber *à posteriori* o seu impacto no consumo energético e depois ter que o monitorizar e otimizar (talvez ainda recorrendo a uma aplicação de monitorização do consumo da bateria, o que agrava ainda mais o consumo energético). Assim, como o processamento requer energia, é nossa prioridade evitar o consumo de alguma energia para conservar uma quantidade maior de energia. Portanto, é proposta uma estratégia preventiva que não requer processamento em nenhuma camada do *smartphone*.

Para resolver este problema, é proposto um modelo de avaliação por classificação baseado em níveis e identificado por estrelas (SREM). Esta abordagem gera uma etiqueta de classificação energética provisória para cada aplicação. Para isso, o SREM adapta as atuais ferramentas de refatoração com reconhecimento de energia para demonstrar o nível de consumo de energia de uma aplicação, apresentando o resultado num esquema de classificação por estrelas semelhante ao dos rótulos ecológicos usados em eletrodomésticos. O SREM também se propõe influenciar quem desenvolve e produz as aplicações, a criarem diferentes versões destas, com diferentes perfis de consumo energético, de modo a atender às necessidades de diferentes categorias de utilizadores e assim classificar as suas próprias aplicações. Para avaliar a eficiência do modelo como um complemento às aplicações da loja Google Play, que atuam como uma rotulagem para orientação dos utilizadores finais. A investigação também analisa a literatura existente relevante, especificamente a que abrange as várias técnicas e ferramentas de economia de energia, propostas para *smartphones Android*. Uma análise secundária foi ainda realizada, focando nos trabalhos de pesquisa que avaliam a perceção dos utilizadores em relação à energia do dispositivo, a partir da bateria. Em complemento, a pesquisa destaca um problema de que as notificações sobre a economia de energia mostradas na tela parecem explorar muita bateria. Este estudo permitiu refletir sobre as formas que podem auxiliar os utilizadores a economizar a bateria do telefone sem usar energia da mesma bateria e, mesmo assim, o poderem fazer de maneira eficiente. A pesquisa oferece uma visão global das alternativas que podem ser usadas para conservar com mais eficiência a energia do *smartphone*, propondo um modelo que envolve os utilizadores finais no processo.

Palavras chave

Computação verde, Computação móvel, Economia de energia, *Smartphones Android*, Aplicativos *Android*, Eficiência energética.

Résumé

Abdullah Mahmoud Almasri: ERM des applications Google Play : Modèle d'évaluation multicritères pour générer des cotes d'énergie indicatives (*Energy Rating Model* ou *ERM*) pour les applications du Google Play Store

(sous la supervision du professeur Luís Borges Gouveia)

Un problème fréquent rencontré par les utilisateurs de smartphones Android a été, tout en l'étant toujours, d'économiser leur batterie et d'éviter la nécessité d'utiliser des ressources de recharge. La croissance considérable de l'utilisation des smartphones s'accompagne clairement d'une augmentation des besoins en énergie. Cette relation préopérationnelle entre la technologie moderne et l'énergie génère des applications gourmandes en énergie, et donc des utilisateurs finaux qui le sont tout autant. De nombreuses applications relevant de la même catégorie dans une boutique partagent généralement des fonctionnalités similaires. Étant donné que les développeurs adoptent différentes approches de conception et de développement, chaque application a ses propres caractéristiques de consommation d'énergie. Comme les applications partagent des fonctionnalités similaires, un utilisateur final disposant d'un accès limité aux ressources de recharge préférerait une application écoénergétique plutôt qu'une autre gourmande en énergie. Cependant, les boutiques d'applications ne donnent aucune indication sur le comportement énergétique des applications qu'elles proposent, ce qui incite les utilisateurs à choisir des applications au hasard sans comprendre leurs caractéristiques en ce domaine. En outre, en ce qui concerne les questions de recherche sur le fait que les applications d'économie d'énergie consomment beaucoup d'électricité, des études antérieures indiquent clairement que la décharge d'une batterie est due à plusieurs facteurs. Ce problème est devenu une préoccupation majeure pour les utilisateurs et les fabricants de smartphones. La principale contribution de notre étude est de concevoir un outil qui peut agir comme un facteur d'aide efficace à la décision pour que les utilisateurs finaux aient une indication initiale du comportement de consommation d'énergie d'une application avant de l'installer. L'idée de base de la philosophie « avant l'installation » est simplifiée par le concept contradictoire d'installer l'application pour ensuite la contrôler et l'optimiser. Puisque les opérations de traitement exigent de l'énergie, éviter la consommation d'une partie d'entre elles pour l'économiser devrait être notre priorité. Nous proposons donc une stratégie préventive qui ne nécessite aucun traitement sur une couche quelconque du smartphone. Pour résoudre ce problème, nous proposons un modèle d'évaluation au moyen d'étoiles (*star-rating evaluation model* ou *SREM*), une approche qui génère une note énergétique indicative pour chaque application. À cette fin, le *SREM* adapte les outils actuels de refactoring sensibles à l'énergie pour démontrer le niveau de consommation d'énergie d'une application et la présente dans un schéma de classement par étoiles similaire aux labels écologiques utilisés sur les appareils électroménagers. Le *SREM* incitera également les développeurs et les fournisseurs d'applications à mettre au point plusieurs versions avides d'énergie d'une même application afin de répondre aux besoins des différentes catégories d'utilisateurs et d'évaluer leurs propres applications. Nous avons proposé d'ajouter le *SREM* au Google Play Store afin de générer le label d'efficacité énergétique pour chaque application. Celui-ci servira de guide à la fois pour les utilisateurs finaux et les développeurs sans exécuter de processus sur le smartphone des utilisateurs finaux. Notre recherche passe également en revue la littérature existante pertinente, en particulier celle qui couvre divers outils et techniques d'économie d'énergie proposés par divers auteurs pour les smartphones Android. Une analyse secondaire a été effectuée en évaluant les documents de recherche et les enquêtes antérieurs qui ont été réalisés pour évaluer la perception des utilisateurs concernant l'alimentation téléphonique depuis leur batterie. En outre, l'étude met en évidence un problème selon lequel les notifications concernant les économies d'énergie affichées à l'écran semblent elles-mêmes soumettre les batteries à une forte utilisation. Par conséquent, cette étude a été entreprise pour refléter les façons qui pourraient aider les utilisateurs à économiser efficacement la batterie de leur téléphone sans pour autant la décharger. L'étude offre un bon aperçu des nouvelles façons d'économiser plus efficacement l'énergie des smartphones, en proposant un cadre qui implique les utilisateurs finaux dans le processus.

Mots clés

informatique verte, informatique mobile, économie d'énergie, applications Android, efficacité énergétique

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DEDICATION

I dedicate this work to the soul of my martyr mother, my legendary father, and my amazing sisters..

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AAL	Android Application Lifecycle
App	Application
API	Application programming interface
APN	Access Point Name
CPU	Central processing unit
D2D	Device-to-Device
DCL	Dynamic Cloudlets
EARMO	Energy-Aware Refactoring Approach for Mobile Apps
ECAR	Energy Consumption After Refactoring
ECBR	Energy Consumption Before Refactoring
GPS	Global Positioning System
GSM	Global System for Mobile Communications
I/O	Input/Output
IFTTT	If This Then That
IP	Internet Protocol
LCD	Liquid Crystal Display
Li-Ion	Lithium-ion
MMS	Multimedia Messaging Service
MVP	Minimum Viable Product
NiCd	Nickel-Cadmium
NiMH	Nickel-Metal Hydride
NIPO	Nature-Inspired Power Optimization
OLED	Organic Light Emitting Diodes

OS	Operating System
RAM	Random-access memory
ROM	Read-only memory
RSSI	Received Signal Strength Indication
SDLC	Systems Development Life Cycle
SMS	Short Message Service
SoC	System on a Chip
SREM	Star-Rating Evaluation Model
UI	User interface
USB	Universal Serial Bus
UTMS	Universal Mobile Telecommunications System
WAP	Wireless Application Protocol
WLAN	Wireless Local Area Network
COVID-19	Coronavirus Pandemic
3D	Three-Dimensional
3G	Third Generation
4G	Fourth Generation
MIPS	Millions of instructions per second
AT	Advanced Technology
B2B	Business-to-Business
XML	Extensible Markup Language
DFD	Data Flow Diagram
DBMS	Database Management System
DOS	Disk Operating System
HID	Human Interface Device

HTTPS	Hypertext Transfer Protocol Secure
IMAP	Internet Message Access Protocol
IDL	Interface Definition Language

CHAPTER 1. Introduction

1.1 Introduction

Today, smartphones have a wide range of capabilities and multi-functionality running on powerful operating systems. This also takes a toll on the battery life of the phone, though. Battery life then is also one of the main worries for smartphone makers, suppliers and consumers alike. For average, most mobile batteries last between one and two days until they are fully exhausted and require a battery bank or recharge. So, as we're waiting for the production of the technology to catch up, the solution is to conserve battery life. The battery life on the handset should be used and managed successfully. Absent a battery charger or a backup battery will cause a smartphone user to do whatever needed to reduce battery juice consumption.

As the planet has experienced a surge in smartphones and handheld apps, the level of accessibility associated with such day-to-day innovations has improved immensely. It is due to the accelerated development trends that have brought to ordinary smartphones all types of emerging technology, beginning with voice over IP, tackling 3D graphics architecture, mastering advanced video editing, and finishing with an infinite array of possibilities. Both of the aforementioned technologies have provided smartphone users the highest degree of happiness as they have been able to substitute old standard cell phones with apps that serve as "*Arsenals of Technologies*" (Choi, Shim and Chang, 2002). At the other hand, mobile users have recently begun to wake up from their intense joy after discovering that using any of these newly introduced technologies would cost them a high amount, which is "*heavy power consumption*", as seen in figure 1.1

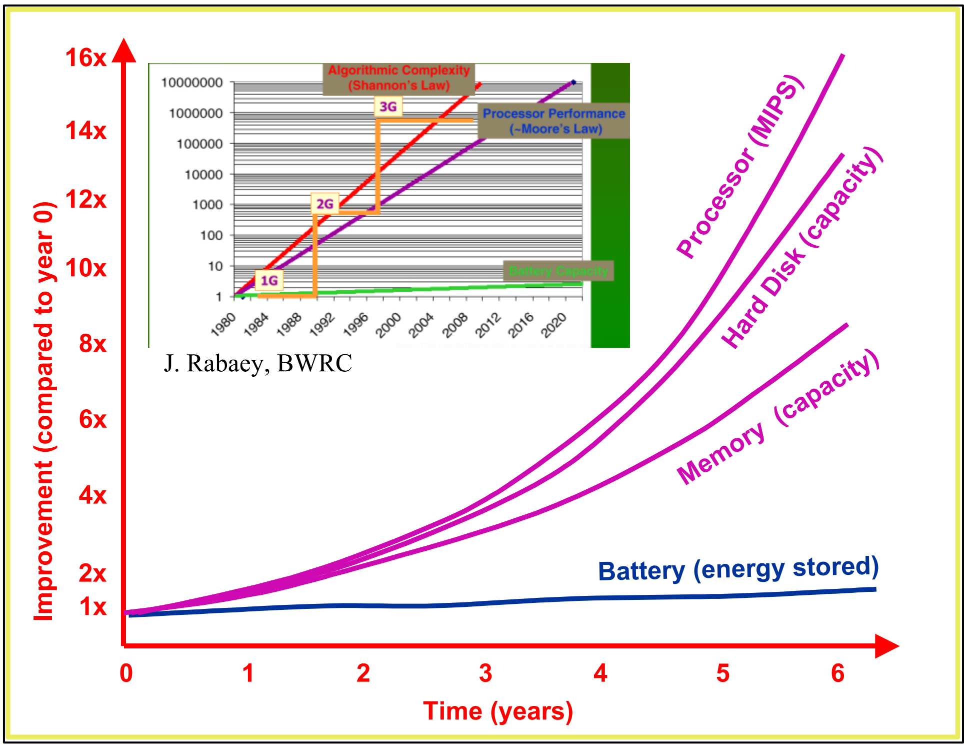


Figure 1.1: Gupta's Representation of Improvements in four smartphones factors during six years (Gupta, 2015)

Power consumption was raised as a critical problem as energy consumption rose in parallel with the rise of the amount of technologies added and used on smartphones. So, the more technology is used in a smartphone, the less ability to keep some energy in the smartphone's battery. Also, current techniques of power-saving used by today's smartphones have many limitations, since smartphones users still suffer from an accelerating pattern of frequent need to recharge their smartphones. Users in some current situations tends to impact the high level of technology used by today's smartphones by using phones with modest levels of technologies in order to survive with less amount of recharging times.

1.2 Motivation

The main motivation of the research is the lack of user guidance for choosing suitable energy-efficient apps before installing and using the apps. The wide popularity of Android as a commonly used operating system among smartphones and smart devices, in addition to its major advantage of being an open-source platform, were the main factors motivating us to use Android apps as a primary area of research in our model. In the following, we propose an improvement to the energy-saving approaches currently used for Android apps especially during the pre-installation and usage stages.

1.3 Research Question

The Research question to be investigated is as follows:

Q1: How can we avoid sacrificing all or parts of a technology that are considered needed for specific smartphone users while still enabling users to extend the phone's battery life in a more efficient way (i.e., user-involved efficient preventive energy-saving)?

This leads the way on providing the directions on how can we avoid wasting any amount of energy from a smartphone's battery while working on saving the energy of the battery (i.e., being preventive rather than detective)?

The main question to be investigated in this research is the possibility to propose a new smartphones energy-saving solution model that will enable end-users to avoid using any of their smartphones battery power or to sacrifice any of their smartphone's modern features for the sake of extending the smartphone battery life. The above research questions promise to solve a critical issue faced by smartphones users on daily basis. The research will provide a model which will enhance the role of end users during the stage of selecting the apps to be installed and used on their smartphones from an energy-efficient point of view.

Since Google Play changes the application's permissions directly at the same time as the application code is changed. Our initial proposed measurement technique benefits from reading up-to-date information on the source code of the application. Then assess the level of awareness of application power without having to apply to third parties to test the application. In addition to certain other factors, these permissions can be used as measurements to calculate an Android application's power levels. The other primary principle of our strategy is to put together developers, device repository companies and academics who have proposed automatic energy-aware solutions for Android system optimization and energy profilers. Such parties should act as inputs to build a scheme for information that allows end users to choose which software to pick and update. Code refactoring is an approach which has proved efficient in previous research to save energy via an automated framework. Either anti-model or pattern-based refactoring was followed by this research.

1.4 Research Aims and Objectives

The aim and objectives of the research are as follows:

- To implement a Multi-Criteria Evaluation Model to Generate Tentative Energy Ratings for Google Play Store Apps which can be used by smartphones end-users and developers to increase the level of energy efficiency for Android apps and therefore extend the smartphones battery-life; by decreasing the need of recharging.

Objectives

- To identify the numerous shortcomings and weaknesses in the latest battery-saving solutions provided by manufacturers and developers.
- To find the missing piece of the puzzle between end-users and apps when it comes to choosing the most energy-efficiency app for the set of apps offered on Google Play while enjoying the needed features of the selected app.
- To formulate the list of requirements and needed criteria to rate an app in terms of its energy-efficiency level from the apps listed on Google Play and the future apps which are to be uploaded on Google Play Store.
- To propose and design a detailed multi-criteria model which will act as a Multi-Criteria Evaluation Model to Generate Tentative Energy Ratings for Google Play Store Apps resolving the energy-saving deficiencies and according to the requirements of end-users.

The proposed model consists of best industry practices, guidelines and recommendations for each criteria, and provides widely agreed minimum standards for enhancing the quality of energy-saving approaches offered worldwide.

1.5 Research Contributions

As the number of mobile computations and services has risen exponentially over the last few years and despite the presence of other factors to consider, Android app stores require users to choose from a variety of apps that share similar features but do not give any indication of the energy behavior of the devices. Users have a problem when trying to pick the best energy-efficient app from the apps mentioned in the Google Play Store due to a lack of details that can be used as a guide during the selection stage.

The main concept is to enhance the role of end-users while selecting a reliable solution that follows a preventive approach, so that end-users will have an alternative to selecting a power-saving mode that will deactivate the modern features of the phone. This proposed upgrade will maintain the same level of technology at the full-phone level and will also allow end-users to select the best applications for their energy-friendly features. The simple scenario, then, is that the end user will be able to choose from a set of apps that share the same functionality but have different energy consumption. In the following, we add a bridge between end-users and apps and then show the model that finally shows the strategy to be followed to measure the energy consumption of the Android app.

Following are some more contributions to the research:

- To Investigate existing energy-saving approaches offered by smartphone manufacturers and developers to identify problems and challenges faced by smartphone users;

- To identify popular battery killers and its alternatives on smartphones then identify its role in investigating the key challenges faced by end user when choosing between saving-energy and switching off modern features;

- To propose a new area of battery-saving between preventive and detective battery-saving approaches on Android smartphones for end-users; offering standards of a middle ground solution;

- To propose a basic permissions-based Android applications rating schema for rating applications which are listed on Google Play Store and then recommend alternative applications in terms of shared features and less power-hungry permission;

- To create a lifecycle that shows the main average stages of an average Android application; in order to demonstrate the main issues with current power-saving approaches and to list the parties involved;

- To classify the different levels of power use between different smartphone resources that will help to sort smartphone components in terms of power consumption; then to extract the permissions for applications that interact with those phone components and to sort those permissions according to their power use based on their interaction with different levels of power use components;

- The research will create a rating scheme for applications with permissions on a scale of six stars to show their level of power usage, taking into account the use of such permissions, under the two most common network connections that are Wi-Fi and Cellular;
- The creation of SREM to as an approach that estimates the energy-friendly level of Android apps and demonstrates it in a star-rating schema similar to the energy-efficiency labels placed on home appliances.

1.6 Structure of the thesis

Here, briefly, it presents the organization and content of the thesis which comprises nine chapters that have been organized to allow the presentation and reporting of the research, namely:

Chapter I –Introduction: presents a general introduction to the research provided by the study model. This chapter also sets out the thesis analysis, its meaning, objectives and relevance. It also introduces the research problem and the resulting key contributions to work.

Chapter II – The chapter focuses on the growing challenge of battery-Saving and the need for more energy. The chapter reflects on key challenges of energy-saving and how charging is considered as a preferred choice compared to energy-saving. The above chapter also provides an insight into the basic concept of green computing and how smartphone Battery-Saving is becoming a global need, it also graphs the technology vs energy curve and the tremendous conversion from mobile phones to smartphones within the revolution of smartphones usage habits. The chapter also emphasises on the importance of apps in the current life routines and how it is affected by popular battery killing applications and habits then finally it justifies the need to save smartphones battery-life during COVID-19 pandemic.

Chapter III – The chapter provides a detailed a review of the existing literature regarding the different solutions, techniques and tools that have been proposed by different authors in response to battery energy consumption problems of applications and smartphones running on the Android OS. The literature review covers studies that provide solutions based on three key approaches proposed classification. The chapter also lists general important tips on how to conserve the battery on a smartphone on 2020 and the good reason behind saving batteries levels during the wide existence of unsecure recharging recourses.

Chapter IV – The chapter explains the power models for mobile as a basic market study from different sectors. The chapter also highlight the adoption of power-saving in different market sectors and what solutions were presented by prior studies in relation to each current approach. The chapter also explores the literature and related works around power saving applications and the available approaches that have either not added or added a negative effect on the area of saving energy on smartphone. The study also presents some potential solutions which helped in reducing energy consumption by mobile applications on Android-based smart-devices and examine the implementation benefits and challenges in these case studies.

Chapter V –The chapter discusses the major research philosophies, as well as their limitations, meaning that current research is more closely aligned with the philosophy of intersubjectivity. As current research of a mixed method nature, both in terms of research method and techniques, discussions on these three methods have helped to conceptualize the benefits and limitations of each of these approaches. Specifically, with regard to the choices made in this research, a case study approach is implemented through the study of Android users, a secondary research strategy is used to synthesize the available literature in the research field, a framework method is used to classify the available battery-saving approaches and, finally, an approach is used to create a solution for the research field.

Chapter VI – The chapter identifies the average Android-application lifecycle and the concerned parties then reveals their involvement while identifying the status of an Android application among different stages of an Android application lifecycle. The chapter also shows the usage of current power-saving approaches among the stages of the Android application lifecycle and relatively reviews the efficiency of the current power-saving approaches while used among the different stages of the averaged lifecycle. The study then proposes the rating schema based on google play applications permissions while giving the detailed processes of using these permissions to measure the amount of power consumption of an Android application. A clear description of the behavior of google play applications permissions groups were also given which also helped to list the power consuming smartphone components. The chapter also proposes using google play applications categories to measure the use of power consumption permissions among each category from all google play applications categories and finally rate the level of power consumption for an application and for each google play category. The chapter finally proposes a flexible multicriteria star-rating evaluation model (SREM) to generate tentative energy rating labels for google play store apps by adding the refactoring approach as the first criterion to be used for the rating process.

Chapter VII – The chapter presents the findings of the research and presents the data collected during the research phase of the investigation. The data is presented in the form of charts, graphs and questionnaire tables.

Chapter VIII – The chapter studies an additional factor related to the relationship between Wi-Fi signal strength and phone battery life through two scenarios which discuss the option of showing only Wi-Fi connections with heavy RSSI during Wi-Fi check and by measuring the saved energy after minimizing discovered networks by reducing the physical existence of network connections.

Chapter IX –The final chapter provides a detailed summary, conclusion and recommendations of the research. The chapter concludes by addressing how the proposed model resolves the lack of energy-efficiency guidance provided by Android users and developers. The chapter also sets out recommendations and other areas of research that can be undertaken.

CHAPTER 2. The Challenge of Battery-Saving – Literature Review

2.1 The Need for More Energy

The amount of computations and services in smartphones increases exponentially over the last couple of years, following a style of growth that correlates with Moore's Law. Specifically, growth is observed in areas such as codecs design, video compression, efficient screen display, yet in terms of the smartphone battery the depletion problem remains. This issue is considered the biggest hindrance of electronic devices in general and smartphone devices in particular (Kennedy et al., 2011). It is considered that this issue will continue becoming more and more relevant as mobile devices (e.g. smartphones and tablets) continue growing in popularity amongst users worldwide (Kennedy et al., 2011). Some studies also demonstrate a trend, where users begin accessing the Web solely or mainly through a smartphone device (Duggan and Smith, 2013) or using smartphones as their main device. Thus, the need to improve battery life is present. The issue is observed by a variety of scholars, some illustrating the lagging development in the area of battery performance when compared to device functionality or hardware characteristics. A study done by Panasonic (one of the leading battery manufacturers in the world) estimates the annual improvement in the life of their batteries to be just 11% (cited in Kennedy et al., 2011). The slow progress is a result of the lack of or slow introduction of new technologies in the field of battery technologies (Kennedy et al., 2011).

Android phones in particular can benefit from an improved battery capacity due to the potentially limitless functionality that the operation system provides to its users with regards to applications, design and other customisable features. The Android power management architecture consists of a power driver to manage the device peripherals, which is inherited from Linux (Datta et al., 2012). In addition, a dedicated power management API is written in Applications Framework layer, which mandates that Android apps request CPU resources with wake locks through the application framework and native Linux libraries as depicted in figure 2.1 below. In addition, power on Android devices can also be controlled through context aware power management, which is typically done through power saving applications. User behaviour can also be used for control of the battery's drainage and its efficiency, as will be explored in upcoming sections. While these techniques and tools exist, their use is not always efficient, nor does it detract from the primary issue at hand, which is that the speed of development of smartphone computational requirements and services does not correlate with battery performance.

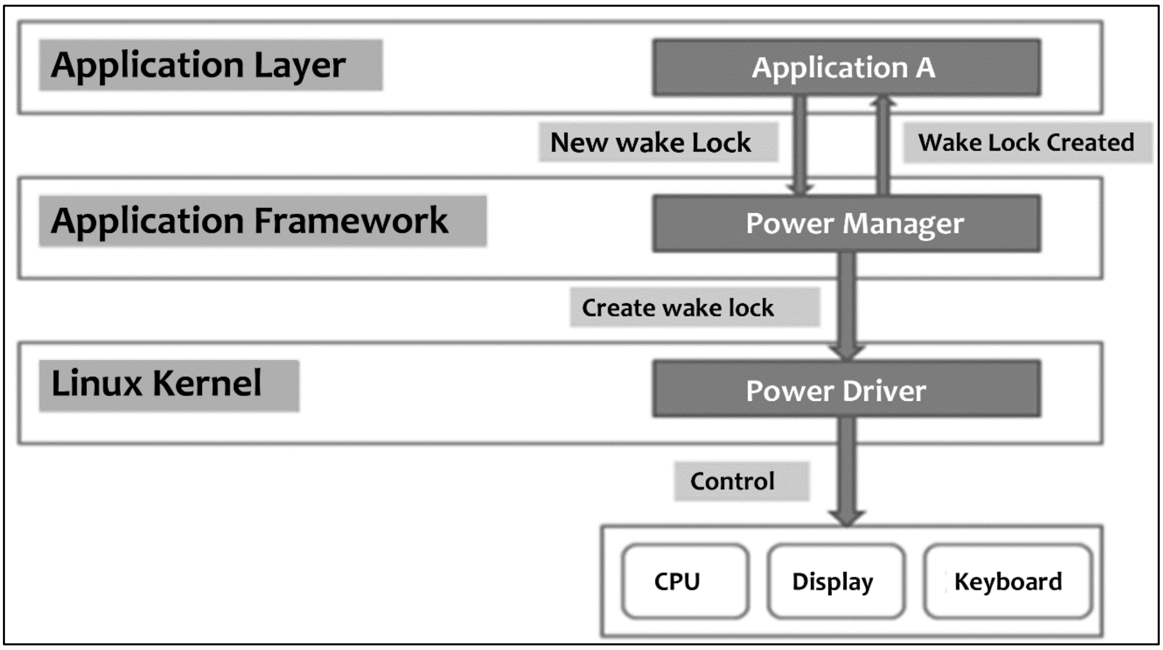


Figure 2.1: Android Power Management Architecture (Datta et al., 2012: 2).

2.1.1 Continuous Recharging versus Saving

Academic research in the area demonstrates that users have inadequate knowledge of smartphone power characteristics, often remaining unaware as owners of such devices of available power-saving settings (Rahmati et al., 2007; cited in Ferreira et al., 2011). While battery life is considered important for a large group of smartphone users, the research demonstrates that existing battery interfaces present limited information, as a result of which users develop erroneous mental models about how the battery discharges and the correlation of remaining battery percentage to the use of apps (Truong et al., 2010). Moreover, users do not understand how they should charge their batteries to support their planned use of the devices (Ferreira et al., 2011). As a result, a variety of behaviours in relation to battery saving are observed, many of which are inefficient in relation to the lifetime of the battery or the device. For instance, many users hinder the utility of their devices through erratic usage behaviour, with data demonstrating that a single user can drain 298% of the battery's capacity one day (charging 3 times) and discharging only 38% on another day (Wagner et al., 2013). Another behaviour is not draining the battery fully, before charging it, as observed in Wagner study. Battery exhaustion (emptying the battery) is considered a failure of the user to manage battery consumption, yet it occurs at least every 11 days for 50% of smartphone users in

Wagner sample group. While complete battery exhaustion is not recommended by battery manufacturers on a regular basis, it is observed that users mainly avoid lower battery levels, with the daily average of the lowest battery percentage values being 30% (Ferreira et al., 2011). Android smartphones only issue a notification to charge the phone by the time it reaches 15%; however, research demonstrates users charge the device before this critical level (as deemed by the manufacturers) is reached. Despite the small variance of the battery levels of users worldwide that researchers observe, the variance on charging patterns is great. Some users prefer to charge for short amounts of time throughout the day, while others allow for a complete discharge, followed by a longer charge period (Ferreira et al., 2011). This can lead to the conclusion that charging behaviour is systematic and simultaneous erratic at times, and users typically interrupt their phones' charging cycle thus reducing battery life (Ferreira et al., 2011).

The listed behaviours are linked with a variety of disadvantages. For instance, the charging duration (which is considered the amount of time the user keeps their phone connected unnecessarily) is considered an issue in two ways (Ferreira et al., 2011). Firstly, in the past, charging a battery for a long period of time would damage the battery from overheating and overvoltage (Xhang et al., 2010), while currently it is considered an issue with regards to energy consumption. While, as previously discussed, the smartphones alert the user when they need to be charged, they do not alert them when they have finished charging, which is considered by scholars another hindrance of current models at work (Ferreira et al., 2011). Thus, a need for involved automated power features to assist with power management is required (Ferreira et al., 2011), as studies show only 80% of users take any measures related to the increased battery lifetime of their devices (Rahmati et al., 2007, cited in Ferreira et al., 2011).

2.1.2 Green Computing as A basic approach

Green computing refers to the practice and procedures of using computing resources in an environmentally friendly way while simultaneously maintaining optimal overall computational performance. It is defined also as "*the study and practice of environmentally sustainable computing or IT*" (Saha, 2014: 46). It is estimated that every year $22 million are spent in electric utility costs by smartphone users as a result of keeping their cell phones plugged into outlets for more time than required, to maintain a full charge (Ferreira et al., 2011). This has resulted in two goals. Firstly, to improve the energy efficiency of mobile devices as means of achieving the goal of green computing and enable energy savings (D' Ambrosio et al., 2014). Secondly, to reduce the consumption of energy required by smartphone devices through not only (as in the past) focus on optimising software and run time, but also through improving the battery's run time through development of battery saving software applications (Couto et al., 2014).

There are a variety of propositions made within recent academic literature regarding potential solutions to the previously specified smartphone battery consumption issues, as well as the recharging user behaviours. For instance, mobile cloud computing is considered one such approach. Mobile cloud computing is the emergence of multiple Internet-based technologies, through which mobile users can acquire benefits of cloud computing and achieve green computing by using their mobile device (Sabharwal et al., 2013; Bonino et al., 2013). Yet, as argued by (D' Ambrosio et al. 2014), the energy consumption of Web browsing activities is not well addressed in academic literature, as a result of the lack of analysis about users' real browsing sessions. This contradiction in the academic literature can be considered also in light of the statistics published by Pew Research Centre (Duggan and Smith, 2013), which demonstrate that over 63% of users now use their mobile devices to go online. Arguably, a gap exists in better understanding mobile Web browsing behaviour, which is unanimously considered by scholars a potential way of enabling green computing. Nonetheless, efforts in the area are being made by researchers. For instance, Gai et al. (2016) suggest a cloud computing model for green computing, which is dynamic, energy-aware, cloudlet-based, and aimed at mobile optimisation. Specifically, it aims to solve the supplementary energy consumptions during the wireless communications through utilisation of dynamic cloudlets (DCL). Couto et al. (2014) propose a technique and a tool for detection of unnatural energy consumption in applications for Android smartphones, subsequently relating it directly with the source code of the application. Specifically, their paper presents a dynamically adjusted model for energy expenditure for the Android ecosystem, which is supported in a variety of devices. Cloud computing for mobile devices is considered promising, with results demonstrating it is able to save 55% to 98% of the energy consumption of conventional server-based clouds while providing comparable computing speed (Ba et al., 2013), thus proving a feasible approach to mobile green computing.

2.1.3 Smartphone Battery-Saving as a Global Issue

Considering the mentioned issues in relation to unsustainable charging behaviours, the issue of battery saving for smartphones can be perceived as a global issue. This is also in light of the findings that show that the number of smartphone users globally is increasing each year as shown on figure 2.2. Research demonstrates that none of the currently used techniques for battery and power management efficiently contribute to the Green computing concept as none take into account the access to technology used, individual user behaviour, and user preferences (Sameh and Al-Masri, 2017). The urgent need for more efficient methods of conserving battery and improving its performance for Android smartphones is, thus, a global ecological concern (Hu, 2012). Not only can this improve the overall user experience, reduce the energy waste, but also reduce the physical waste of failed batteries, which are unsuitable for recycling, as a battery can only be charged a certain number of times prior to its collapse (Hu, 2012).

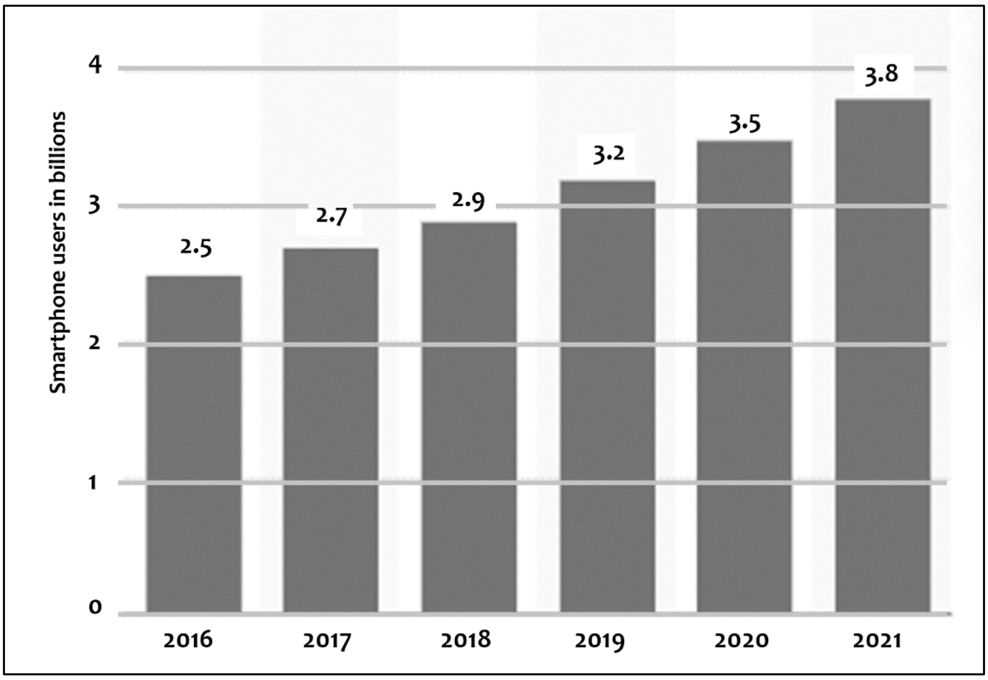


Figure 2.2: Number of Smartphone users worldwide (in billions) (Statista, 2020).

2.2. Technology Vs Energy Curve

It can be argued based on the made thus far arguments that there is an observed reverse relationship of the available technological capacity of smartphone devices and their battery life. This is signified graphically on figure 2.3, demonstrating that current smartphones, while providing a variety of capabilities to the user, limit their availability of taking advantage of them through a comparatively smaller battery life than previously, in times where phones had a considerably smaller amount of functionalities or otherwise performance capabilities. In addition, this can be a result of the increased digital dependency that the improved device functionality enables, which promotes the usage of the phones for a larger proportion of the day from consumers across all ages (Park et al., 2013; Ting et al., 2011; Bae et al., 2017).

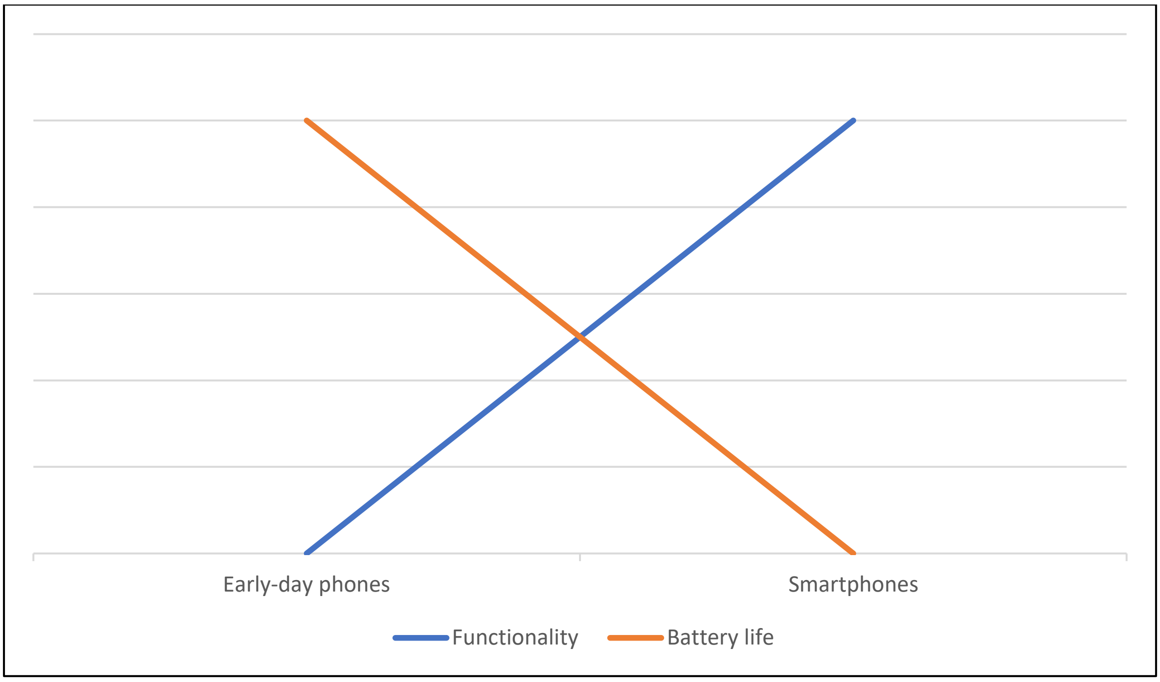


Figure 2.3: Visualisation of the Reverse Relationship between phone functionality and battery life

2.2.1 The Conversion from Mobile phones To Smartphones

Many scholars believe the most influential years for the development of the smartphone happened between 2007 and 2011 as shown on figure 2.4, which is when the smartphone surpassed traditional mobile phones in sales and revenue (Sellwood and Crampton, 2013). Specifically, this shift happened throughout this period sequentially in various parts of the world, such as in 2010 in the UK and Spain, early 2011 in Germany and France and later that year in Italy and Canada and the US (Sellwood and Crampton, 2013).

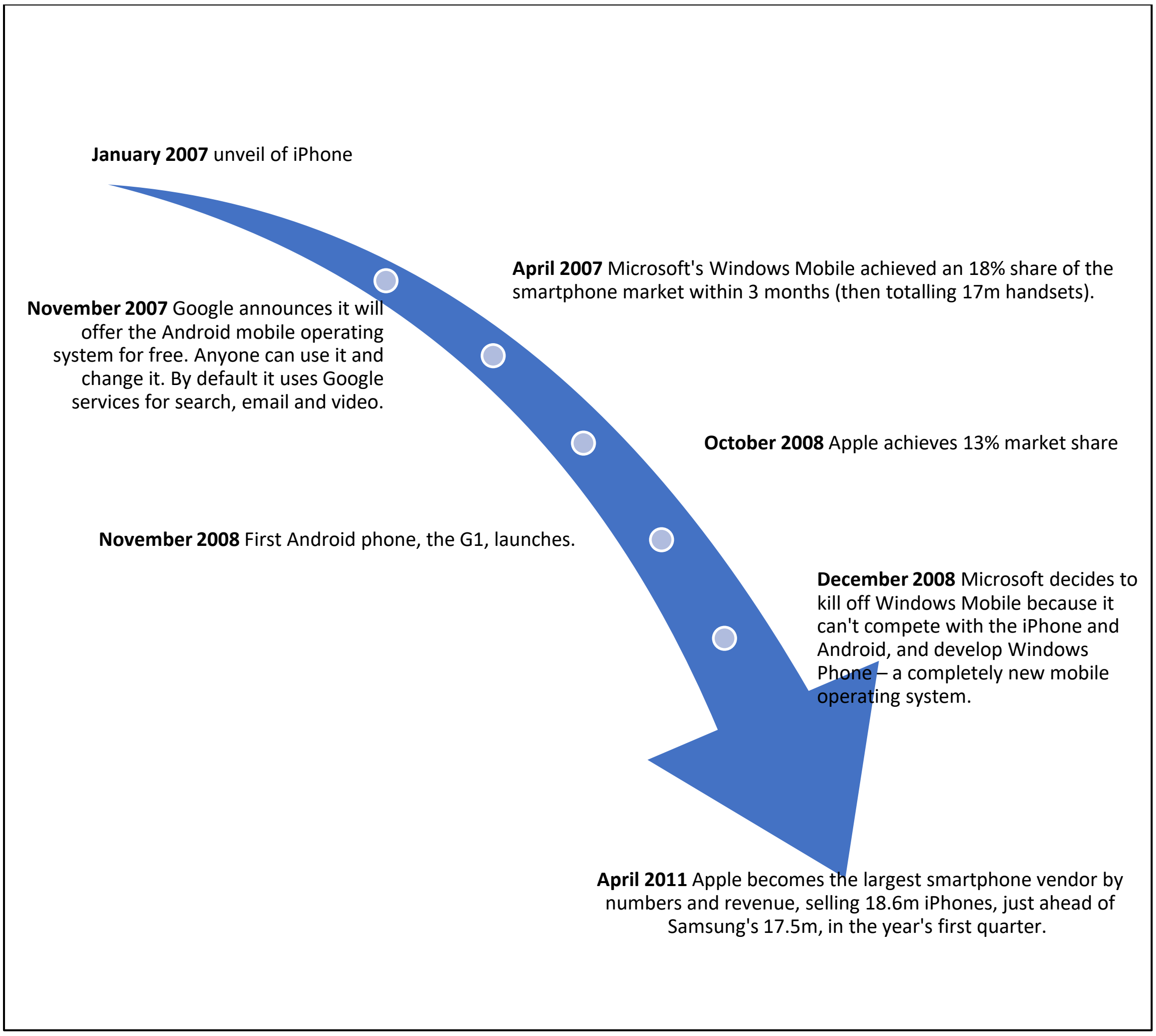


Figure 2.4: Conversion of world usage from mobile to smartphones (Key events) (2007-2011) (adapted from Arthur, 2012)

Android phones in particular have experienced a significant development in the past 10 years. In terms of its performance characteristics, researchers believe the operating system outperforms iOS as Android relies on a more robust hardware and software architecture as presented on figure 2.5. The performance jump can be correlated with the introduction of big.LITTLE octa-core SoCs in Android smartphones, as well a significant improvement of battery life in less demanding tasks.

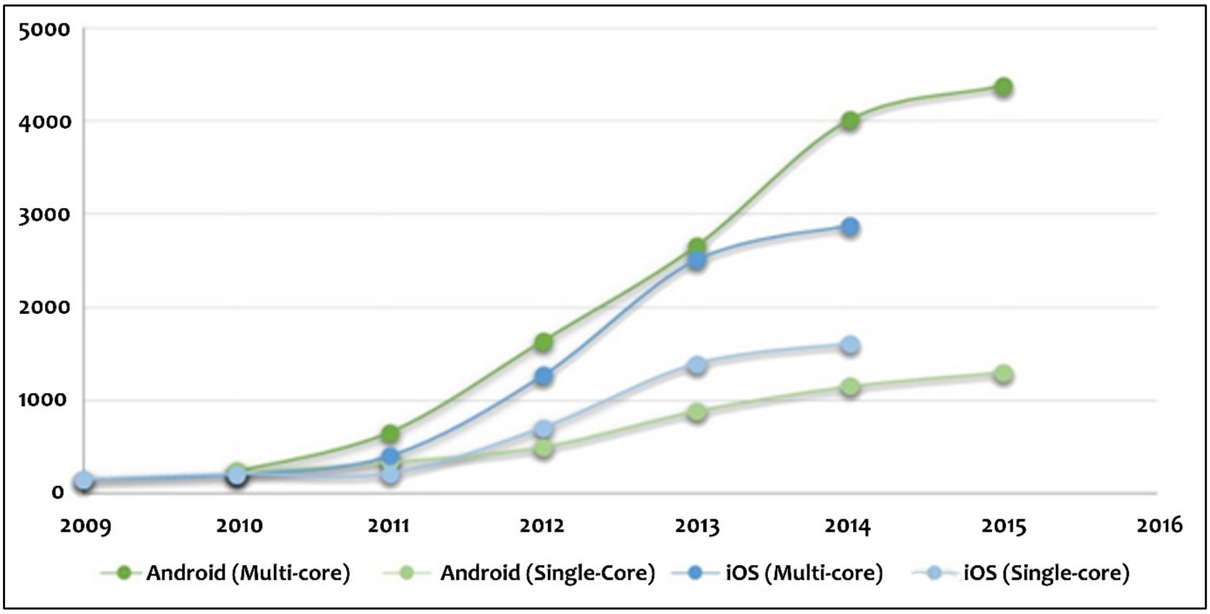


Figure 2.5: Android Vs iOS – A performance timeline (Triggs, 2015)

The figure 2.6 below demonstrates that the industry average with regards to battery life of Android devices has improved in the period between 2013- 2016. In addition, data demonstrates that for the same period the recharging time has rapidly decreased from 140 minutes in 2013 (reaching 170 minutes in 2014) to 100 minutes in 2016 (Phone Arena, 2016).

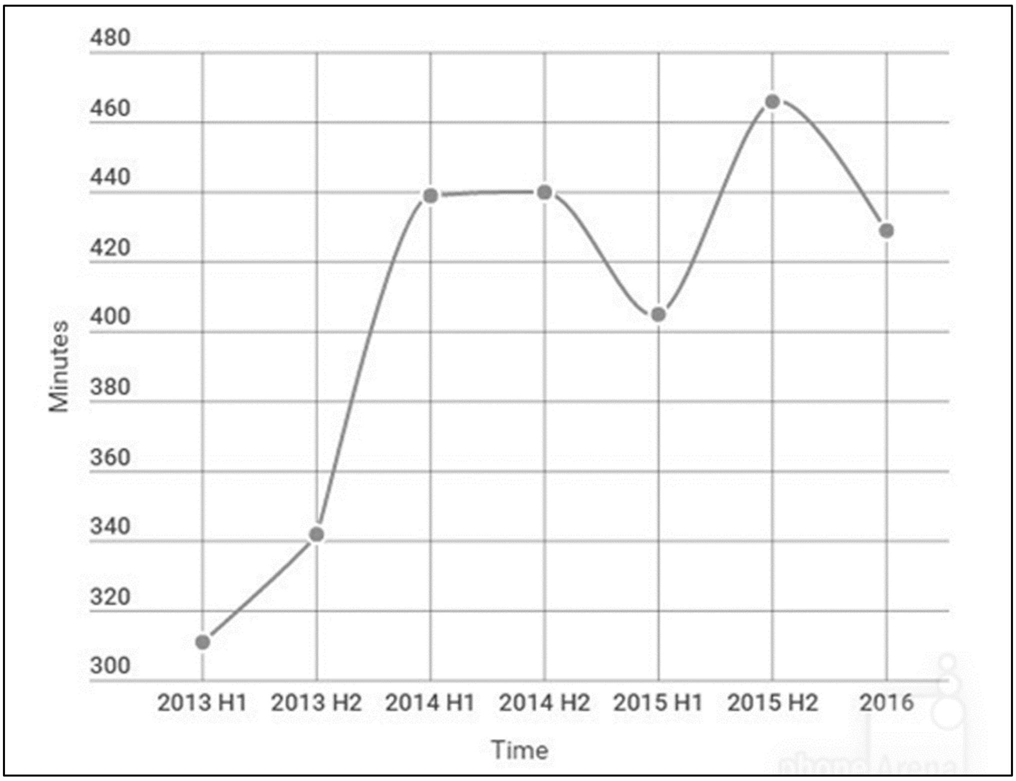


Figure 2.6: Battery life industry average (Phone Arena, 2016).

2.2.2 Revolution of Smartphones Usage Habits

There has also been an observed shift in smartphone usage habits for users across all ages. While previously, mobile devices were used primarily for communication purposes, today smartphones are used for a variety of reasons varying from entertainment to child emotion control. For instance, several studies have demonstrated that smartphones are used extensively by parents as an aid for controlling their children's emotions, creating a digital dependency from an early age (Bae et al., 2017; Ahad and Anshari, 2017). In teenage years, the devices can provide as sense of independence to their users, and are currently used for creation of digital socio-cultural values and religious beliefs and practices, which are shared amongst teens across the world through the medium of the smartphone device (Ahad and Anshari, 2017). Millennials and young adults use their devices for entertainment purposes (Ramos Méndez. and Ortega-Mohedano, 2017), while the older generation is currently following a trend of discovering online social networks through their smartphones (Rosales and Fernández-Ardèvol, 2016). Smartphones are also becoming more common in developing nations, with a variety of technologically-focused organisations introducing services and products, tailored to the needs of individuals in those regions (Poushter, 2016).

2.2.3 Smartphones Apps Ubiquity in the Life Routines

Due to the rapid development of mobile applications for a variety of purpose and the demonstrated previously period of app competitiveness for user attention, app developers have devised ways to capture and keep user attention. One such approach is gamification of the app (Zichermann and Cunningham, 2011), while other apps, such as those in the social media category implement psychological gratification mechanisms to sustain the attention of the users. As a result, smartphone apps have become intricately integrated with life routines (Zichermann and Cunningham, 2011). For instance, Wang et al.'s (2016) study demonstrates that smartphone apps are integrated in every aspect of travel from the booking of the travel medium, to the check in process at the airport or at the hotel, through the navigation at the destination and sharing of memories in a digital format (e.g. through prototypes or status updates) and so on. Smartphone applications are also becoming more and more prevalent in health management and weight management, as well as fitness and bodybuilding routines (Morrison et al., 2014; Payne et al., 2015; Frizzo-Barker and Chow-White, 2012). Arguably one of the most important aspects, in which smartphone applications are intertwined with daily routines and rituals is that of socialisation. Ongoing debates fail to resolve the question whether the presence of such a variety of social media apps in daily lives is positive or toxic, with some arguing it reduces social isolation (Cho, 2015; Hoffner, and Lee, 2015), and others claiming it leads to reduces overall well-being quoting the rise in depression and mental health disease (Elhai et al., 2017).

2.3. History of Android Apps at a Glance

According to industry analysts, there are three phases of app development, illustrated in the figure 2.7 below. Scholars believe that the development of the Android OS has significantly promoted the development of a variety of applications, increasing both the demand and supply for such applications (Chandnani and Wadhvani, 2012). The development of the OS has seen rapid change in a variety of features offered, which have made a measurable impact on mobile app development (Chandnani and Wadhvani, 2012).

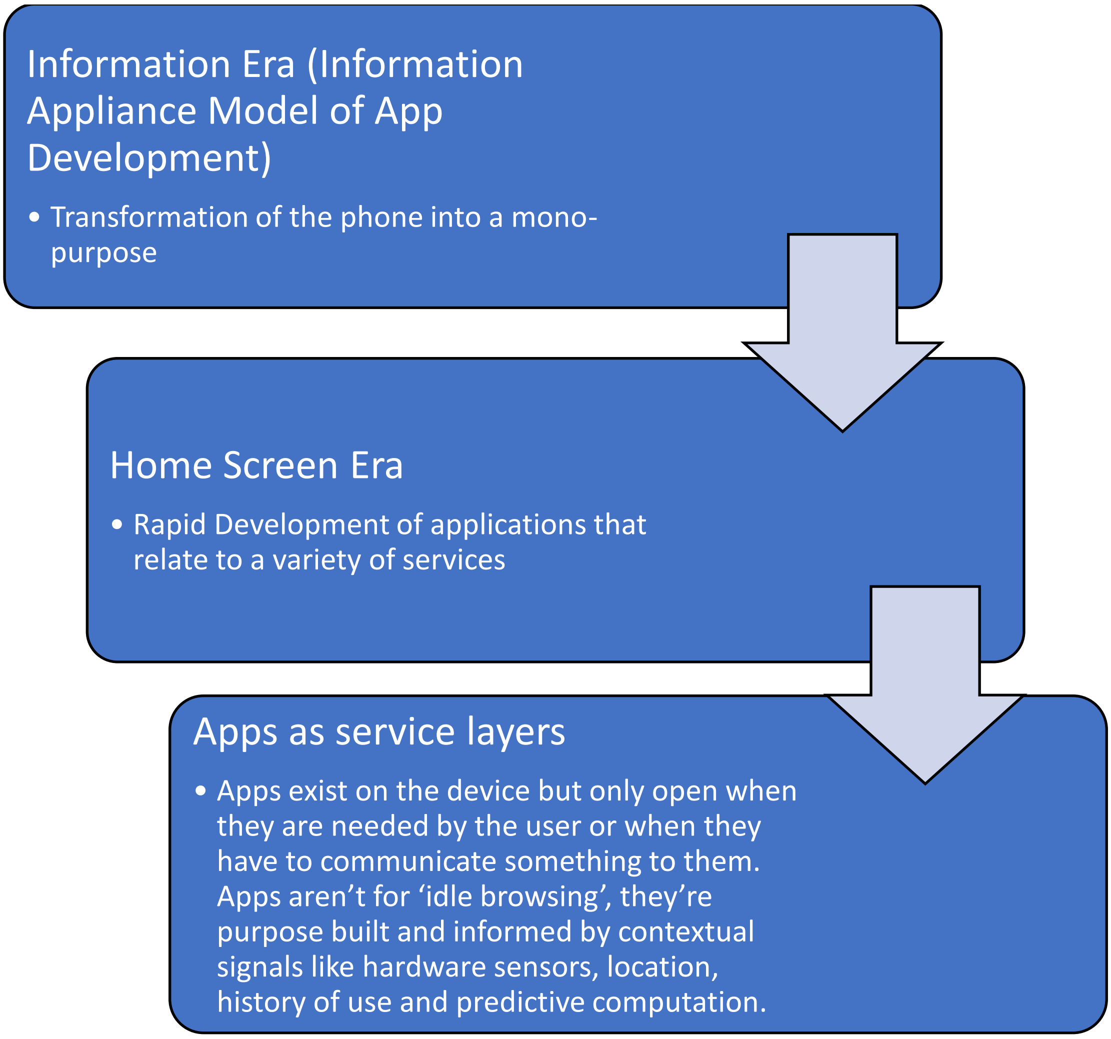


Figure 2.7: Historical Timeline of Android App Development (adapted from Panzarino, 2014).

2.4 Popular Battery Killers and their Alternatives

2.4.1 Popular Battery Killing Applications and Habits

Amongst the most negative applications for a smartphone's battery are Google Mobile Services, who play a major role on battery drain running in the background of the device (Martins et al., 2015), dynamic Web components displayed in browsers (Thiagarajan et al., 2012), and location-aware applications running in the background (Liu et al., 2013). The reason for the latter being power-intensive is the use of the inevitable operation of location detection by GPS (Man and Ngai, 2014). In addition, modern-day applications, which use emerging technology such as artificial intelligence, such as those that use fingerprint scanning or face recognition, are also amongst the battery-killers of the Android smartphone battery (Cuervo et al., 2010).

While not commonly discussed, one of the biggest battery killers is slow connection. This is demonstrated in (Wagner et al.'s 2013) study where it is discussed that energy costs per byte transmitted can be as much as six times higher if the connection is weak as opposed to when it is strong. This is especially noticeable in a communication-heavy application. The same study also demonstrates that the user habit of keeping Wi-Fi or Bluetooth searching on has a similar battery-draining effect. Specifically, (Wagner et al.'s 2013) illustrate: 'When Wi-Fi is enabled, 50% (or 10%) of users spend up to half (or 90%) of their time with Wi-Fi enabled but not connected, highlighting the potential for energy savings. The frequency and duration of user interactions with their device for tasks such as checking the time or checking for notifications is another negative habit. 50% of users perform such status checks on average 9 times or more during the day, while 10 % check their device on average 52 times per day (Wagner et al., 2013).

2.4.2 Power-Hungry Components Alternatives

With regards to the applications listed, there are some alternatives available, such as using energy-efficient automatic location-triggered applications on smartphones (Man and Ngai, 2014). The use of proximity beacons is also an alternative in this context (Zidek et al., 2018). Remote task execution is another way of reducing the workload of the smartphone and improving its battery life (Cuervo et al., 2010). In addition, due to the recognised issue with varying connectivity characteristics of application users, some applications have started releasing versions of their applications that spare the battery life through disabling the automatic processing of content or dynamic elements. An example of such application is

Facebook Lite. In terms of habits, Android applications such as the large-scale mobile battery awareness application, called Carat, can assist long-term users to save more battery, charge their devices less often, as well as learn to manage their battery with less help from Carat overtime, as demonstrated by Athukorala et al. (2014) study.

2.5 Carroll and Heiser Study in 2010 as an Example

A very interesting study was presented by Carroll (Carroll and Heiser, 2010), in their research, the authors presented a detailed analysis of the power consumption of the recent mobile phone. They measured not only the overall system power, but also the exact breakdown of power consumption by the main hardware components of the device. Carroll and Heiser presented this power breakdown both for micro-benchmarks and for a number of realistic usage scenarios. The results were validated by overall power measurements of two other devices. The authors have developed a power model for the system and examined energy use and battery life in a variety of usage patterns.

The findings of the Carroll and Heiser studies have shown that the bulk of the power consumption can be traced to the GSM module and the monitor, including the LCD panel and touchscreen, the graphics accelerator / driver and the backlight.

Figure 2.8 shows that the total battery life varies by nearly a factor of 2.5 between use cases. It shows that GSM is the dominant energy drain, followed by CPU and graphics.

	Power (% of total)							Battery life
Workload	GSM	CPU	RAM	Graphics	LCD	Backlight	Rest	[hours]
Suspend	45	19	4	13	1	0	19	49
Casual	47	16	4	12	2	3	16	40
Regular	44	14	4	14	4	7	13	27
Business	51	11	3	11	4	11	10	21
PMD	31	19	5	17	6	6	14	29

Figure 2.8: Daily energy use and battery life under a number of usage patterns.

2.6 The Need to Save Smartphones Battery-Life During COVID-19 Pandemic

Finally, it is important to consider the need for battery saving in context of the recent COVID-19 Pandemic. During a state of global lockdown, the use of smartphone devices has skyrocketed, and many governments have implemented location-tracking applications for their citizens as means of ensuring that the imposed governmental restrictions are being adhered to (Kitchin, 2020; Stanley and Granick, 2020). Since smartphones are battery-powered, the ability of saving energy to ensure that the phone does not have to be charged too often or that it will not die and obstruct the location-tracking during this time of crisis is of crucial importance, which affects not only the efficiency of the tracking, but also the smartphone device's usability (Kindt et al., 2020). In the applications developed, both signal emission as well as reception costs energy (Kindt et al., 2020). Moreover, the exact patterns of signal emission and reception are controlled by a ND protocol that tries to balance the discovery latency and the energy spending (Kindt et al., 2020). Such applications, as demonstrated previously, have a significant impact on the battery life, resulting in the development of battery saving applications, technologies and habits ever more necessary.

2.7 Consuming Some of the Battery under the Premise of Saving the Same Battery – A Detailed Review

2.7.1 Overview

Power management has been considered as one of the basic features in the mobile phones; however, mobile companies have been urged in introducing advanced power management features and different power interface and advanced configuration (Datta, Bonnet and Nikaein, 2012). Not only the computer engineers but the mobile phone application developers have been seen to show their interest in encouraging power saving features that must be advanced and must not incur power of the phone. Android version of phone holds the Linux Kernel and has put forward its power management systems including Google I/O (Zhuang, Kim and Singh, 2010). Moreover, it has been reported in the research that there are around 400,000 devices of Android which have activated the power management systems but for some of the individuals, these applications have become an issue. The developers of power management systems and applications have been seen to be very sophisticated thus the hardware components available in the applications have been seen to consume a lot of battery power and also the storage of the mobile phones. High drain of power from the energy saving applications has become a major issue for the users thus they are having really bad experience. Moreover, there are some of the important components such as GPS, Wi-Fi and OLED which are consuming high energy level and power (Paek, Kim and Govindan, 2010). As per another study and research, in the power saving applications there is a role of third party advertisements that aim at consuming around 30% of the total power consumed by application (Ravi et al., 2008). This is the reason that the persistent usage of the applications could increase the advertisements and automatically decrease the uprightness of the battery. Android aims at developing an aggressive policy and application for the power saving that includes "*wake locks*" and helps in conserving the battery life but this is not enough and sufficient for saving the battery. In addition, there are several applications in the Google play store that provide the users to get facilitated with the power saving applications. In order to understand its consistency and power saving modes without wasting the power of the phone, an in-depth analysis to check its operating principle has been done. It has been explored that most of the current power-saving-applications tend to control the features of a smartphone including Wi-Fi, 2G and 3G, brightness level, GPS as they have a significant impact in making the battery life prolong. In addition, the deep analysis also revealed that the use of power-saving modes is statically significant which also controls the features of smartphone. There are several mobile phones which have a pre-define control on saving the battery life. With the changing patterns of smartphone usage, the idea of dissipation of power has been seen to be varied (Ravi et al., 2008). In order to deal with the threats regarding the investigation of the research, it is clear that there are various aspects of Android battery saving development which have identified major semantic bugs and syntactical errors. These errors play a major role in destroying the capability of the power saving applications in showing up their capability (Payet and Spoto, 2012).

In this contemporary world, the increase in the application developers have also showed an increase in uncovering various vulnerabilities. This is the reason that several developers have urged in developing the criteria to save the power. For this, the researchers and developers have done research by performing every step statically and ensured that there could be an Android application code that might help the users in ensuring high scalability and save the power of the mobile phones (Moran et al., 2015) and (Arzt et al., 2013). At that time, the study remained incomplete because of severe obstructions in the specific Android features and the biggest hindrance in the completeness of analysis made the researchers dissatisfied in proposing a mode of power saving (Li et al., 2015) (Lu et al., 2012). One of the common barriers that have been confronted by Android is the lack of the main point of entry or the construction of call graph. These issues regarding the introduction of saving modes without compromising the battery of the mobile devices might be controlled if the handlers of Android and other mobile phones work more efficiently.

Not only is this, there are several other challenges carried by the mobile application that include the support of Java programs. Java reflection statements help in dealing with the dynamic code loading; however, major support of Java application would be helpful in obtaining a hype on power saving solution (Moran et al., 2015). According to the recent survey and analysis, securing the mobile phone from viruses is the only way to use it for long term; however, responses from multiple smartphone users indicated that downloading and using power saving applications caused a negative impact on their phones thus it is exploiting their battery usage adversely (Lu et al., 2012) (Payet and Spoto, 2012). The fact about using smartphone is that they are energy constrained and their life relies on limited use of battery supply (Li and Halfond, 2014). The researchers have been playing very well in showing up advanced battery technology that could help in saving the consumption of battery and helps in alleviating the limitations in using the phone. It is important to improve the capability of the developers to construct an energy saving methodology which could be used as an essential source of reducing effect of energy constraints (Hao et al., 2013).

2.7.2 Estimated Energy Cost of a Smartphone and Measuring Consumption

In the present era, smartphone devices are taking the first place among other technology platforms as users now prefer them for different life purposes. In the past few years this trend has increased, and there has been a significant increase in the number of smartphone users. Smartphones are known to intake an unusual amount of energy budget of the world due to the repeated charging of battery (Ahmad et al., 2016). Besides that, a report provided by Barry Flscher (Fischer, n.d.) showed that the volume of energy it takes in charging a smartphones globally is equal to the accumulated power utilized by 54000 United States households for each year. Following this report, the power demanded by a smartphone each year is ranging from 3.5 to 4.9 kWh.

The task of modeling consumption of power could be divided along two aspects (Kjærgaard and Blunck, 2012). Initial aspect is related to the approach through which measurements are collected for designing the framework. These calculations can be gathered through utilizing an internal battery interface or through external equipment. The second aspect is the sort of data through which the framework was built. Such a power framework can be planned from: computation of system usage, for instance processer data accessible from OS level, consumptions of power computation for each system call construct to OS and consumption of power computations each application program interface call constructed in a particular language of programming. Numerous research attempts have been managed on the gathering of power models for various hardware building elements of a cell phone device for assisting application developers for estimating energy needs of the mobile application.

Power Tutor (Zhang et al., 2010) utilizes data taken from voltage drop for determining the battery discharge rate to approximate the consumption of power. These frameworks are assembled and approved for single-core mobile processors. The calculations identified that application of the identical model for contemporary high-performance multi-core mobile devices would be somewhat incorrect. Moreover, the Wi-Fi model is unable to discriminate among the energy consumed while sending and receiving states producing not so precise results. Shye et al. (Shye, Scholbrock and Memik, 2009) provided a solution in which he used a background logger which was monitoring the resource usage by emphasizing various hardware elements of the cell phone device periodically. A linear regression framework was planned through accumulating present calculations with an external device, with OS described statistics of battery operating voltage and logger information. Even though, the framework is developed for a sole core Central processing unit, and lower Central processing unit frequencies are not considered while planning the model of power whereas it is rather imprecise for the offloading utilize case. Powerprof (Kantardzie, 2005) also uses a smart battery to calculate the consumption of power at the length of time they take to run through a particular Application Program Interface (API) and such data are utilized for measuring the energy operation of application API calls. Utilizing genetic algorithms (Yoon, 2012), an energy usage profile is identified for every method call. This method is implacable solely when a smart battery applying that particular Application Program Interface is accessible, and it supposes that every time a way is called, the similar quantity of power will be utilized, which is usually over-elaborated. AppScope (Jung et al., 2012) is an energy based on an Android mentoring system that utilizes power frameworks and usage facts or data for every hardware element. Linear regression power frameworks are built utilizing DevScope (Kim, Kong and Chung, 2012), and equipment resource utilization examining is taken by loading extra modules into the Linux kernel. For estimating the utilization data of each trace, application, and inter-process communication are examined, showing a significant overhead. Moreover, this equipment is not managing the multi-core processors. Figure.2.9 clearly illustrates that there are certain categories of applications which are more towards the consumption of battery in smartphones. However, those categories include Entertainment, lifestyle and productivity, travel and transportation, music and media applications, camera, utilities and other tools.

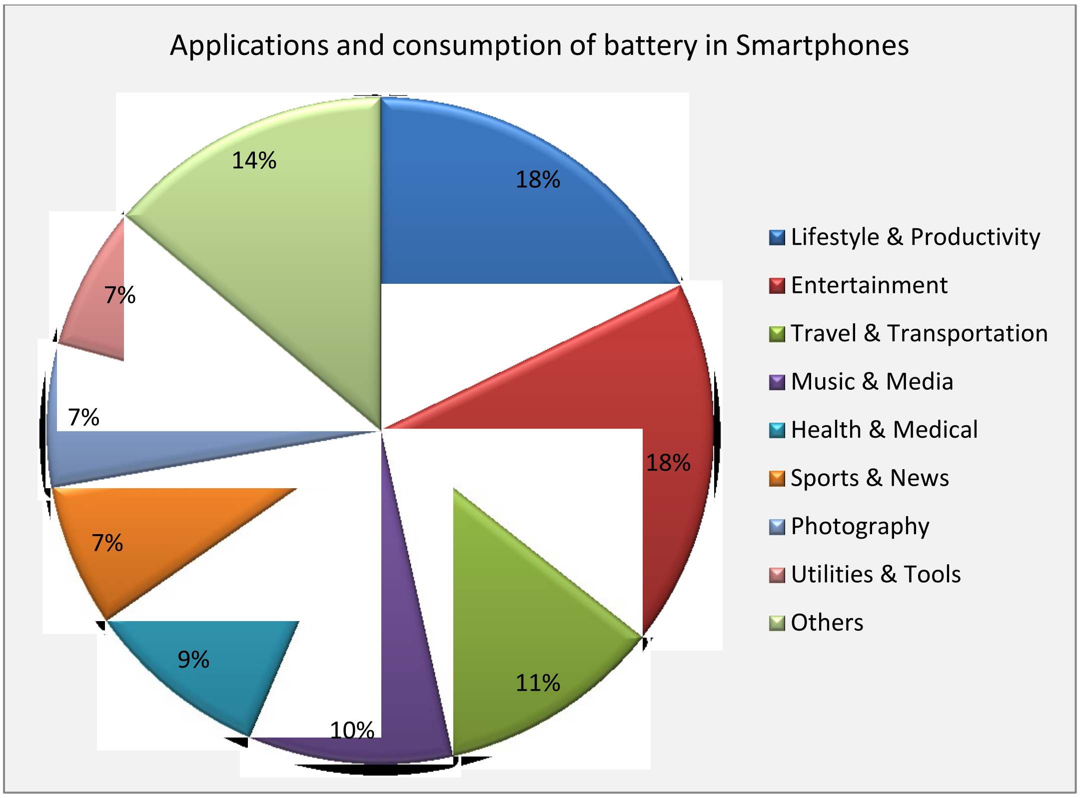


Figure 2.9: Applications and consumption of battery in Smartphones (Kim, Kong and Chung, 2012)

Figure 2.10 points out the list of non-idle energy and their percentage of consumption of battery. Non-Idle energy refers to the power that is active or in-use, however the most common and active energy includes the power of Internet, UI and Camera that seems to consume a lot of battery.

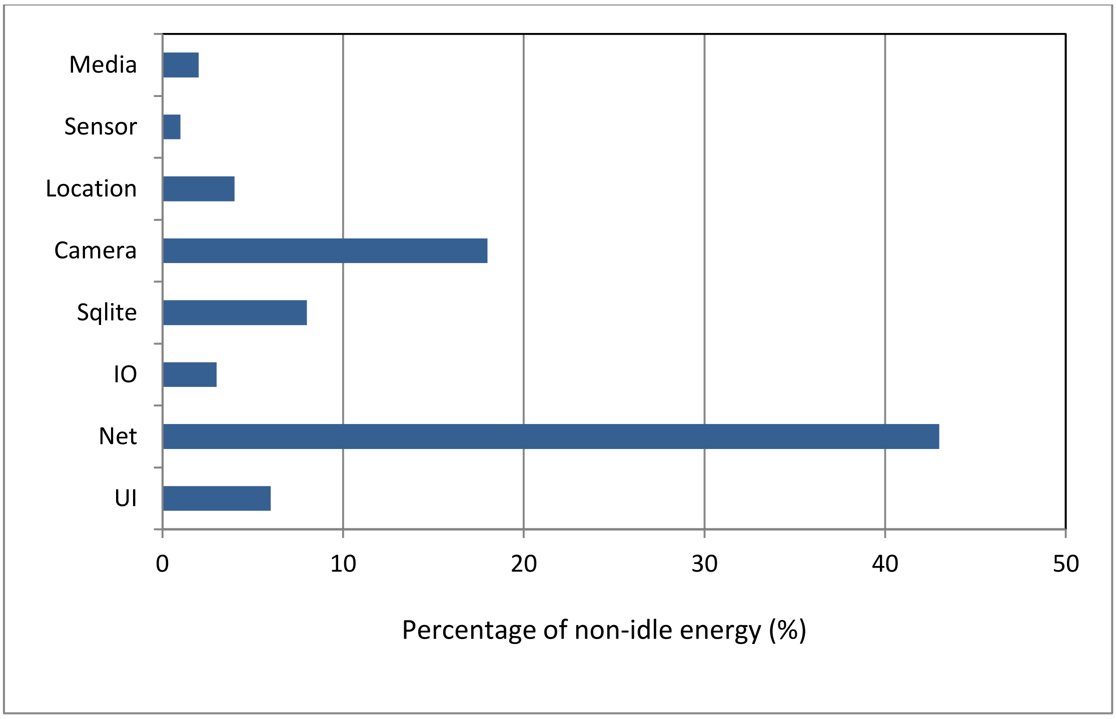


Figure. 2.10: Percentage of non-idle energy (%) (Kim, Kong and Chung, 2012)

Besides that, the method described in Kim et al. (Ali et al., 2016) provided an expanded online power approximation method for multi-core smartphones which are utilizing an external meter of power.

Present power models, as concluded in Figure 2.11, are lacking one or more than one attribute of present mobile hardware: they are outlined for single core Central Processing Units, disregarding the energy proportionality of Central Processing unit frequency scaling or it does not discriminate among the various energy states of network interface cards. Furthermore, specialized hardware and software application program interfaces are needed for measuring the power consumption of the application program interface calls.

Moreover, it is proven for multi-core Central Processing Units, and all assisted frequencies are contemplated. In addition to that, Wi-Fi power framework precisely discriminates among various conditions of the wireless interface card. There is no need for specific software or hardware support, and there is no requirement of extra overhead in the analysis of various traces. This framework also observes the power consumption because of memory acquired to the application (RAM).

Comparison of previous work related to power modeling.

	CPU		Display unit	Memory	Network
	Cores	Auto-scaling			Wi-Fi
CloneCloud (Chun et al., 2011)	On–Off model		x		On–Off model
MAUI (Cuervo et al., 2010)	Single-core tested				Simplified[a]
Power Tutor (Zhang et al., 2010)	Single-core	2 freq. supported	x		Simplified[a]
AppScope (Yoon et al., 2012)	Single-core	x	x		Simplified[a]
PowerProf (Kjrgaard and Blunck, 2012)	Single-core	Not mentioned			Simplified[a]
Online Estimation (Kim et al., 2012)	Dual-core	x	x		Simplified[a]
Into the Wild (Shye et al., 2009)	Single-core	2 freq. supported	x		Simplified[a]
Our work	Multi-core support	x	x	x	Detailed[b]

[a] Wi-Fi simplified model does not differentiate between Send and Receive states.
[b] Wi-Fi detailed model takes into account Send, Receive, Tail and Idle states.

Figure 2.11: Mobile device power models for energy efficient dynamic offloading at runtime (Ali et al., 2016).

2.7.3 Power-saving Applications Basic Mechanism

For extending the battery life of Android smartphones, developers have offered many applications which are accessible in the Google Play Apps store. Many such applications were analyzed at the time of this research for understanding the power saving methods. The researches study how these applications increase efficiency of power saving, their principles and restrictions of operating that gather different ways in encouraging the improvements. It was identified that these energy saving applications have two different methods for managing the consumption of the energy of smartphones. The Central Processing Unit for Root Users (Kang, Seo and Hong, 2011), Juice Defender (Pathak, Hu and Zhang, 2012), and Central Processing unit tuner (Pathak, Hu and Zhang, 2012). These applications are selected on the basis of their high user rating, positive feedback of the user and their popularity.

It is essential to know the operating principle of the applications for investigating their restrictions. When the app is installed in a rooted smartphone and the root permissions are given then there are sliders which allow the management of the Central Processing Unit frequency done by hands (Rahmati, Qian and Zhong, 2007). After that, Central Processing Unit administrator must be chosen. It manages how the frequencies of Central Processing unit are scaled among the utmost and minimum set frequencies. Mostly kernels considered as smartphones have ‘performance’ and ‘on demand’. The moment central processing unit load gets to a threshold, on demand increases the frequency instantly and decreases the frequency when the load is on its minimum. Other present Central Processing Unit administrator is mentioned in Rahmati, Qian and Zhong, (2007). A few of them have expert condition controlling attributes. The profiles design the application to set the Central Processing Unit frequency in certain situations. Furthermore, there is a "*monitor with condition*" which repeatedly monitors the situations set in profiles. If such a situation is true, then a particular profile is activated. For instance, the profile 'Battery' is place when battery level decreases below a provided level. The profile 'Time' is activated for a specific time frame. Specific priority is given to all the profiles. If situations of many profiles are correct, then the priority of these profiles is inspected. The profile with the most priority is triggered. In the mobile saving applications, there are various profiles that aim at controlling over the smartphone features (Wood et al., 2008).

Many hardware elements such as GPS, Wi-Fi of tablets and smartphones take very extraordinary energy (Pathak, Hu and Zhang, 2012). Hence, energy can be saved by turning them off when they are not being utilized. Moreover, there are various characteristics like auto sync, frequency of recent notifications which uses the hardware and other connectivity. Reducing the rate at which notification occurs (mainly of Gmail, Facebook) also reduces the utilization of smartphone elements and extends the battery life. The following list shows the basic apparent precautionary procedures which most power-saving applications applies on an average smartphone in order to extend the battery life. The listing is not comprehensive:

- Fastening command on Bluetooth, Wi-Fi, auto-sync, GPS, auto screen lock, airplane mode, USB, screen-always-on, mass storage, 2G, torch, 3G, 4G/Wimax (if available) and the cell phone data (APN);
- Fluctuate the brightness level of cell phone's display;
- Vibration and volume management;
- Screen alteration time value;
- Development – night, peak, weekend;
- Timeout of setting Wi-Fi;
- Getting a home screen with dark wallpaper for organic light-emitting diode (OLED) display;
- The stated three applications utilize all or a subset of these characteristic in their profiles of power saving.

From the above list and by exploring the different control features in Android OS, it is clear that there are various features that could be customized to help in setting the smartphone in a manner to optimize and conserve the consumption of battery efficiently without the need for a power-saving application to do these asks. For example, by toggling and pinning the options, the users could easily find and use them. Another example, the best thing a user could do to save the power without compromising battery is switching off Wi-Fi and data connection when it is not needed. Moreover, there are several setups in the phone such as do not disturb option that is included for the purpose of power management. In addition, there are some of the smart applications such as IFTTT that helps the user to create their own rules to save the life of a battery efficiently (AndroidPIT, n.d.).

2.8 Chapter Summary

The chapter has identified that smartphone user behaviour impacts energy consumption in the context of battery usage, as well as charging duration. While there are methods to reduce the battery's drain from mobile app use, they are not fully utilised by users. Simultaneously, the review has demonstrated the growing prevalence of mobile applications in daily lives, as well as the disproportionally (to battery life) increasing phone functionality, which results in the creation of a dependency towards smartphone use. Considering the identified trends of smartphone ownership growth globally (including in developing nations), growing integration of the digital dependency on individuals and increasing integration of the smartphones in lives of their owners, findings technical and behavioural solutions for improving the battery life is paramount. Overall, it can be argued that an emphasis should be placed on developing more techniques for battery saving in Android smartphones in the medium- to long-term, as this is considered by scholars as a potential way to reduce the impact smartphone use has on the planet is aspects such as energy consumption. In the short-term, there is identified importance of developing informational mechanisms for guiding smartphone users' behaviour to (1) take advantage of the available battery saving settings, (2) develop habits and practices that spare the battery of their device, and (3) reduce the overcharging practices of their device's battery.

CHAPTER 3. Battery-Saving Approaches

3.1 Saving Batteries during the Wide Existence of Recharging Recourses

Users might wonder why if they have a wide variety of recharging resources at home, car, and work or in pocket, they should even bother about the battery level. The answer is that repeated charging is eating up the battery volume for certain kinds of batteries. There are generally two types of rechargeable batteries commonly used for smartphones when it comes to phone charging: Lithium-ion (Li-Ion) and Nickel-based batteries: Nickel-Metal Hydride (NiMH) and Nickel-Cadmium (NiCd). The power of the batteries in NiCd batteries is each time they reload them. Nevertheless, the life cycles of NiCd batteries are longer, i.e. they can be recharged more frequently than the NiMH batteries until they stop operating. When they are more or less out of power, nickel-based batteries should be charged (to the full amount) and not when there is still a good amount of energy left. Li-ion batteries have the longest life span of the three types of batteries, but they do need to be charged more often in order to retain their original power (even though the battery is not completely used up).

3.1.1 Recommendations for Users to Extend Battery Life Based On Previous Studies

3.1.1.1 Vibration

Vibration mode is useful for notifying users of incoming calls or texts when users are in a position where they need to prevent their phone from ringing. Nonetheless, it is recommended for users to use their ringtone as reminder when vibration is not needed. Reason is that vibration mode in general requires more power than ringtones (Almasri and Sameh, 2019). The sounds that ringtones produce are just very tiny vibrations in the speaker of a smartphone. The same holds for sensory feedback using vibration. If users don't think it's important then they need to disable vibrations or at least lower the vibration amplitude.

3.1.1.2 Screen Brightness

This one trick dramatically affects battery life. If a smartphone is illuminated brightly every few minutes as a user checks an email and so on, all the battery energy will inevitably be drained out (Wang, Guo, Shen and Chen, 2017). The auto-brightness setting allows the smartphone to adjust the brightness to its optimum reading level while preserving battery life. But, on the other hand, users can consider permanently changing the level to the dimmest level at which users can still read, without straining their eyes. In the long run, doing so might be doing wonders for the battery life. Similarly, if users want their screen display smartphone's power consumption to be minimized, they should consider shortening the screen timeout. This decides how long after users finish interacting with the phone the screen will stay lit. Some users don't have the practice of 'locking' the phone; so, they just let it go lights out by itself. Keeping the timeout short will ensure the phone will not waste power when users don't use it.

3.1.1.3 On/Off Phone

Although turning on the phone consumes more power than unlocking the phone, switching it off for a few hours can save more battery than sleeping or inactive. When users know they won't access their phone for an extended period of time, or when they are having a conference or resting, they will potentially reduce a huge amount of energy usage if they just turn it off.

3.1.1.4 Killing Unused Apps and Control GPS Connection

Many users open app after app, and don't mind closing them long though they don't intend to use them anymore. The power of multitasking is a standard characteristic of smartphones, but it is also the key reason why the battery life is quickly drained away. Something most users do not know is that when they don't even use these apps, they are wasting battery power (Cuervo et al., 2010). Apps need to be killed as often as possible, if they are not used. Some apps eat more battery juice than others, notably apps that use GPS. Smartphone has a GPS unit that lets users determine their exact location by sending and receiving signals to and from the satellites (Man and Ngai, 2014). For certain applications this feature is essential to operate, e.g. map-based software like Google Maps or Facebook check-in. Some of those apps may continue to send and receive signals when left running in the background. Continuously doing that takes a lot out of the phone’s battery, even if users are not aware of it. Therefore, users should make sure to close those particular apps when they don't really need them. A more extreme way is to disable location services when those apps are prompted. This can slow down the performance of these devices, but users won't be watched at their place and for safety purposes certain people may intentionally do so.

3.1.1.5 GPS/Wi-Fi/Bluetooth Connections

When a smartphone searches for signals – Wi-Fi, 3G or Bluetooth, etc. The phone will start scanning to achieve a decent connection when the signal is low. Repeated searches for these signals can make it easy to drop a notch in the battery (Almasri and Sameh, 2019) (Wagner et al.’s 2013). When users don't need to be connected, they should turn off their Wi-Fi or Bluetooth. One easy way to do so is to go to 'Airplane Mode' or just switching off cell when they know they can't get a signal. In the other side, if users need decent mobile reception, they need to put their phone in high coverage zones or spot it in them. This would keep a smartphone from constantly looking for a contact and losing their precious battery capacity jumping from one signal to another.

3.1.1.6 Notifications

Users continue to get reminders on their smartphones all the time with regular access to the Internet, whether it's alerts on the latest news, tweets, app add-ons etc. Since users want to be notified about the more essential things like new text messages, or Whatsapp messages. Not only is it irritating to continually get unnecessary alerts that can potentially wait, but with most of these updates it is also a power-sucker (Martins et al., 2015). Each incoming notification will light up the screen, alert or vibrate with a sound. Some users might have observed that when our smartphones are warm our battery runs out more quickly.

3.2 Installed Applications and Power Consumption

Based on the existing literature, a significant share of power consumption in smartphones is largely caused by installed applications (Taleb et al., 2013). Depending on the applications' functionality, they entail activities such as data downloading, content display, and use of built-in-sensors such as GPS (Global Positioning System) related sensors. There are various components of smartphones that facilitate the above activities including; GPS sensors, device' display, the CPU, and network interfaces among others. Consequently, activities/functions of different Android smartphone applications increase the energy consumption of any of the above-mentioned components. As a result, there has been a lot of effort in the existing literature geared towards identifying and investigating the underlying potential for energy savings in relation to these smartphone applications at applications layer and OS layer levels. This following sections reports different research themes towards the reduction of smartphone power consumption.

3.2.1 Latest Research Themes towards the Reduction of Apps Power Consumption

Westfield & Gopalan contribute towards finding a solution towards power saving techniques in smartphones through proposing an approach called Orka. According to Westfield & Gopalan, the Orka approach works by providing feedback to developers of software used in smartphones. The proposed approach is designed to provide feedback on the basis of API usage by an application as well as providing feedback on the usage of energy of the application, down to the level of the method used (Westfield and Gopalan, 2016). The authors of the study believe that it is relatively important that energy usage of software is not disassociated from energy usage of the hardware, hence Orka is designed to generally provide feedback on the consumption of energy as a result of usage of hardware. Orka carries out tests on the app through using an execution trace that is dynamically created and generated through a test script that is provided by the developer of the application. In addition, the authors suggest that the proposed Orka performs the analysis on the hardware running on emulators instead of running on physical devises. Orka pulls estimations of internal energy from the emulator, after running the application, in order to provide feedback on the basis of the different components utilized. Using the energy consumption data/metrics provided by the Orka approach, the developer of the application can make adjustments to their code in order improve the energy efficiency of their applications. According to Westfield & Gopala, Okra was designed specifically for applications installed on Android OS. Despite the fact that Orka appears to operate in a similar manner as energy profiling solutions presented in the existing literature, Westfield & Gopalan suggest that Orka's independence from the hardware makes it different from other energy profiling systems/solutions. However, it is worth noting that, the approach used in the study does not necessarily make readings on the basis of battery discharge and it does not attempt to estimate accurately an application's energy usage.

Wang, are concerned with the energy testing stage of the app development as they believe that applications developers have to understand both, the rate of energy consumption of their applications and the underlying reason why energy is consumed by the application. In their study, Wang, propose E-Spector as a potential online based tool/method the inspects energy usage, visualizes the application's energy consumption online in a manner that is instant, and it can also inform the developer what happened behind each hotspot of energy on an energy curve. According to Wang, E-Spector mainly relies on static analysis and the instrumentation of the application to collect the underlying activities in real time from the execution of an application. These activities are then presented on an instant energy curve in such a way that the user is able to recognize what actually took place behind each raise in energy usage (Wang, Guo, Shen and Chen, 2017), and (Zhang et al., 2010). The authors believe that their proposed solution is particularly more beneficial because it does not require hardware meters like many other solutions in order to calculate instant power figures for each application at runtime since it is an online-based software solution/power model. Furthermore, Wang, suggest that E-Spector provides detailed breakdowns of energy for each running process on the device, including applications running both background and foreground services. In their study, Wang, evaluated and tested the overhead and accuracy of E-Spector and the results indicate that using E-Spector has the ability of providing an estimation of energy within a less than 10% error, as well as providing an estimation of energy overhead within a less than 4% error. However, tests energy model used by the authors only considers three hardware consumers of energy including; network (both cellular and Wi-Fi network), the screen and the CPU, instead of considering all energy consumers thus presenting a key limitation to the study.

Moamen & Jamali are concerned with finding a solution that to sensor dependent applications that demand a lot of the phone's energy in order to continuously use sensor feed to provide services (Moamen and Jamali, 2015). The authors of the study believe applications that simultaneously monitor multiple sensors tend to amplify the problem as they consume significant amounts of the phone's battery. In their research, Moamen & Jamali propose ShareSens as a potential solution to the above problem. ShareSens is an approach to merge applications' independent sensing requirements. According to the authors of the report, this is achieved through utilizing sensing schedulers for the sensors that would essentially determine the underlying lowest sensing rate which would mainly satisfy all the existing requests. Custom filters are then used to only send out the required data to each application on the device. Based on the report, any sensing requests that are made through the authors' proposed ShareSens API are generally sent to the respective schedulers that determine the overall optimum rates for sensing in order to satisfy all the prevailing requests. Based on the experimental tests carried out on the ShareSens' capabilities, the authors found that there is significant power savings that can be attained when the ShareSens solution is used particularly when overlapping sensing requests exist. However, the current form of the ShareSens approach does not allow programmers to opportunistically choose sampling rates that are higher once they are available, at a relatively low marginal cost. Power-saving approach among the lifecycle stages.

3.3 Proposed Classification of Power-Saving Approaches

In order to demonstrate the main issues with current Power-Saving approaches, first we proposed summarizing the current power saving approaches that are used in today's smartphones in a S3 classification (Simulate, Supervise and Sacrifice), the following gives a detailed review of each classification.

3.3.1 Simulate and Estimate Approach

The approach reflects the concept of “simulating and estimating” the energy consumption of Android apps before making these apps available to end users by implementing green coding techniques, energy-aware designs, mobile battery simulators, historical analytical data, etc.. The predominant purpose of this approach is to direct Android app designers and developers by considering metrics and measurements generated by simulators and profilers of power consumption in addition to green code readers and evaluators. It also aims towards detecting energy leaks and measuring overall power consumption based on multi factor models which may include: memory usage per minute, processing time, background live services, loopholes that may cause continues unintended running and length of code. This approach also aims at reducing or eliminating the use of the platform's local processing and storage resources by offering a web link under a simple device interface (Thin-Client and/or Cloud).

3.3.1.1 Review of Concept Implementations

An example of a real-life application of this approach is the power consumption profilers/compilers and green code readers/evaluators. Also, the energy-aware-best practices suggested on the official Android developer’s website (Android Developers, 2020) e.g. “Remove location updates”, “Set timeouts” in addition to all cloud-based-processing apps which relies only on the internet by providing a link or a Web-based interface to users. Another example of the approach is the model introduced by Joakim v. Kistowski, Maximilian Deffner and Samuel Kounev. In their paper, the authors introduced a model to predict the power consumption of component placements at run-time based on the load and power profile collected for a running distributed application in a heterogeneous environment (von Kistowski, Deffner and Kounev, 2018). They were able to predict the amount of consumption based on load intensity and performance counters with percentage error of 2.21% and with an error of 1.04% when predicting a previously unobserved load level.

In a study conducted by Zhang, the authors proposed the use of an online power estimation tool and a model generation framework in their contribution towards improving power-saving capabilities of Android smartphones on both the applications layer and the OS layer (Zhang et al., 2010). Zhang proposed a tool called the PowerTutor which was designed as an online power estimation system for the Android platform smartphones. The tool provides real-time, accurate power consumption estimates for components of the smartphone that are power intensive such as display, the CPU, cellular interfaces, GPS, and Wi-Fi interfaces. The PowerTutor was designed to be used by both application developers and smartphone users. Applications developers use to conveniently, accurately and rapidly determine the overall impact of changes in software design on power consumption while smartphone users can use the tool to determine the underlying power consumption characteristics the relate to competing mobile applications thus facilitating informed decision-making for both parties. PowerTutor, according to Zhang, has a power model that includes six different components including: GPS, LCD display, CPU, audio interfaces, Wi-Fi and cellular interfaces. Based on the experiments that authors carried out, it was found that PowerTutor was accurate within an average of 0.8% with at most 2.5% error for intervals of 10 seconds. In addition to the PowerTutor tool, Zhang also proposed the PowerBooster tool which was designed an automatic state of battery discharge on the basis of a technique called the power model generation technique. According to Zhang, the experimental tests carried for 10-second intervals indicated that PowerBoost was accurate within 4.1%.

Abhijeet Banerjee & Abhik Roychoudhury were concerned with the energy spent by within an application with the aim of finding ways to reduce such energy consumption (Banerjee and Roychoudhury, 2016). In their study, the authors presented a design-expression that can be described as a regular-expression representing the ordering of energy-intensive resource usages and invocation of key functionalities (event-handlers) within the app. According to their study, they used a refactoring tool that adopts the last-trigger accounting policy to capture intuitively the asynchronous modern smartphone components' power behavior in mapping of energy activities to respective program smartphone entities. The tool was designed to be concerned with energy consumption profiling which is not linear as time and it has the capability of measuring intra-app consumption of energy including providing insights into the overall energy breakdown per application routine and per thread. Their tool was also designed to be a general-purpose energy profiler that is fine grained works by assisting an application developer for Android smartphones to optimize the application's energy consumption. Their tests showed that refactoring shed light on the applications' internal energy dissipation and it further exposed surprising findings such as 65%-75% free applications' energy is consumed third-party advisement modules of the applications. They also revealed numerous "wakelock bugs" (a family of smartphone applications energy bugs) and it efficiently pinpoints their location within the application's source code for to inform decision-making. Based on the experiments conducted by Abhijeet Banerjee & Abhik Roychoudhury, their proposed accounting presentation of application 1/O energy (bundles) helped to reduce the consumption of energy of four applications involved in the test by 3 % to 29 %.

Mehmet Fatih Tuysuz & Murat Ucan, proposed an energy-aware algorithm that was based on measurements of energy consumption in relation to 802.11 WLAN and UMTS networks on smartphones running on an Android OS (Tuysuz and Ucan, 2017). The proposed algorithm generally utilizes application traffic size estimations in order to determine the overall alternative of the minimum energy-cost through comparing the cost associated with the utilization of UTMS with the underlying cost associated with performing a downward vertical opportunistic handoff back to WLAN, while utilizing WLAN for data transfer. The authors show in their study that the proposed solution has the ability of predicting how much data will be transferred as a result of actions taken by the user. Based on experimental tests, Petander found that energy consumption of the smartphone increases by 18.3% whenever Wi-Fi and UTMS are both powered on simultaneously, compared to powering on UTMS alone at any one time.

In a study conducted by Cai the authors were focused on power wastage in mobile devices with 3G/4G networking that resulted from 'tail time' where the device's radio is kept running despite the fact that no communication is taking place. Cai proposed DelayDroid as a framework which would provide a developer with the capability to add the required policies for reducing such energy wastage to existing Android application that are unmodified without any 'human' effort. The tool that Cai proposed uses bytecode refactoring and static analysis in order to identify method calls which send network related requests and modify the calls in order to detour them to the run-time of the DelayDroid. The tool's runtime then batches them by applying a pre-defined policy, hence avoiding energy waste related to tail time hence improving energy efficiency. The universality and correctness of the DelayDroid mechanisms were evaluated and tested using 14 popular applications for Android and results indicated that DelayDroid was capable of reducing energy-waste related to 3G/4G tail time by 36% (Cai et al., 2015). However, it is worth noting here that while the test results indicate that DelayDroid was effective in reducing the energy waste, it only reduces waste related 3G/4G tail time but not from screen and CPU usage which account for a large portion of the phone battery drain.

3.3.1.2 Limitations

From the previous implementations of the main concept they all share the same issue which is addressed to the approach. The first issue is that not all hardware is created equal and not all apps works the same on all hardware. In the same time, methods of normalizing energy consumption measurements across different platform with either linear or nonlinear scaling still ignores the usage habits and the lifestyle of the end user (Heavy gamer, Outdoor Field Engineer), figure 3.1 shows workload deployment power prediction data flow model proposed by Joakim v. Kistowski, Maximilian Deffner and Samuel Kounev, it is clear that the model does not include any of the user characteristics which may influence the final result. Added to this, apps energy consumption is not stable across different versions of the app. Furthermore, testing a single build of the code might not be enough, a partial or entire energy consumption profile should probably be built. In addition to all the previous, continuous need of Internet connectivity uses local connection hardware resources that require complicated power aware connectivity algorithms on both the sender and receiver side (router, tower, satellite, etc.) in addition to the connection method and technology.

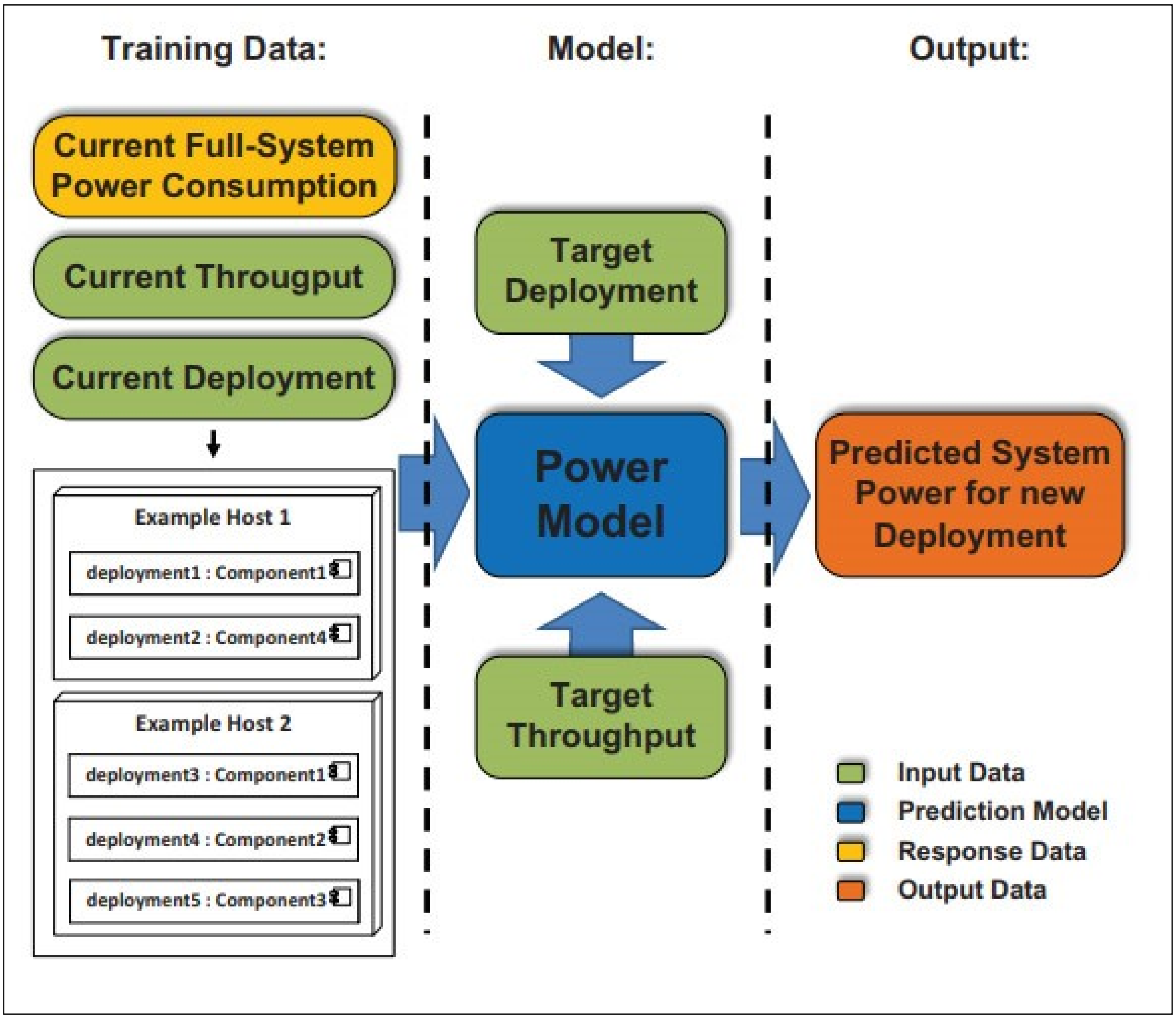


Figure 3.1: Workload deployment power prediction data flow with example deployment (von Kistowski, Deffner and Kounev, 2018).

3.3.2 Supervise, detect and control app behavior

The approach follows the "Supervise, detect and control" philosophy, so it applies this on the behavior of an Android application while it is running on an end-user's phone and optimizing the power consumption. Its basic concept is to run a real-time power-usage monitoring code and then keep notifying the user by proposing instant actions to optimize power usage. It also takes the chance whenever needed to interrupt the built-in runtime schedule of background apps in order to kill whatever apps it may found causing a high level of power consumption, it also applies the same for features called by applications e.g. continuous synchronization.

3.3.2.1 Review of Concept Implementations

The most common example of a real-life implementation of this approach is the battery optimizers available in various app stores, commonly known as "battery-saving apps," along with built-in power management and saving algorithms originally equipped with smartphones. Another technical example is TIDE which was presented by Dao (Dao et al., 2017). The authors are concerned with the difficulty in identifying applications that are heavy power consumers on a smartphone as well as understanding why these applications are heavy power consumers. The authors believe that there is real need for phone users to be aware of applications on their smartphones that are heavy power consumers so that they are able to take appropriate action quickly enough by preventing their phone batteries from being completely drained. In their study, Dao, proposes TIDE, a tool that they believe can identify applications which are heavy energy consumers and provide an understanding of the reasons why an application is consuming a lot of energy on the phone. TIDE, according to Dao, operates as user-centric tool which can be installed on a user's smartphone and it continuously performs monitoring tasks on the application usage of the user as well as monitoring the resources that the application consumes. Dao, conduct an evaluation of their proposed tool using emulation of usage pattern traces from seventeen volunteer users and the results indicate that TIDE correctly estimated the energy consumption level for 225 applications out of 238. However, the tool does not provide a breakdown of the screen consumed energy in relation to individual applications yet the screen consumed the most amount battery power in most cases. Hence the results that the TIDE tool provide do not show the full picture of energy consumption. Wang is concerned about the difficulty in the diagnosing energy inefficiency of applications that often use sensors to operate (Wang et al., 2016). In their study, Wang proposes the GreenDroid approach that is designed to systematically diagnose problems associated with energy inefficiency among applications used in smartphones particularly those running on the Android platform. The proposed approach leverages the Application Execution Model (AEM) to realistically simulate the runtime behaviors of an application and it is also designed to have the ability of automatically analyzing the sensory utilization data of an application reporting the resulting information to the application's developers. Wang evaluated the E-GreenDroid approach using 13 real applications on Android in two separate experiments and the results from the tests indicated that the tool was effective in executing its intended mandate. However, E-GreenDroid does not support concurrency of Android applications as it simply places all the execution into a single thread.

A solution which was presented previously in the existing literature that provides attempts to cover all areas of a smartphone's energy consumption is the E-Spector that was proposed by Chengke Wang, Yao Guo, Peng Shen and Xiangqun Chen (2017). In their study they suggest that the E-Spector is an Android application that works by employing a monitoring module to collect data which relates to all features of the smartphone. There are various modules, each collecting data on a specific feature including; the application monitor – collects data on running applications and their CPU load; battery monitor – collects data on battery status; CPU monitor – collects data on CPU operating frequency and load; the context monitor – collects data on system time, date and coarse location; the network monitor – collects data on the status of the mobile data, Wi-Fi, network traffic used by applications and GPS status; and the display monitor – collects data on the screen timeout, level of brightness and devise interaction time. They suggest that E-Spector, stores the collected data locally and deploys a learning engine that is designed to generate various usage patterns that may exist within the smart device. Thereafter power saving patterns for each pattern are generated dynamically. The collection of the usage data of the smart device raises various privacy related questions for the tool.

In their study Pandey, Verma, and Kumar (2019) proposes NIPO, a framework which aim to optimize smartphone power consumption. The NIPO framework is generic in nature in that it can be used for power optimization on any smart device or computer subsystem. It has system-based client-server architecture. Many of its components reside on the server while others are on the device. The main components of the proposed system on the device side are: User Interface module, Battery Monitoring module, Power State Monitoring module, Time Monitoring module and Server Interface module. On the server side, the two main components of the system are: Device Interface module and Power Optimization Engine. The key task was to select the optimum parameters (Brightness and Transparency) by maintaining a defined battery level to fulfill the time-to-last requirements. Their analysis found that the till battery power level is above 30 percent, by controlling transparency and brightness, the battery power was optimized. Adding brightness to the power optimization variables therefore allows improved power control. However, NIPO does not endorse Android applications participation, as it simply places all execution at parameter-based monitoring stage.

Min C, from a similar perspective, discussed the various factors that have a significant impact on smartphone batteries to the point of making their current battery models obsolete and further examined the initial approach aimed at helping smartphone users understand the underlying cause and effect of their physical activity between them and the battery life of their smartphone (Min et al., 2015). Min C, suggested Sandra, a mobility-aware battery information advisor for smartphones. Sandra was developed with various key features including; a forecaster that offers forecasts of battery life under different conditions of potential mobility of the user, and a database designed to provide a historical overview of past battery drain levels, classified by different mobility conditions. Sandra was found to be particularly helpful to mobile users, based on the tests performed by the proposed solution. However, the tool that Min, presented is neither an omniscient battery predictor nor a reconfiguration tool that extends batter's life like Power monitor v2. According to Min, Sandra's main goal is user enlightenment regarding new causal factors of their changes in mobility that impacts the standby life of the phone batteries.

In their study, Forkan Uddin, proposed a scheduling algorithm that is designed to make use of a network signal with high strength (Uddin, 2017). His philosophy is that applications have to preferentially communicate when there is a strong network signal in order to realize energy savings, either through deferring communications that are not urgent or through advancing communications that are anticipated in order to coincide with strong signal periods. To take advantage of a strong signal, Forkan Uddin, developed a scheduling algorithm that focused on two specific kinds of applications, including streaming applications on one hand and sync applications on the other. For streaming applications, the algorithm that the authors developed modulates the traffic stream in order to match with characteristics of radio energy while for sync applications the algorithm utilizes flexible synchronization intervals. His proposed energy-aware scheduling algorithm thereby takes into account tail energy as well as communication energy.

In their study, Taleb proposes a technique that involves dynamic switching between Wi-Fi and 3G communication on the smartphones (Taleb et al., 2013). Taleb aims at achieving the ability to effectively switch to an alternative Wi-Fi connection from a primary cellular network. Taleb conducted a set of experimental measures in relation to various network scenarios with the aim of identifying the key components which affect consumption of energy within a smartphone while they are connected to Wi-Fi and 3G networks. The authors then used the measurement results to derive at generic analytical model for energy as a function of effective download bit rate and download data size. They developed an Android-based mobile application whose intended design is to test, in real scenarios, the overall performance of the algorithm for dynamic switching between Wi-Fi and 3G connections. The results of the tests showed that it was possible to dynamically switch between Wi-Fi and 3G communications and, when 3G only and Wi-Fi only connections were compared, it was found that energy savings of 30% and 18% respectively were possible. This particular study highlights the underlying potential benefits that intelligent switching within heterogeneous networks can provide.

3.3.2.2 Limitations

The main and critical issue of the concept which is addressed by its implementations is that is requires power which causes it to fail in delivering its main goal of saving energy. Simply, monitoring and announcing consumes power for the sake of saving power. Plus, whatever runs on the application and/or the OS layers of the phone consumes power from the same phone battery. By using any power usage profilers in order to rank the usage of power consumed by each running application we were able to rank two power-optimizing applications both as one of the top most power-consuming applications as Figure 3.2 shows.

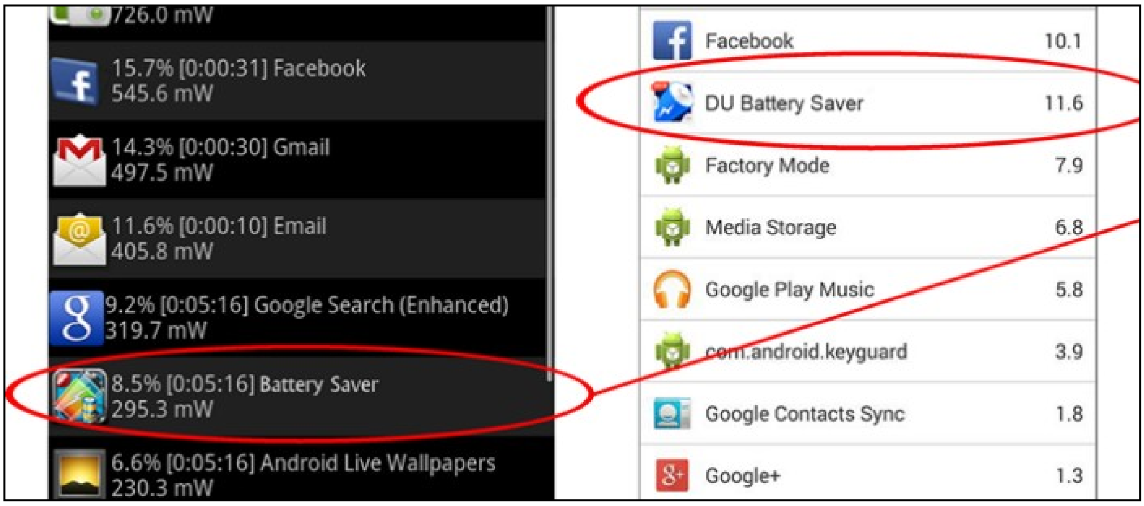


Figure 3.2: Using PowerTutor and Trepn Profiler to read the amount of energy consumed by two popular power-optimizing applications.

3.3.3 Sacrifice Modern features

The approach is more about "Sacrifice" smartphones technology or performance by switching off a number of features for the sake of saving power philosophy. Its basic concept is to sacrifice smartphone's modern features for the sake of saving power by switching some of the optional modern features off or by reducing the level of the smartphone's performance or any of its components.

3.3.3.1 Review of Concept Implementations

An example of a real-life application of this approach is the "power-saving modes" that are used among different brands, models and versions of Android smartphones e.g. Samsung Maximum Power Saving Mode (Use power saving modes on your Galaxy phone, 2020). Another example is a research implemented by F. Chesterman, G. Muliuk, B. Piepers, T. Kimpe, P. D. Visschere, and K. Neyts (2016). The authors analyzed the underlying influence of the content displayed on the overall energy-usage for displays whose design is based on the OLED technology (Chesterman et al., 2016). Through their research, the authors found that energy usage largely depends on the content displayed as different content contains different colors and for the devise to display different colors a certain amount of energy would be consumed. Hence, the authors concluded that designers of graphical user interface generally have a significant impact on the device's energy consumption. In this regard, they proposed different energy models which were designed to estimate the display content's power consumption. The authors also proposed different transformation methods such as the utilization of a lighter foreground color and a dark background color. They also used the transformation methods to evaluate the overall influence of their methods and found that energy usage can be reduced by approximately 75% hence saving the smartphone battery from draining. Similarly, Li, Tran & Halfond concentrated on the idea of reducing the consumption of energy by device-displays that use OLED technology (Li, Tran and Halfond, 2014). However, Li, Tran & Halfond proposed a different approach in which they suggested that it is necessary to change the source code of the applications as a way of reducing the power consumption of the applications. They developed a tool they called Nyx which they suggested was capable of performing color schemes transformations for applications. According to Li, Tran & Halfond (2014), the test on their proposed solution found that battery savings of up to 40% for such modified applications were possible but only if users are willing to accept color transformations in the name of saving battery.

A method proposed by Vishwakarma and Bhadauria (2015) was to create a cooperative network where users with high battery level support bring low battery level user traffic. This scheme helps to increase the amount of valued battery in the network, thereby reducing the probability that users run out of battery early. The technique takes the form of a service that uses a device-to-device communication architecture instead of using direct network connection e.g. 3G or 4G. By reducing the power consumed by communications, the proposed system provided considerable gain for the overall battery life. However, the proposed solution relies on the existence and usage of the hexagonal cell environment, *helpees* and D2D communication which also raises concerns related to data privacy and security.

WANDA-CVD was introduced by authors in Alshurafa et al. (2014) with a new method of battery optimization that improves the battery life of smartphones tracking physical activity. Their technique of battery optimization increased the battery life by 300%. The smartphone could enter sleep mode to decrease the accelerometer's sampling rate while the user is not in motion, knowing that individuals spend most of their day inactive. Authors created a battery management technique such that it reaches an initial state when the phone is connected to a charger, where the accelerometer can be switched off. It enters an active state once the phone is disconnected, where the accelerometer is switched on and the sampling rate is set at 10Hz. If the user is idle, sits on a sofa or dinner table, no physical movement is detected and the device enters an inactive state where the sampling rate drops to 1Hz. In both in-lab and real-world environments, the WANDA-CVD device has proven effective in battery optimization. The healthcare industry could benefit from such a system. However, active auto-synchronization is considered as an essential requirement for most smartphones' users. So, the usage of sleep modes for the sake of saving energy is to be reconsidered as a current solution.

3.3.3.2 Limitations

From the previous implementations the main issues of the concept are related to the predefined saving plans which does not differentiate between smartphone users in terms of using habits and claims to provide a one-size-fits-all solution which converts the colorful screen of the smartphone to a semi-black and white old screen for either a heavy gamer or a 70 years old user as shown in figure 3.3. Additionally, Flexible Saving Plans relies on user's personal estimations to control the phone components/technologies "on/off switches" which the user may never bother to go through. Furthermore, the idea of having a "One Size Fit All" power saving plans is gradually receding (Almasri, 2015). Also, these power-saving modes does not serve different users categories based on their usage of different applications categories which causes the majority of users to avoid using these power saving modes for reasons related the user's need to use the new technology itself rather than sacrificing it for the sake of saving energy.

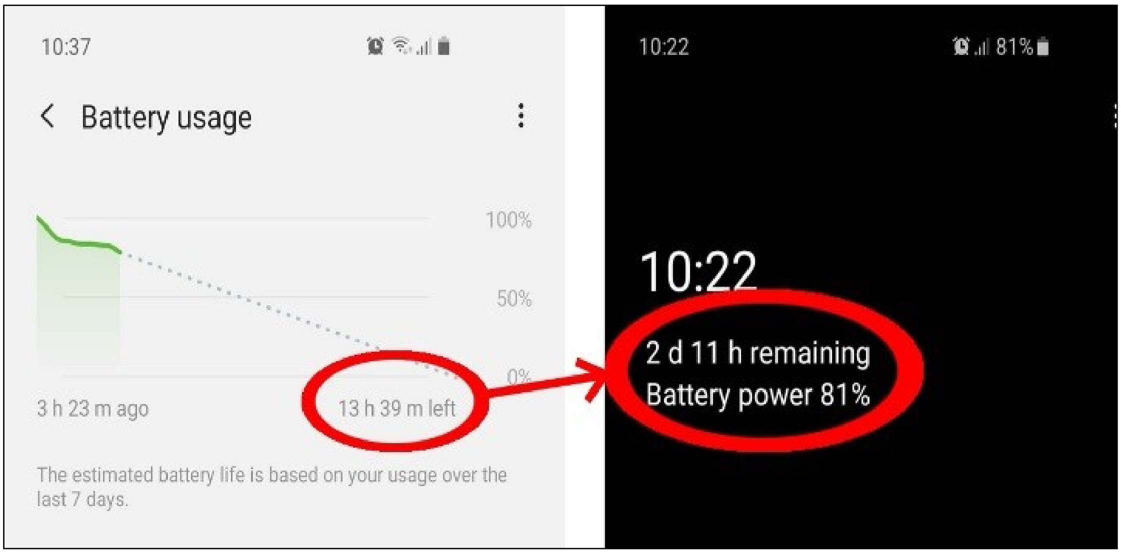


Figure 3.3: Activating "Ultra/Maximum Power Saving Mode" Gives more battery life time at the expense of technology (Less or No Colors).

Figure 3.4 shows the result of a simple survey that we implemented on a sample of ten users from six users' categories which either care about the technology or the battery life. Finally, downtime is often cited as one of the biggest disadvantages of cloud computing. Since cloud computing systems are Internet-based, service outages are always an unfortunate possibility and can occur for any reason, which is the biggest challenge that faces most thin-client solutions nowadays.

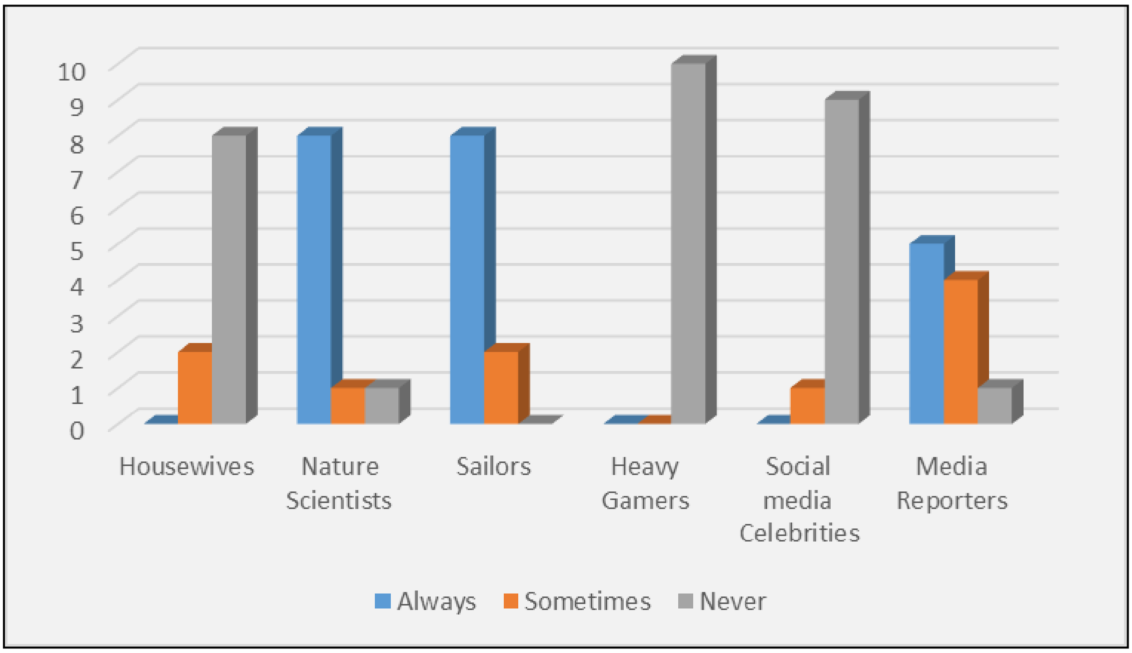


Figure 3.4: Usage of "Ultra Power Saving Modes" among six categories of smartphones users.

3.4 Discussion and Further Research Areas

While much attention has been drawn to energy saving, there are many challenges that the current researchers need to pay more attention to. The previous review tackled these battery savings implemented on the smartphone's applications layer, OS layer and even during the development stage of an Android app. A primary motivation for future research is to improve end-users' involvement in exploiting the degree of versatility between the aforementioned S3 approaches while preserving or improving energy consumption levels. A good area of future research to resolve this particular common limitation is to find a solution that would not require end-users to compromise all or parts of a technology that is considered "required" while also allowing end-users to extend the battery life of their phone. Another future research area is to avoid adopting the argument that "waste" some energy from the battery of a smartphone under the pretext of saving the same battery's energy. Finally, additional efforts are to be made to define the fundamental shortcomings of the battery savings that are developed and implemented in future smartphones.

We believe that we have implemented a deep review study that derived us to a set of results which can support proposing a new power-saving approach to be used in smartphones. Our main contribution is to create a new research direction towards helping in proposing a new power saving approach that does not require consuming any of the energy of the same battery while keeping the user able to both save energy and enjoy all of the new features of a smartphone. Although there are various improvements in the area of smartphones applications development in terms of power saving, the inclusion of many other factors which are mainly related to using habits of smartphones users may cause for example pop up advertisements and other interrelated factors which force the smartphone user to consume energy from the battery. As per to the battery saving features that could help in resistance of battery includes the flight mode, do not disturb, powering off Wi-Fi and data connections. Moreover, with respect to the research questions regarding the fact that power saving application consumes a lot of energy it is clearly stated by the past studies that due to many factors there is a lot of battery exploitation and these issues have been becoming a major issue for smartphone users and manufactures. The study provides a clear insight that there are several ways which could be designed and developed to save the power of smartphones more efficiently.

3.5 Chapter Summary

This chapter has provided a review of the existing literature regarding the different solutions, techniques and tools that have been proposed by different authors in response to battery energy consumption problems of mobile applications for smart devices running on the Android OS. The literature review covers studies that provide solutions based on three key approaches, including; approach 1 estimating and simulating power consumption of Android applications, approach 2 monitoring, detecting and controlling the Android applications' behavior, and approach 3 switching off smartphone features when not in use in order to reduce power consumption. Based on the review of the literature, solutions presented by prior studies in relation to approach 1 reveal that the average estimations that the proposed tools/techniques provide tend to conflict the actual usage habits of device and the accuracy of the power consumption measurements and simulators remains an issue of debate. The review of the existing literature in relation to the approach 2 reveals most solutions that monitor and control app behavior also consume power from the devise' battery for instance E-GreenDroid, Eprof, and among others. Prior studies that propose solutions in the line of approach 3 reveal that the proposed techniques use predefined saving plans that provide a one-size-fits-all approach which does not necessarily provide customized/personalized solutions for users. Therefore, while the techniques presented herein provide some potential solutions for reducing energy consumption by mobile applications on Android-based smart-devices, they are limited in their usage.

CHAPTER 4. Wi-Fi As A Preferred Connectivity Option by Smartphones Users and Its Role in Energy Consumption

4.1 Relationship between Wi-Fi Signal Strength and Phone Battery Life

Previous researches have shown that the strength of the Wi-Fi signal is strongly linked to the power consumption of the smartphone battery (Gurun, Krintz and Wolski, 2004). Therefore, the stronger the Wi-Fi signal, the more energy-efficient the mobile battery becomes. When the Wi-Fi signal intensity is small, the amount of energy stored in the smartphone battery will be depleted rapidly because the phone will continue to try to communicate with any access point that provides this weak signal and to keep sending and receiving data through this weak communication. The weaker the Wi-Fi signal, the more energy it requires to transmit and receive data. If the smartphone is under a strong Wi-Fi coverage area and is connected to this powerful Wi-Fi, it is the opposite of the past point, meaning that the smartphone battery will not consume its energy quickly because it does not need to consume a lot of power attempting to transmit and receive power through a strong connection.

4.2 RSSI Strength and Energy Cost

If a smartphone with its Wi-Fi functionality is turned ON spends a lot of time away from a wireless connection, the phone will spend a lot of energy searching for a wireless access point, which will cause the amount of energy on the battery to be consumed quickly. In this case, a number of recommendations have been made to disable the Wi-Fi feature if it is not used to save more battery life (Gurun, Krintz and Wolski, 2004). A previous study by Rajesh K Gupta and Prasant Mohapatra shows the difference in average power generated in different phone states using Wi-Fi connections with different RSSIs (Power Aware Software Architecture Rajesh K. Gupta University of California, Irvine – [PPT Powerpoint], 2020). The Figure 4.1 below shows that the amount of power consumed under a high RSSI (-35dBm to-50dBm) Wi-Fi connection in both “On Call” and “In Standby” states is lower than the amount of power consumed under a low RSSI (-65dBm to-77dBm) Wi-Fi connection, as shown in the above section.

802.11a	# of APs	Current Drawn on Call (mA)		Current Drawn in Standby (mA)		Current Drawn Out of Network (mA)	
Voltage		4.2 V	3.7 V	4.2V	3.7V	4.2V	3.7V
High RSSI (-35dBm to –50dBm)	1	117.4	129.9	16.2	18.6	12.4	16.1
	2	115.5	126.1	16.1	18.2	12.4	18.1
Low Signal Strength (-65 to –77 dBm)	1	119.3	132.0	24.0	26.7	12.4	16.1
	2	114.2	126.1	21.0	24.5	12.3	18.1

Figure 4.1: Difference in the average power drawn in different states of a phone that is using a Wi-Fi connection with different RSSI (Power Aware Software Architecture Rajesh K. Gupta University of California, Irvine – [PPT Powerpoint], 2020)

4.2.1 Energy-Efficient Connections Among "Available Wi-Fi Connections"

Once the Wi-Fi feature is activated on any smartphone, the smartphone will automatically start searching for wireless connections and show the available connections sorted by different factors including the strength factor, which actually gives the users the freedom to choose their preferred connection, regardless of the effect of each connection on the battery life of the connection. Users may try to connect to a Wi-Fi connection simply because the network key is unsecured so that they can enjoy free internet access without paying much attention to the strength of this connection. A previous study by Almasri proposed a tentative new connectivity policy (Almasri, 2015). The policy operates on showing users only a strong RSSI link, and depending on the previous classification of weak and strong signals provided by Gupta and Prasant Mohapatra (Power Aware Software Architecture Rajesh K. Gupta University of California, Irvine – [PPT Powerpoint], 2020) considering (-35dBm to-50dBm) as high RSSI and (-65dBm to-77dBm) as low RSSI, it will be possible to show only network connections between (-35dBm to-50dBm) to users who are concerned about their smartphone battery life. The same study also presented the common rule in networking that Wi-Fi routers running on a 2.4 GHz band can cover up to 46 meters indoors and 92 meters outdoors. Other routers running on 5 GHz bands can reach up to 15 meters indoors and 30 meters outdoors. The market has a number of new router technologies operating on the two previously mentioned 2.4 GHz and 5 GHz bands. These routers differ in the lengths they reach. Structures that houses or offices are constructed of or exist in buildings row materials such as cement or metal decrease the Wi-Fi network by 25% or more and, as a result of the laws of physics, 5 GHz Wi-Fi connections are more vulnerable to interference than 2.4 GHz. Radio signal interference from microwave ovens and other devices often adversely affects the Wi-Fi network spectrum. Since 2.4 GHz radios are widely used in consumer gadgets, these Wi-Fi connection protocols are more likely to interfere with residential buildings. As the study focused on improving smartphones power-saving techniques, the study proposes to pay more attention to the amount of energy consumed every time a smartphone searches for a signal through its Wi-Fi radio. The study also proposed reducing the range of searches that the Wi-Fi radio smartphone covers for users who are concerned about their smartphone battery life.

4.2.2 Saving Smartphones Battery by Reducing Wi-Fi Interfaces – An Auxiliary Basic Experiment

In the following, the study will try to prove the basic concept regarding reducing the number of available networks around a smartphone in order to save its battery. The amount of consumed energy will be measured when a smartphone tries to search for a network connection and define a network to a user as an "Available Nearby Network" on an area that has either one or many network connections by removing all available networks connection and keeping only one connection available. In another scenario by adding more available network connection aside to the available one. This experiment wasn't implemented in the previous study of, Almasri because of the complicated implementations of hardware side which is not covered in their study (Almasri, 2015). But in order to mimic this idea and since the Wi-Fi connection basically stands on two main parties which are the smartphone and the network interface the experiment preferred to reduce the number of available networks from the network interface side. The following shows the results on both scenarios:

4.2.2.1 Scenario I, Single Wi-Fi Nearby Connection:

By setting up a smartphone with its Wi-Fi feature deactivated in a 12 m^2 apartment room located on a partially constructed new building, with only one Wi-Fi dual-band router accessible in the same space, ensuring that no nearby wireless connections are usable as shown on Figure 4.2.

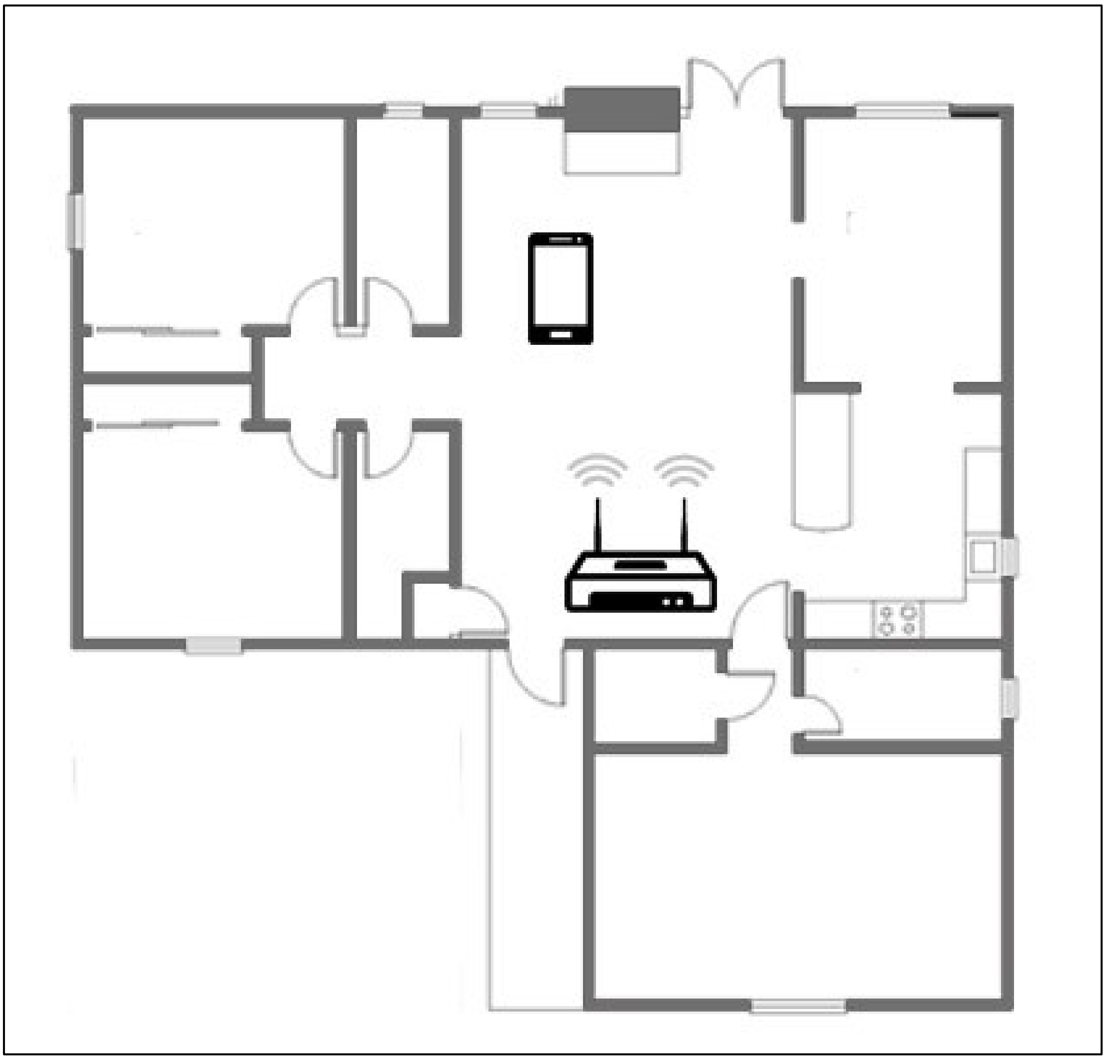


Figure 4.2: Location of a Smartphone and a single router in a 12 m^2 room of an apartment located on a partially constructed new building.

An important move was to deactivate as many features as possible on the smartphone, including cellular data, in order to be as precise as possible with the measurements. After enabling the Wi-Fi feature on the smartphone, the amount of power consumed after 10 seconds of activating the Wi-Fi feature, the smartphone took three seconds to locate the connection and to identify it as the "Available Nearby Network" of the only available router in the 12 m^2 room.

Figure 4.3 shows the amount of energy consumed by the Wi-Fi radio to search for a nearby link with 10 seconds of running time, regardless of the time spent identifying it as a "Accessible Nearby Network", the test was performed on the Samsung I9500 running Android OS,v4.2.2 (Jelly Bean), v4.3 with a power profiler.

Stage (with only one nearby connection available)	**Average Consumption**
Wi-Fi feature deactivated	~ 573 mW Off
After 10 Seconds of Activating the Wi-Fi feature	~ 592 mW On

Figure 4.3 Amount of energy consumed by a searching Wi-Fi radio with 10 seconds running time and a single network router.

The above figure showed that the average power consumption of a smartphone looking for a Wi-Fi signal with only one nearby connection is 19 mW. The next stage is to move to the second scenario of applying the same measurements, but with adding more nearby wireless connections, and see how the smartphone will deal with finding each connection from the power consumption side.

4.2.2.2 Scenario II, Multi Wi-Fi Nearby Connection:
In this scenario, the smartphone was kept with its Wi-Fi feature disabled in a 12 m^2 apartment room located on a partially constructed new building with only one Wi-Fi dual-band router accessible in the same room. At the same time, three more routers were placed in three more adjacent rooms, one router in each room, as shown in Figure 4.4 below:

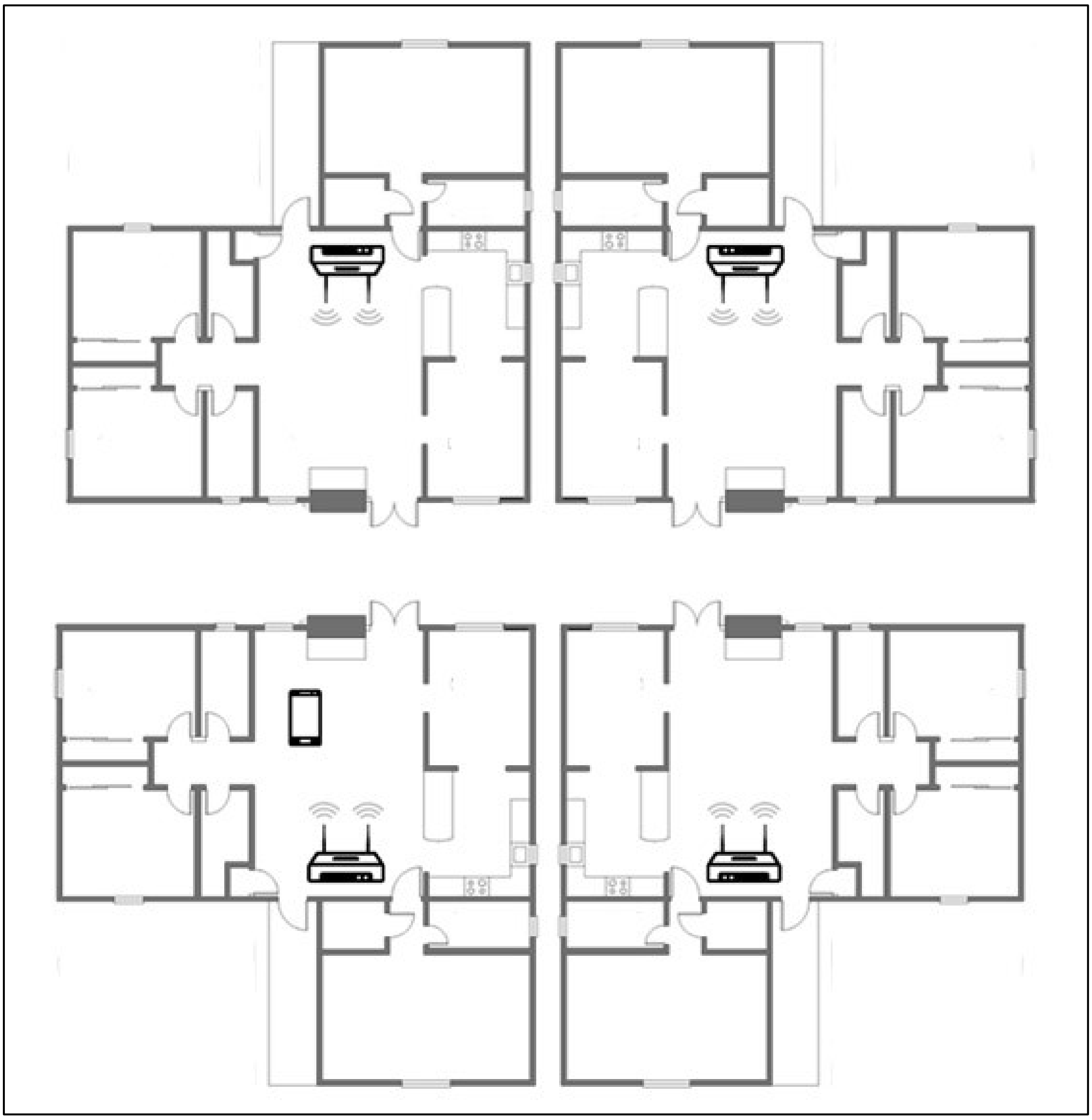
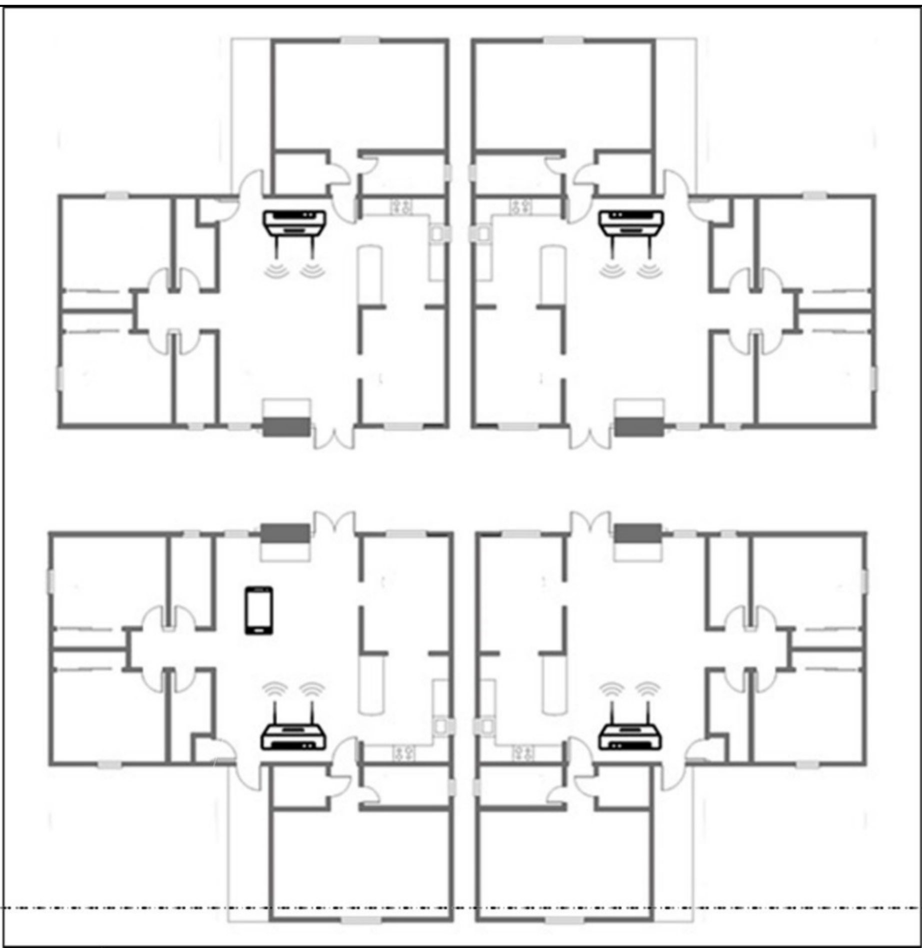


Figure 4.4: location of a smartphone and a router in a 12 m2 room of an apartment with three more routers fixed in three nearby rooms located on a partially constructed new building.

As done in the previous scenario, the device had as many deactivated features as possible, including cellular data, in order to be as accurate as possible with the measurements. After enabling the Wi-Fi feature on the smartphone, the amount of power consumed after 10 seconds of activation was calculated; the smartphone took 8 seconds to locate all four nearby connections of all accessible routers in the nearby rooms and defined them as "Accessible Nearby Networks".

Figure 4.5 below shows how much energy the Wi-Fi radio consumes to search for a number of nearby connections with 10 seconds of running time, regardless of the time spent defining them as "Available Nearby Networks", the test was performed on the Samsung I9500 running Android OS,v4.2.2 (Jelly Bean), v4.3 with a power profiler.



Stage (with four nearby connection available)	**Average Consumption**
Wi-Fi feature deactivated	~ 573 mW Off
After 10 Seconds of Activating the Wi-Fi feature	~ 620 mW On

Figure 4.5 Amount of energy consumed by a searching Wi-Fi radio with 10 seconds running time and multi network connections.

The above figure showed that the average power consumption of a smartphone looking for a Wi-Fi signal with multi nearby connections (routers) is 47 mW.

4.2.2.3 Conclusion

The previous experiment studied the relationship between Wi-Fi signal strength and smartphone battery life and concluded that a smartphone which is surrounded by many nearby available network connections consumes more power during the stage of scanning for and defining each and every nearby network. The opposite applies on a smartphone which is surrounded by a few numbers of nearby networks where the smartphone will not need to consume much power trying to define the few number of nearby networks. Merging the experiment with all previous studies that proposed modifying the commands responsible for delivering the power voltage to the Wi-Fi antenna for the sake of minimizing the range of searching for wireless connection will give the smartphone the advantage of dealing with only what is near to its range.

4.3 Chapter Summary

The chapter was able to identify and compare different Wi-Fi connectivity scenarios on smartphones in terms of energy-efficiency. This helped to understand the relationship between Wi-Fi signal strength and phone battery life which showed that the weaker the Wi-Fi signal, the more energy it requires to transmit and receive data. Also showed that if the smartphone is under a strong Wi-Fi coverage area and is connected to this powerful Wi-Fi, then it is the opposite. The chapter also tackled the RSSI strength and energy cost and concluded that that the amount of power consumed under a high RSSI (-35dBm to-50dBm) Wi-Fi connection in both 'On Call' and 'In Standby' states is lower than the amount of power consumed under a low RSSI (-65dBm to-77dBm) Wi-Fi connection. Then the chapter proposed basic energy-efficient connections among "available Wi-Fi connections" which were in the form of paying more attention to the amount of energy consumed every time a smartphone searches for a signal through its Wi-Fi radio. The chapter also proposed reducing the range of searches that the Wi-Fi radio smartphone covers for users who are concerned about their smartphone battery life. Then the chapter implemented a set of experiments to simulate three connectivity scenarios and to measure the amount of energy consumed under each scenario. Then the results were demonstrated and concluded that a smartphone which is surrounded by many nearby available network connections consumes more power during the stage of scanning and defining each nearby network. The opposite applies on a smartphone which is surrounded by a few numbers of nearby networks where the smartphone will not need to consume much power trying to define the few number of nearby networks.

CHAPTER 5. Methodology

5.1 Research Approaches (Philosophy, Paradigm and Strategy)

In the research philosophy shows how knowledge is generated as such and how the researcher conceptualizes this process. It is important to illustrate the philosophy as it impacts the research design, as well as the result interpretation. Broadly, there are two approaches to knowledge generation: objective and subjective. The former is scientific and results-oriented, while the latter is exploratory and reason-searching (Davidson, 1996).

Objective research is separated from society and is not inclusive of individualized perceptions of reality, instead only serving to provide an interpretation of raw data (Cooper and Schindler, 2014) Subjective research, on the other hand, interprets observations through a lens of cause and effect, examining events in-depth (Cooper and Schindler, 2014). As a result, objective research is recognized as the more transparent and accurate, and thus scientific, of the two philosophies (Sarantakos, 2012). Objective research also provides a more modest, focused understanding of the subject. The Figure 5.1 below summarizes the limitations of the two research philosophies, as well as introduces intersubjectivity as an approach.

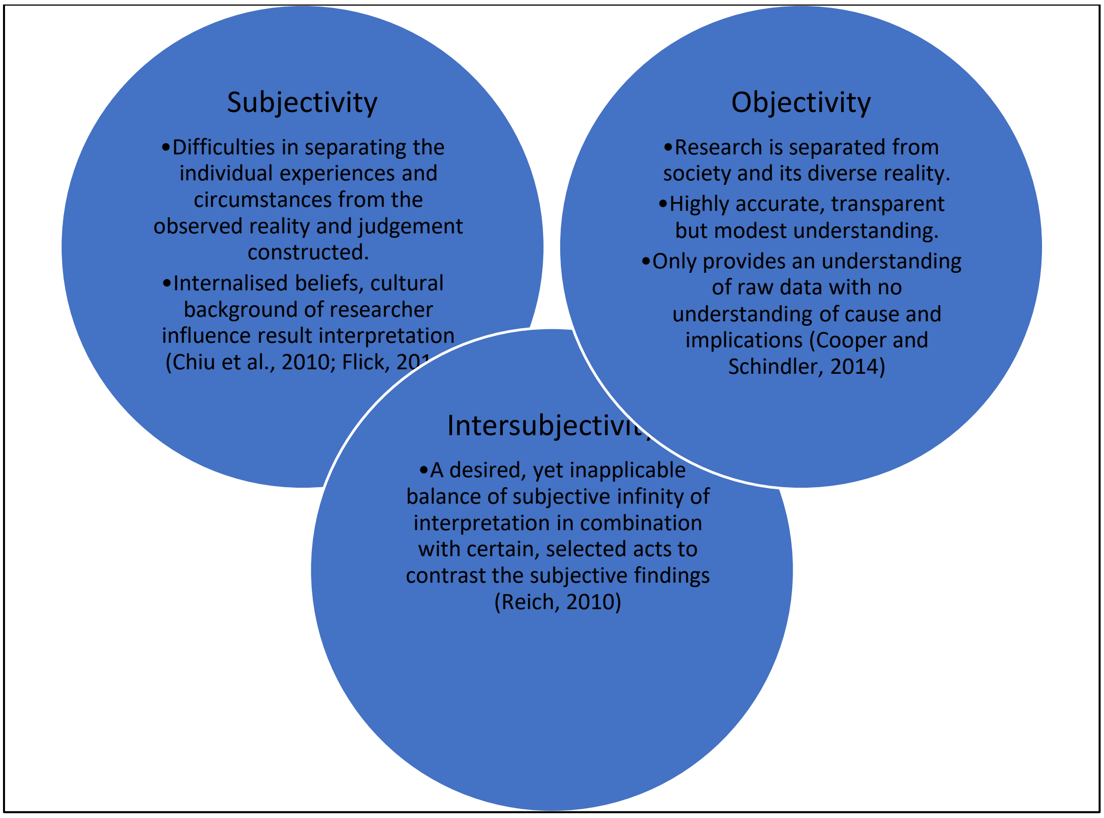


Figure 5.1: Limitations of Research Philosophies

The research paradigm is the method of perception of reality or phrased otherwise a representation of values and beliefs (Saunders et al., 2016). It guides the methodology in solving the research problem. The ontology and epistemology are two components of the paradigm. The ontology describes the researcher's philosophical beliefs regarding reality in a social context (Goodson and Phillimore, 2004), while the epistemology describes how knowledge is established as such (Patton, 2002). The epistemology centers around the understanding of knowledge, and how views are justified and rationalized (Norris, 2005), as well as what knowledge is considered by the investigator as sufficient to satisfy the research questions (Saunders et al., 2016). The current research is formed under the assumption of inter-subjectivism, which has guided the planning, execution and interpretation of the research. The subjects within the research are separated from the object of research and their individual realities are not investigated in-depth (as they would be if the research would have been qualitative), yet the investigator recognizes that differences in reality exist, which allows for observation of various realities, shared amongst the subjects. The latter observation obstructs the research being called purely quantitative as it does not aim to uncover a single, objective truth through the reasoning method engaged.

The last part of the paradigm is the axiology, which broadly explains the role the researcher plays in shaping the written piece and whether their values and opinions influence the reporting style. Saunders et al. (2016) recommend a statement regarding this manner is made to ensure the transparency between the reader and researcher. It is considered that researcher's background or studies have no impact on the reporting of findings, with no affiliations known. The indication thus far leads to the reasoning applied within the research being inductive as opposed to reductive (Saunders et al., 2016) as the knowledge is acquired through a process of conceptualization, modelling and analysis.

5.2 Overview of Possible Research Methods

There are many types of research, as is illustrated by the Figure 5.2 below. One categorization is based on the type of information sought, research can be quantitative, qualitative, or in some cases also mixed methodology.

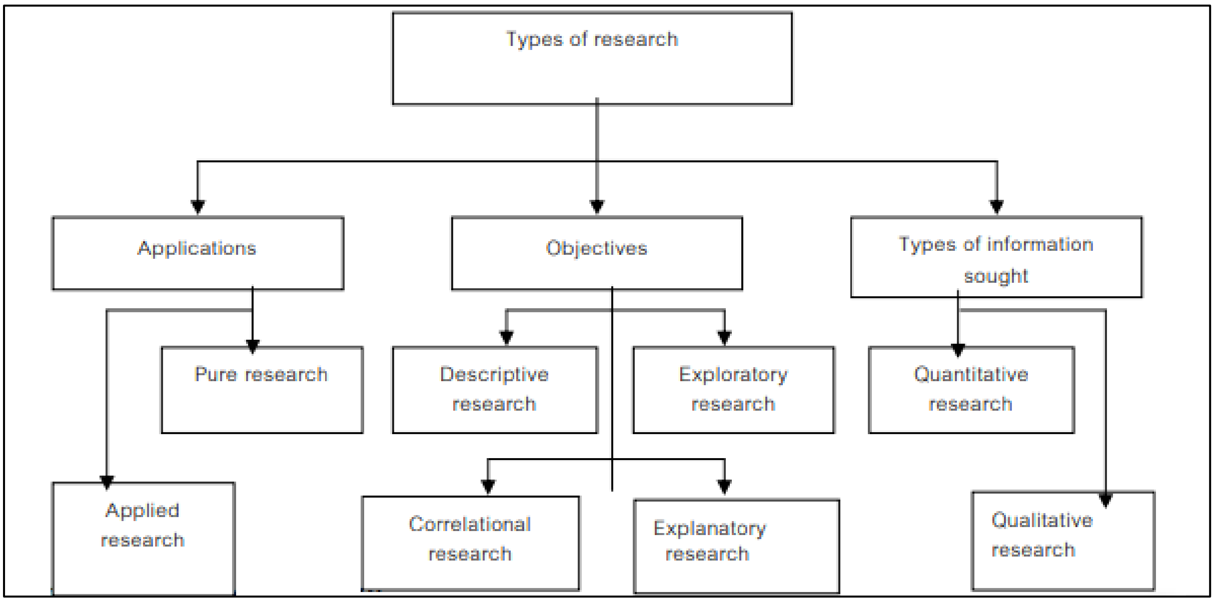


Figure 5.2: Types of Research (Sukamolson, 2007)

The qualitative approach questions the reasoning behind behaviour, proposing a perception strategy that considers small, individual truths and observations, proposing no universal line of reasoning (Grant and Giddings, 2002). The quantitative approach on the other hand questions operative features of behaviour through a systematic observation of facts through reasoning, hypothesis and testing (Grant and Giddings, 2002). The interpretivism approach, which is stems for the intersubjectivity philosophy seeks to understand the experience of meaning through interactions, doing so through mixing qualitative and quantitative approaches of research. Overviews of the three approaches will be provided in the following sections

5.2.1 Quantitative Method

Quantitative research is a systematic investigation of phenomena by gathering quantifiable data and doing statistical and mathematical computations to validate it. It is a numerical representation of observations with the aim of describing and explaining the phenomena that the made observations reflect. Saunders et al. (2016) considered the research approach is social research, which employs empirical methods to make empirical statements. Empirical evaluations are defined as a form that seeks to determine the degree to which a specific program or policy empirically achieves or does not achieve a given standard or norm. Moreover, Creswell (1994: 207) has given a very concise definition of quantitative research as a type of research that is `explaining phenomena by collecting numerical data that are being analysed using mathematically based methods (in particular statistics). There are several types of quantitative research, namely survey research, correlational research, experimental research and causal-comparative research.

5.2.2 Qualitative Method

Qualitative research, as discussed by Schurink (1998: 241) stems from "*an antipositivistic, interpretative approach, is idiographic, thus holistic in nature, and the main aim is to understand social life and the meaning that people attach to everyday life*'. The keywords, which can be used to describe this approach are complexity, contradiction, and de-construction (Cheek, 2000). Qualitative research strategies are typically considered on their own less rigorous in the context of academic research, hence why the aim of this research method is to ensure credibility, transferability, dependability and confirmability. The Figure 5.3 below demonstrates possible types of qualitative research, with their respective research questions, strategies and data collection techniques.

Purpose of the study	*Research question*	*Research strategy*	*Example of collection techniques*
EXPLORATORY • To investigate little understood phenomena • To identify/discover important variables • To generate hypotheses for further research	• What is happening in the industry? • What are salient themes, patters, categories in participants' meaning structures? • How are these patterns linked with one another?	• Case study • Field study	• Participant observation • In-depth interviewing • Expert opinion • Focus groups
EXPLANATORY • To explain the forces causing the phenomenon in question • To identify plausible causal networks shaping the phenomenon	• What events, beliefs, attitudes, policies are shaping this phenomenon? • How do these forces interact to result in the phenomenon?	• Multisite case study • History • Field study • Ethnography	• Participant observation • In-depth interviewing • Survey questionnaire • Document analysis
DESCRIPTIVE • To document the phenomenon of interest	• What are the salient behaviours, events, attitudes, structures, processes occurring in this phenomenon?	• Case study • Field study • Ethnography	• Participant observation • In-depth interviewing • Document analysis • Unobtrusive measures • Survey questionnaire
PREDICTIVE • To predict the outcomes of the phenomenon • To forecast the events and behaviours resulting from the phenomenon	• What will occur as a result of this phenomenon? • Who will be affected? • In what ways?	• Experiment • Quasi experiment	• Survey questionnaire (large sample) • Kinesics • Content analysis

Figure 5.3 Qualitative research – research questions matched with research strategies (Marshall and Rossman, 1989, cited in Levy and Henry, 2003: 8)

The qualitative case study strategy enables researchers to examine and describe a phenomenon in the context, using a variety of data sources (Baxter and Jack, 2008). It enables exploring the individuals through complex interventions, relationships, communities, or programs (Yin, 2003), and it does so through deconstruction and reconstruction of phenomena (Baxter and Jack, 2008). Case studies can be explanatory, exploratory, descriptive, multiple, intrinsic, instrumental and collective (Yin, 2003; Baxter and Jack, 2008). This most closely resembles the chosen approach for the current research from a qualitative perspective, as the research is tailored to the usage habits of Android smartphone users. To further elaborate, the current study is tightly linked with the descriptive approach from the figure above, as the case study method is engaged to observe the behaviour of Android smartphone users, study the events and activities that occur that deplete the users' smartphones batteries, and examine the attitudes that the users have towards battery saving techniques. Nonetheless, quantitative methods are also employed. The research strategy thus combines case study with a field study, with the quantitative approach being a survey technique, the application of which will be further detailed in later sections. The advantages and disadvantages of this qualitative research are indicated in the Figure 5.4 below. Understanding the method's disadvantages has inspired the combination of qualitative tools with quantitative techniques, resulting in a selection of a mixed method approach, an analysis of which is presented in the section below.

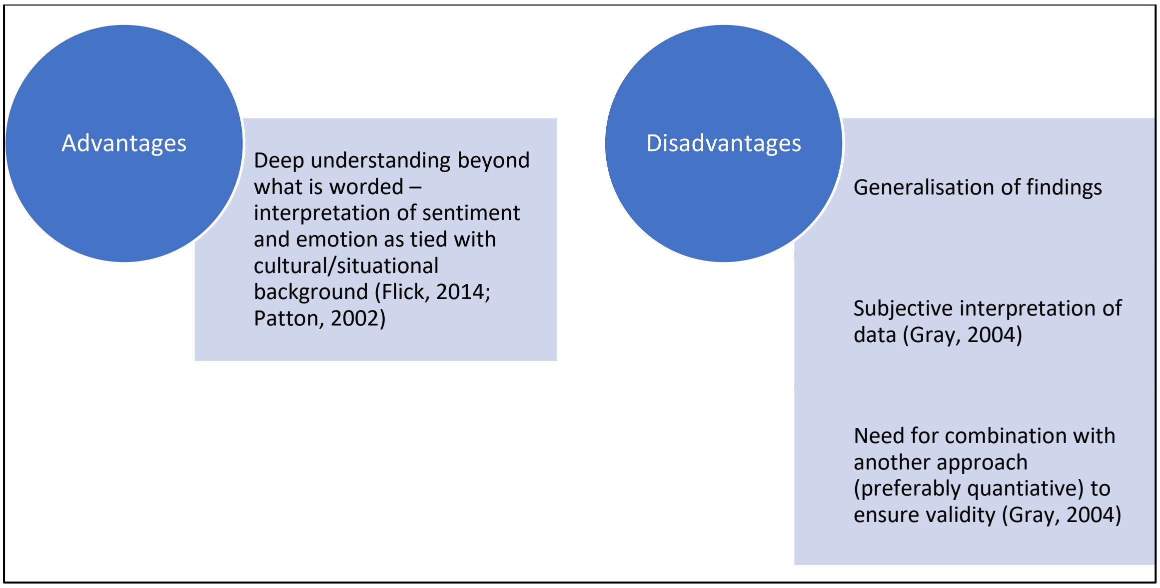


Figure 5.4: Advantages and Disadvantages of Qualitative Research

5.2.3 Mixed Model

A mixed method approach merges the qualitative and quantitative data collection techniques and analysis techniques, enabling a stronger scientific component to the research (Saunders et al., 2016). This approach is useful for undertaking in research contexts, in which the researcher aims to answer research questions that challenge the set understanding of the research environment, and does so through interferences and combinations of various types of collected data (Saunders et al., 2016). Mixed method stems for the intersubjective philosophy and the interpretivism approach. Thus, the mixed method approach to research ensures that the bias that is inherent to qualitative research per se is minimised through the deployment of quantitative (statistical) observations (Saunders et al., 2016). Buchanan and Bryman (2009) have argued that this improves the academic rigour of the study, especially as it aims to challenge the understanding of the researcher through the interferences observed in the various types of data collected. Mixed method research can be done through combining data gathered from primary research and data gathered through secondary research. The latter is typically done through literature synthesising, industry data research and gathering of insights, that later enable comparative analysis and contrast of own findings with another academic research. As a result, the study's own validity is improved. This process is often named 'triangulation', which is defined as the cross-use of two or more independent sources of data or techniques of collective data to verify research findings within a given study (Saunders et al., 2016; Buchanan and Bryman, 2009). It can also be considered a strategy in validation academic findings that were previously made through new research (Flick, 2004). The types of triangulation are illustrated in the Figure 5.5 below.

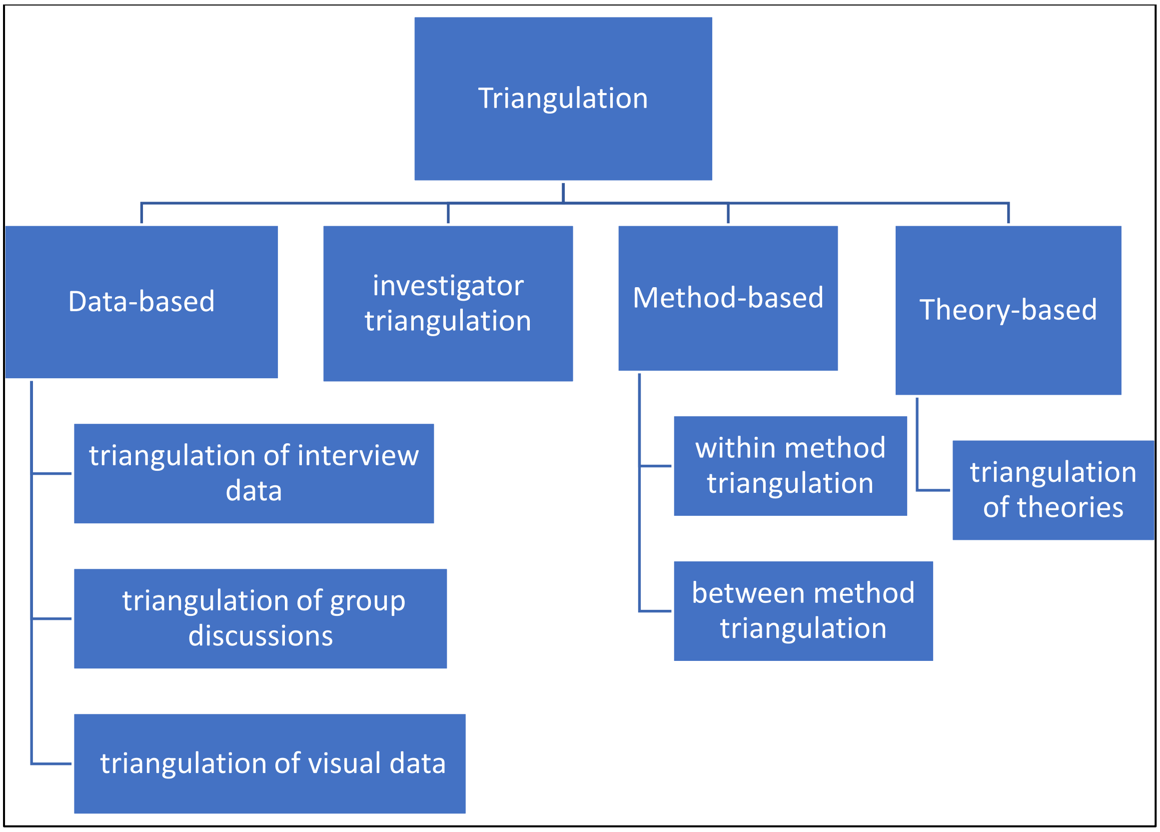


Figure 5.5: Triangulation Approaches (adapted from Flick, 2004)

Some practical issues of triangulation include the researcher workload, which can in some cases become unmanageable or the high requirements from participants, which can potentially lead to high drop-out rates (Flick, 2004). Nonetheless, when executed in an efficient manner, this approach can lead to highly rigorous research. The Figure 5.6 explains the approach simplistically

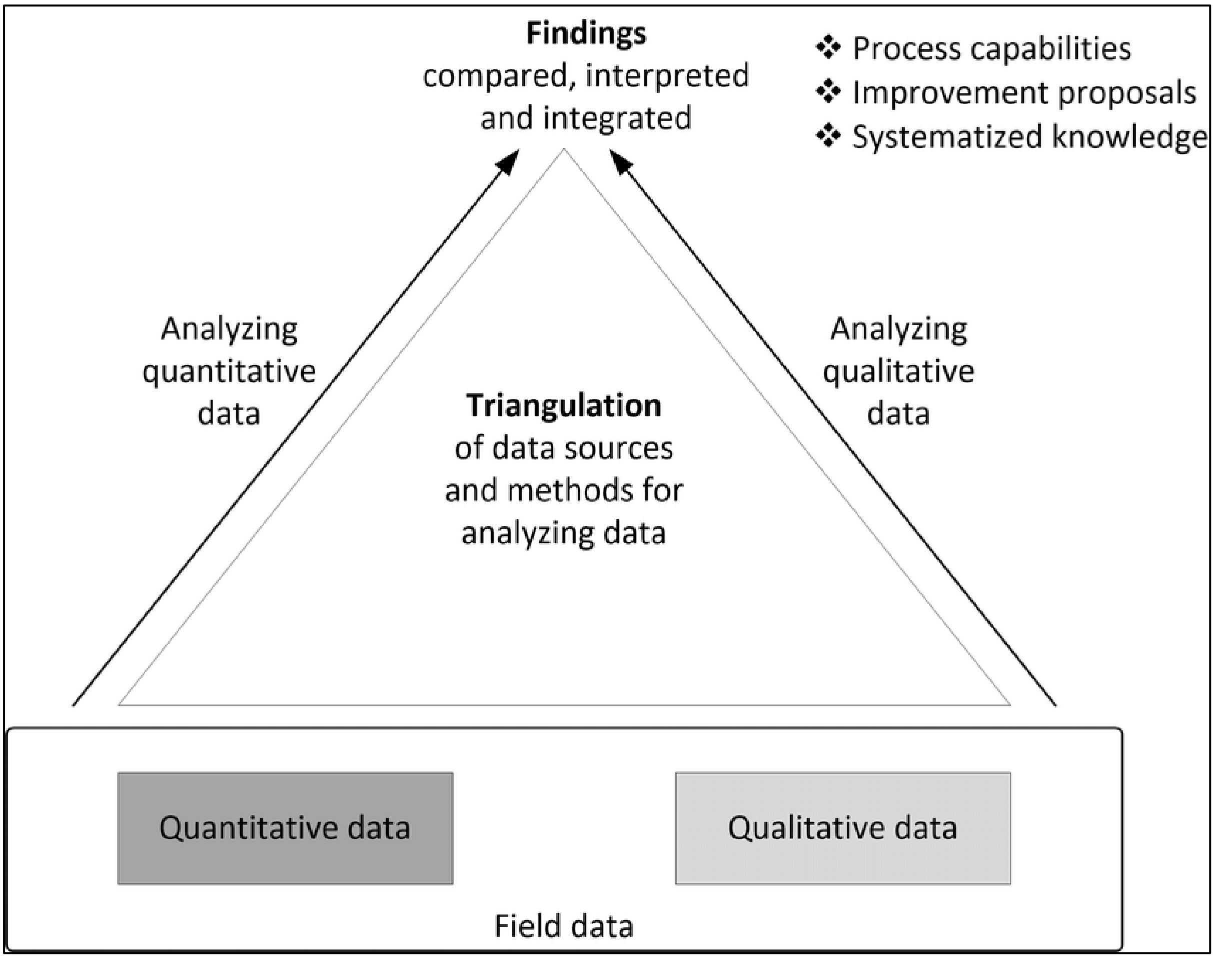


Figure 5.6: triangulation Overview (Triangulation of data (Stojanov, 2016: 9)

To review, qualitative research techniques permit an in-depth, data-rich, yet disjointed view of the researched setting (Hallebone and Priest, 2009; Atieno, 2009), while quantitative research permits for generalisations to be extracted and a holistic overview to be achieved (Atieno, 2009; Saunders et al., 2016). Through combination of the two, a higher academic rigor is achieved, hence why a mixed method approach is selected for the current study.

5.3 Selection of Research Method

Considering the Saunders et al.'s (2016) research onion ontology, illustrated in the Figure 5.7 below, the following choices are made. The philosophy of research is interpretivism, the approach is deductive. The approached strategy is a case study, survey and archival research, with a choice of mixed method. The time horizon is cross sectional. The following section will elaborate on the complete process followed for conducting the current research.

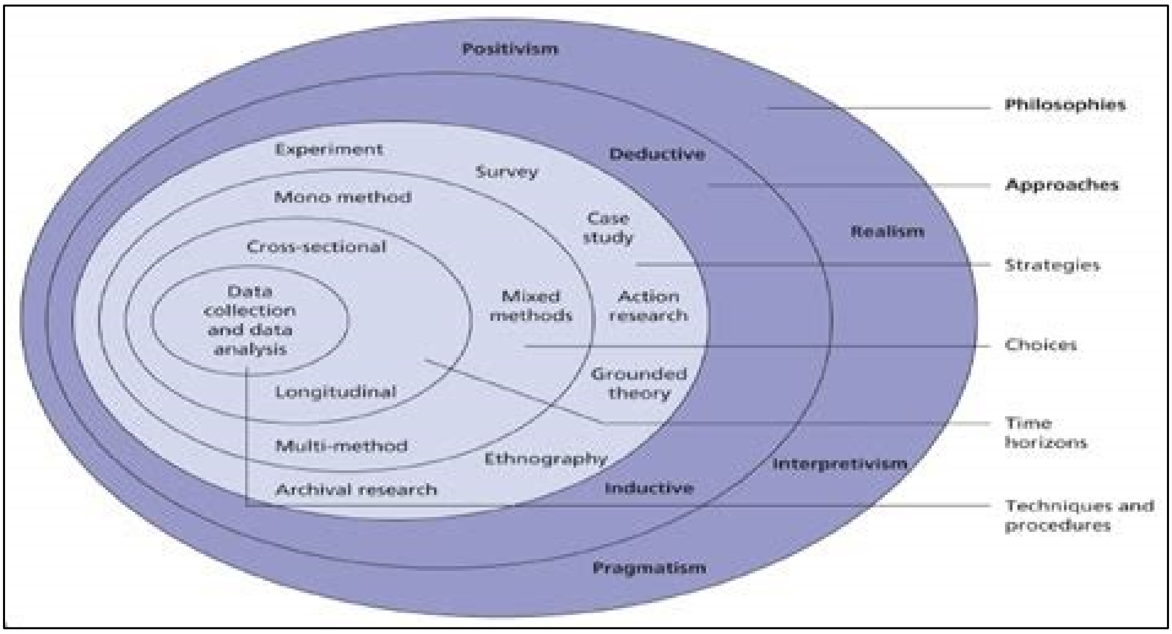


Figure 5.7: Research Onion (Saunders et al., 2016)

The research essentially examines the need of enhancing the end users' role in extending Android smartphone battery life, aiming to prove that current battery saving approaches on Android smartphones do not allow a wide level of involvement for end users. The first step made in the research process was the conducting of a literature review. This constitutes as secondary research, the aim of which is interpretation of pre-existing finding in a new context. This is done through selection and discussion of theoretical and descriptive material in the new context, which in the current study is the case study of Android users and their battery-saving behaviors. Secondary research, as with other methods, has particular advantages and disadvantages, illustrated in the Figure 5.8 below.

ADVANTAGES	DISADVANTAGES
Inexpensive: Conducting secondary research is much cheaper than doing primary research	Inappropriateness: Secondary data may not be fully appropriate for your research purposes
Saves time: Secondary research takes much less time than primary research	Wrong format: Secondary data may have a different format than you require
Accessibility: Secondary data is usually easily accessible from online sources.	May not answer your research question: Secondary data was collected with a different research question in mind
Large scope of data: You can rely on immensely large data sets that somebody else has collected	Lack of control over the quality of data: Secondary data may lack reliability and validity, which is beyond your control
Professionally collected data: Secondary data has been collected by researchers with years of experience	Lack of sufficient information: Original authors may not have provided sufficient information on various research aspects

Figure 5.8: Advantages and Disadvantages of Secondary Research (adapted from Stewart and Kamins, 1993, p. 5-6)

Through a literature review in the area, it is demonstrated that the users have limited opportunities to improve their battery-saving behaviour, as illustrated in the Figure 5.9 below.

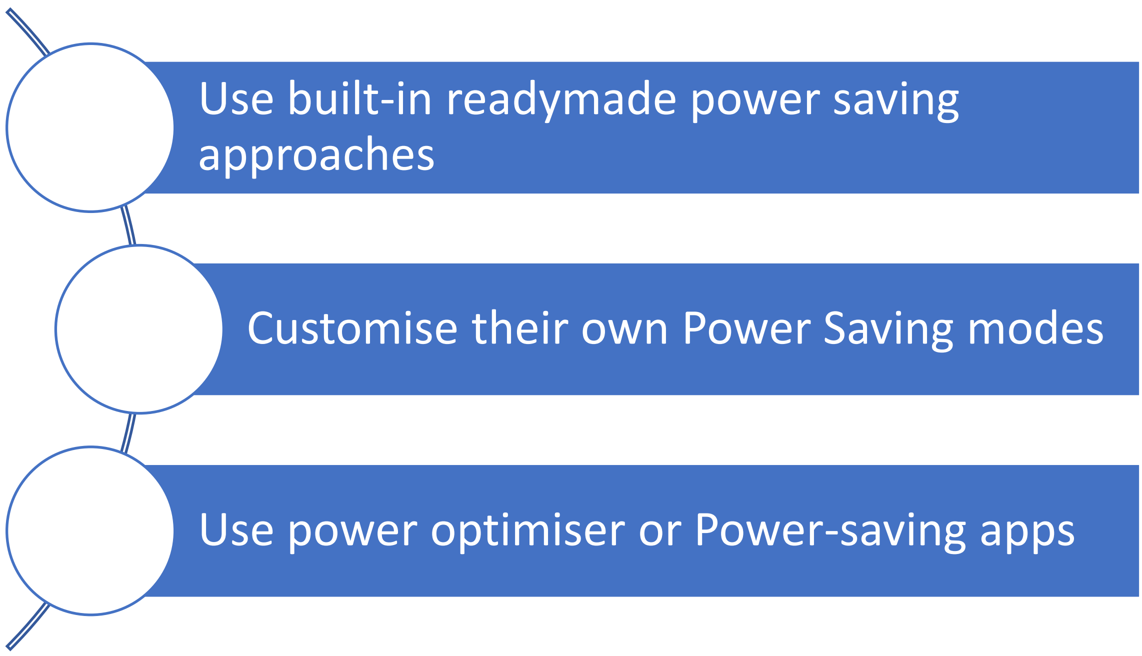


Figure 5.9: Currently available customer choices for battery saving

Following the conducted literature review, an implementation of "The Framework Method" is made, originally developed by Ritchie and Spencer in the late 1980s but has since found application in a broad range of disciplines (Ritchie et al., 2013; Gale et al., 2013). The framework approach is defined by its output, which is typically a classification or a form of matrix, with rows, columns and cells, the latter of which are populated with re-interpreted secondary research data, collected through a variety of sources (Gale et al., 2013). This approach is well suited for multi-disciplinary research, such as the current research as it enables different aspects of a given phenomenon to be captured (Ritchie et al., 2013). For example, in the case of the current research, the Android user base is researched as a group, however their battery saving habits are approached not only from a technical standpoint, through illustration of the impact this has on the environment or how the applications operate. They are also approached from a user standpoint, signifying why current practices are not optimal for the users, as well as demonstrating how the user behaviour of different sub-groups makes it challenging for a single approach to be developed that suites the needs of the entire subject group. Thus, a cross sectional approach emerged, which captures different aspects of the same phenomenon, seeking for the best solution. Finally, the framework method is chosen also due to its straightforward output – a classification, which enables the recognition of patterns in the observed subject and environment, specifically drawing attention to areas where the research should continue (Gale et al., 2013).

Following the creation of the classification, the research continues with a test of the created hypothesis through a quantitative tool – a survey, which was implemented to a group of 60 subjects in total, split into groups of ten into six categories. The categories used are illustrated in the Figure 5.10 below and were devised following a review of smartphone usage behaviour in Android users.

Figure 5.10: Categories of Android users based on whether they care about technology or the battery life

The survey was chosen as a method as it enables the collection of public opinion data through direct communication. The method is cost and time efficient, which was of high importance for the current research. The method encourages the provision of truthful responses as it offers no incentives that could impede the participant lack of bias. The application of this technique was sought in light of the illustrated previously limitations of purely qualitative research, specifically as it enables a quantification of findings (Saunders et al., 2016). The survey was structured purposively short as its aim was to capture the engagement of participants and to only provide a validation to a short number of assumptions regarding Android users. Structural decisions also aimed to sustain the lack of participant bias, namely through an application of the funnel technique, which ensures that general questions, such as demographic data capture, are asked first and specific questions regarding the study are asked later on (Zikmund and Babin, 2012). The sampling approach was purposive convenience sampling, using subjects that responded to the recruitment tactics. Kemper et al. (2003) specifies that the sampling method should be efficient and cost-effective, as well as corresponding the research aim, hence why the approach was used. To elaborate, a convenient access to individuals was sought, while also addressing the studies subject. In order to ensure the latter, inclusion and exclusion criteria were used, primarily related to the participant ability to command the English language and thus access the survey and provide truthful responses, and whether they currently use an Android device. Recruitment was done through digital means, and the survey distribution and the survey itself was also entirely digital. The survey was distributed using social media and personal networks. The data analysis involved a summary of the data into graphs, charts, figures and other visually engaging formats, which convey the numerical merits of the collected findings. The analysis did not require the use of specialized statistical software, however for visualization, the functionality of Microsoft Excel was exploited.

The last part of the undertaken approach involves proposing a solution regarding the identified problems in the context of Android battery-saving. The solution proposed involves the development of an online resource for users, where they can inform themselves regarding the energy consumption of each application. This resource requires the involvement of a virtual environment as means of measuring the amount the application uses and demonstrating it to the user. The aim of the platform is thus, educational. This enables the end users to have a clear indication about all applications and then act as a decision maker in order to decide whether the app is good for them in terms of energy efficiency or not before having the application installed and running on their smartphones. Within the design process of the solution, the concept of the minimum viable product (MVP) was applied. This software development concept relates to the notion that a working prototype, which solves an existing problem is delivered as soon as possible, which can later be improved during subsequent iterations. The Figure 5.11 below shows an overview of potential ways an MVP can be created. The chosen approach is through the creation as a design artefact, specifically a visualization of a design idea and through a clarification of the user expectation-output mismatches. The latter will be achieved through a critical analysis of the limitations of the current solutions for battery-saving for Android users, which will be presented alongside the created classification of the currently available solutions.

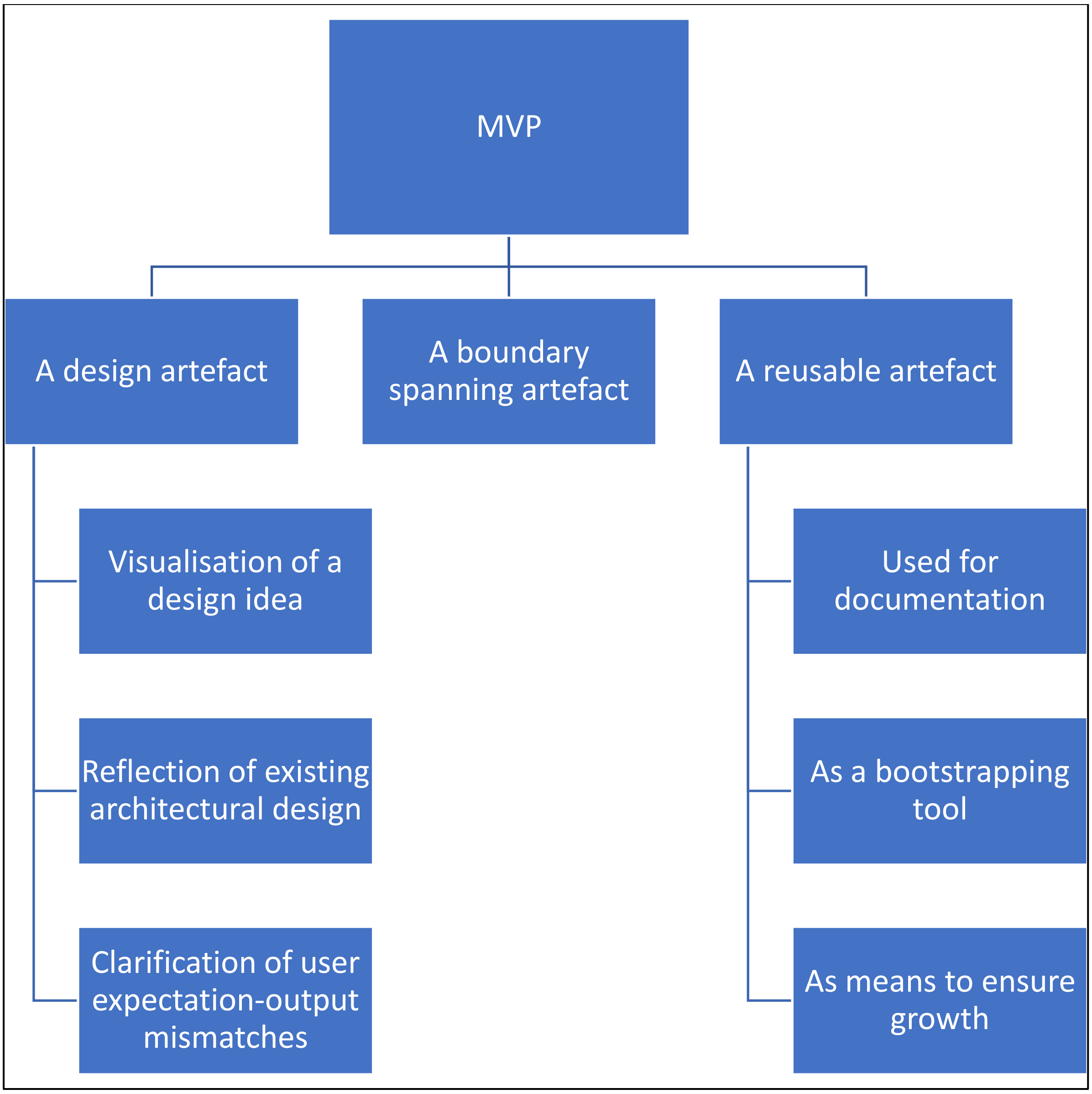


Figure 5.11: MVP Typology (adapted from Duc and Abrahamsson, 2016)

5.4 Justification (Ethics, Reliability and Triangulation)

The axiology, or otherwise the ethical considerations taken as part of research that requires human participants is a vital part for assessing the academic merit (Patton, 2002). Ethical research is of paramount importance for the development of the academic discipline, hence why in any form of data collection norms and moral considerations must be demonstrated. The proposed study is not considered in defiance to the ethical research code of conduct, however, when participants were contacted, the following Figure 5.12 shows the values that were upheld with the relevant steps taken to ensure their security throughout the study.

Transparancy	Privacy	Right to opt-out
• Transparency of goals and objectives of study, illustrated and declared through a written agreement amongst researcher and participants in any stage of the study, aiming to achieve an operating standard of informed consent for the duration of the project • Informed consent was achieved	• Participants' right of privacy, anonymity and confidentiality, aiming to protect the individual, who has assisted with the research.	Participants' right to opt out of the study or communication stream at any given point in time.

Figure 5.12: Ethical Research Values and Undertaken Steps (Cooper and Schindler, 2014; Flick, 2014)

Reliability of the study, as well as the research's repeatability are ensured through engaging in transparent communication of the techniques, tools and practices used throughout the research process. Triangulation is also used to allow for the testing of the results to be made in a reliable manner, which is typical for a study of a mixed method nature. Testing and analysis of the results using a mixed-method approach ensures reporting of results, which are validated through comparative analysis.

5.5 Validation Process

The following section will consider the validation process applied for the proposed solution, discussed previously in section 5.3. The usefulness of a formal model of a software process lies in the ability of the process to accurately predict the behaviour of the process (Cook and Wolf, 1999). When process models and process executions diverge, the level of correspondence between the two is low, which is a challenge for both the system user and the system developer. Process validation takes a process execution and a process model, and measures the level of correspondence between the two (Cook and Wolf, 1999). The validation process in the current development would rely on a formal framework for reasoning about inconsistencies and deviations in a process, which will be based on academic research. To elaborate, any deviations from using the proposed system will be reasoned through analysis of user behaviour and rationalisation of the actions taken, the result of which can identify areas for improvement of the system. In addition, an event-based approach can be used for behavioural abstraction, which can in subsequent cycles of development be used for creating additional components of the model that measure the projected behaviour and the user behaviour, aiming to minimize the differences. The latter can enable user behaviour prediction. As the current research will not result in system development, a discussion of the possible approaches will be provided as part of the system's requirements as recommendations for the development of the system and mitigation of risk (i.e. risk of users not coherently using the model and not taking advantage of the service it provides as a result of design or functionality flaws).

5.6 Chapter Summary

The chapter examined the theoretical foundations of methodological constructs in academic research. The chapter discussed the prominent research philosophies, as well as their limitations, signifying that the current research aligns closest to an inter-subjectivity philosophy. Various types of research were introduced, yet specific focus was provided to quantitative and qualitative methods, as well as mixed method approaches. As the current research of a mixed method nature, both in terms of research method, as well as techniques, the discussions of these three methods assisted the conceptualization of the benefits and limitations of each of these approaches. The importance of the mixed method research was illustrated through a discussion of triangulation as a technique for improving the academic rigor of the research that is being conducted. Specifically, regarding the choices made within this research, a case study approach is implemented through the study of Android users, a secondary research tactic is used for synthesising available literature in the research field, a framework method is used for creating a classification of the available battery-saving approaches and finally, an MVP approach is used for creating a solution to the identified issues in the form of a model design. The procedural model of the study involves the following steps:

- Conducting a narrative-style Literature Review with a thematic analysis (Dixon-Woods et al., 2005), which allows familiarisation of the researcher with the subject matter;
- Establishing a hypothesis regarding the battery saving behaviour of Android Users;
- Conceptualising a classification that is able to categorise existing power saving techniques and charting the data in a matrix framework;
- Interpretation of the created matrix/ classification in relation to user behaviour, highlighting the limitations of current practices through a survey;
- Propose a solution, using existing information technologies on how to better matching user types with battery saving solutions.

Finally, ethical considerations were also discussed, as well as means for ensuring reliability and validity of the proposed research. Validation methods were also proposed regarding the development of the proposed solution, with an identified risk observed in the context of user behaviour that the design of the system could misalign with the demonstrated behaviour of users, for which it is designed. This is recognized as both a risk and a limitation of the current research, as due to limitations regarding the scope of the project, the development would not result in the system's implementation, testing and maintenance, and thus, could potentially result in misaligning with user expectations.

Chapter 6. Basic Evaluation Model to Generate Tentative Energy Ratings

6.1 Introduction

Although a big number of researches were conducted in the general field of "Saving Energy in Android Smartphones", another big number of researches were also conducted in the subfield of "Saving Energy in Android Smartphones at the Application Layer". Both fields did generate a good amount of proposed methodologies, models, frameworks and algorithms that were provided as market products or approaches. However, here we try to simplify our area of contribution by proposing a solution in the form of an addition to Google Play Store this addition will guide users to find and choose the best application in terms of power consumption based on their energy needs.

6.2 Current Applications General Characteristics

6.2.1 Identifying an Average Android-Application Lifecycle

In order to locate our area of contribution among the different research areas that provided the current power-saving approaches, first we proposed creating an Android Application Lifecycle (AAL) that shows the main average stages of an average Android application. The proposed cycle is shown in Figure 6.1. AAL begins with any new application as an idea or an updated version of a current application. This is considered as the first stage of the proposed average AAL. The cycle then continues with the actual development of the new app or its updated version which includes all the technical steps and procedures needed to finish with a fully running user-friendly app. This is considered as the second stage of the proposed average AAL which takes its feed from the first stage. The cycle then goes with the key step of publishing the app through uploading it or its updated version to the public. The publishing takes the form of uploading it to an Android app store. Since an actual running and efficient app is needed to achieve this step, this stage is considered as the third stage in the proposed AAL. Next, the app is supposed to be available for users through ordinary listings of the app store or after searching its main category (i.e. Music, Entertainment, Tools ...etc.). Users will be educated about its existence in addition to several other informative aspects like reviews, rating, size and permissions needed. This is considered as the fourth stage of the AAL which requires the app to be uploaded to the app store, so the third stage is its prerequisite. The fifth stage is simply when users install the app on their smartphones and start the actual usage. Users will then provide their reviews which will ignite the ideas of either updating the app of proposing a new app with similar functionalities which goes back to the first stage of the AAL.

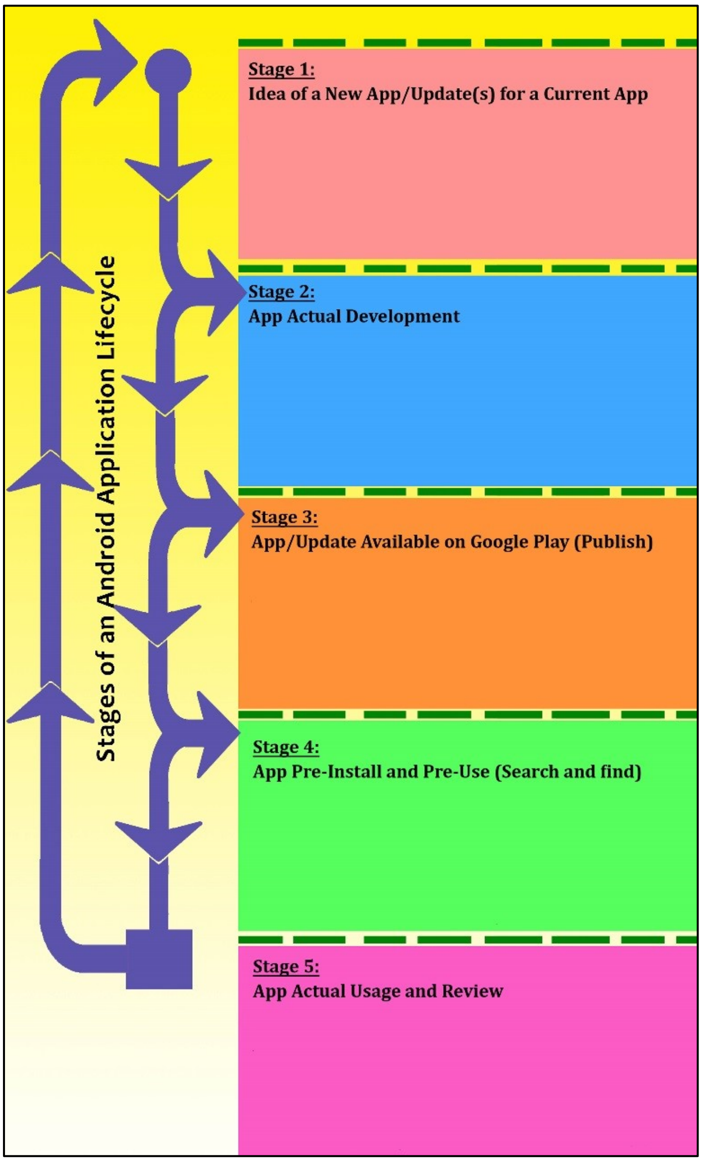


Figure 6.1: Average Android-Application Lifecycle

6.2.2 List the Concerned Parties and Identify their Involvement in an AAL

Following the previous step in demonstrating our area of contribution, we then list the parties which are involved in our AAL. For an average Android app, it normally starts with an inventor who develops the main idea of the app, who is also identified as the app owner. For the technical part, an app inventor may seek the help of a developer to translate the idea into a fully running app which then will be uploaded to an app store (i.e. Google Play). Finally the app gets installed and used by an End-User. Concerned Parties in an AAL are shown in Figure 6.2, while the involvement of each party among the AAL is described in Figure 6.3.

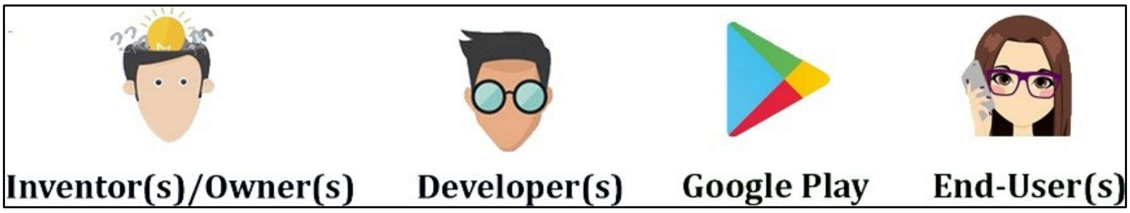


Figure 6.2: Parties Involved in an Android Application Lifecycle

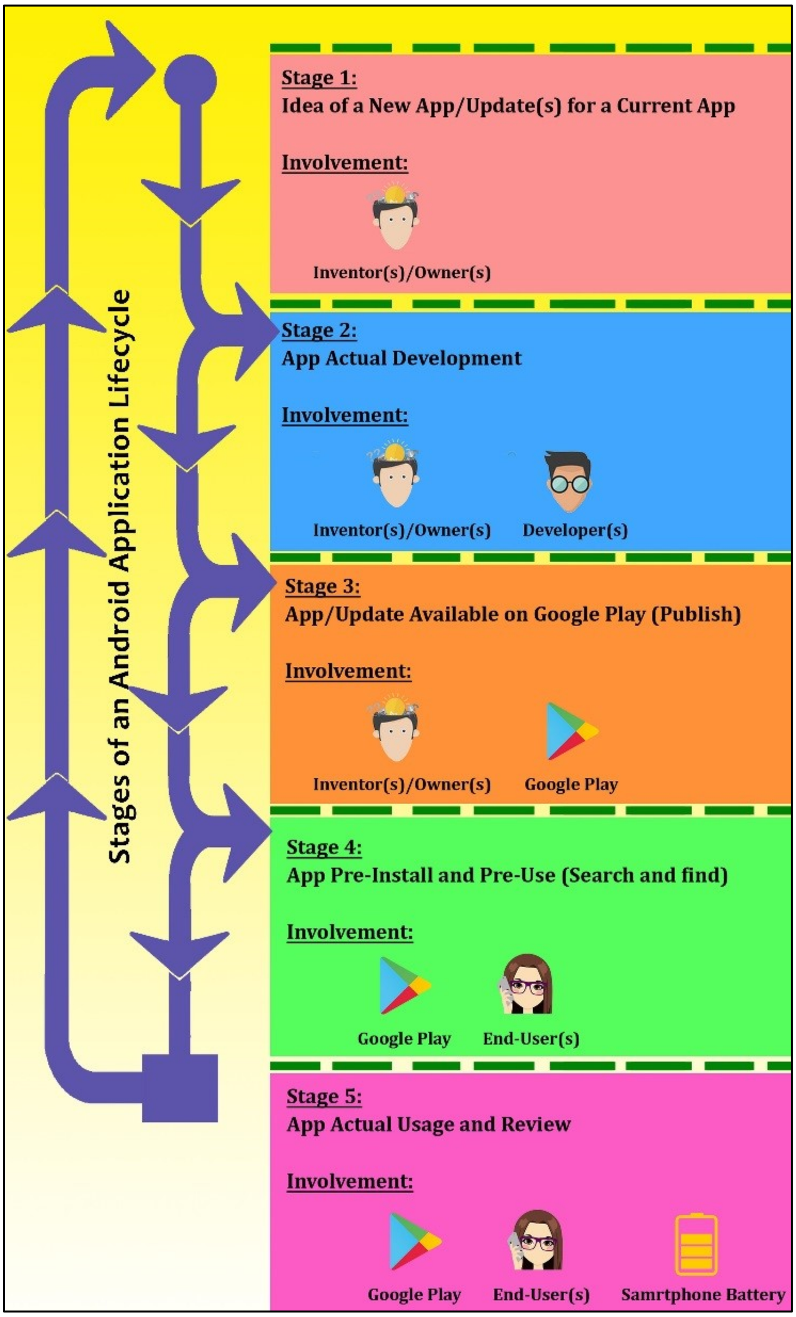


Figure 6.3: Involvement of Parties Among the Different Stages of an Android Application Lifecycle.

6.2.3 Identify the Status of an Android Application among Different Stages of an AAL

Following the above, we here list the main statuses of an Android application in terms of its presence in an Android smartphone also among the different stages of our AAL, the two main statuses were "Outside the End-User's Smartphone" (Under development or Available on Google Play) or "Inside the End-User's Smartphone" (Installed & Running). The Figure 6.4 will map the above statuses to the different stages of our Android application lifecycle:

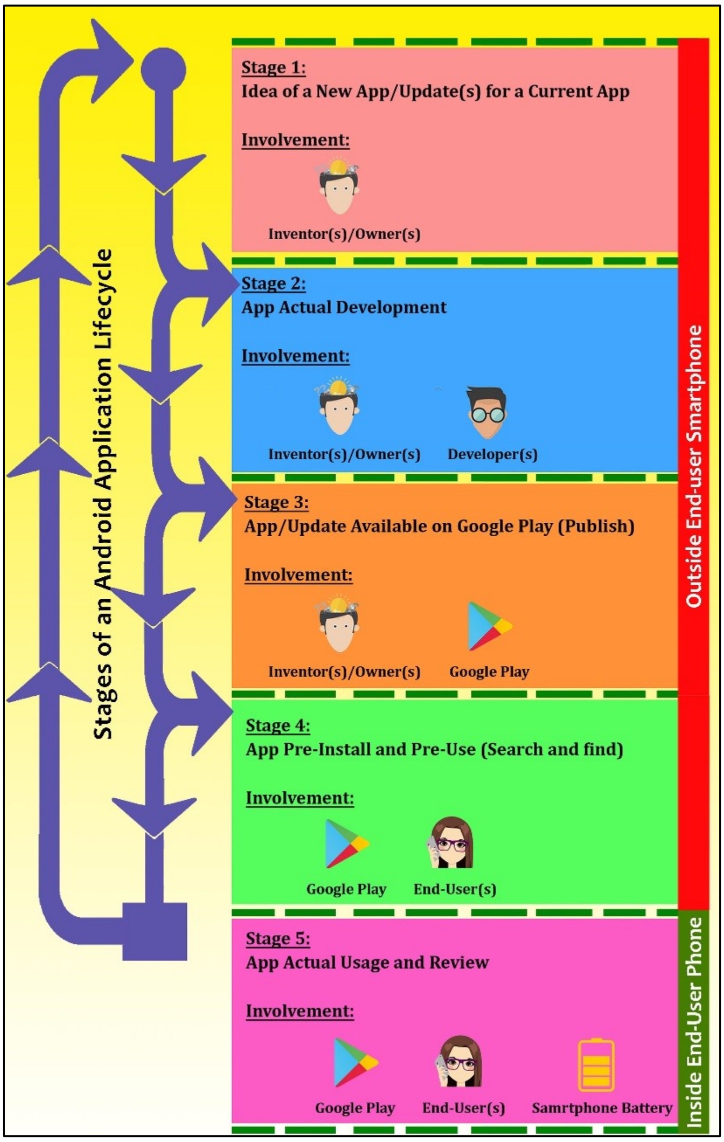


Figure 6.4: Status of an Android Application among Different Stages of an Android Application Lifecycle

6.2.4 The Usage of Power-Saving Approaches among The Five stages of AAL

In order to summarize the classification of the current power saving approaches which were thoroughly reviewed in chapter three, the following classification were made: Approach 1, follows the philosophy of “Simulate and estimate” the power consumption of and Android application before making it available for end-user(s) by using techniques that may include but not limited to green coding, energy-aware designs, smartphone batteries simulators, historical analytical data, etc.. Approach 2, follows the “Supervise, detect and control” philosophy, so it applies this on the behavior of an Android application while it is running on an end-users phone and optimizing the power consumption. Approach 3, is more about Sacrifice smartphones technology or performance by switching off a number of features for the sake of saving power philosophy. The next stage is to show the usage of the above approaches among the five stages of the AAL. From all of the above, Approach 1 is used in the second stage of the AAL and involves the app inventor(s) and the app developer(s), while Approaches 2 and 3 are used in the fifth stage of the AAL and involve Google Play store and the end-user(s). The usage is shown more clearly in Figure 6.5

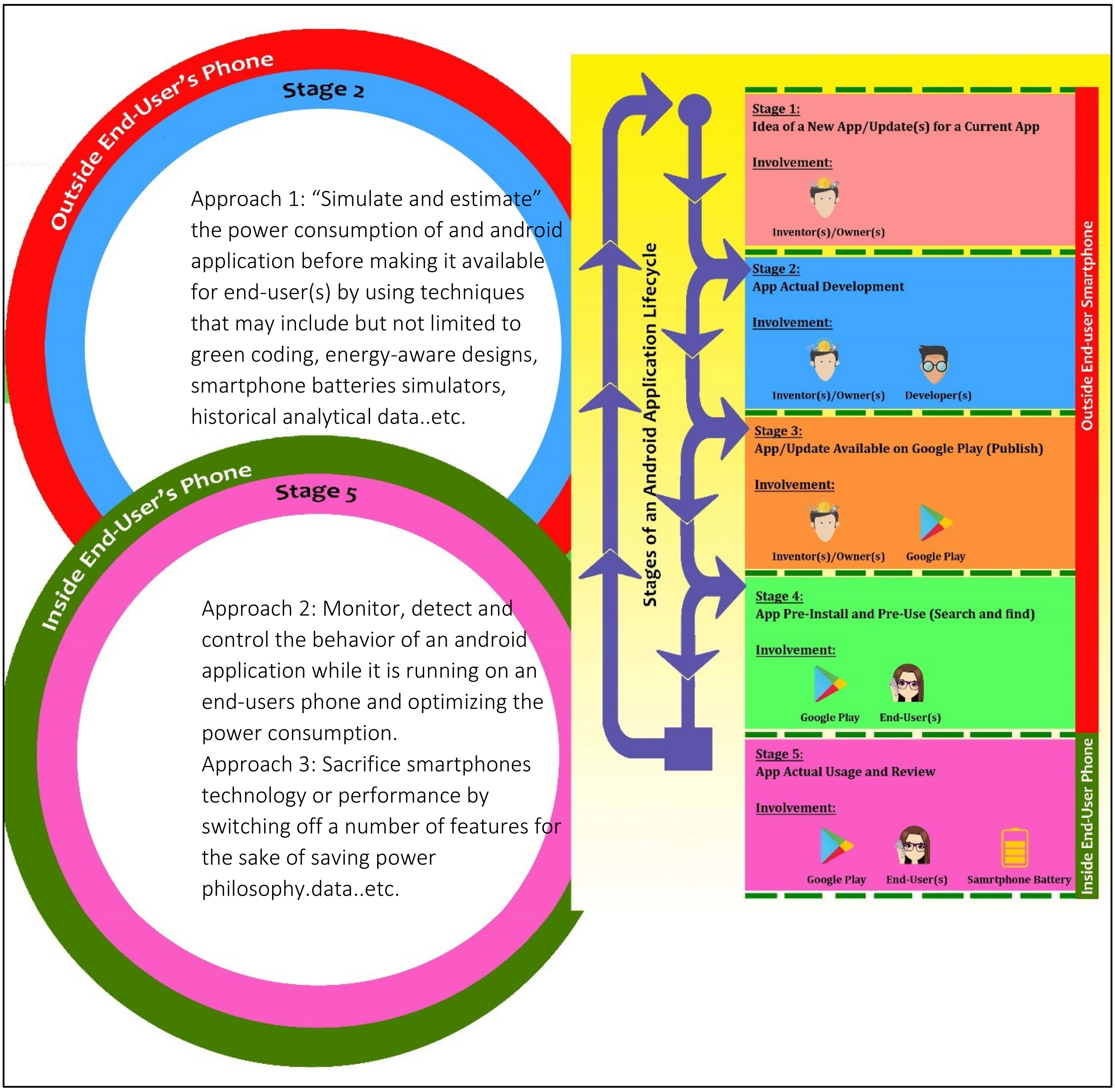


Figure 6.5: Usage of Current Power-Saving Approaches among the Stages of the Android application lifecycle

By recalling the detailed analysis of the three approaches from chapter three of the thesis, the general key concepts and the limitations of each approach are illustrated visually in Figure 6.6, Figure 6.7 and Figure 6.8 below.

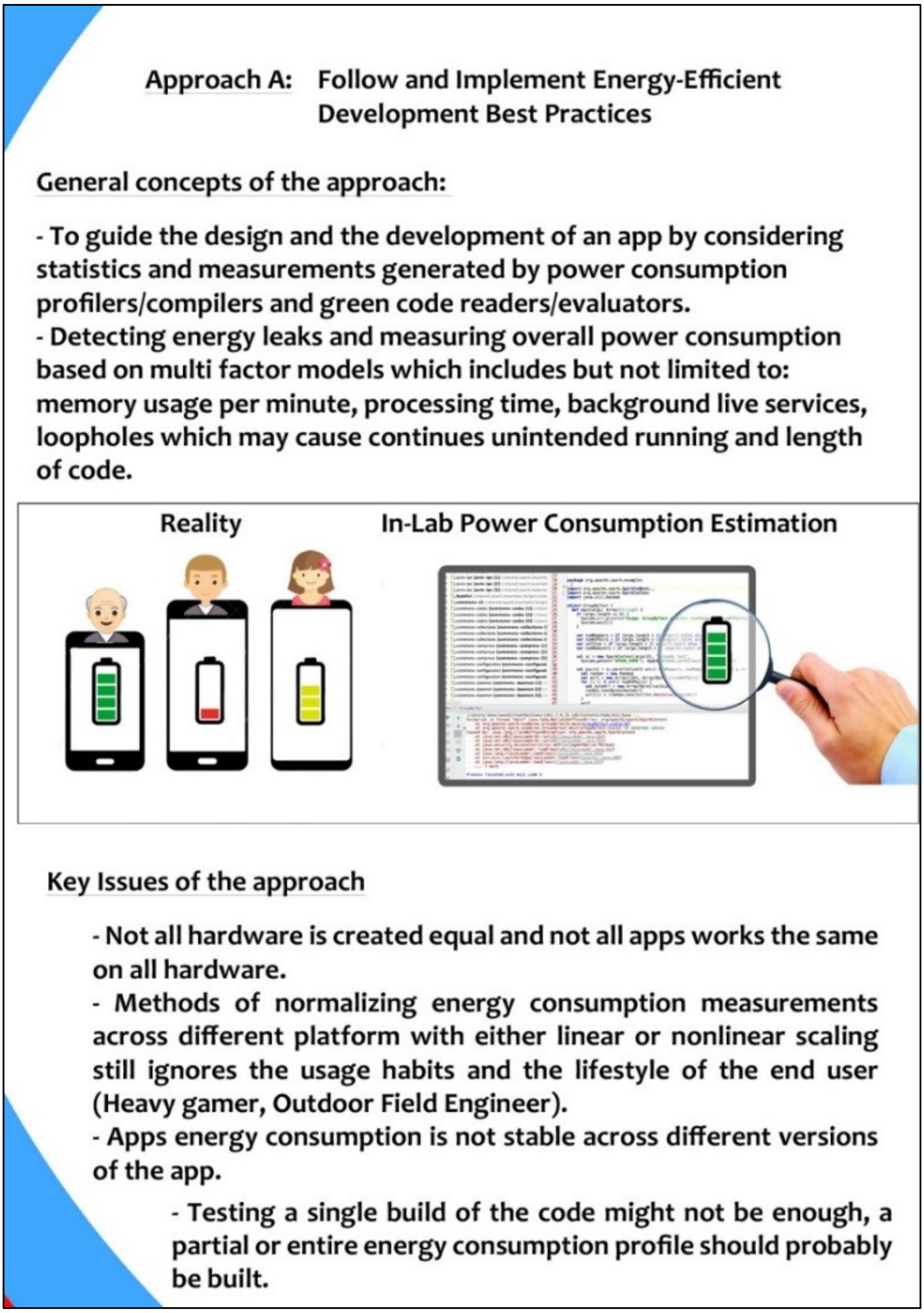


Figure 6.6: General Concepts and Key Issues of the Energy-Efficient Development Approach

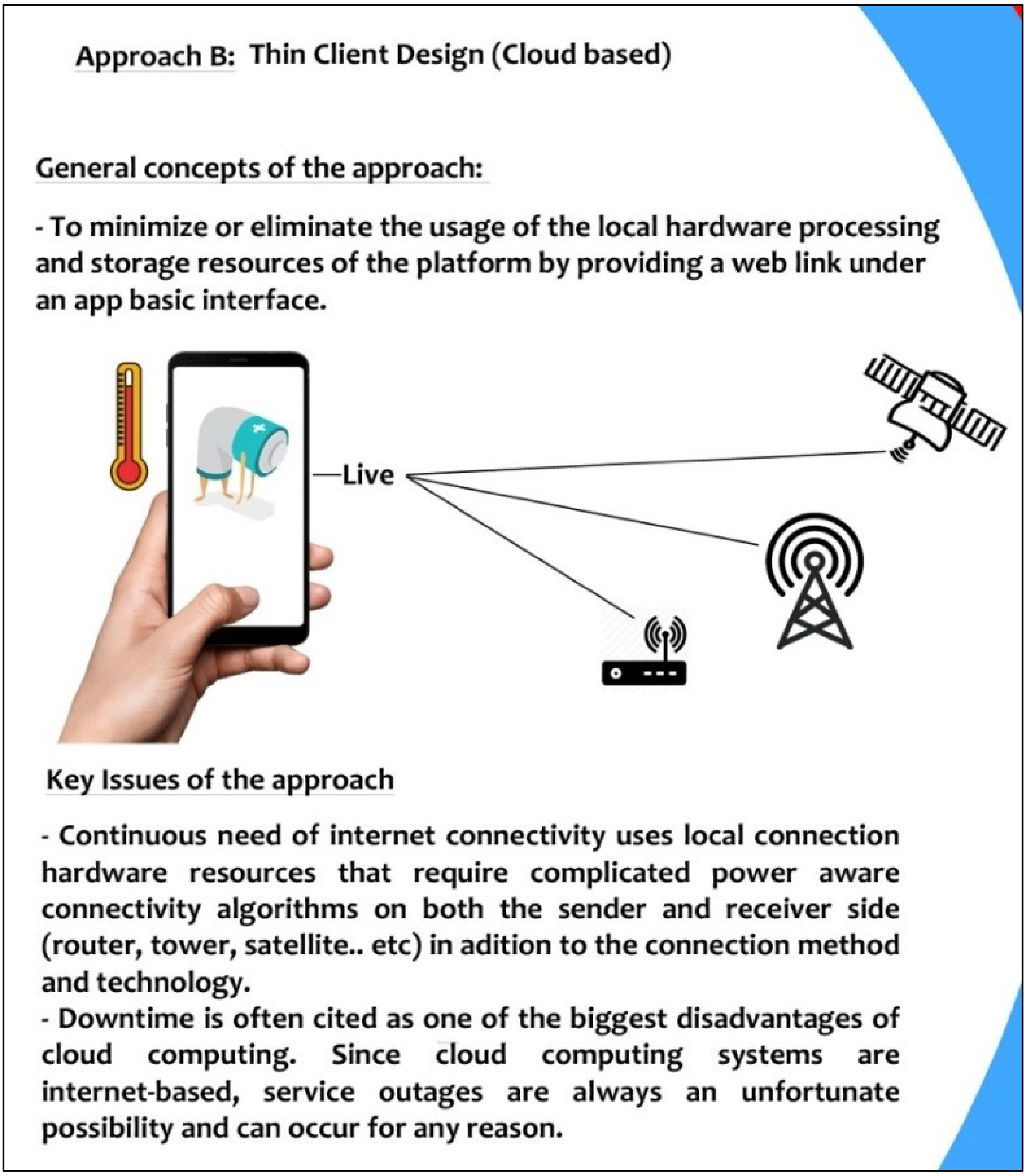


Figure 6.7: General Concepts and Key Issues of the Thin Client Approach

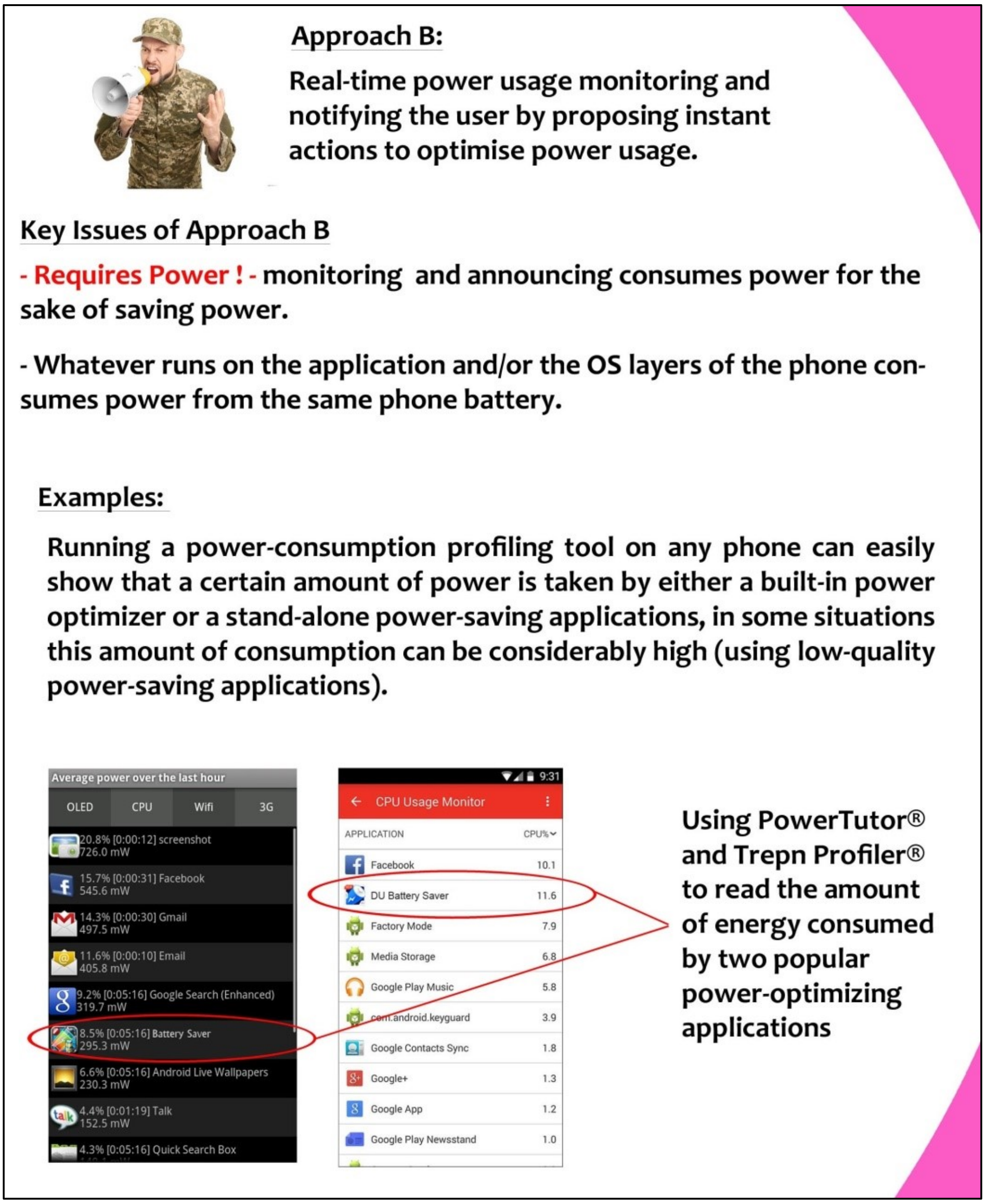


Figure 6.8: General Concepts and Key Issues of the Monitoring Approach

6.3 Permissions-Based Energy-Efficiency Rating of Google Play Applications

6.3.1 Relating Google Play Applications Permissions to Power Consumption

The huge success of Android smartphones is mainly due to the variety of applications available, plus the open-source OS which allow it to grow exponentially. Android users enjoyed the way applications can be downloaded and installed from an online market, but were also concerned about giving the green light to a number of flashing permissions. These permissions need to be given to an application in order to work properly. The idea behind alerting the user about these permissions is mainly related to the privacy and the security of the user. The idea of the following basic model is to add another dimension to Android app stores by alerting users about the amount of power consumption of each application they are about to install and run on their smartphones. Relating permissions to power consumption in order to achieve the task is the main contribution of this chapter.

6.3.2 Google Play Applications Permissions at a Glance

"A permission is a restriction limiting access to a part of the code or to data on the device. The limitation is imposed to protect critical data and code that could be misused to distort or damage the user experience" (Android Developers, 2020).

As presented to Android application developers and coding standards, an application to be uploaded to Google Play must have a "manifest file" which shows important information about the application to Android system. This type of information must be given to the Android system before it can run the application code. The manifest file name is "AndroidManifest.xml", which inform the system about many things including our main target which is listing the permissions used by the application.

The following example shows permissions in source code and their translation that is shown to the user:

Code: <permission-group .... ndroid.permission.ACCESS_COARSE_LOCATION ..../>

Translation (What is shown to user before downloading the application): "Allows an app to access approximate location derived from network location sources such as cell towers and Wi-Fi."

Examples of some permissions in code view and from readable text view are shown in Table 1 below:

Code String	Description
ACCESS_CHECKIN_PROPERTIES	Allows read/write access to the "properties" table in the check-in database, to change values that get uploaded.
ACCESS_COARSE_LOCATION	Allows an app to search approximate location derived from network location sources such as cell towers and Wi-Fi.
ACCESS_FINE_LOCATION	Allows an app to search precise location from location sources such as GPS, cell towers, and Wi-Fi.

ACCESS_LOCATION_EXTRA_COMMANDS	Allows an application to access extra location provider commands
ACCESS_MOCK_LOCATION	Allows an application to create mock location providers for testing
ACCESS_NETWORK_STATE	Allows applications to access information about networks
ACCESS_SURFACE_FLINGER	Allows an application to use SurfaceFlinger's low level features.

Table 1 Examples of Google Play Permissions code String and Description.

These permissions flashes out to inform about the different components of the phone that will be used in order to have the application to work. It mainly helps in taking one and final decision whether or not to install an application, and since the user does not have the option to select from an application permissions list, they can be accepted or rejected as one full package.

6.3.3 Using Permissions to Detect the Energy-Friendly Level of an Android Application

By our own assumption an efficient and accurate way to go into reading, analyzing or Static-testing an application is by having the application in its source code format. Unfortunately, as per to the privacy and security standards of Google Play, the source code of an available application is not to be shown or reveled to public. At the same time Google Play does give informative translation and summarization of the code named as “application permissions”. These permissions came directly from the source code of the application but in a much more understandable format for an average technology user. Though these permissions do not reflect all the commands under the source code but they reveal the nature of an application behavior in dealing with the components of a smartphone.

Since Google Play store updates permissions of an application directly at the same time the code of the application gets updated. An advantage of our proposed detecting technique is that it will read up-to-date information about the application source code. Then will measure the application energy-friendly level without the need of having a third-party application in order to test the application. Simply having a third-party application running on a smartphone means increasing the current level of power consumption which conflicts with the primary goal of the research. In the same time our study preferred not to rely on a side study that was previously made on a “lab smartphone” or on a simulator for reasons related to accuracy and in order to make the study as near as possible to real-life usage scenarios of an average user.

As a result, these permissions were trusted as a measurement factor in addition to other factors to compute the level of power consumption of an Android application as it will be shown in the next sections.

6.3.4 Behavior of Google Play Store Applications Permissions Groups

Google Play did categorize all the permissions used by applications into 12 different categories (Android Developers, 2020). Since users do not have enough knowledge on how could these permissions affect their smartphone battery life, following will list the categories and give a short description of each category describing the behavior of the permissions under each category. The will enable the users to have a basic idea on the overall behavior of an application which they are about to be install and use. Table 2 shows the latest grouping of these permissions as per Google Play:

Permission Group	**Description**
In-app purchases	An app can ask you to make purchases inside the app.
Device & app history	An app can use one or more of the following: • Read sensitive log data • Retrieve system internal state • Read your web bookmarks and history • Retrieve name of running apps
Cellular data settings	An app can use settings that control your mobile data connection and potentially the data you receive.
Identity	An app can use your account and/or profile information on your device. Identity access may include the ability to: • Find accounts on the device • Read your own contact card (example: name and contact information) • Modify your own contact card • Add or remove accounts
Contacts/Calendar	An app can use your device’s contacts and/or calendar information. Contacts and calendar access may include the ability to: • Read your contacts • Modify your contacts • Read calendar events plus confidential information • Add or modify calendar events and send email to guests without owners' knowledge

Location	An app can use your device's location. Location access may include: • Approximate location (network-based) • Precise location (GPS and network-based) • Access extra location provider commands • GPS access
SMS	An app can use your device's text messaging (SMS) and/or multimedia media messaging service (MMS). This group may include the ability to use text, picture, or video messages. Note: Depending on your plan, you may be charged by your carrier for text or multimedia messages. SMS access may include the ability to: • Receive text messages (SMS) • Read your text messages (SMS or MMS) • Receive text messages (MMS, like a picture or video message) • Edit your text messages (SMS or MMS) • Send SMS messages; this may cost you money • Receive text messages (WAP)
Phone	An app can use your phone and/or its call history. Note: Depending on your plan, you may be charged by your carrier for phone calls. Phone access may include the ability to: • Directly call phone numbers; this may cost you money • Write call log (example: call history) • Read call log • Reroute outgoing calls • Modify phone state • Make calls without your intervention
Photos/Media/Files	An app can use files or data stored on your device. Photos/Media/Files access may include the ability to: • Read the contents of your USB storage (example: SD card) • Modify or delete the contents of your USB storage • Format external storage • Mount or unmount external storage
Camera/Microphone	An app can use your device's camera and/or microphone. Camera and microphone access may include the ability to: • Take pictures and videos • Record audio • Record video
Wi-Fi connection	An app can access your device's Wi-Fi connection information, like if Wi-Fi is

information	turned on and the name(s) of connected devices. Wi-Fi connection information access may include the ability to: • View Wi-Fi connections
Device ID & call information	An app can access your device ID(s), phone number, whether you're on the phone, and the number connected by a call. Device ID & call information may include the ability to: • Read phone status and identity

Table 2 Grouping of Google Play Permissions as Per to Google Play 2014

A Simple conclusion from Table 2 shows that Google Play did its categorization strategy based on three main factors which are:

- Privacy: How far does an application go into dealing with the private details of the users which is shown clear in the listing of the following categories: Device & app history, Contacts/Calendar, SMS, Photos/Media/Files, Camera/Microphone, Device ID & call information;
- Security: How secure it is to leave this application to deal freely with sensitive information that belongs to or identifies the user which is shown clear in the listing of the following categories: Identity, Location, Phone, Wi-Fi connection information;
- Additional Charges: Does using this application going to cost the users an additional charge without their notice or approval? This is shown clear in the listing of the following categories: In-app purchases, Cellular data settings, SMS, Phone;

Next is to list all the permissions used by Google Play applications and filter them under a new category that focuses more into power consumption.

A start is by listing components of an average Smartphone which is operated by Android. Then measuring the behavior of each component in terms of power consumption in order to find components that can be classified as most power consuming components. The next step is by going back to the full list of permissions and then extract the permissions that deal with these "Most Power Consuming Components" and name them as "Google Play Power Consuming Applications Permissions".

In short, our contribution in this part is adding a new categorization feature to the three already provided by Google play. In fact, permissions were always investigated relative to privacy, security, additional-charges but rarely with power-consumption.

6.3.5 Listing Power-Hungry Smartphone Components through Empirical Experimentation

The following list contains the most key and common components or features that can be found on any average Android Smartphone as per to popularity of use today:

- Application Processor;
- Cellular Radio (GSM, 3G, 4G, etc.);
- Screen (Including Sensors);
- Vibration;
- Cameras;
- Flash Light;
- Audio Speaker;
- Microphone;
- GPS;
- Wi-Fi Radio;
- Bluetooth Radio.

The next step is to start measuring the amount of power consumed by each of the above components using PowerTutor wich a tool proposed by Zang et al. (2010) assuming that the component is used continuously for a period of 60 seconds. Since most of the components in any Android phone do work as a group in order to achieve a certain purpose, it was difficult to force a component to work alone without having other components involved. This caused accuracy issues about having valid power measurement results of each. This uncertainty was taken care of later by implementing some pre-testing techniques. What helped more in this regards was the flexibility of Android phones that gave us the chance to perform a number of steps easily like: Hard restart, Kill all processes and background applications, Clear RAM, Deactivate all features that are not essential to make the component work alone. Table 3 shows the results of the experimental measurements done by us on a Samsung I9500 running Android OS, v4.2.2 (Jelly Bean), v4.3, using PowerTutor. Results are ordered starting from the most consuming till the least consuming.

Smartphone Component	Capacity of the phone Battery before fully activating the component (mAh) (Fully Charged)	Capacity of Battery after fully activating the component alone for 60 seconds (mAh)	Average Amount of Energy Consumption measured (mAh/m)
GPS	2600	~ 2575	~ 25
Application Processor	2600	~ 2580	~ 20
Flash Light	2600	~ 2581	~ 19
Cellular Radio (GSM, 3G, 4G, etc.)	2600	~ 2583	~ 17
Cameras	2600	~ 2583	~ 17
Screen (Including Sensors)	2600	~ 2584	~ 16
Vibration	2600	~ 2585	~ 15
Wi-Fi Radio	2600	~ 2588	~ 12
Bluetooth Radio	2600	~ 2590	~ 10
Audio Speaker	2600	~ 2591	~ 9
Microphone	2600	~ 2595	~ 5

Table 3 Smartphone Components Sorted By Average Amount of Energy Consumption

The next step in our empirical experimentation is to create a scale in order to rate the above components in terms of the amount of power consumption of each. While the above results showed us the highest power consumption measurement ~ 25 mAh and the lowest ~ 5 mAh, it is recommended to scale up the result pool in order to make the rating criteria compatible with future measurements. So by assuming that the scale of rating a smartphone component is between ~ 1 to ~ 30 mAh, From the previous it is now simple to start fetching our results.

Table 4 shows the rating of smartphone components in terms of the amount of Energy consumption on a scale of six stars, where one star means light power consuming component and five starts means heavy power consuming component. The number of stars representing the level of power consumption is generated by averaging the amount of power consumption of all components then measuring the amount of power consumption of each component.

Smartphone Component	Average Amount of Energy Consumption Per Minute	Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
GPS	~ 25 mAh	★★★★★
Application Processor	~ 20 mAh	★★★★
Flash Light	~ 19 mAh	★★★★
Cellular Radio (GSM, 3G, etc.)	~ 17 mAh	★★★
Cameras	~ 17 mAh	★★★
Screen (Including Sensors)	~ 16 mAh	★★★
Vibration	~ 15 mAh	★★★
Wi-Fi Radio	~ 12 mAh	★★
Bluetooth Radio	~ 10 mAh	★★
Audio Speaker	~ 9 mAh	★★
Microphone	~ 5 mAh	★

Table 4 Rating Smartphone Components In Terms of Energy Consumption using Stars Scale

6.3.6 Listing Google Play Store Energy-Hungry Applications Permissions

Based on the previous ratings of Smartphone components power consumption level, and in order to identify permissions classified as power consuming permissions, following is a list of all permission used by Google Play. The list is generated in order to use it as data to be compared with Table 4 of Smartphone components. The following is the full list of permission used by Google Play applications:

Permissions Used by Google Play Applications		
access Bluetooth settings	full network access	read your own contact card
access extra location provider	Google Play billing service	read your social stream
commands	Google Play license check	read your text messages (SMS or
access mail information	install shortcuts	MMS)
access USB storage file system	make app always run	read your Web bookmarks and history
add or modify calendar events and	measure app storage space	receive data from Internet
send email to guests without	mock location sources for testing	receive text messages (MMS)
owners' knowledge	modify or delete the contents of your	receive text messages (SMS)
add or remove accounts	USB storage	receive text messages (WAP)
adjust your wallpaper size	modify phone state	record audio
allow Wi-Fi Multicast reception	modify secure system settings	reorder running apps
approximate (network-based)	modify system settings	reroute outgoing calls
location	modify your contacts	retrieve running apps
Broadcast data messages to apps	modify your own contact card	run at startup
change network connectivity	modify/delete internal media storage	send SMS messages
change system display settings	contents	send sticky broadcast
change your audio settings	pair with Bluetooth devices	set an alarm
change/intercept network settings	precise (GPS) location	set preferred apps
and traffic	prevent phone from sleeping	set wallpaper
choose widgets	read calendar events plus confidential	take pictures and videos
close other apps	information	take pictures and videos, record audio
connect and disconnect from Wi-	read call log	test access to protected storage
Fi	read call log, write call log	toggle sync on and off
control flashlight	Read email attachments	uninstall shortcuts
control Near Field	read Gmail	use accounts on the device
Communication	read Google service configuration	view configured accounts
control vibration	read Home settings and shortcuts	view network connections
create accounts and set passwords	read instant messages	view Wi-Fi connections
delete all app cache data	read owner data	write call log
directly call phone numbers	read phone status and identity	write Home settings and shortcuts
disable your screen lock	read sensitive log data	write subscribed feeds
download files without	read subscribed feeds	write to user-defined dictionary
notification	read sync settings	write to your social stream
draw over other apps	read sync statistics	write web bookmarks and history
edit your text messages (SMS or	read terms you added to the dictionary	write web bookmarks and history, set
MMS)	read your contacts	an alarm
expand/collapse status bar	read your contacts, choose widgets	
find accounts on the device	read your contacts, read call log	

Table 5. Permissions Used by Google Play Applications

By going through Table 5 a number of permissions were identified as permissions that are related to one or more phone components listed in Table 3 and after taking a fundamental step of extracting the common words that are related to one or more phone components, our results were presented on Table 6 which shows the extracted common words and their relation with the phone components.

Keyword Classified as Energy-Hungry keyword	**Reason of selecting the word (Relation with Energy-Hungry Component)**
GPS	GPS
System settings	Application Processor
Reception	Wi-Fi Radio, Cellular Radio
Call phone	Wi-Fi Radio, Cellular Radio, Audio Speaker
Always run	Application Processor
Download	Wi-Fi Radio, Cellular Radio
Network settings	Wi-Fi Radio, Cellular Radio
Network connectivity	Wi-Fi Radio, Cellular Radio
Network access	Wi-Fi Radio, Cellular Radio
Display	Screen
Record	Audio Speaker, Screen
Audio	Audio Speaker
Vibration	Vibration
Take pictures	Flash light, Screen
Take Videos	Flash light, Screen
Stream	Screen, Wi-Fi Radio, Cellular Radio
Flashlight	Flash light
Sleeping	Application Processor
Phone state	Application Processor
Bluetooth	Bluetooth Radio
Wi-Fi	Wi-Fi Radio
Toggle	Screen
Broadcast	Wi-Fi Radio, Cellular Radio
Startup	Application Processor

Table 6 Keywords Classified as "Power Consumption Related" keyword

Proceeding with our empirical experimentation sequence, after matching the common words of the above table with the full list of permissions that are used by all Google Play Store applications, permissions that can be classified as energy-hungry permissions were listed in the Table 7.

Google Play Energy-Hungry Applications Permissions	
• access Bluetooth settings • allow Wi-Fi Multicast reception • Broadcast data messages to apps • change network connectivity • change system display settings • change your audio settings • change/intercept network settings and traffic • connect and disconnect from Wi-Fi • control flashlight • control vibration • directly call phone numbers • download files without notification • full network access • make app always run	• modify phone state • modify secure system settings • modify system settings • pair with Bluetooth devices • precise (GPS) location • prevent phone from sleeping • read your social stream • record audio • run at startup • send sticky broadcast • take pictures and videos • toggle sync on and off • view Wi-Fi connections • write to your social stream

Table 7 Google Play Power Consuming Applications Permissions

Since the previous steps were able to distinguish which applications permissions can be marked as energy-hungry permission based on matching with the key words that are related to smartphones components which are marked as energy-hungry permissions. Our next step is to rate each one of these newly extracted permissions which we called Google Play Store Energy-Hungry Applications Permissions. This will lead us to the last stage of this empirical experimentation which is to rate an application in terms of power consumption based on the permissions related to this application. In the following the study will list each power consuming permission side by side with the ratings of the components it uses in order to find an overall average rating of each power consuming permission.

6.3.7 Variable Amounts of Energy Consumption for Network Connectivity Permission

As per the two commonly used types of network connections, Wi-Fi and Cellular connections, the study had to be more precise in giving the approximate amount of average power consumption amount of each "power consuming" permission under the two situations of network use. A mandatory split was done to each permission that does deal with the phone network connections into two main situations:

1. Using the permission "Indoor" (assuming using Wi-Fi network connection); and
2. Using the permission "Outdoor" (assuming using the Cellular network connection)

The above two situation had to be incorporated within the previous calculations of the average power consumption for each power consuming permission. This will give as a result two new average amounts of energy consumption for each component that deals with the phone network connectivity. Calculating the two new amounts will simply take into consideration the use of either Wi-Fi or Cellular connection. Then recalculate the overall power consumption average of the permission as per to the situation. For example if a permission uses either Wi-Fi connection or Cellular connection in order to keep the network connection and the same permission were used "outdoor" then the average amount of power consumption will be calculated by assuming that the permission is only using the cellular network connection in order to keep the network connections. So the Wi-Fi average amount of power consumption will be discarded when calculating the overall average power consumption of the permission. The same case goes if the same permission was used Indoor, then the average power consumption will be recalculated by assuming that the permission is only using the Wi-Fi network connection in order to keep the connection with the network. So the Cellular average amount of power consumption will be discarded when calculating the overall average of power consumption of the same permission. As per to the above assumptions a list was generated showing the new average amounts of power consumption of all the power consumption permissions that deal with network connections under the two previously mentioned situations. Table 8 shows the average power energy consumption amount and ratings for energy-hungry permission. They are calculated from the average rating of each component in Table 6 that is used by the permission. Figure 6.9 illustrates the mapping of apps permissions to smartphone's components and energy-hungry Levels

Power Consuming Applications Permissions	**Amount of Energy Consumption of each Used Component**	**Permission Average Energy Consumption Amount per minute**	**Permission Star Rating out of Six Stars (~ 1 to ~ 30 mAh)**
Access Bluetooth settings	Bluetooth Radio (~ 10 mAh)	~ 10 mAh	★★
Allow Wi-Fi Multicast reception	Wi-Fi Radio (~ 12 mAh)	~ 12 mAh	★★

Broadcast data messages to apps	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh)	~ 15 mAh	★★★
Change network connectivity	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh)	~ 15 mAh	★★★
Change system display settings	Screen (~ 16 mAh)	~ 16 mAh	★★★
Change your audio settings	Audio Speaker (~ 9 mAh)	~ 9 mAh	★★
Change/intercept network settings and traffic	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	★★★
Connect and disconnect from Wi-Fi	Wi-Fi Radio (~ 12 mAh)	~ 12 mAh	★★
Control flashlight	Flash Light (~ 19 mAh)	~ 19 mAh	★★★★
Control vibration	Vibration (~ 15 mAh)	~ 15 mAh	★★★
Directly call phone numbers	Cellular Radio (~ 17 mAh) Microphone (~ 5 mAh) Audio Speaker (~ 9 mAh)	~ 10 mAh	★★
Download files without notification	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	★★★
Full network access	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	★★★
Make an app to always run	Application Processor (~ 20 mAh)	~ 20 mAh	★★★★
Modify phone state	Application Processor (~ 20 mAh)	~ 20 mAh	★★★★
Modify secure system settings	Application Processor (~ 20 mAh)	~ 20 mAh	★★★★
Modify system settings	Application Processor (~ 20 mAh)	~ 20 mAh	★★★★
Pair with Bluetooth devices	Bluetooth Radio (~ 10 mAh)	~ 10 mAh	★★★★
Precise (GPS) location	GPS (~ 25 mAh)	~ 25 mAh	★★★★★
Prevent phone from sleeping	Application Processor (~ 20 mAh) Screen (~ 16 mAh)	~ 18 mAh	★★★★
Read your social stream	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	★★★
Record audio	Microphone (~ 5 mAh)	~ 5 mAh	★
Run at startup	Application Processor (~ 20 mAh)	~ 20 mAh	★★★★
Send sticky broadcast	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	★★★
Take pictures and videos	Cameras (~ 17 mAh) Flash Light (~ 19 mAh) Microphone (~ 5 mAh)	~ 14 mAh	★★★
Toggle sync on and off	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	★★★
View Wi-Fi connections	Wi-Fi Radio (~ 12 mAh)	~ 12 mAh	★★
Write to your social stream	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	★★★

Table 8 Average Power Energy Consumption Amount and Ratings of Power Consuming Permissions

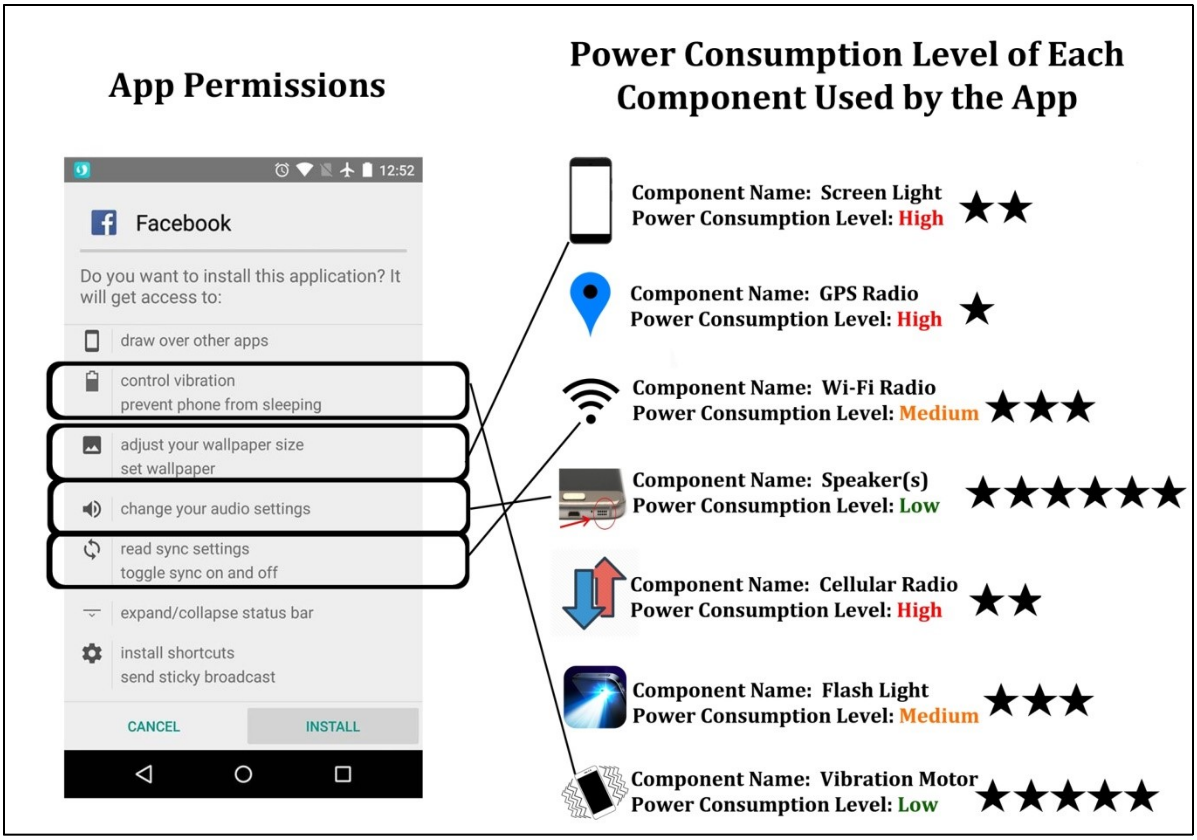


Figure 6.9: Mapping Apps Permissions to Smartphone's Components and Energy-Consumption Levels

Table 9 shows the two different average amounts and ratings for only power consuming permissions highlighted in grey since they deal with network connectivity. They are calculated from the average rating of each component used by the permission, and on each different situation either Wi-Fi or Cellular was eliminated from the calculation:

Power Consuming Applications Permissions	**Amount of Energy Consumption of each Used Component**	**Permission Average Energy Consumption Amount per minute**		**Permission Star Rating out of Six Stars (~ 1 to ~ 30 mAh)**	
		Indoor (Using Wi-Fi)	**Outdoor (Using Cellular)**	**Indoor (Using Wi-Fi)**	**Outdoor (Using Cellular)**
Access Bluetooth settings	Bluetooth Radio (~ 10 mAh)	~ 10 mAh	~ 10 mAh	★★	★★
Allow Wi-Fi Multicast reception	Wi-Fi Radio (~ 12 mAh)	~ 12 mAh	~ 12 mAh	★★	★★
Broadcast data messages to apps	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh)	~ 12 mAh	~ 17 mAh	★★	★★★
Change network connectivity	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh)	~ 12 mAh	~ 17 mAh	★★	★★★
Change system display settings	Screen (~ 16 mAh)	~ 16 mAh	~ 16 mAh	★★★	★★★

Change your audio settings	Audio Speaker (~ 9 mAh)	~ 9 mAh	~ 9 mAh	★★	★★
Change/intercept network settings and traffic	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	~ 18 mAh	★★★	★★★★
Connect and disconnect from Wi-Fi	Wi-Fi Radio (~ 12 mAh)	~ 12 mAh	~ 12 mAh	★★	★★
Control flashlight	Flash Light (~ 19 mAh)	~ 19 mAh	~ 19 mAh	★★★★	★★★★
Control vibration	Vibration (~ 15 mAh)	~ 15 mAh	~ 15 mAh	★★★	★★★
Directly call phone numbers	Cellular Radio (~ 17 mAh) Microphone (~ 5 mAh) Audio Speaker (~ 9 mAh)	~ 10 mAh	~ 10 mAh	★★	★★
Download files without notification	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	~ 18 mAh	★★★	★★★★
Full network access	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	~ 18 mAh	★★★	★★★★
Make app always run	Application Processor (~ 20 mAh)	~ 20 mAh	~ 20 mAh	★★★★	★★★★
Modify phone state	Application Processor (~ 20 mAh)	~ 20 mAh	~ 20 mAh	★★★★	★★★★
Modify secure system settings	Application Processor (~ 20 mAh)	~ 20 mAh	~ 20 mAh	★★★★	★★★★
Modify system settings	Application Processor (~ 20 mAh)	~ 20 mAh	~ 20 mAh	★★★★	★★★★
Pair with Bluetooth devices	Bluetooth Radio (~ 10 mAh)	~ 10 mAh	~ 10 mAh	★★★★	★★★★
Precise (GPS) location	GPS (~ 25 mAh)	~ 25 mAh	~ 25 mAh	★★★★★	★★★★★
Prevent phone from sleeping	Application Processor (~ 20 mAh) Screen (~ 16 mAh)	~ 18 mAh	~ 18 mAh	★★★★	★★★★

Read your social stream	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	~ 18 mAh	★★★	★★★★
Record audio	Microphone (~ 5 mAh)	~ 5 mAh	~ 5 mAh	★	★
Run at startup	Application Processor (~ 20 mAh)	~ 20 mAh	~ 20 mAh	★★★★	★★★★
Send sticky broadcast	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	~ 18 mAh	★★★	★★★★
Take pictures and videos	Cameras (~ 17 mAh) Flash Light (~ 19 mAh) Microphone (~ 5 mAh)	~ 14 mAh	~ 14 mAh	★★★	★★★
Toggle sync on and off	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	~ 18 mAh	★★★	★★★★
View Wi-Fi connections	Wi-Fi Radio (~ 12 mAh)	~ 12 mAh	~ 12 mAh	★★	★★
Write to your social stream	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	~ 18 mAh	★★★	★★★★

Table 9 Average Power Consumption Amounts and Ratings of Power Consuming Permissions. (Only the Ones Dealing with Network Connectivity under Indoor/Outdoor Usage)

Continuing with our empirical measurements experimentation work, from the above results a simple comparison can be made between the two average amounts of energy consumption and to come up with an average approximate rate of either increase or decrease in the average amount of power consumption of permission. In order to use it with the coming stage of finding the average amount of energy consumption of a Google Play application for a full Applications Category, Table 10 below shows the comparison as follows:

Power Consuming Applications Permissions	Amount of Energy Consumption of each Used Component	Permission Average Energy Consumption Amount per minute, either Indoor or Outdoor	Permission Average Energy Consumption Amount per minute for Indoor/Outdoor		Increase/Decrease Percentage	
			Indoor (Wi-Fi)	**Outdoor (Cellular)**	**Indoor (Wi-Fi)**	**Outdoor (Cellular)**
Access Bluetooth settings	Bluetooth Radio (~ 10 mAh)	~ 10 mAh	~ 10 mAh	~ 10 mAh		
Allow Wi-Fi Multicast reception	Wi-Fi Radio (~ 12 mAh)	~ 12 mAh	~ 12 mAh	~ 12 mAh		
Broadcast data messages to apps	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh)	~ 15 mAh	~ 12 mAh	~ 17 mAh	-20%	12%
Change network connectivity	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh)	~ 15 mAh	~ 12 mAh	~ 17 mAh	-20%	12%
Change system display settings	Screen (~ 16 mAh)	~ 16 mAh	~ 16 mAh	~ 16 mAh		
Change your audio settings	Audio Speaker (~ 9 mAh)	~ 9 mAh	~ 9 mAh	~ 9 mAh		
Change/intercept network settings and traffic	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	~ 16 mAh	~ 18 mAh	0%	12%
Connect and disconnect from Wi-Fi	Wi-Fi Radio (~ 12 mAh)	~ 12 mAh	~ 12 mAh	~ 12 mAh		
Control flashlight	Flash Light (~ 19 mAh)	~ 19 mAh	~ 19 mAh	~ 19 mAh		
Control vibration	Vibration (~ 15 mAh)	~ 15 mAh	~ 15 mAh	~ 15 mAh		
Directly call phone	Cellular Radio	~ 10 mAh	~ 10	~ 10 mAh		

numbers	(~ 17 mAh) Microphone (~ 5 mAh) Audio Speaker (~ 9 mAh)		mAh			
Download files without notification	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	~ 16 mAh	~ 18 mAh	0%	12%
Full network access	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	~ 16 mAh	~ 18 mAh	0%	12%
Make app always run	Application Processor (~ 20 mAh)	~ 20 mAh	~ 20 mAh	~ 20 mAh		
Modify phone state	Application Processor (~ 20 mAh)	~ 20 mAh	~ 20 mAh	~ 20 mAh		
Modify secure system settings	Application Processor (~ 20 mAh)	~ 20 mAh	~ 20 mAh	~ 20 mAh		
Modify system settings	Application Processor (~ 20 mAh)	~ 20 mAh	~ 20 mAh	~ 20 mAh		
Pair with Bluetooth devices	Bluetooth Radio (~ 10 mAh)	~ 10 mAh	~ 10 mAh	~ 10 mAh		
Precise (GPS) location	GPS (~ 25 mAh)	~ 25 mAh	~ 25 mAh	~ 25 mAh		
Prevent phone from sleeping	Application Processor (~ 20 mAh) Screen (~ 16	~ 18 mAh	~ 18 mAh	~ 18 mAh		

	mAh)					
Read your social stream	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	~ 16 mAh	~ 18 mAh	0%	12%
Record audio	Microphone (~ 5 mAh)	~ 5 mAh	~ 5 mAh	~ 5 mAh		
Run at startup	Application Processor (~ 20 mAh)	~ 20 mAh	~ 20 mAh	~ 20 mAh		
Send sticky broadcast	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	~ 16 mAh	~ 18 mAh	0%	12%
Take pictures and videos	Cameras (~ 17 mAh) Flash Light (~ 19 mAh) Microphone (~ 5 mAh)	~ 14 mAh	~ 14 mAh	~ 14 mAh		
Toggle sync on and off	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	~ 16 mAh	~ 18 mAh	0%	12%
view Wi-Fi connections	Wi-Fi Radio (~ 12 mAh)	~ 12 mAh	~ 12 mAh	~ 12 mAh		

Table 10 Difference in the amount of power consumption for Power Consuming Permissions under "Indoor" and "outdoor" usage

Table 10 summarizes the average amount of power consumption for a power consuming permission which deals with the phone connectivity is decreased approximately by 4% if this permission was used Indoor. The average amount of power consumption for a power consuming permission that deals with the phone connectivity is increased approximately by 12% if this permission was used outdoor. This conclusion can be used in the next stages of the study to come up with more accurate results.

6.3.8 Permission-Based Rating of Apps and Categories

Based on the sections, Table 13 below shows an example of power consuming rating for 4shared application, where power consuming permissions are highlighted in grey:

Category	Top 10 Popular Apps	Needed Permissions for the App	Permissions consumption	Application Average	Application Star Rating out of Six
Entertainment	1. 4shared	test access to protected storage		~ 18 mAh	★★★★
		approximate (network-based) location			
		full network access	~ 16 mAh		
		view network connections			
		receive data from Internet			
		modify or delete the contents of your USB storage			
		read phone status and identity			
		send sticky broadcast	~ 16 mAh		
		prevent phone from sleeping	~ 18 mAh		
		run at startup	~ 20 mAh		

Table 10 Rating “4shared” Application Using Power Consumption Stars Scale

From the above example, next is to rate the power consumption level of same application under the two network usage situations, which are “Wi-Fi” and “Cellular”.

Table 14 shows the same example under the two network usage situations

Category	Top 10 Popular Apps	Needed Permissions for the App	Permission Average Energy Consumption Amount per minute for Indoor/Outdoor		Application Average Energy Consumption Amount per minute for Indoor/Outdoor		Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)	
			Indoor (Wi-Fi)	Outdoor (Cellular)	Indoor (Wi-Fi)	Outdoor (Cellular)	Indoor (Wi-Fi)	Outdoor (Cellular)
Entertainment	1. 4shared	test access to protected storage			~ 17 mAh	~ 19 mAh	★★★	★★★★
		approximate (network-based) location						
		full network access	~16 mAh	~ 18 mAh				
		view network connections						
		receive data from Internet						
		modify or delete the contents of your USB storage						
		read phone status and identity						
		send sticky broadcast	~ 16 mAh	~ 18 mAh				
		prevent phone from sleeping	~ 18 mAh					
		run at startup	~ 20 mAh					

Table 11 Rating "4shared" Application Using Power Consumption Stars Scale Under Two Different Network Connectivity Modes

Table 15 shows an example where power consuming rating is made for the Entertainment category also under the two network usage situations:

Category	Top 10 Popular Apps	Application Average Energy Consumption Amount per minute for Indoor/Outdoor		Category Average Energy Consumption Amount per minute for Indoor/Outdoor		Category Star Rating out of Six Stars (~ 1 to ~ 30 mAh)	
		Indoor (Wi-Fi)	Outdoor (Cellular)	Indoor (Wi-Fi)	Outdoor (Cellular)	Indoor (Wi-Fi)	Outdoor (Cellular)
Entertainment	1. 4shared	~ 17 mAh	~ 19 mAh	~ 15 mAh	~ 18 mAh	★★★	★★★★
	2. Netflix	~ 12 mAh	~ 20 mAh				
	3. Talking Tom Cat 2 Free	~ 14 mAh	~ 14 mAh				
	4. "Talking Ben The Dog Free"	~ 14 mAh	~ 14 mAh				
	5. Audiko Ringtones	~ 16 mAh	~ 16 mAh				
	6. Twitch	~ 14 mAh	~ 21 mAh				
	7. "MP3 Music Download"	~ 15 mAh	~ 20 mAh				
	8. Talking Ginger	~ 15 mAh	~ 15 mAh				
	9. "9GAG-Funny pics and videos"	~ 15 mAh	~ 22 mAh				
	10. "Talking Tom & Ben News Free"	~ 14 mAh	~ 14 mAh				

Table 12 Rating "Entertainment" Applications Category Using Power Consumption Stars Scale Under Two Different Network Connectivity Modes

In the following, Table 16 shows all Google Play applications categories sorted by their power consumption rating scores:

Category	Category Average Energy Consumption Amount per minute		Category Star Rating out of Six Stars (~ 1 to ~ 30 mAh)	
	Indoor (Wi-Fi)	**Outdoor (Cellular)**	**Indoor (Wi-Fi)**	**Outdoor (Cellular)**
Social	~ 26 mAh	~ 30 mAh	★★★★★	★★★★★★
Tools	~ 26 mAh	~ 26 mAh	★★★★★	★★★★★
Communication	~ 25 mAh	~ 28 mAh	★★★★★	★★★★★
Personalization	~ 20 mAh	~ 22 mAh	★★★★	★★★★
Lifestyle	~ 21 mAh	~ 21 mAh	★★★★	★★★★
Productivity	~ 21 mAh	~ 21 mAh	★★★★	★★★★
Travel & Local	~ 19 mAh	~ 21 mAh	★★★★	★★★★
Health & Fitness	~ 17 mAh	~ 17 mAh	★★★	★★★
Business	~ 15 mAh	~ 18 mAh	★★★	★★★★
Music & Audio	~ 15 mAh	~ 18 mAh	★★★	★★★★
Photography	~ 16 mAh	~ 16 mAh	★★★	★★★
Entertainment	~ 15 mAh	~ 18 mAh	★★★	★★★★
Media & Video	~ 15 mAh	~ 19 mAh	★★★	★★★★
Shopping	~ 15 mAh	~ 18 mAh	★★★	★★★★
Transportation	~ 14 mAh	~ 16 mAh	★★★	★★★★
Medical	~ 14 mAh	~ 14 mAh	★★★	★★★
Books & Reference	~ 12 mAh	~ 12 mAh	★★	★★
Weather	~ 11 mAh	~ 14 mAh	★★	★★★
News & Magazines	~ 9 mAh	~ 11 mAh	★★	★★
Education	~ 10 mAh	~ 10 mAh	★★	★★
Libraries & Demo	~ 4 mAh	~ 4 mAh	★	★

Table 13 Rating All Google Play Applications Categories Using Power Consumption Stars Scale under Two Different Network Connectivity Modes

Next, the chapter will propose a detailed model of rating Google Play Store apps which will include additional factors to increase the level of accuracy and technical feasibility through refactoring.

6.4 Refactoring-Based Energy-Efficiency Rating of Google Play Applications

6.4.1 Preventive vs. Detective Battery-Saving Approaches on Android Smartphones

Android smartphones come with many built-in features that are provided to end users with a minimum level of participation (Almasri, 2015). These techniques and features follow certain philosophies. We were able to classify these into two approaches, detective and preventive, as shown in Figure 6.10. In the following we provide an overview of the current approaches and their implementations and limitations.

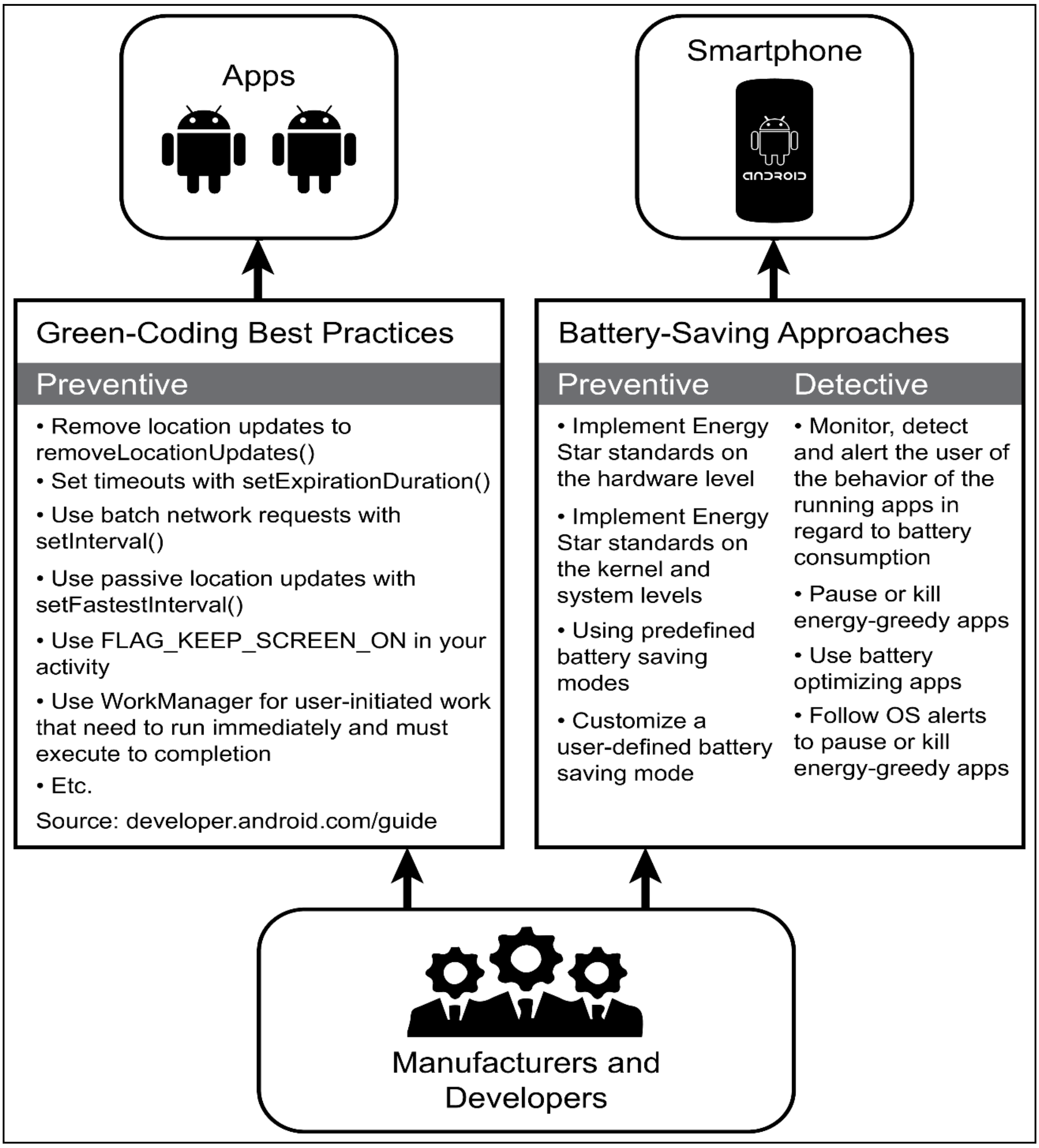


Figure 6.10: High-level design of current battery-saving approaches implemented on Android smartphones and applications.

Solutions that are considered to follow the detective approach run on the system level of the Android smartphone and monitor the behavior of each app and component toward the battery (Li et al., 2017); these algorithms either act or warn the user or even kill an energy-greedy application. On the other hand, solutions that are provided by developers and manufacturers, which are considered under the preventive approach, are built-in battery-saving standards implemented on the hardware and kernel level (Chen and Zong, 2016), e.g., Energy Star Saver (ENERGY STAR, 2020). Another solution that is considered to follow the detective approach is the battery optimizers, which are usually uploaded on Google Play as battery-saving applications. These applications do the same job that is achieved by the built-in algorithms but with additional features, since they run on the application and system level they require power to run from the same battery which they work on saving as shown on Figure 6.11. The second approach that we were able to classify is the preventive approach, which is also given by manufacturers and developers. One example of the preventive approach is the power-saving modes that the new Android smartphones are equipped with. These ready-made power-saving modes follow the preventive strategy. So instead of acting as a watch and monitor, they follow the idea of switching off most of the features and components that are considered as energy-greedy, e.g., GPS, flashlight, and Wi-Fi connection (Almasri and Sameh, 2019). These components or features will be switched off in order to save the battery. Some of these power-saving modes may provide maximum discharging periods, which can reach weeks in some smartphone's brands. At the same time, all this comes with the cost of using only basic and limited features of the smartphone. In other words, the screen brightness will be reduced or, in other extreme modes, it will be converted to grayscale, the Wi-Fi connection will be terminated, and the performance of the phone will be markedly reduced, keeping the option to exclude a small set of allowed apps. These power-saving modes that follow the preventive approach can be also customized by end users to suit their own needs, but it involves many complications, which can complicate the balance between saving energy and using the latest technology. Under the preventive energy-saving approach, we will be demonstrating an example that clearly highlights the key issue of having limited capacity of decision-making among end users when it comes to choosing from either high performance (full HD screen, continued GPS usage, etc.) and long battery life (minimizing the discharging time).

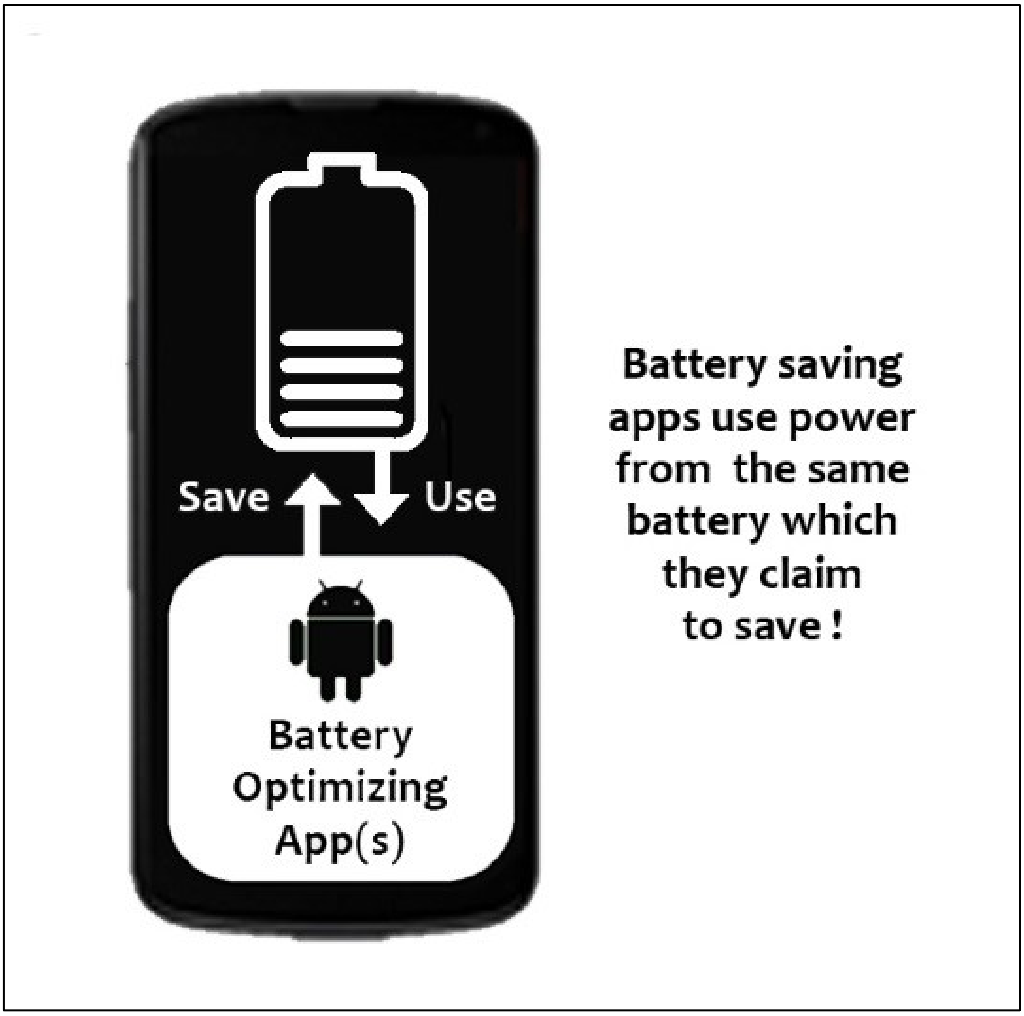


Figure 6.11: General limitation of approach adapted by battery-saving apps.

6.4.2 Android Apps Green Coding Practices

During the applications development, all solutions that are used during this stage are considered to follow the preventive approach, since these applications are neither downloaded nor running on a smartphone, thus are considered to be in the "before install and use" zone (Montenegro, Pinto and Fuentes, 2018). These applications can run on a simulated environment using virtual Android platforms, but the actual management related to energy consumption is considered to be an estimation of the apps behavior (Banerjee, Chong, Ballabriga and Roychoudhury, 2018). Speaking about coding and software development, the standards that are followed are all considered as "Best Development Practices". These practices are often used to implement quality standards related to performance, security, and, in our area, energy efficiency. The official Android online resource lists a number of battery killers (Behrouz et al., 2015). These battery killers are either physical or virtual components in a smartphone, which usually consume a notable amount of energy whenever they are used.

This online resource also proposes a set of best practices that are related to energy saving and power management during the development stage. These practices propose minimizing the lines of code, avoiding the use of functions or loops that cause the application to run continuously, and putting restrictions on commands that take control of components considered to be battery killers (Donatiello and Marfia, 2018). As shown in Figure 6.10, the best practices used during development propose idling of the highest battery killers: the GPS, the screen, and the background processing. Following these recommendations is one way to ensure that an application is considered energy efficient. However, the effect of installed apps on a smartphone's battery is not easily understood by applications users.

6.4.3 Demonstrating the Research Problem Through an Example

In the following we demonstrate a comprehensive example which clearly highlights the key issue of having limited capacity of decision-making among end users when it comes to choosing from either, high performance and long battery life. The example is about a construction engineer who spends most of his time in open work areas that have either limited or no recharging resources or Wi-Fi connections. This engineer has an essential need to use a texting application similar to WhatsApp or Facebook Messenger through a cellular data Internet connection, at the same time he needs to view a set of colorful architectural designs on his phone, and on top of that, he needs to save as much as he can of his smartphone's battery life. As a result, the engineer is left with a limited set of options: The first option is to enable a ready-to-use power-saving mode, which will have an effect on all of his phone, as shown on Figure 6.12. This effect may be in the form of switching off the cellular data connection in order to save the battery to place and receive ordinary GSM calls, which will deprive him of an Internet connection, and as a result not allow him to use a texting application. Another effect of enabling a power-saving mode is converting the screen into grayscale mode, which also will not allow the construction engineer to view the colorful architectural designs. He second option is to have him involved in customizing a new power-saving mode by giving him the ability to enable the mode and then exclude the cellular data connection, the colored screen, and all the other apps he needs from the list of restriction given by the power-saving mode. This will markedly minimize the efficiency of the power-saving mode in terms of minimizing the discharging time, since it will be per app or feature usage, as shown in Figure 6.12.

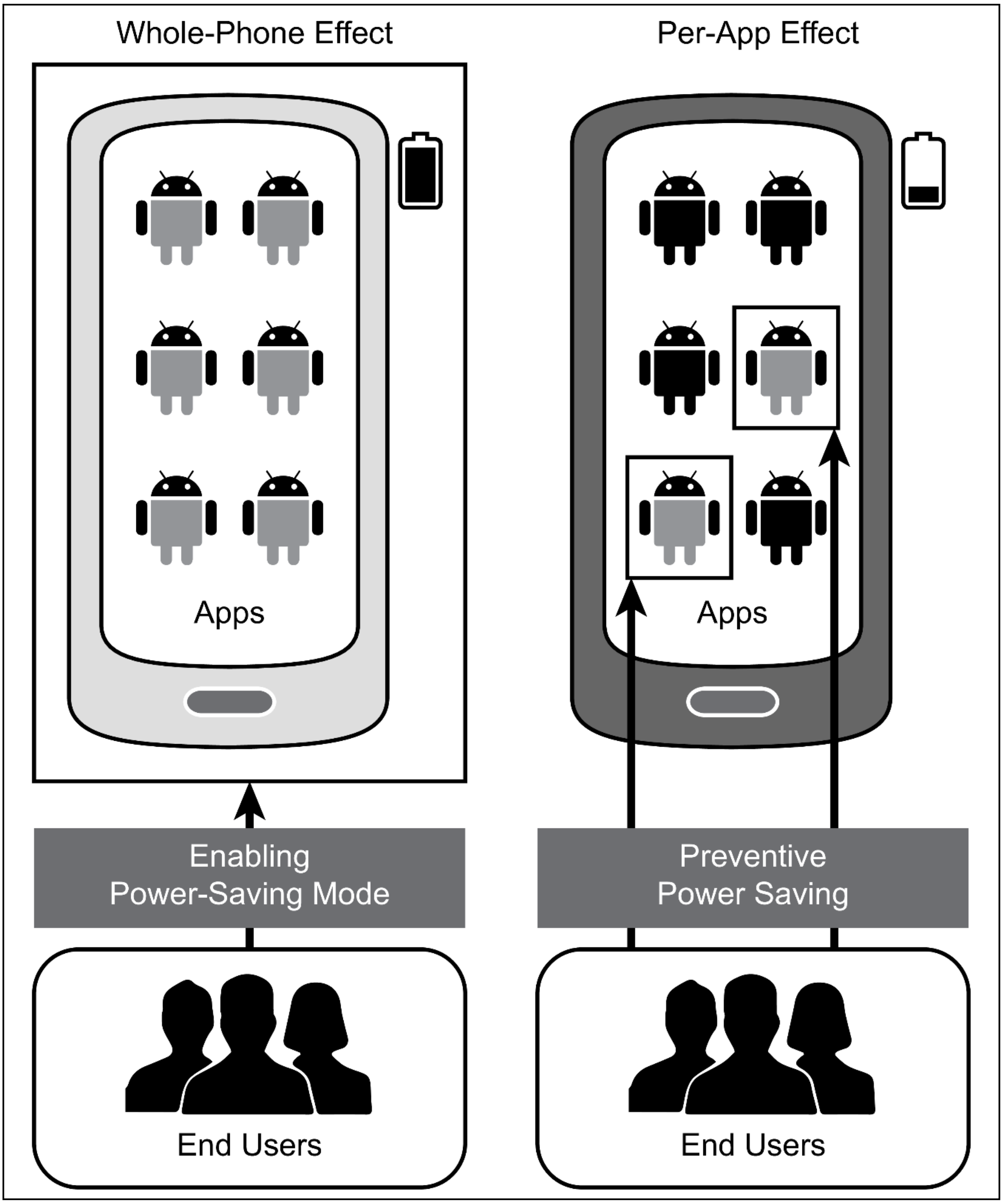


Figure 6.12: Whole-phone vs. per-app effects of preventive power-saving approaches given to users.

6.4.4 Studying the User Acceptance Level of The Current Power-Saving Approaches

This section proposes a novel way to enhance the current preventive energy-saving approaches for Android applications. To achieve this goal, the first step is to measure the efficiency level and popularity of the current preventive approaches. Knowing the level of user acceptance of using the current preventive approaches is important for researchers and developers interested in improving these approaches. A survey implemented among a sample of more than 443 Android smartphone users got different results (See Appendix I for the used questionnaire), which we first averaged and then classified by age groups from 16 to 60 years old. The survey had a primary question about using power-saving modes that Android smartphones are equipped with. Choices of answers were: Yes, uses the ready-made power-saving modes (YR); Yes, uses the customized power-saving mode (YC); and No, never uses the power-saving modes (N). This part was expected to give a general view of the popularity of usage among these power-saving modes, therefore a good indication about their main contribution to extending battery life by end users, as well as show their role in the big picture of green computing. Other popular techniques offered by Android developers and manufacturers are battery optimizers and battery-saving applications. These applications run on the application layer and are intended to extend the battery discharge time. This technique is claimed to save energy under the detective approach, which follows the monitoring, control, and optimization of behavior of each running application. In order to know the efficiency of power-saving applications, battery-saving tools, and battery optimizers, we implemented a short statistical and technical analysis on Google Play store applications. We picked a sample of the top 20 applications that offer the service of battery saving and management. We ordered the applications as per to the reviews, as it was the only indication of popularity and then by the number of downloads. In the statistical part we used PowerTutor as a power profiler to measure the amount of power consumption of each application per five minutes of continuous running (Zhang et al., 2010). There were other tools available to measure the amount of energy consumption, such as Msoon Power Monitor, Trepn, and LEAP power measurement devices, but the main purpose was to give a general impression of the energy consumption by each app (Cruz, Abreu and Rouvignac, 2017) (Digvijay and W J, 2010). The survey results were the most important source of inspiration to start looking for new approaches to save energy on smartphones since all current power-saving techniques follows either a Preventive or a Detective Power-saving approaches. The results of studying both examples under preventive and detective approaches are further demonstrated in the following section and then discussed with regard to the background and the main research questions.

6.4.5 Results and Discussion

The results of the preliminary study related to measuring the popularity of usage among power-saving modes were charted, as shown in Figure 6.13. From these results we were first able to get an initial position about the popularity of usage of the two main categories of current power-saving modes. The average usage of these modes did not exceed 31% among the total 443 Android smartphone users. With this percentage taken into account and as far as the end user has the option to either activate or avoid using a power-saving mode, this clearly makes the concept of offering power-saving modes critically questionable in terms of real-life functionality and the main contribution to the big picture of extending battery life. However, since preventive approaches give the option either to enjoy the modern features of a smartphone or to enjoy a longer battery life, it always has to be offered as an optional solution. Therefore, we also studied the detective approaches, examples of which were battery optimizers and battery-saving apps offered in the Google Play store. The results of the measurements generated by PowerTutor and Trepn are shown in Table 17. Additionally, by using the same power usage profilers in order to rank the power consumed by each running application, we were able to rank two power-optimizing applications, as both were ranked among the top three most power-consuming applications, as shown in Figure 6.14. Before going through the measurement results, these optimizers addressed a key issue related to the main concept of saving power. The main and critical issue is that they require power to run, which causes them to fail in delivering their main goal of saving energy. Put simply, monitoring and announcing consume power for the sake of saving power as shown in. Plus, whatever runs on the application and/or the operating system (OS) layer of the phone consumes power from the same phone battery. Additionally, regarding these results, we were able to see that these applications actually consume a large amount of energy while running, and these results show a major limitation of this approach for energy-saving, since there is a conflict of interest, as shown in Figure 6.11. This also makes this technique questionable in terms of its efficiency level compared to the main role of saving energy.

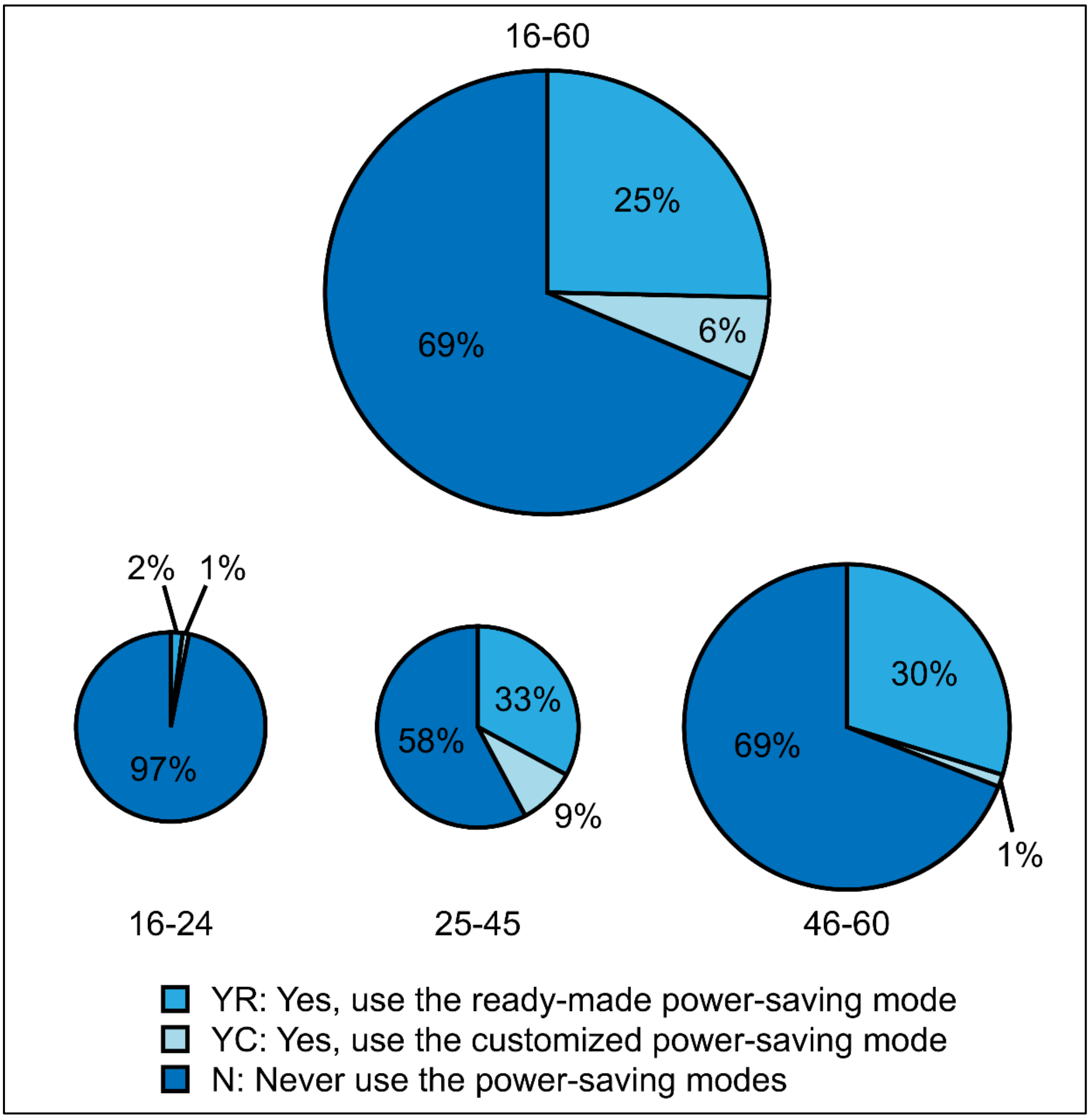


Figure 6.13: Popularity of usage of power-saving modes among four end-user age groups.

	Size	Rating	Reviews	Consumption Per 5m
App1	10 MB	4 . 5 *	8000000	~ 298.3 mW
App12	2 . 9 MB	4 . 4 *	1000000	~ 165.7 mW
App6	15 MB	4 . 6 *	189000	~ 785.9 mW
App11	7 . 6 MB	4 . 5 *	135000	~ 454.6 mW
App2	12 MB	4 . 6 *	118000	~ 652.1 mW
App13	4 . 0 MB	4 . 2 *	112000	~ 258.6 mW
App14	8 . 8 MB	4 . 3 *	58000	~ 488.7 mW
App16	3 . 0 MB	4 . 3 *	19000	~ 655.2 mW
App17	6 . 2 MB	4 . 3 *	8000	~ 212.6 mW
App7	3 . 8 MB	4 . 6 *	3000	~ 215.8 mW
App9	9 . 0 MB	4 . 6 *	3000	~ 348.0 mW
App10	6 . 0 MB	4 . 5 *	3000	~ 277.6 mW
App18	23 kB	4 . 2 *	3000	~ 102.6 mW
App20	7 . 9 MB	4 . 4 *	2000	~ 258.6 mW
App5	11 MB	4 . 2 *	1000	~ 189.5 mW
App3	2 . 1 MB	4 . 4 *	921	~ 154.7 mW
App4	4 . 1 MB	4 . 6 *	853	~ 345.8 mW
App8	8 . 4 MB	4 . 1 *	697	~ 305.62mW
App15	2 . 2 MB	4 . 2 *	503	~ 708.0 mW
App19	8 . 4 MB	3 . 7 *	269	~ 387.6 mW

Table 17 Average Power Consumption Per 5 minutes for 20 power-saving/optimizing apps.

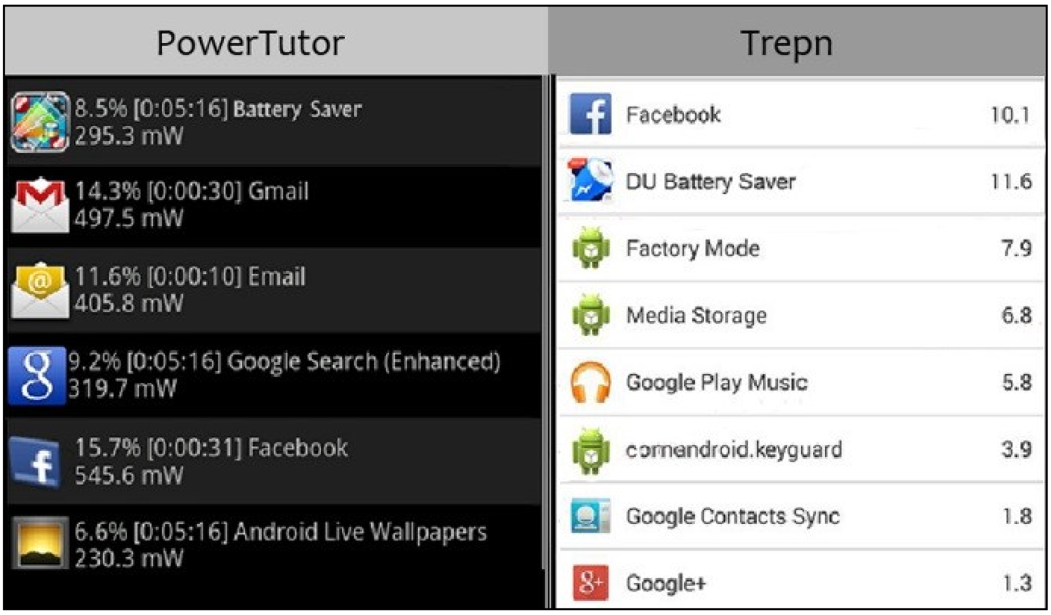


Figure 6.14: Using PowerTutor and Trepn profilers to read the amount of energy consumed by two popular power-optimizing applications.

6.4.6 The Missing Piece of the Puzzle

This research was aimed at finding the missing piece of the puzzle in the current framework of battery and energy saving in Android smartphones. Figure 6.15 demonstrates the current framework for the division of authorities and roles in energy saving among Android smartphones. The most popular factors that smartphone users take into consideration when deciding which app to download and use are related to the main function of the app and its popularity. With the existence of other factors to consider, Android app stores allow users to choose from a variety of apps that share similar functions but gives no indication of the energy behavior of the apps. The area that shows our proposed solution is the area between applications that are not yet installed on the smartphone and the end user, as shown in Figure 6.15. We propose that end users will act as decision-makers with regard to the applications that are about to be downloaded on their smartphones after taking into consideration the level of power consumption for each app. The main concept is to enhance the role of the end users while selecting a reliable solution that follows the preventive approach, so end users will have a replacement option other than selecting a power-saving mode that will deactivate the modern features of the phone. This enhancement will keep the same level of technology at the whole-phone level and will also allow end users to select the best applications in terms of their energy-friendly features.

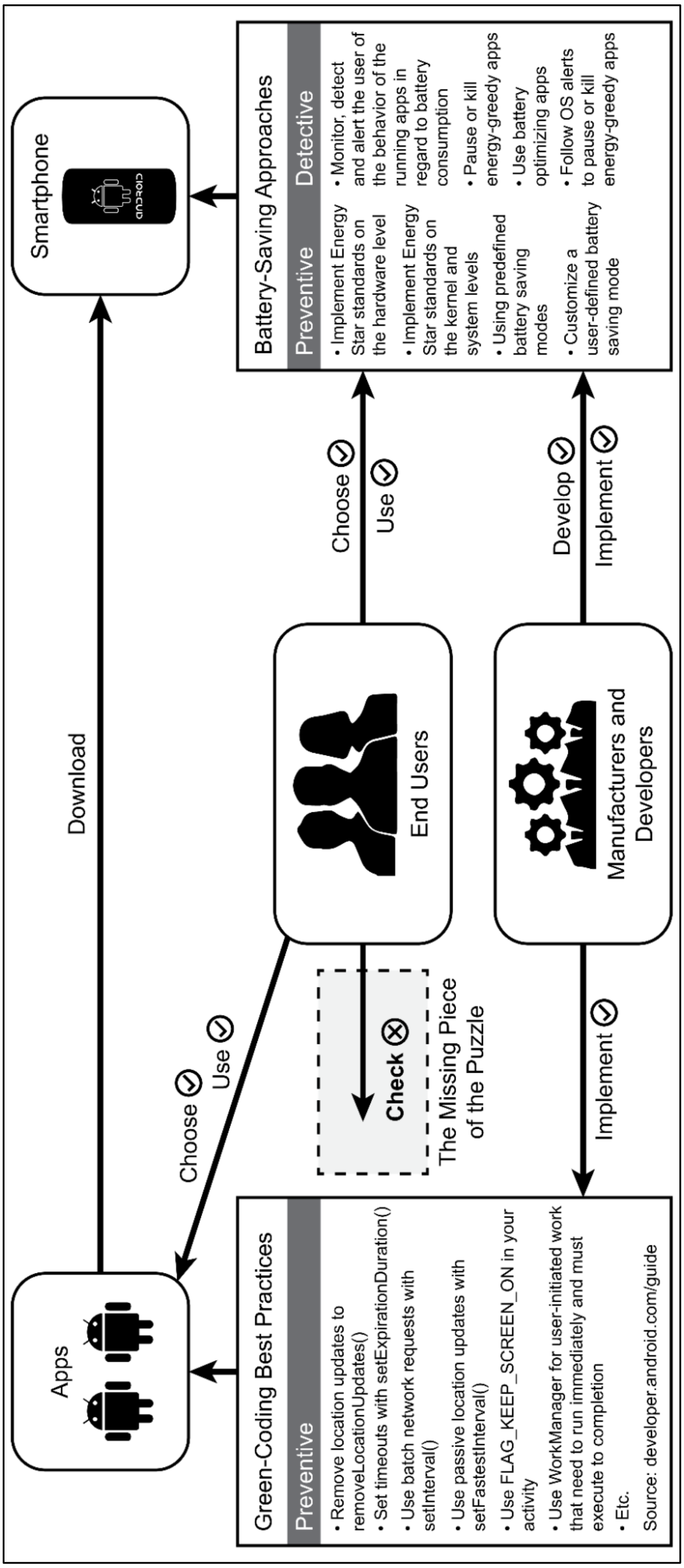


Figure 6.15: Current battery- and energy-saving framework for Android smartphones

Referring to our previous overview example related to the field construction engineer, this will enable the engineer to select the level of functionalities by choosing a power-friendly app that still gives him more modern features while consuming less of his smartphone's battery compared to ordinary usage. So, the simple scenario is that an end user will be able to choose from a set of apps that share the same functionalities but have different energy consumption levels. In the following, we add the bridge between end users and apps and then demonstrate the model that finally shows the strategy to be followed in order to rate the amount of energy consumption of an Android application.

6.4.7 Energy Star Rating Schema as An Efficient Decision Support Tool for End Users

One of the main contributions of our research is that we discuss the efficiency of running a power-optimizing process on the OS and application layers of a smartphone. Since processing requires power, consuming some of the battery under the premise of saving the same battery is a concept which we kept avoiding. Instead, we propose a preventive strategy that requires no processing in any layer of the smartphone and gives end users the option to decide which apps to install after viewing their energy behavior. The nearest similar solution is the energy rating labels used on home appliances. Android users enjoy the way applications can be downloaded and used, but are also concerned about giving the green light to a number of flashing permissions. End users will also be able to see the star rating of each application available on the Google Play store, and then decide which applications to install and use.

6.4.8 Concept and Challenges

The basic idea of the proposed solution is to benefit from the relevant proven results of researches which produced energy-friendly code restructuring or reformulating tools. The proposed solution merges these newly designed tools in order to use it as a set of baseline factors which will finally crystalize a concept of a reliable and trustful evaluation tool. This evaluation tool will be then used as an x-ray belt to evaluate any Android application in terms of its level of energy efficiency. The tool is supposed to be a hidden built-in feature added to Google Play Store which will show the level of energy efficiency of an app to all users of Google Play Store Similar to the current user satisfaction start-rating schema which is shown beside each app. We preferred to use the current refactoring tools as baselines to our tool because of the availability of the source code on Google Play which makes it an extremely valuable resource for these refactoring tools to be implemented on most popular apps. So, the idea of bringing the source code of an app which is available on Google together with the latest refactoring tools is the primary contribution of this research. However, the tool which we are proposing can be flexible to allow future baseline factors to be included in the evaluation process. The proposed solution in its simplified and final form is similar to the Echo-Star Schema or the "energy efficiency information sticker" which is placed on electrical home appliances. We will try to demonstrate the level of energy efficiency of each app in a similar star rating schema. This rating will be shown beside each app on Google Play aside from the ordinary reviews of current users. With this, we intend to enhance the authority of an Android app user to be able to decide which application to use based the level of energy efficiency which is calculated using verified and tested tools. The additional new part of our contribution here is that the Android users will be using a new preventive strategy which will not cost any waste of energy. The users will be standing at the door of their smartphones and allowing in only energy efficient apps in rather than letting whatever apps in and then trying to find a way to balance the energy consumption which will also cost energy consumption. For the technical part, the proposed tool is based on the principle of simple mathematical comparison. So, we first measure the maximum amount of energy consumption for the application by running it with its fullest capacity for a specified period of time on a simulated Android environment. Then we pass the source code of the app among the available refactoring tools in order to generate an energy friendly version of the code. After that, we measure again the maximum amount of energy consumption for the application by running it with its fullest capacity for the same period of time on the same simulated Android environment. Finally, the greater the difference between the two readings, the weaker the Energy Efficiency Index for the application is, or in other words, fewer stars. Conversely, the smaller the difference between the two readings, the more the original code of the application shows adherence to the energy-friendly development practices, which means more stars. The top question which comes in mind is why not to easily provide the users with energy efficient version of the app which was generated after passing it through the refactoring tools instead of demonstrating its default energy efficiency level? The answer to this question is based on the code handling policy which is followed by Google Play in addition to the agreements between the developers and Google which avoids implementing alterations to the source code of an app except for scanning it for security and privacy breaching loopholes, so usually the code is uploaded and provided as is to end-users after in addition to notifying them about the required permission for the app to function correctly. This also raises a very big concern in terms of the need for the application. Some applications that are currently running cannot be replaced by others because of their popularity, e.g., WhatsApp, Twitter, Snapchat, etc. Even if the star rating showed these applications as energy greedy, users will still install and use them on their smartphones. To address this concern, we believe that a new area of inspiration is now open for developers to provide different versions of applications: basic, light, or full. Each version will have a different level of energy vs. modern features, and end users can choose both based on their own needs. Also, this will encourage developers to apply whatever recommendations are available on their apps to provide the highest energy-friendly ratings. In addition to the above, we proposed this option to end-users to be able to choose the best energy-friendly app from the list of apps that shares the same high-level goal, for example, texting apps, music players, VOIP apps, etc.. Therefore, going through the usefulness of each app is beyond the scope of our research. To be more clear, considering the echo-star rating sticker which is placed on home appliances, even-though appliances form the same category do not perform similar tasks the sticker does not go through the usefulness of each home appliance e.g. a washing machine of model X performs additional features (tasks) than a washing machine from model Y. But finally, the echo-star rating sticker shows only how much energy-friendly are both machines without going through the usefulness of each machine.

6.4.9 Approach

The main concept of our approach is to bring together developers, app repositories (Google Play), and researchers who have proposed automated energy-aware approaches to restructuring Android apps and those who have developed energy profilers. All of these parties will act as inputs to generate a knowledge-based schema that will help end users to decide which applications to choose and install. An approach that previous research has proven to be efficient in saving energy through an automated framework is code refactoring (Banerjee and Roychoudhury, 2016). The previous research followed either an anti-pattern or pattern-based refactoring approach (Li and Gallagher, 2016). Since we need a comparable reliable factor and in order for the model to be interoperable, we used one tool from each approach. The tool, called Energy-Aware Refactoring Approach for Mobile Apps (EARMO), proposed by Morales et al. (Morales et al., 2018), follows a novel anti-pattern correction approach that accounts for energy consumption when refactoring mobile anti-patterns. The results generated by this tool were used as a primary factor for our study. Another tool that uses the refactoring approach is Leafactor, proposed by Cruz et al., which refactors the source code to follow a set of patterns known to be energy efficient (Cruz, Abreu and Rouvignac, 2017). Here we propose a flexible multicriteria star-rating evaluation model (SREM) to generate tentative energy rating labels for Google Play store apps by adding the refactoring approach as the first criterion to be used for the rating process. The model, shown in Figure 6.16, shows where the tools are to be used in the process. At the first stage, the source code of an Android application is provided. The source code is then installed on an Android platform before measuring its power consumption. The energy measurements are generated by profilers, which is the preferred solution since they allow finer-grained measurements and also because the experiments can be reproduced, which is not always possible with hardware solutions; PowerTutor was adapted to automate the profiling procedure. The amount of power consumption that is first reported by PowerTutor is recorded as E_1 mW/time. After that, the app goes through the refactoring process, which is expected to refine the code in order to make it more energy-efficient. Next, the app is run again with its new refactored code in order to measure its new power consumption, E_2 mW/time. Finally, a simple comparison can then show the difference and be scaled to an equivalent 1–5 stars. Compared to E_1, as E_2 shrinks after refactoring, fewer stars are given to the app. Whenever E_2 stays the same or changes slightly compared to E_1, more stars are given to the app. Based on the previous results, we can now help end users to have an initial indication of the energy-efficiency of the app they are about to install and use. We believe that the SREM approach will enhance the role of end users to act not only for energy-saving techniques, but to also participate as decision-makers by choosing what apps suit them in terms of energy consumption. As Figure 6.16 shows, we also kept the model open and flexible for any additional tools or approaches that can improve the power consumption measurements or the approaches used for converting the source code of any app to be energy-efficient, and both improvements will increase the resolution of the comparison and improve the rating process. Although there is a large body of work on the energy consumption of Android apps, and research on saving energy suggests estimating the energy usage of an app, compared to our approach, most of these techniques do not compare apps to their lighter version in terms of power consumption. Our approach leverages the rating process to obtain the energy consumption of Android apps more efficiently.

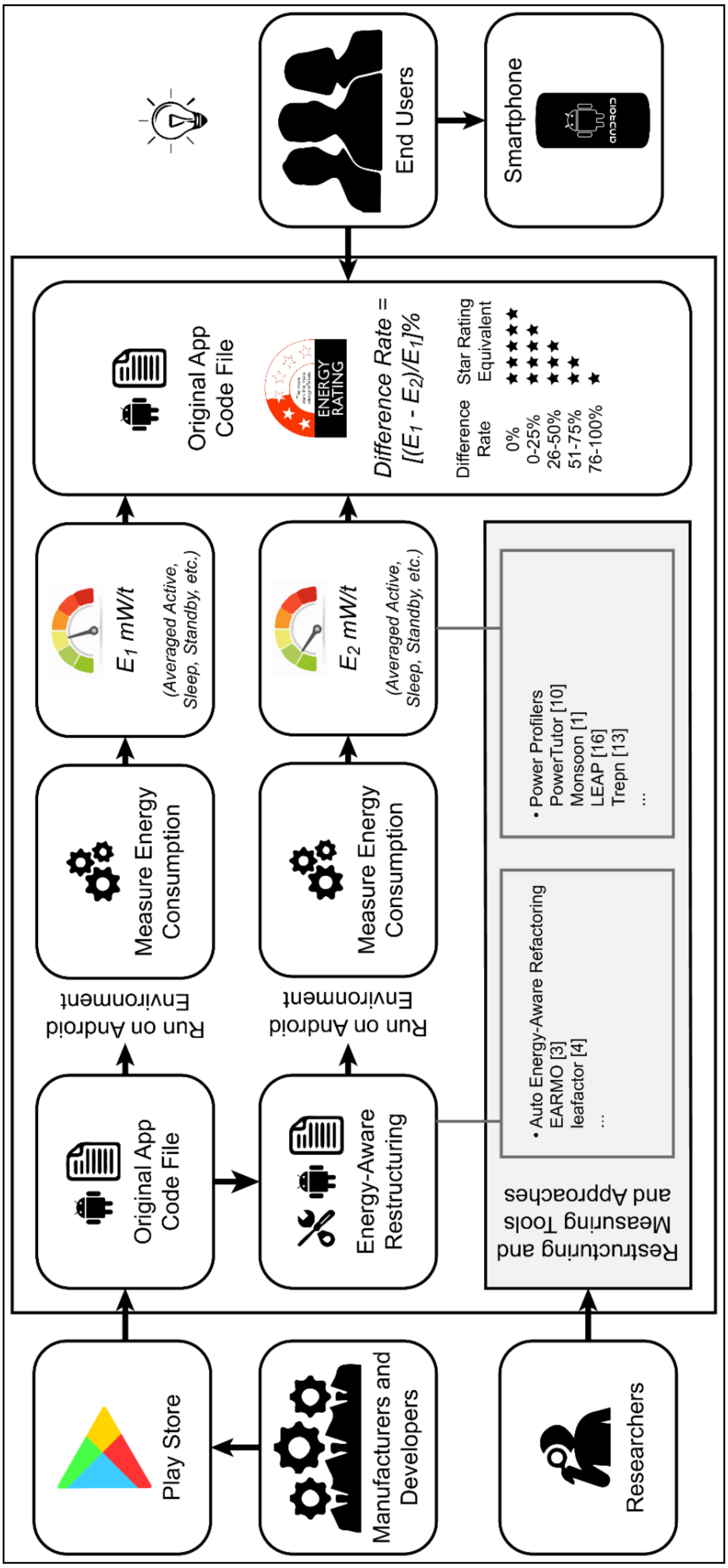


Figure 6.16: Star-rating evaluation model (SREM)

6.4.10 Evaluation

Since the SREM follows a comparison-based approach to rate apps, in addition to our model tending to combine and leverage the use of previously evaluated approaches, what comes next is to evaluate the outcomes of the whole model by knowing the total amount of energy saved after implementing the SREM. We conducted an initiatory evaluation of the SREM to demonstrate its ability to rank apps according to differences in power measurements before and after using the reconstructing approaches. To generate ground-truth estimates, we picked 20 open-source apps to act as a primary evaluation sample. Since we are proposing inter-usage of current automated energy-aware app restructuring and measuring approaches, we first needed to re-emphasize the efficiency of the current approaches. We used one approach as an automated energy-aware refactoring approach. Refactoring was proven to reduce the amount of energy consumption according to Morales et al., who followed a novel anti-pattern correction approach that accounts for energy consumption when refactoring mobile anti-patterns, EARMO. Another approach is Leafactor, proposed by Cruz et al., which refactors the source code to follow a set of patterns known to be energy efficient. Table 18 demonstrates the results of using EARMO and Leafactor with the set of applications that we prepared for the evaluation. The first column refers to the app names shown by abbreviations. The second column refers to the amount of energy consumption before the refactoring per 30 minutes of continuous exhaustive usage (abbreviated by *ECBR)*. The third column, which has two sub-columns, refers to the amount of energy consumption of the app after implementing the two refactoring approaches per 30 minutes of continuous exhaustive usage (abbreviated by *ECAR*). The two sub-columns show the use of EARMO and Leafactor. The fourth column shows the energy consumption of the app after averaging the consumption measurements taken from the two approaches. Then we show the amount of change and the change rate. The rate is calculated according to the equation represented in the SREM (Figure 6.16). So whenever the rate increase is large, it indicates that the refactoring approach had to wipe a good number of patterns related to energy-greedy processing. On other hand, whenever the percentage indicates a small change, it shows that the refactoring tools did not have to go through a lot of effort to remove unwanted patterns. This clearly shows that unwanted patterns either did not exist or existed in low numbers. Measuring the difference in consumption and using this to rate the app is the primary point that was evaluated in this section, while considering previous evaluations of both refactoring approaches used.

App	ECBR [1]	ECAR [2]		Average ECAR	Change Rate	Star Rating
		Leafactor	*EARMO*			
App1	895 mW	787 mW	795 mW	795 mW	13%	*****
App2	285 mW	258 mW	250 mW	250 mW	12%	*****
App3	153 mW	150 mW	153 mW	153 mW	1%	*****
App4	450 mW	150 mW	198 mW	198 mW	101%	*
App5	640 mW	505 mW	516 mW	516 mW	25%	****
App6	321 mW	150 mW	120 mW	120 mW	138%	*
App7	125 mW	100 mW	100 mW	100 mW	25%	****
App8	977 mW	850 mW	750 mW	750 mW	22%	****
App9	154 mW	150 mW	132 mW	132 mW	9%	*****
App10	820 mW	550 mW	498 mW	498 mW	56%	***
App11	604 mW	540 mW	498 mW	498 mW	16%	*****
App12	650 mW	600 mW	620 mW	620 mW	7%	*****
App13	410 mW	350 mW	360 mW	360 mW	15%	*****
App14	325 mW	320 mW	310 mW	310 mW	3%	*****
App15	264 mW	250 mW	198 mW	198 mW	18%	*****
App16	169 mW	105 mW	150 mW	150 mW	33%	****
App17	97 mW	90 mW	85 mW	85 mW	11%	*****
App18	364 mW	309 mW	278 mW	278 mW	24%	****
App19	215 mW	215 mW	215 mW	215 mW	0%	*****
App20	347 mW	340 mW	300 mW	300 mW	8%	*****

Table 18 Results of using Energy-Aware Refactoring Approach for Mobile Apps (EARMO) and Leafactor as inputs to SREM with 20 apps to generate star ratings.

In order to evaluate the efficiency of the model as an addition to Google Play store apps, which will act as labeling to guide end users, a future study is to be implemented in the next chapter to know the effect of the SREM on the decisions of end users and, as a result, on the main goal of extending the battery life of smartphones. The next chapter will address the rates of those who are still selecting power-greedy apps and those who decided to switch to power-friendly apps.

6.4.11 Limitations of Refactoring

Refactoring is a software maintenance activity that transforms the structure of a code without altering its behavior. It is widely used by software maintainers to counteract the effects of design decay due to the continuous addition of new functionalities or the introduction of poor design choices. The process of refactoring requires the identification of places where code should be refactored (e.g., anti-patterns). Developers also have to determine which kind of refactoring operations can be applied to the identified locations. This step is cumbersome, as different anti-patterns can have different impact on the software design. Moreover, some refactoring operations can be conflicting, hence, finding the best combination of refactorings is not a trivial task. Therefore, researchers have reformulated the problem of automated refactoring as a combinatorial optimization problem and proposed different techniques to solve it. The techniques range from single-objective approaches to evolutionary techniques like genetic algorithm, and multiobjective approaches. Recent works (Lee, Kim and Hong, 2016) have provided empirical evidence that software design plays also an important role in the energy consumption of mobile devices; i.e., high-level design decisions during development and maintenance tasks impact the energy consumption of mobile apps. More specifically, these research works have studied the effect of applying refactorings to a set of software systems; comparing the energy difference between the original and refactored code.

6.5 Chapter Summary

The chapter was able to classify the different levels of power-usage among different smartphone resources. This helped to sort the smartphone components in terms of their level of power consumption. Also helped to extract applications permissions that interact with those phone components and sort these permission as per to their power-usage based on their interaction with different levels of power-usage components. Then the study started rating the permissions on a scale of six stars to demonstrate their level of power consumption, taking into consideration using these permissions under the two most familiar network connections which are Wi-Fi and Cellular. Then the results were used to provide a clear strategy to users who wanted to view the amount of power consumption of an application before downloading this application. Which was finally achieved by putting a final strategy to rate an application, then we gave a much wider image by rating each applications category in terms of power consumption levels. We then introduced the SREM as an approach to estimates the energy-friendly level of Android apps and demonstrates it in a star-rating schema similar to the energy-efficiency labels placed on home appliances. The main aim of this work was to generate the number of stars for each application from the difference between the amount of ordinary power consumption and the amount of power consumption after applying an energy-aware restructuring approach to the app. We relied on the refactoring approach as a previously evaluated efficient approach to restructure apps to energy-aware versions. We also proposed using the rating schema by Android app stores to enhance the role of end users in deciding which apps meets their energy-consumption needs.

Chapter 7. Simulation of Usage and Findings

7.1 Simulation Prerequisites

After implementing the previous solution, the final proposed outline of the Google Play store search results will look similar to the screenshot shown in Figure 7.1. Users will be able to have a clear indication of the energy-efficiency level of each application offered in Google Play Store. As per to what we indicated in a previous section this will solve the missing piece of the puzzle between the end-users and the applications in terms of educating the user about the adherence of a specific app to the green-coding practices.

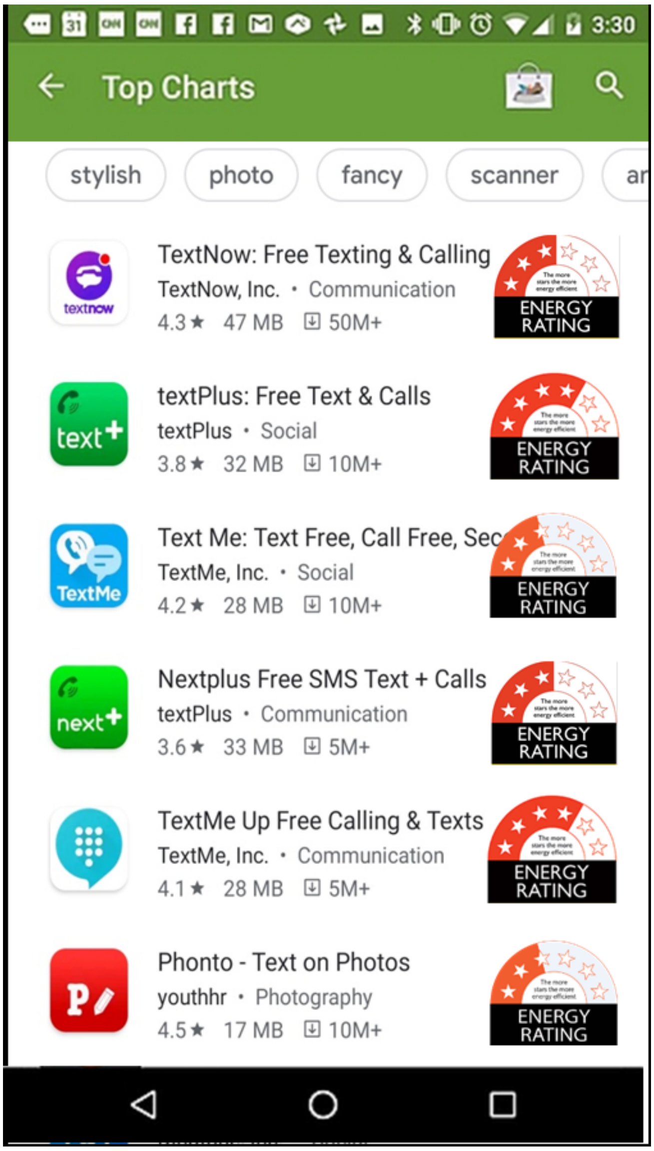


Figure 7.1: The final proposed outline of the Google Play store

In order to simulate the usage of the proposed solution and to measure the efficiency of the model we have taken into account the factors that could distinguish different users of smartphones. For example, the design of the user's workspace (indoor / outdoor), age, gender, user's application categories of interests, etc. A well-known example of the current “One Size Fits All” technique is “Samsung Ultra Power Saving Mode” which pressures the user to end-up using a black and white screen smartphone even if the user was a 60-year-old book reader or a 17-year-old heavy online gamer for 14 days of battery life. The following chapter simulates our novel approach which was introduced as a new addition to the existing detective power-saving school. The suggested implementation is based on the grouping of smartphones users into categories based on various criteria as shown in Figure 7.2 below.

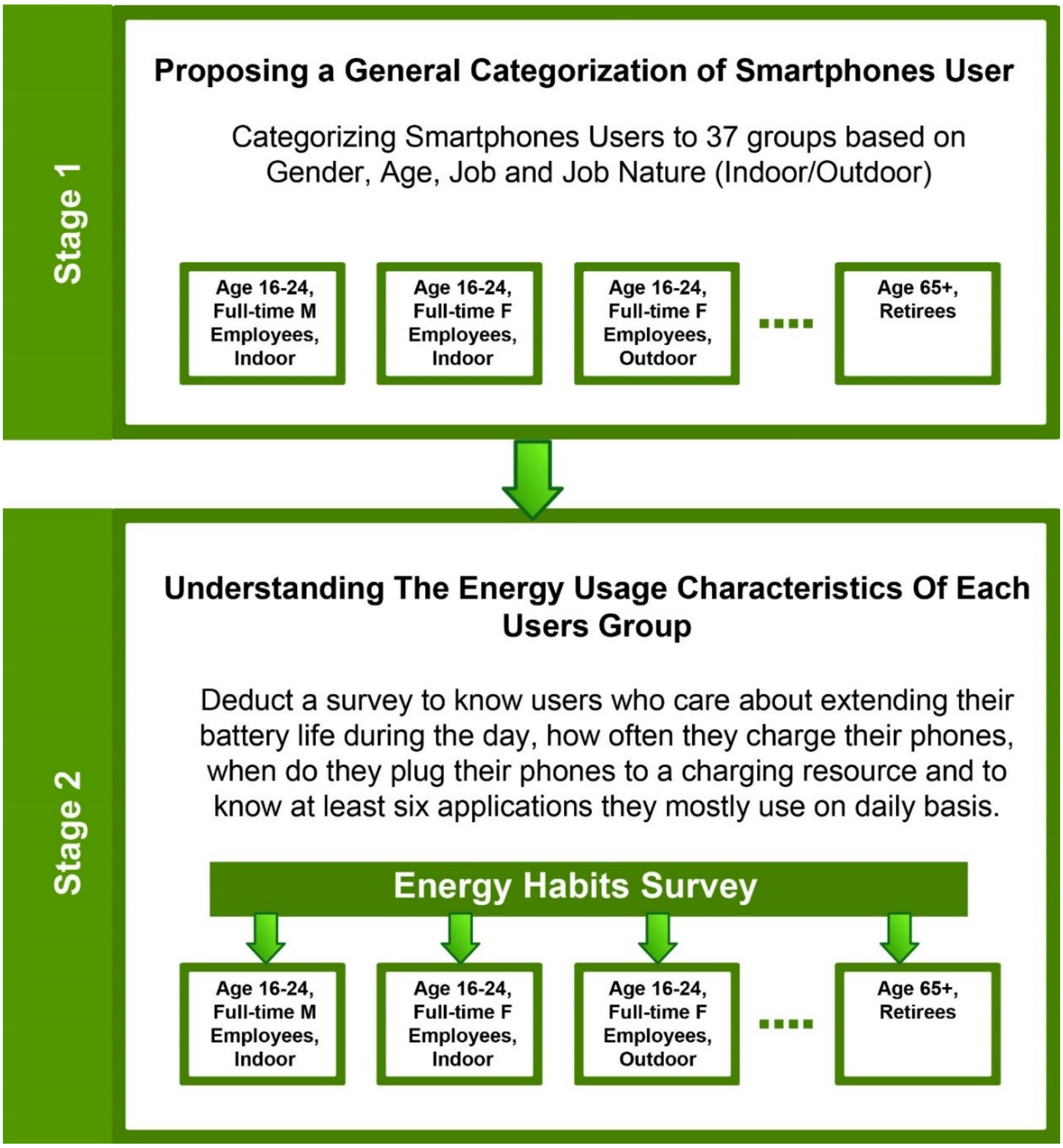


Figure 7.2: Stages 1 & 2 of the Simulation of Usage Process

7.1.1 Proposing Categories of Smartphone Users Based on Suggested Criteria

In order to study the power use patterns of a smartphone owner, the study had to classify all smartphones users into categories of users. This distinction is based on the general sectors of society taking into account age, the work nature of the user and the various rates of concern within the different types of applications. Using the job nature of a smartphone user as a grouping factor refers to the place where the smartphone owners spends much of their time. This will give an indication of the accessibility of battery recharging resources from around the smartphone owners, plus the kind of network connectivity the users mostly use, e.g. Wi-Fi or cellular. By listing all the previous use patterns beside the categories of applications used and commonly installed by smartphone owners, the study is supposed to be able to extract a set of findings to illustrate the different rates of power consumption across different types of smartphone owners. These findings will allow us to put in place a policy based on the age of the user, the interests and the work nature, in order to help the users to save more of their battery life. At the same time, taking into account the availability of the recharging resources around the user.

By having the above results in hand, this will enhance the possibility of answering to the question related to the efficiency of the current "one-size-fits-all" preventive energy-saving techniques after providing different preventive energy-saving strategies for different classifications of smartphones users. The following figures 7.3 and Figure 7.4 describe the proposed classification with the average age and job nature of each classification field for both male and female users:

Users Age Range	Job Nature
8 to 16	Full-time Students
16 to 24	Full-time Students
	Part-time Employees
	Full-time Employees
25 to 34	Part-time Students
	Full-time Employees
	Businessmen
35 to 64	Part-time Students
	Full-time Employees
	Businessmen
	Part-time Employees
65+	Retirees

Figure 7.3: Proposed grouping of male smartphone users with average age and job nature

Users Age Range	Job Nature
8 to 16	Full-time Students
16 to 24	Full-time Students
	Part-time Employees
	Full-time Employees
25 to 34	Part-time Students
	Full-time Employees
	Businessmen
	Housewives
35 to 64	Part-time Students
	Full-time Employees
	Businessmen
	Part-time Employees
	Housewives
65+	Retirees
	Housewives

Figure 7.4:
Poposed categorization of female smartphone users with average age and jobs in each market

As per the description suggested above, the analysis continued with the introduction of an important additional factor to the “Indoor”/“Outdoor” environment of the user job nature. Other groups that do not have this factor were assumed by common sense to have either option. The following Figure 7.5 and Figure 7.6 display the potential user categories with the average age and job nature of each category after adding the “Indoor”/“Outdoor” factor for both male and female users:

Users Age Range	Job Nature	
8 to 16	Full-time Students	
16 to 24	Full-time Students	
	Part-time Employees	Indoor
		Outdoor
	Full-time Employees	Indoor
		Outdoor
25 to 34	Part-time Students	
	Full-time Employees	Indoor
		Outdoor
	Businessmen	
35 to 64	Part-time Students	
	Full-time Employees	Indoor
		Outdoor
	Businessmen	
	Part-time Employees	Indoor
		Outdoor
65+	Retirees	

Figure 7.5: Proposed classification of male smartphone users with the average age and job nature after adding the Indoor/Outdoor factor to each category.

Users Age Range	Job Nature	
8 to 16	Full-time Students	
16 to 24	Full-time Students	
	Part-time Employees	Indoor
		Outdoor
	Full-time Employees	Indoor
		Outdoor
25 to 34	Part-time Students	
	Full-time Employees	Indoor
		Outdoor
	Businessmen	
	Housewives	
35 to 64	Part-time Students	
	Full-time Employees	Indoor
		Outdoor
	Businessmen	
	Part-time Employees	Indoor
		Outdoor
	Housewives	
65+	Retirees	
	Housewives	

Figure 7.6: Proposed classification of female smartphone users with the average age and job nature after adding the Indoor/Outdoor factor to each category.

After the above classification has been done, all smartphone users have been categorized into 17 potential male groups and 20 suggested female groups as follows:

Male Smartphones Users Proposed Groups

1- Age 8-16, Full-time Students

2 - Age 16-24, Full-time Students

3 - Age 16-24, Part-time Employees, Indoor

4 - Age 16-24, Part-time Employees, Outdoor

5 - Age 16-24, Full-time Employees, Indoor

6 - Age 16-24, Full-time Employees, Outdoor

7 - Age 25-34, Part-time Students

8 - Age 25-34, Full-time Employees, Indoor

9 - Age25-34, Full-time Employees, Outdoor

10 - Age25-34, Businessmen

11 - Age 35-64, Part-time Students

12 - Age 35-64, Full-time Employees, Indoor

13 - Age 35-64, Full-time Employees, Outdoor

14 - Age 35-64, Businessmen

15 - Age 35-64, Part-time Employees, Indoor

16 - Age 35-64, Part-time Employees, Outdoor

17 - Age 65+, Retirees

Female Smartphones Users Proposed Groups:

1 - Age 8-16, Full-time Students

2 - Age 16-24, Full-time Students

3 - Age 16-24, Part-time Employees, Indoor

4 - Age 16-24, Part-time Employees, Outdoor

5 - Age 16-24, Full-time Employees, Indoor

6 - Age 16-24, Full-time Employees, Outdoor

7 - Age 25-34, Part-time Students

8 - Age 25-34, Full-time Employees, Indoor

9 - Age25-34, Full-time Employees, Outdoor

10 - Age25-34, Businesswomen

11 - Age 25-34, Housewives

12 - Age 35-64, Part-time Students

13 - Age 35-64, Full-time Employees, Indoor

14 - Age 35-64, Full-time Employees, Outdoor

15 - Age 35-64, Businessmen

16 - Age 35-64, Housewives

17 - Age 35-64, Part-time Employees, Indoor

18 - Age 35-64, Part-time Employees, Outdoor

19 - Age 65+, Retirees

20 - Age65+, Housewives

7.1.2 Studying the Interests of Each Users Category among Google Play Store Applications Categories

By recalling the categories of Google Play applications from chapter 6 (Table 13), our next step is to map the groups of our proposed users to these categories in order to detect the interests of each group. These interests are to be translated into the categories of previously mentioned Google Play applications, this step will be achieved by collecting the number of installed applications that each group uses which was also part of the survey implemented on chapter 6 (See Appendix I for the used questionnaire). After having the numbers in hand, it was possible to recall our results from the same chapter on what was classified as "Energy-Hungry Applications Permissions" (Table 7) and use it to identify the levels of energy consumption among the proposed groups of smartphones users.

Following the same previous survey, users were asked to list six or more applications they mostly uses on a daily basis. The name of each application in each user list was replaced by the name of the category of the same application. After that, the lists of categories for each user group were averaged and converted to percentages to show the popularity of each Google Play application category for each user group. The following Figure 7.7, Figure 7.8 and Figure 7.9 shows the final results of the survey for both male and female proposed user groups. However, the figures were shortened for visual representation, full tables are listed in Appendix II.

Users Age Range	Smartphone User Category		Social	Tools	Communication	Personalization	Lifestyle	Productivity	Travel & Local	Health & Fitness	Business	Music & Audio
8 to 16	Full-time Students		7%	3%	10%	0%	0%	0%	0%	7%	0%	10%
16 to 24	Full-time Students		7%	7%	7%	2%	5%	2%	0%	5%	0%	10%
	Part-time employees	Indoor	7%	7%	7%	2%	5%	5%	0%	5%	2%	10%
		Outdoor	4%	8%	6%	2%	2%	6%	2%	2%	2%	10%
	Full-time Employees	Indoor	10%	5%	5%	5%	2%	7%	0%	5%	5%	10%
		Oudoor	6%	6%	4%	4%	2%	8%	4%	2%	4%	10%
25 to 34	Part-time students		4%	4%	4%	2%	2%	9%	4%	2%	4%	4%
	Full-time employees	Indoor	6%	3%	3%	3%	3%	9%	3%	3%	6%	3%
		Outdoor	3%	5%	8%	3%	3%	5%	8%	8%	3%	8%
	Buisenssmen		2%	2%	7%	2%	2%	2%	7%	2%	11%	2%
35 to 64	Part-time students		3%	8%	5%	0%	0%	0%	5%	3%	5%	3%
	Full-time employees	Indoor	5%	5%	8%	3%	3%	5%	5%	5%	8%	3%
		Outdoor	7%	7%	9%	2%	2%	7%	7%	5%	5%	2%
	Buisenssmen		2%	2%	7%	2%	2%	2%	11%	2%	11%	2%
	Part-time employees	Indoor	2%	4%	4%	6%	4%	6%	4%	4%	6%	2%
		Outdoor	4%	6%	6%	4%	6%	9%	2%	2%	9%	4%
65+	Retirees		2%	2%	5%	0%	2%	0%	5%	7%	2%	2%

Figure 7.7: Average percentage of applications for each category of applications that are installed and frequently used by various sample male smartphone users

Users Age Range	Smartphone User Category		Social	Tools	Communication	Personalization	Lifestyle	Productivity	Travel & Local	Health & Fitness	Business	Music & Audio
8 to 16	Full-time Students		9%	3%	12%	0%	6%	0%	0%	3%	0%	12%
16 to 24	Full-time Students		9%	7%	9%	2%	7%	2%	0%	2%	0%	11%
	Part-time employees	Indoor	10%	7%	7%	2%	7%	5%	0%	2%	2%	12%
		Outdoor	7%	9%	7%	2%	7%	7%	2%	4%	2%	9%
	Full-time Employees	Indoor	8%	4%	6%	6%	8%	2%	0%	2%	2%	10%
		Oudoor	9%	4%	7%	4%	9%	4%	2%	4%	2%	7%
25 to 34	Part-time students		6%	4%	4%	2%	6%	8%	4%	4%	4%	6%
	Full-time employees	Indoor	9%	3%	6%	3%	9%	9%	3%	6%	3%	9%
		Outdoor	5%	2%	7%	2%	7%	5%	7%	10%	2%	7%
	Buisenss women		4%	2%	6%	2%	6%	2%	6%	4%	10%	6%
	Housewives		9%	2%	7%	2%	7%	0%	4%	9%	0%	7%
35 to 64	Part-time students		4%	6%	4%	0%	6%	0%	4%	4%	4%	6%
	Full-time employees	Indoor	6%	6%	6%	2%	6%	4%	4%	8%	4%	6%
		Outdoor	6%	6%	9%	2%	6%	6%	4%	6%	4%	6%
	Buisenss women		4%	2%	6%	2%	6%	2%	9%	6%	9%	6%
	Housewives		8%	2%	6%	2%	6%	0%	4%	8%	2%	6%
	Part-time employees	Indoor	9%	3%	7%	3%	7%	5%	3%	3%	3%	5%
		Outdoor	7%	4%	5%	4%	5%	5%	2%	4%	5%	7%
65+	Housewives		4%	2%	4%	0%	7%	0%	2%	9%	2%	7%
	Retirees		4%	2%	4%	0%	6%	0%	4%	8%	2%	6%

Figure 7.8: Average percentage number of applications from each applications category that are installed and frequently used by different proposed smartphone female users

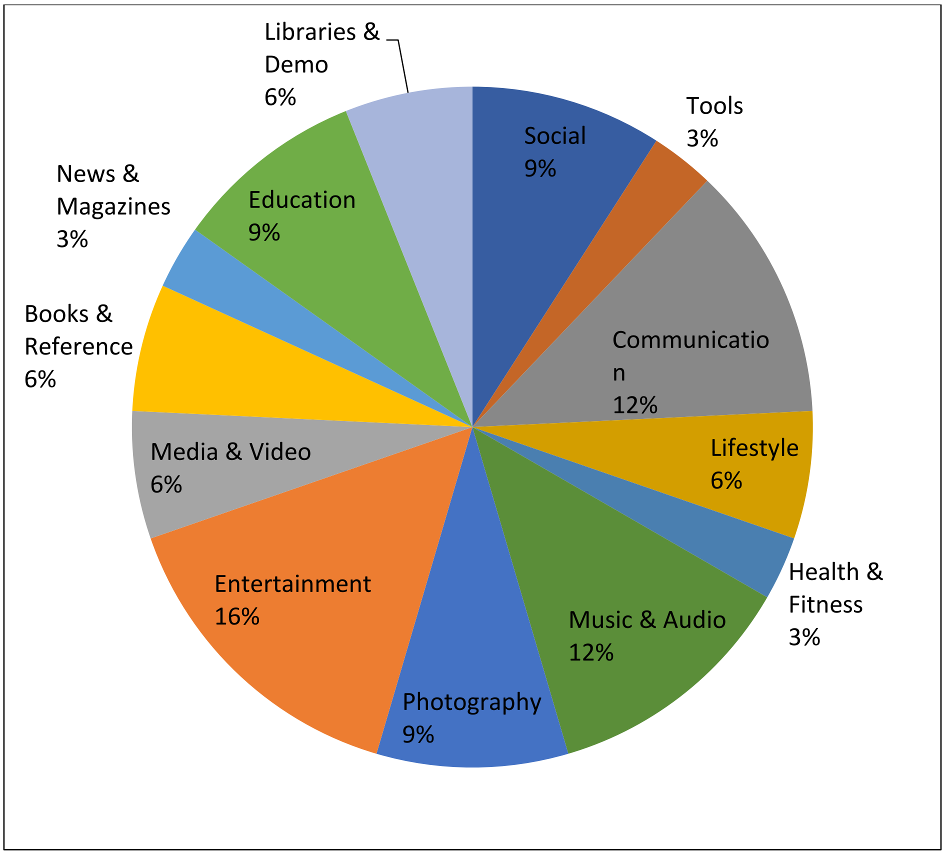


Figure 7.9: Percentage of each smartphone app category that belongs to the average user out of six users in the first user group "Female, 8-16 years of age, full - time students"

Following an approximation of the interests of each proposed user group by reading the above numbers, the next step is to find the average energy consumption rate for each category of users.

7.1.3 Calculating Approximate Energy Consumption Rate for each Group of Users and the Rank of each Group.

In order to calculate the energy consumption for each group of users, it is necessary to recall the results of the average amounts of energy consumption for each Google Play application category from Table 13 in chapter 6 and then to multiply it with the percentage of popularity of these categories among the categories installed by the groups of users. Additionally, we will find the sum of all results in order to find the weighted sum which will represent the average power consumption for each user group. For groups that are not explicitly classified into either "indoor" or "outdoor" users, the average power consumption value for their categories is calculated from the average of the two amounts of power consumption for each of their categories into their categories. Figure 7.10 shows the equation used to calculate the average consumption rate for each suggested group of users. An example of a calculated average consumption rate for a user group is shown in Figure 7.11.

$$\text{Average Power Consumption Rate of a User Group} = \sum \left(\text{Category Average Energy Consumption Amount per minute "Outdoor or Indoor"} * \text{Percentage of Popularity of each application category} \right)$$

Figure 7.10: Equation Used to Calculate the Average Consumption Rate of a User Group

Application Category	Popularity Among Installed Apps	App Category Energy Consumption Rate /min (Averaged)	Weighted Number for each Category
Social	0.07	~ 28 mAh	1.80
Tools	0.03	~ 26 mAh	0.87
Communication	0.10	~ 27 mAh	2.60
Personalization	0.00	~ 21 mAh	0.00
Lifestyle	0.00	~ 21 mAh	0.00
Productivity	0.00	~ 21 mAh	0.00
Travel & Local	0.00	~ 20 mAh	0.0
Health & Fitness	0.07	~ 17 mAh	1.13
Business	0.00	~ 17 mAh	0.00
Music & Audio	0.10	~ 17 mAh	1.60
Photography	0.07	~ 16 mAh	1.07
Entertainment	0.17	~ 17 mAh	2.67
Media & Video	0.17	~ 17 mAh	2.67
Shopping	0.00	~ 17 mAh	0.00
Transportation	0.00	~ 15 mAh	0.0
Medical	0.00	~ 14 mAh	0.00
Books & Reference	0.07	~ 12 mAh	0.80
Weather	0.00	~ 13 mAh	0.00
News & Magazines	0.00	~ 10 mAh	0.00
Education	0.10	~ 10 mAh	1.00
Libraries & Demo	0.07	~ 4 mAh	0.27
Average Energy Consumption Amount Per Minute			**~ 17 mAh**

Figure 7.11: An Example of a Calculated Average Consumption Rate for "Male, Age 8-16, Full-time Students" User Group

The following Figure 7.12 and Figure 7.13 demonstrates the number of power consumption for each group of proposed user groups and the rating of each group:

Users Age Range	Smartphone User Category		User Group Average Energy Consumption Amount /min	User Group Rank
8 to 16	Full-time Students		~ 17.27 mAh	6
16 to 24	Full-time Students		~ 17.27 mAh	6
	Part-time employees	Indoor	~ 16.64 mAh	8
		Outdoor	~ 18.19 mAh	5
	Full-time Employees	Indoor	~ 17.19 mAh	7
		Outdoor	~ 19.22 mAh	2
25 to 34	Part-time students		~ 15.98 mAh	12
	Full-time employees	Indoor	~ 15.63 mAh	14
		Outdoor	~ 18.28 mAh	4
	Businessmen		~ 16.57 mAh	10
35 to 64	Part-time students		~ 14.59 mAh	16
	Full-time employees	Indoor	~ 16.33 mAh	11
		Outdoor	~ 19.37 mAh	1
	Businessmen		~ 16.60 mAh	9
	Part-time employees	Indoor	~ 15.96 mAh	13
		Outdoor	~ 18.45 mAh	3
65+	Retirees		~ 14.66 mAh	15
Male Users Average Consumption Amount per minute			**~ 16.89 mAh**	

Figure 7.12: Amount of energy consumption for each group from the proposed male users groups and the ranking of each group.

Users Age Range	Smartphone User Category		User Group Average Energy Consumption Amount /min	User Group Rank
8 to 16	Full-time Students		~ 17.50 mAh	10
16 to 24	Full-time Students		~ 17.60 mAh	9
	Part-time employees	Indoor	~ 16.88 mAh	14
		Outdoor	~ 18.28 mAh	4
	Full-time Employees	Indoor	~ 16.56 mAh	15
		Outdoor	~ 18.85 mAh	1
25 to 34	Part-time students		~ 16.28 mAh	16
	Full-time employees	Indoor	~ 17.29 mAh	11
		Outdoor	~ 18.19 mAh	5
	Business women		~ 16.94 mAh	13
	Housewives		~ 17.89 mAh	7
35 to 64	Part-time students		~ 17.89 mAh	7
	Full-time employees	Indoor	~ 14.73 mAh	19
		Outdoor	~ 18.78 mAh	2
	Business women		~ 18.30 mAh	3
	Housewives		~ 17.14 mAh	12
	Part-time employees	Indoor	~ 16.00 mAh	17
		Outdoor	~ 18.08 mAh	6
65+	Housewives		~ 14.98 mAh	18
	Retirees		~ 17.88 mAh	8
Female Users Average Consumption Amount per minute			**~ 17.30 mAh**	

Figure 7.13: Amount of energy consumption for each category from the proposed groups of female users and the ranking of each group.

As shown in the above, the user group which can be classified as the most energy consuming group from the list of proposed male users is “Age 35 to 64, Full-time employees, Outdoor”. While the group that can be classified as the least energy consuming group form the same list of male users is “Age 35 to 64, Part-time students”. On the other hand, from the full list of female users, the group which can be considered as the most power consuming group is “Age 16 to 24, Full-time Employees, Outdoor” while the least energy consuming group from the same list of users is “Age 35 to 64 Full-time Employees, Indoor”.

7.2 Measuring the Amount of Energy Saved After the Implementation of the Proposed Solution

After having the previous prerequisites passed and after studying the different consumption habits for each user category, we can now start applying the proposed solution into specific groups of users in order to calculate the estimated amount of energy saved among these groups. In the following we will use statistical tables to list these groups of users with its current energy consumption rates and then estimate the amount of energy consumption after providing each user group with our proposed solution in the form of energy efficiency labels for apps they are either using or about to install.

We will assume that each group will go for the most energy efficient application from each category of applications this group is using. For example, if a user from the category “Female, Age 35-64, Full-time Employees, Indoor” is using an application from the entertainment application group, she will be given two to four options of applications with different power efficiency levels to choose from. So, we will assume that the user will use the most power efficient option. The amount of energy consumed by the same user is then measured before and after using the power-efficient application using one of the available power profilers which were used previously in this study. The results will be then shown and an analysis will be graphed in order to make the results clearer for reading.

7.2.1 Evaluating the Attention of Smartphones Users Groups towards Their Battery Life

After collecting the results of the survey, these results were analyzed in terms of the level of attention towards the phone battery level. The analysis showed that not all groups are concerned about the battery level because most of them have continuous access to a wide range of recharging resources. In the other hand, other categories of users are really concerned about battery usage and do not have the luxury of reaching a lot of recharging resources for reasons related to their job nature so they care more about saving their smartphone battery. The survey is given in Appendix I for reference. Table 19 shows the amount of attention each group pays towards their phone’s battery level. Each user group average energy consumption amount was recalled from the first section of this chapter.

Users Age Range	Smartphone User Category		User Group Average Energy Consumption Amount per minute	The level of attention towards the phone battery level
8 to 16	Full-time Students		~ 17.27 mAh	Moderate Attention
16 to 24	Full-time Students		~ 17.27 mAh	Moderate Attention
	Part-time employees	Indoor	~ 16.64 mAh	Weak Attention
		Outdoor	~ 18.19 mAh	High Attention
	Full-time Employees	Indoor	~ 17.19 mAh	Weak Attention
		Outdoor	~ 19.22 mAh	High Attention
25 to 34	Part-time students		~ 15.98 mAh	Moderate Attention
	Full-time employees	Indoor	~ 15.63 mAh	Weak Attention
		Outdoor	~ 18.28 mAh	High Attention
	Businessmen & Women		~ 16.57 mAh	High Attention
	Housewives		~ 13.88 mAh	Weak Attention
35 to 64	Part-time students		~ 14.59 mAh	High Attention
	Full-time employees	Indoor	~ 16.33 mAh	Weak Attention
		Outdoor	~ 19.37 mAh	High Attention
	Businessmen & & Women		~ 16.60 mAh	High Attention
	Part-time employees	Indoor	~ 15.96 mAh	Weak Attention
		Outdoor	~ 18.45 mAh	High Attention
	Housewives		~ 12.87 mAh	Weak Attention
65+	Retirees		~ 14.66 mAh	Moderate Attention
	Housewives		~ 12.12 mAh	Weak Attention

Table 19 The level of attention paid by different users groups towards their phone battery level

As shown on Figure 7.14, the next step is to extract only the user categories which pays a high level of attention towards their battery level rather than searching for recharging resources. This will then take us to the stage of simulating the usage of our solution among these specific user groups which will give a better resolution of the rehearsed usage. Table 20 shows the user categories which pays a high level of attention towards their phone's battery level, the average energy consumption amount for each group was recalled from the first sections of this chapter.

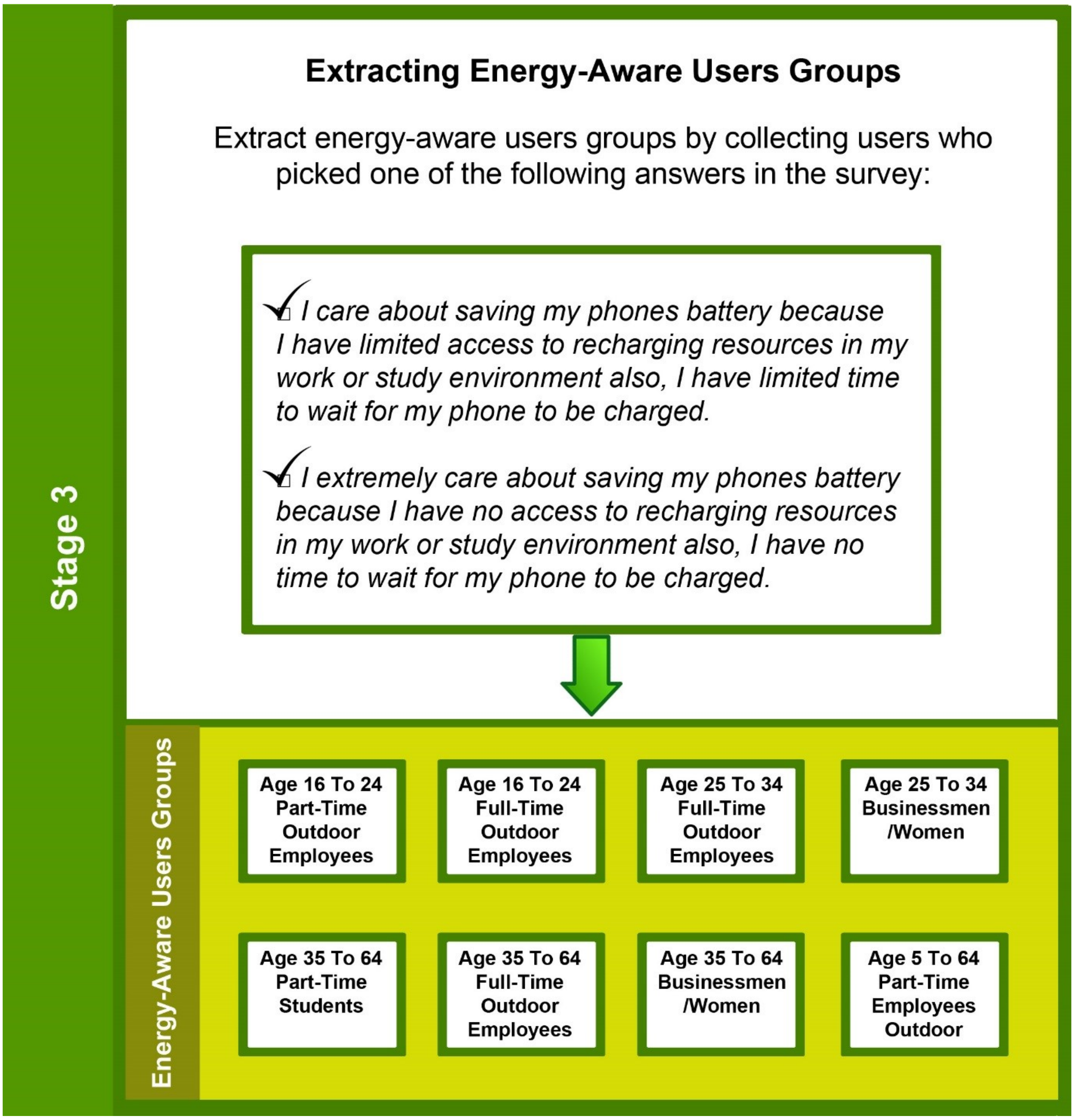


Figure 7.14: Stage 3 of the Simulation of Usage Process

Users Age Range	Smartphone User Category		User Group Average Energy Consumption Amount per minute	The level of attention towards the phone battery level
16 to 24	Part-time employees	Outdoor	~ 18.19 mAh	High Attention
	Full-time Employees	Outdoor	~ 19.22 mAh	
25 to 34	Full-time employees	Outdoor	~ 18.28 mAh	
	Businessmen & women		~ 16.57 mAh	
35 to 64	Part-time students		~ 14.59 mAh	
	Full-time employees	Outdoor	~ 19.37 mAh	
	Businessmen & women		~ 16.60 mAh	
	Part-time employees	Outdoor	~ 18.45 mAh	

Table 20 Groups of users who pay high level of attention towards their phone battery level (Energy-Concerned Users Groups)

7.2.2 Extracting Popular Apps & Apps Categories from Energy-Concerned Users Groups

After we were able to extract groups of users who pay high level of attention towards their phone battery level. Next, we will compare the amount of battery consumption before and after using the solution. The simulation of usage as described in the previous sections of the chapter is based on using an application from a specific application category and then using an alternative application from the same category which does the same primary task but is rated as more energy efficient. In order to achieve this task, we will recall the table of average percentage of applications for each category of applications that are installed and frequently used by various sample male and female smartphone users. Then we will focus on categories with the highest percentages in order to replace its apps with more energy-efficient apps as shown on Figure 7.15.

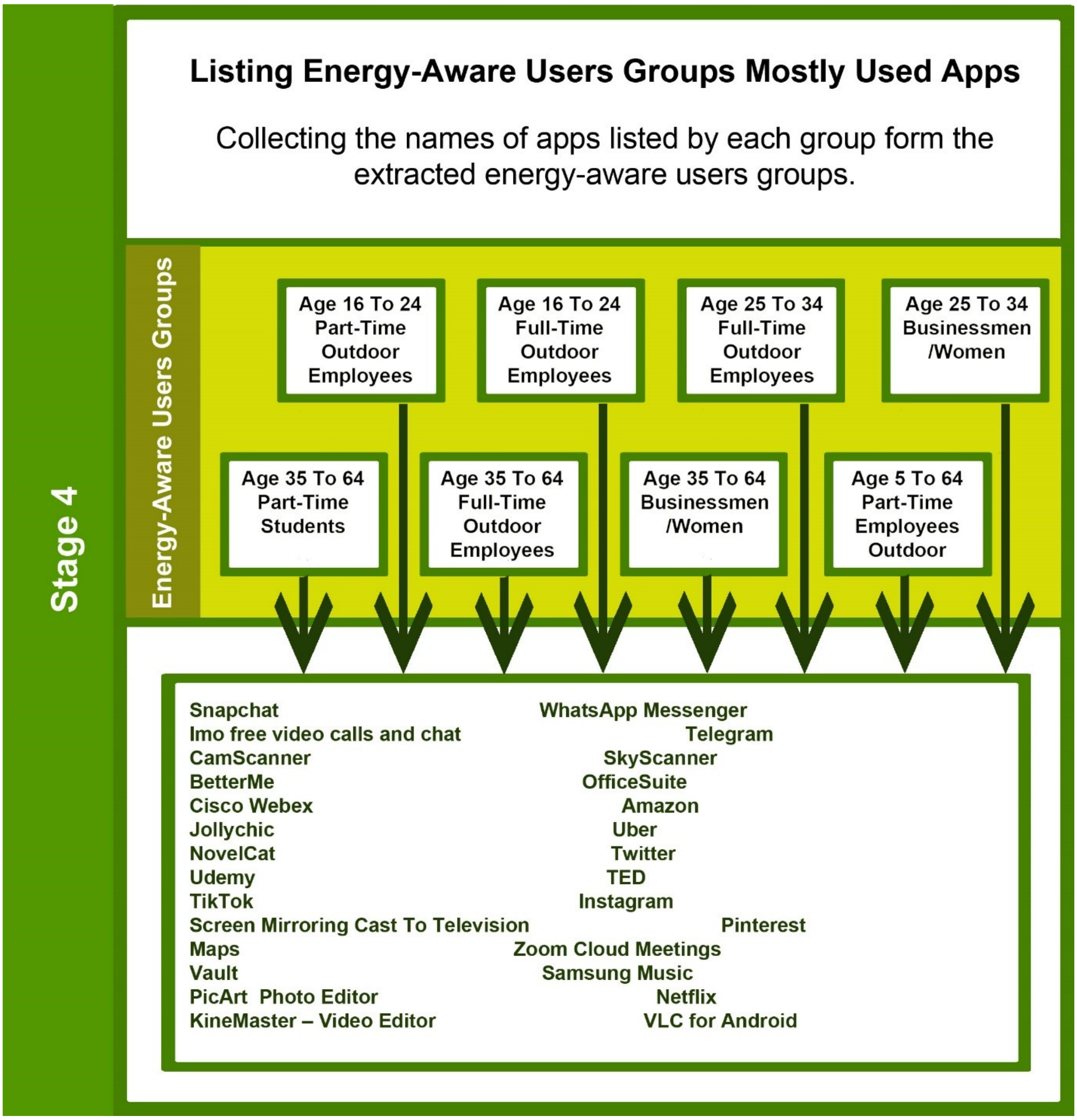


Figure 7.15: Stage 4 of the Simulation of Usage Process

In the following, Table 21 through 28 shows the selected users' groups after adding the 2nd dimension which shows the highest popular applications categories for each group. The tables also show the names of the applications which were listed by each survey participant under the group.

Apps Categories	Apps Mostly Used on Daily Basis
Social	• TikTok • Instagram • Snapchat
Tools	• DuckDuckGo Privacy Browser • Free VPN & Security • Screen Mirroring Cast To Television
Communication	• WhatsApp Messenger • Imo free video calls and chat • Telegram • Chrome • Gmail
Lifestyle	• Pinterest
Productivity	• CamScanner
Travel & Local	• SkyScanner • Maps
Health & Fitness	• BetterMe
Business	• OfficeSuite • Cisco Webex
Music & Audio	• Spotify
Entertainment	• IMdb • Netflix
Shopping	• Amazon • Jollychic
Maps & Navigation	• Uber
Books & References	• NovelCat
News & Magazines	• Twitter
Education	• Udemy • TED
Lifestyle	• Tinder
Video Players & Editors	• YouTube

Table 21 Most popular apps and categories used among users from 16 to 24 part-time outdoor employees' user group

Apps Categories	Installed Apps
Social	• TikTok • Instagram • Snapchat
Tools	• Hotspot Shield • Free VPN & Security
Communication	• WhatsApp Messenger • Imo free video calls and chat • Telegram
Lifestyle	• Pinterest
Productivity	• CamScanner
Health & Fitness	• BetterMe
Business	• OfficeSuite • Cisco Webex • Zoom Meeting
Music & Audio	• Spotify • Samsung Music
Entertainment	• Netflix
Media & Video	• KineMaster – Video Editor • VLC for Android
Shopping	• Amazon • Jollychic
Maps & Navigation	• Uber
Books & References	• NovelCat
News & Magazines	• Twitter
Parenting	• Be Closer

Table 22 Most popular apps and categories used among users from 16 to 24 full-time outdoor employees' user group

Apps Categories	Installed Apps
Social	• TikTok • Instagram • Snapchat
Tools	• Screen Mirroring Cast To Television
Communication	• WhatsApp Messenger • Imo free video calls and chat
Lifestyle	• Pinterest
Productivity	• CamScanner
Travel & Local	• SkyScanner
Health & Fitness	• BetterMe
Business	• OfficeSuite • Cisco Webex
Music & Audio	• Spotify
Photography	• PicArt Photo Editor
Entertainment	• Netflix
Media & Video	• KineMaster – Video Editor • VLC for Android
Shopping	• Amazon • Jollychic
Maps & Navigation	• Uber
Medical	• Davis's Drug Guide for Nurses • VIDAL
Books & References	• NovelCat
Weather	• RainViewer • Weather Live
News & Magazines	• Twitter
Education	• Udemy • TED

Table 23 Most popular apps and categories used among users from 25 to 34 full-time outdoor employee's user group

Apps Categories	Installed Apps
Social	• TikTok • Instagram • Snapchat
Tools	• Screen Mirroring Cast To Television
Communication	• WhatsApp Messenger • Imo free video calls and chat
Lifestyle	• Pinterest
Productivity	• CamScanner
Travel & Local	• SkyScanner • Maps
Business	• OfficeSuite • Cisco Webex • Zoom Cloud Meetings • Vault
Music & Audio	• Samsung Music
Photography	• PicArt Photo Editor
Entertainment	• Netflix
Media & Video	• KineMaster – Video Editor • VLC for Android
Shopping	• Amazon • Jollychic
Maps & Navigation	• Uber
Weather	• RainViewer • Weather Live
News & Magazines	• Twitter

Table 24 Most popular apps and categories used among users from 25 to 34 businessmen/women user group

Apps Categories	Installed Apps
Social	• TikTok • Instagram • Snapchat
Communication	• WhatsApp Messenger • Imo free video calls and chat • Telegram
Lifestyle	• Pinterest
Productivity	• CamScanner
Travel & Local	• SkyScanner
Business	• OfficeSuite • Cisco Webex
Music & Audio	• Spotify
Entertainment	• IMdb • Netflix
Shopping	• Amazon • Jollychic
Maps & Navigation	• Uber
Books & References	• NovelCat
News & Magazines	• Twitter
Education	• Udemy • TED

Table 25 Most popular apps and categories used among users from 35 to 64 part-time students' user group

Apps Categories	Installed Apps
Social	• Snapchat
Communication	• WhatsApp Messenger • Imo free video calls and chat • Telegram
Productivity	• CamScanner
Travel & Local	• SkyScanner
Health & Fitness	• BetterMe
Business	• OfficeSuite • Cisco Webex
Shopping	• Amazon • Jollychic
Maps & Navigation	• Uber
Books & References	• NovelCat
News & Magazines	• Twitter
Education	• Udemy • TED

Table 26 Most popular apps and categories used among users from 35 to 64 full-time outdoor employee's user group

Apps Categories	Installed Apps
Social	• TikTok • Instagram • Snapchat
Tools	• Screen Mirroring Cast To Television
Communication	• WhatsApp Messenger • Imo free video calls and chat
Lifestyle	• Pinterest
Productivity	• CamScanner
Travel & Local	• SkyScanner • Maps
Business	• OfficeSuite • Cisco Webex • Zoom Cloud Meetings • Vault
Music & Audio	• Samsung Music
Photography	• PicArt Photo Editor
Entertainment	• Netflix
Media & Video	• KineMaster – Video Editor • VLC for Android
Shopping	• Amazon • Jollychic
Maps & Navigation	• Uber
Weather	• RainViewer • Weather Live
News & Magazines	• Twitter

Table 27 Most popular apps and categories used among users from 35 to 64 businessmen/women user group

Apps Categories	Installed Apps
Social	• Snapchat
Communication	• WhatsApp Messenger • Imo free video calls and chat • Telegram
Productivity	• CamScanner
Travel & Local	• SkyScanner
Health & Fitness	• BetterMe
Business	• OfficeSuite • Cisco Webex
Shopping	• Amazon • Jollychic
Maps & Navigation	• Uber
Books & References	• NovelCat
News & Magazines	• Twitter
Education	• Udemy • TED

Table 28 Most popular apps and categories used among users from 35 to 64 part-time employees' outdoor user group

After having the above information in hand, we are now able to list all applications that are shared by the eight user Battery-Concerned users groups. The next step is to rate all these applications in terms of power efficiency as shown in Figure 7.16. This rating will be achieved using the permission-based rating which was covered in chapter 6.

Table 29 lists the popular applications shared by eight user groups all sharing the same concern of having enough battery life.

Users Groups	
16 To 24 Part-Time Outdoor Employees User Group 16 To 24 Full-Time Outdoor Employees User Group 25 To 34 Full-Time Outdoor Employees User Group 25 To 34 Full-Time Businessmen/Women User Group 35 To 64 Part-Time Students User Group 35 To 64 Full-Time Outdoor Employees User Group 35 To 64 Businessmen/Women User Group 35 To 64 Part-Time Employees Outdoor User Group	
Popular Apps	
Snapchat	WhatsApp Messenger
Imo free video calls and chat	Telegram
CamScanner	SkyScanner
BetterMe	OfficeSuite
Cisco Webex	Amazon
Jollychic	Uber
NovelCat	Twitter
Udemy	TED
TikTok	Instagram
Screen Mirroring Cast To Television	Pinterest
Maps	Zoom Cloud Meetings
Vault	Samsung Music
PicArt Photo Editor	Netflix
KineMaster – Video Editor	VLC for Android
RainViewer	Weather Live
Spotify	IMdb
Davis's Drug Guide for Nurses	VIDAL
Hotspot Shield	Free VPN & Security
Zoom Meeting	Be Closer
DuckDuckGo Privacy Browser	Chrome
Gmail	Tinder
YouTube	

Table 29 Popular Applications Shared by Eight User Groups All Sharing the Same Concern of Having Enough Battery Life

7.2.3 Rating the Apps Used by Energy-Concerned Users Groups

The process of rating each application from the above table starts now. It begins with listing all the required permissions for the application. These permissions are listed on Google Play Store which will then be mapped to the previous table proposed in chapter six. The table is recalled below and represented as Table 31. In order to demonstrate the rating in a clear and summarized way, the permissions of only one application is being showed below in Table 30. The final rating of the app is then shown in Table 32.

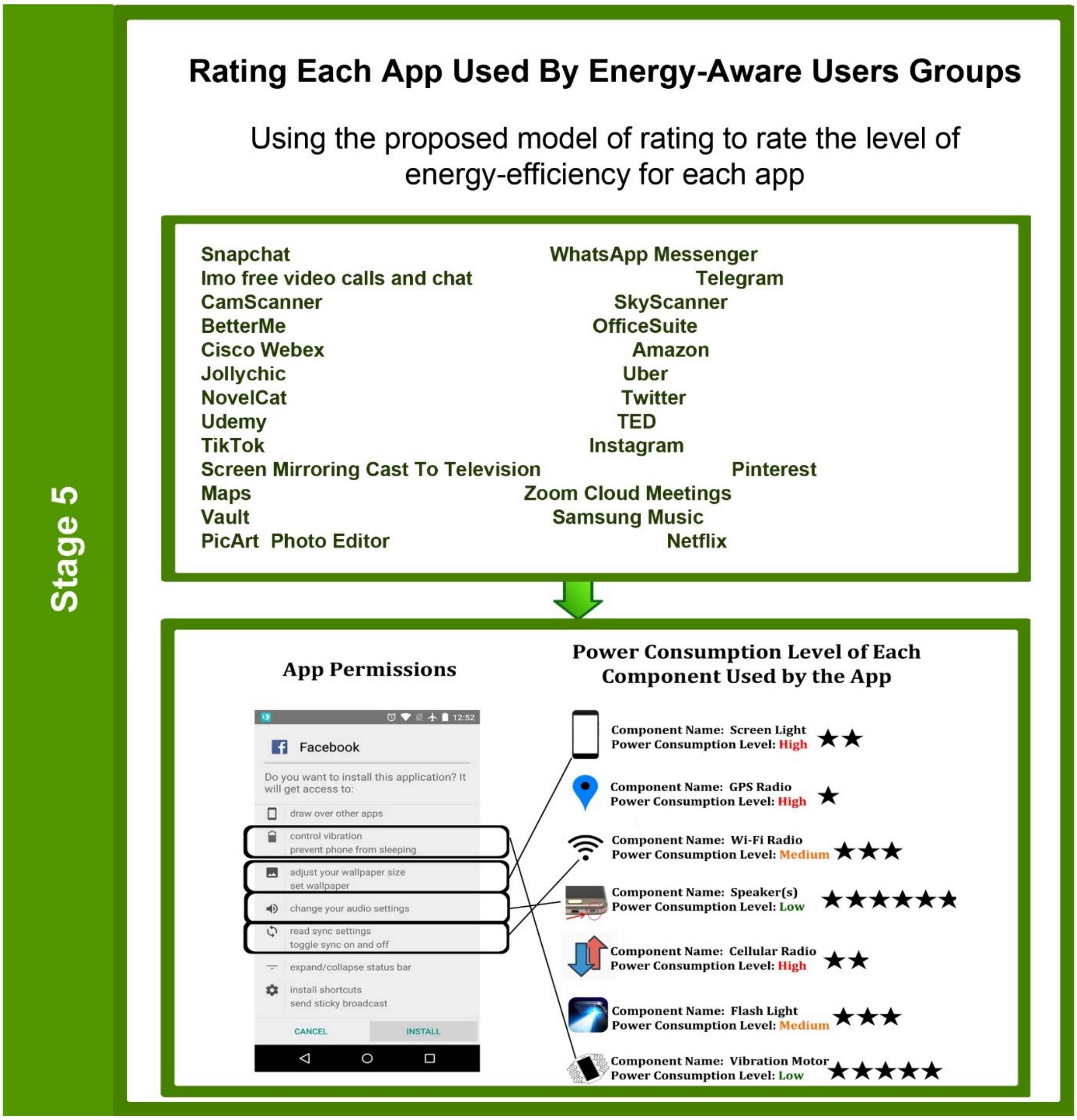


Figure 7.16: Stage 5 of the Simulation of Usage Process

Permissions for all versions of Snapchat app as per to January 2020	
read your own contact card	find accounts on the device
view Wi-Fi connections	take pictures and videos
record audio	read phone status and identity
modify or delete the contents of your USB storage	read the contents of your USB storage
modify or delete the contents of your USB storage	read the contents of your USB storage
precise location (GPS and network-based)	find accounts on the device
read your contacts	read phone status and identity
receive data from Internet	change your audio settings
access Bluetooth settings	control flashlight
control vibration	prevent device from sleeping
run at startup	view network connections
pair with Bluetooth devices	connect and disconnect from Wi-Fi
full network access	change network connectivity

Table 30 Permissions for all versions of Snapchat app (Snapchat - Apps on Google Play, 2020)

Power Consuming Applications Permissions	Amount of Energy Consumption of each Used Component	Permission Average Energy Consumption Amount per minute	Permission Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
access Bluetooth settings	Bluetooth Radio (~ 10 mAh)	~ 10 mAh	★★
allow Wi-Fi Multicast reception	Wi-Fi Radio (~ 12 mAh)	~ 12 mAh	★★
Broadcast data messages to apps	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh)	~ 15 mAh	★★★
change network connectivity	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh)	~ 15 mAh	★★★
change system display settings	Screen (~ 16 mAh)	~ 16 mAh	★★★
change your audio settings	Audio Speaker (~ 9 mAh)	~ 9 mAh	★★
change/intercept network settings and traffic	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	★★★
connect and disconnect from Wi-Fi	Wi-Fi Radio (~ 12 mAh)	~ 12 mAh	★★
control flashlight	Flash Light (~ 19 mAh)	~ 19 mAh	★★★★
control vibration	Vibration (~ 15 mAh)	~ 15 mAh	★★★
directly call phone numbers	Cellular Radio (~ 17 mAh) Microphone (~ 5 mAh) Audio Speaker (~ 9 mAh)	~ 10 mAh	★★
download files without notification	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	★★★
full network access	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	★★★
make an app to always run	Application Processor (~ 20 mAh)	~ 20 mAh	★★★★
modify phone state	Application Processor (~ 20 mAh)	~ 20 mAh	★★★★
modify secure system settings	Application Processor (~ 20 mAh)	~ 20 mAh	★★★★
modify system settings	Application Processor (~ 20 mAh)	~ 20 mAh	★★★★
pair with Bluetooth devices	Bluetooth Radio (~ 10 mAh)	~ 10 mAh	★★★★
precise (GPS) location	GPS (~ 25 mAh)	~ 25 mAh	★★★★★
prevent phone from sleeping	Application Processor (~ 20 mAh) Screen (~ 16 mAh)	~ 18 mAh	★★★★
read your social stream	Wi-Fi Radio (~ 12 mAh) Cellular Radio (~ 17 mAh) Application Processor (~ 20 mAh)	~ 16 mAh	★★★
record audio	Microphone (~ 5 mAh)	~ 5 mAh	★
run at startup	Application Processor (~ 20 mAh)	~ 20 mAh	★★★★

Table 31 Recalled Average Energy Consumption Amount and Ratings of Power Consuming Permissions

Needed Permissions for Snapchat	Permissions consumption rate (in mAH)	Application Average Energy Consumption Amount per minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
read your own contact card		~ 15	3 stars out of 6
view Wi-Fi connections			
take pictures and videos	~ 17		
record audio	~ 5		
modify or delete the contents of your USB storage			
read the contents of your USB storage			
precise location (GPS and network-based)	~ 25		
find accounts on the device			
read your contacts			
read phone status and identity			
receive data from Internet	~ 16		
change your audio settings	~ 9		
access Bluetooth settings			
control flashlight	~ 19		
control vibration	~ 15		
prevent device from sleeping	~ 18		
run at startup	~ 20		
view network connections			
pair with Bluetooth devices	~ 10		
connect and disconnect from Wi-Fi	~ 12		
full network access	~ 16		
change network connectivity	~ 16		

Table 32 Rating "Snapchat" Application Using Power Consumption Stars Scale (Almasri and Sameh, 2019)

The rating stage covered all the remaining applications the same way shown in the above table and the final results were given in Table 33 below. The full rating of all the 42 applications is available in the Appendix IV.

No.	Application	Application Average Energy Consumption Amount per minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
1	RainViewer	20	2
2	Weather Live	20	2
3	Free VPN & Security	18	2.4
4	PicArt Photo Editor	18	2.4
5	SkyScanner	18	2.4
6	DuckDuckGo Privacy Browser	18	2.4
7	Hotspot Shield	17	2.6
8	Udemy	17	2.6
9	Be Closer	17	2.6
10	Jollychic	17	2.6
11	BetterMe	16	2.8
12	YouTube	16	2.8
13	Pinterest	16	2.8
14	VIDAL	16	2.8
15	OfficeSuite	16	2.8
16	NovelCat	16	2.8
17	Vault	16	2.8
18	Twitter	15	3
19	Snapchat	15	3
20	Screen Mirroring Cast To Tele	15	3
21	TED	15	3
22	CamScanner	15	3
23	Davis's Drug Guide for Nurses	15	3
24	IMdb	15	3
25	Maps	14	3.2
26	Zoom Meeting	14	3.2
27	Cisco Webex	14	3.2
28	Imo free video calls and chat	14	3.2
29	WhatsApp Messenger	14	3.2
30	Telegram	14	3.2
31	VLC for Android	14	3.2
32	Chrome	14	3.2
33	Instagram	14	3.2
34	TikTok	14	3.2
35	Uber	14	3.2
36	Spotify	14	3.2
37	Amazon	14	3.2
38	Zoom Cloud Meetings	14	3.2
39	Samsung Music	14	3.2
40	KineMaster – Video Editor	13	3.4
41	Gmail	13	3.4
42	Netflix	12	3.6

Table 33 Star Rating of Popular Applications Shared by Eight User Groups.

7.2.4 Proposing Energy-Efficient Alternatives for Apps Used By Energy-Concerned Users Groups

Next, an alternative is to be chosen for each none-energy-efficient application as shown on Figure 7.17. These alternatives will be based on the same features or tasks and listed under the same app category on Google Play but with a smaller number of power-hungry permissions. Table 34 shows an example of proposing an alternative application based on the shared features and less required power-hungry permissions of an app. Table 35 shows the possible proposed alternatives of all the apps which are rated between 0 and 2.5 stars.

Finally, we will calculate the amount of saved energy after using these proposed alternatives by each users group as shown on Figure 7.18.

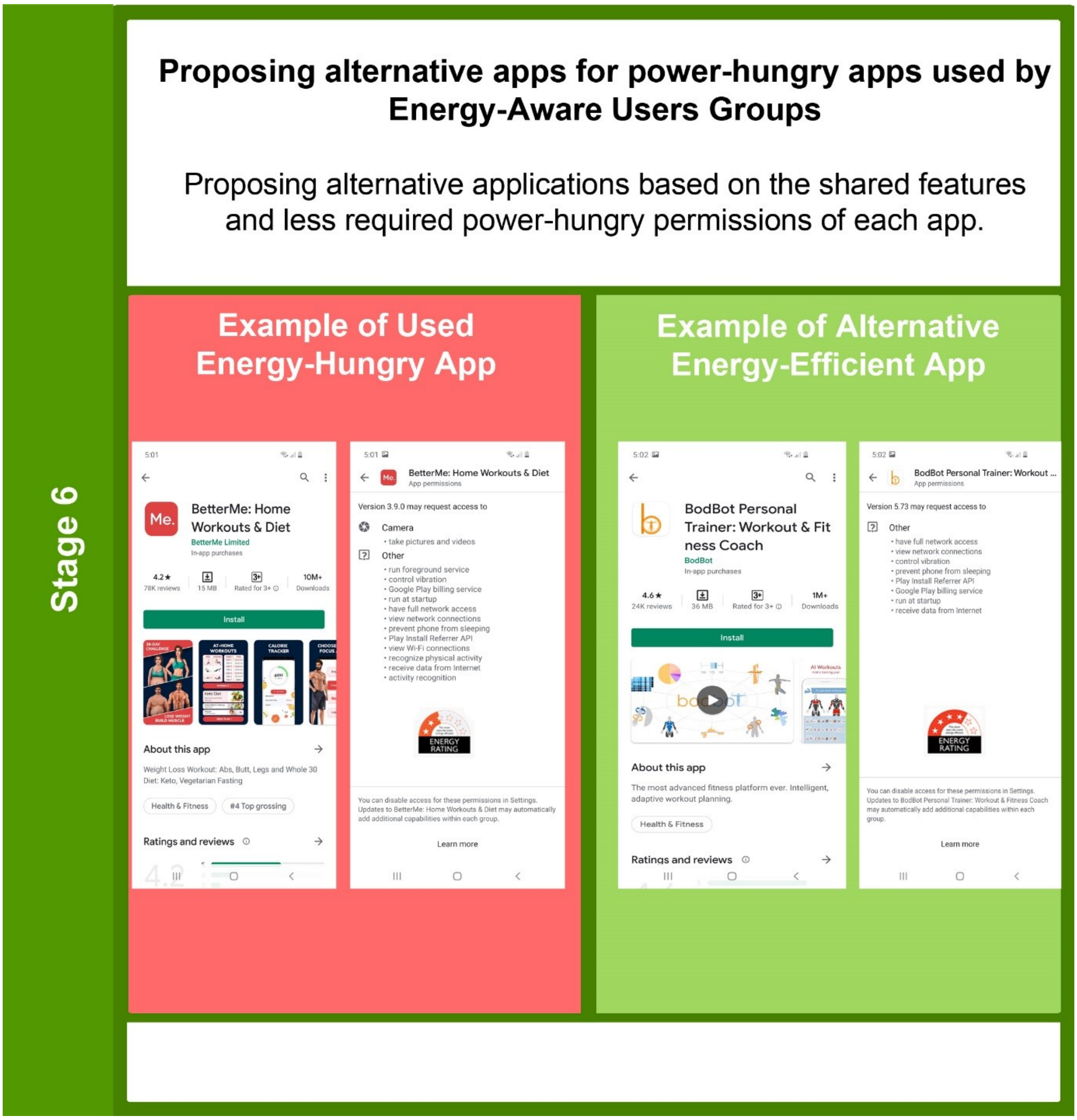


Figure 7.17: Stage 6 of the Simulation of Usage Process

Power-Hungry Application	Power-Hungry Application Required Permissions	Alternative Application	Alternative Application Required Permissions
RainViewer	• precise location (GPS and network-based) • approximate location (network-based) • modify or delete the contents of your USB storage • read the contents of your USB storage • receive data from Internet • view network connections • full network access • prevent device from sleeping • run at startup	World Weather	• receive data from Internet • view network connections • full network access • control vibration • run at startup

Table 34 Example of proposing an alternative application based on the less required power-hungry permissions of an app

Application	Application Average Energy Consumption Amount per minute	Alternative Application	Alternative Application Average Energy Consumption Amount per minute
RainViewer	20	Rain Alarm	~ 8 mAh
Weather Live	20	World Weather	~ 15 mAh
Free VPN & Security	18	VPN Free - Betternet	~ 14 mAh
PicArt Photo Editor	18	Snapseed	~ 15 mAh
SkyScanner	18	Tripadvisor Hotel, Flight	~ 14 mAh
DuckDuckGo Privacy Browser	18	Messenger – Text and	~ 15 mAh
Hotspot Shield	17	VPN Free - Betternet	~ 9 mAh
Udemy	17	edX: Online Courses	~ 9 mAh
Be Closer	17	GeoZilla	~ 10 mAh
Jollychic	17	Rain Alarm	~ 8 mAh

Table 35 Proposing possible alternatives for some power-hungry apps
(Apps without alternatives were removed for accurate measurements)

In the following, Table 36 shows the comparisons for user categories after using the alternative applications and also gives an indication to us on how this affects the results and what kind of limitations we are expecting.

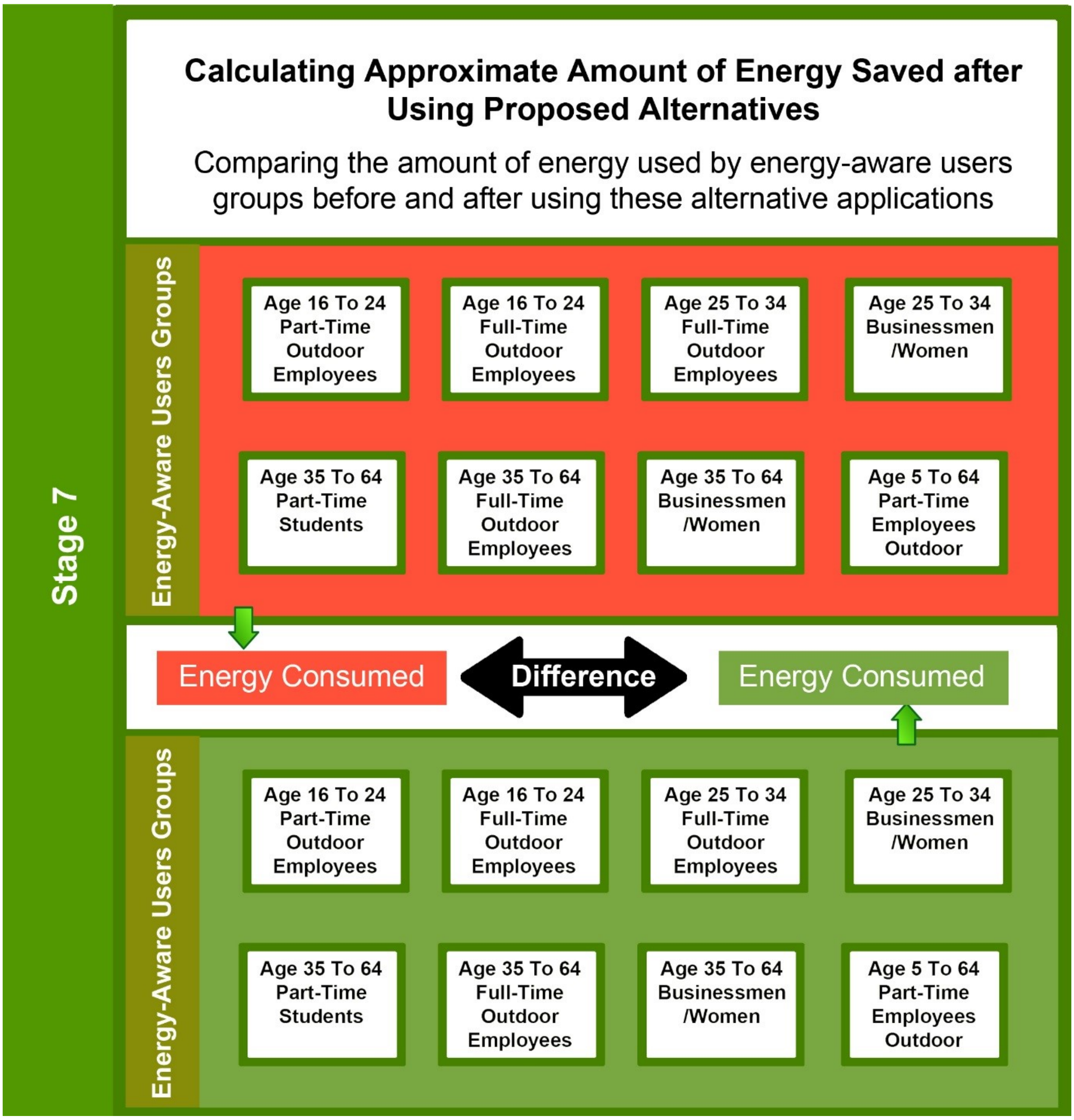


Figure 7.18: Stage 7 of the Simulation of Usage Process

Users Age Range	**Smartphone User Category**		**User Group Average Energy Consumption Amount per minute**	**User Group Average Energy Consumption Amount Per Minute After Using the Alternative Apps**	**Percentage of Saved Energy**
16 to 24	Part-time employees	Outdoor	~ 18.19 mAh	~ 16.10 mAh	**11%**
	Full-time Employees	Outdoor	~ 19.22 mAh	~ 16.15 mAh	**16%**
25 to 34	Full-time employees	Outdoor	~ 18.28 mAh	~ 17.19 mAh	**6%**
	Businessmen & women		~ 16.57 mAh	~ 15.19 mAh	**8%**
35 to 64	Part-time students		~ 14.59 mAh	~ 11.19 mAh	**23%**
	Full-time employees	Outdoor	~ 19.37 mAh	~ 17.11 mAh	**12%**
	Businessmen & women		~ 16.60 mAh	~ 15.19 mAh	**8%**
	Part-time employees	Outdoor	~ 18.45 mAh	~ 14.19 mAh	**23%**

Table 36 Percentage of Saved Energy among Users Groups That Pays High Level of Attention towards Their Phone Battery Level

7.2.5 Limitations of Current Stage

A primary limitation of the current stage is how often the users who are concerned about their battery life will be able to exchange the convenience of using popular apps by using unpopular alternatives in order to save the battery life. This limitation is the main concept in this stage. The next section will show how the research will work towards improving this main point as many end users will prefer to use specific popular apps. In other words, using a popular app is no more an option in our days because of the pressure of the society, the work environment, communicating with relatives and friends and with the outer world since most of the society is requesting a specific application as a channel of communication. As per to this, the end user does not have a choice to use an alternative application that does the same task. This is what the research is proposing but in real life, the question is about whether having the solution used by end-users or not.

7.3 Chapter Summary

The chapter was able to prove the efficiency of newly-added piece to the puzzle between the end-users and the applications by educating the end-users about the adherence of a specific app to the energy-efficient development practices or recommendations. The chapter also demonstrated how users were able to benefit from the energy-efficiency star-rating level of each application offered in Google Play Store. The chapter simulated the usage of the proposed solution which was introduced as a new addition to the existing detective power-saving strategies. The chapter indicated a primary prerequisite of the usage simulation which was to evaluate the attention of smartphones users groups towards their battery life and then to simulate the usage of the solution on the groups which are considered as Energy Concerned users' groups. This evaluation was done through proposing a set of the users groups based on their energy needs and their interest of saving their smartphones battery in addition to their interests among applications categories. The study collected the results after implementing a survey to identify the levels of energy needs among the proposed groups of smartphones users and which groups are considered as Energy Concerned users' groups. These Energy Concerned users' groups were then identified as the primary research sector where the simulation of usage was implemented. The chapter simulated the usage of the solution by assuming that each user from these groups considers switching to an energy efficient alternative for each energy-hungry application, this ability to consider and to switch was given to the users after educating them about the energy efficiency level of each app through the star-rating schema (SREM). The chapter then demonstrated the results of the usage simulation which showed the percentages of saved energy among Energy-Concerned users groups reaching up to 23% amount of saved energy. Finally, the chapter listed the primary limitation of the research stage which was about the ability and the intention of the users who are concerned about their battery life to exchange the convenience of using popular apps by using unpopular alternatives in order to save the battery life.

Chapter 8: Discussion of Results

8.1 Introduction

The following chapter aims to contextualize the findings presented previously in the context of academic literature, which was examined and presented as part of the literature review, as well as in light of additional research, incorporated in the discussion in light of the study's findings. The chapter will demonstrate that using the proposed model to rate Android applications has helped the end-users to save energy and extend their battery life, emphasizing the value-in-use of the proposed approach and model of app assessment.

The chapter is organized as follows. Firstly, a recap of the problem statement and the study's findings will be provided, followed by a discussion of the results in a triangulation-based approach, aimed at contextualizing the current research into the body of other works. Later, the validity of findings will be discussed, as well as the study's limitations. Finally, the implications of the study's findings will be discussed for key stakeholders and the overall significance of the study will be summarized.

8.2 Recap of Problem Statement

The problem that this research aims to address from a holistic standpoint can be pinned as the underwhelming battery performance of Android smartphones. Approaching this issue from a more granular standpoint, the problem relates to the reverse relationship between phone functionality and battery life, the growing prevalence of the smartphone in daily lives, the lack of user awareness regarding the different habits, which affect battery performance and the most common app features that drain their battery, and the resulting energy consumption issue, impacting the environment. Thus, the problem, addressed through the current research is multi-dimensional, namely:

- Increasing the awareness of users for apps that drain their battery;
- Propose applications alternatives for minimizing the impact of smartphone functionality on battery;
- Highlight the current lack of personalization in the battery performance management approach and available power saving techniques, as well as the need for personalization, from the standpoint of a user.

The procedural model of the study is shown in Figure 8.1 below.

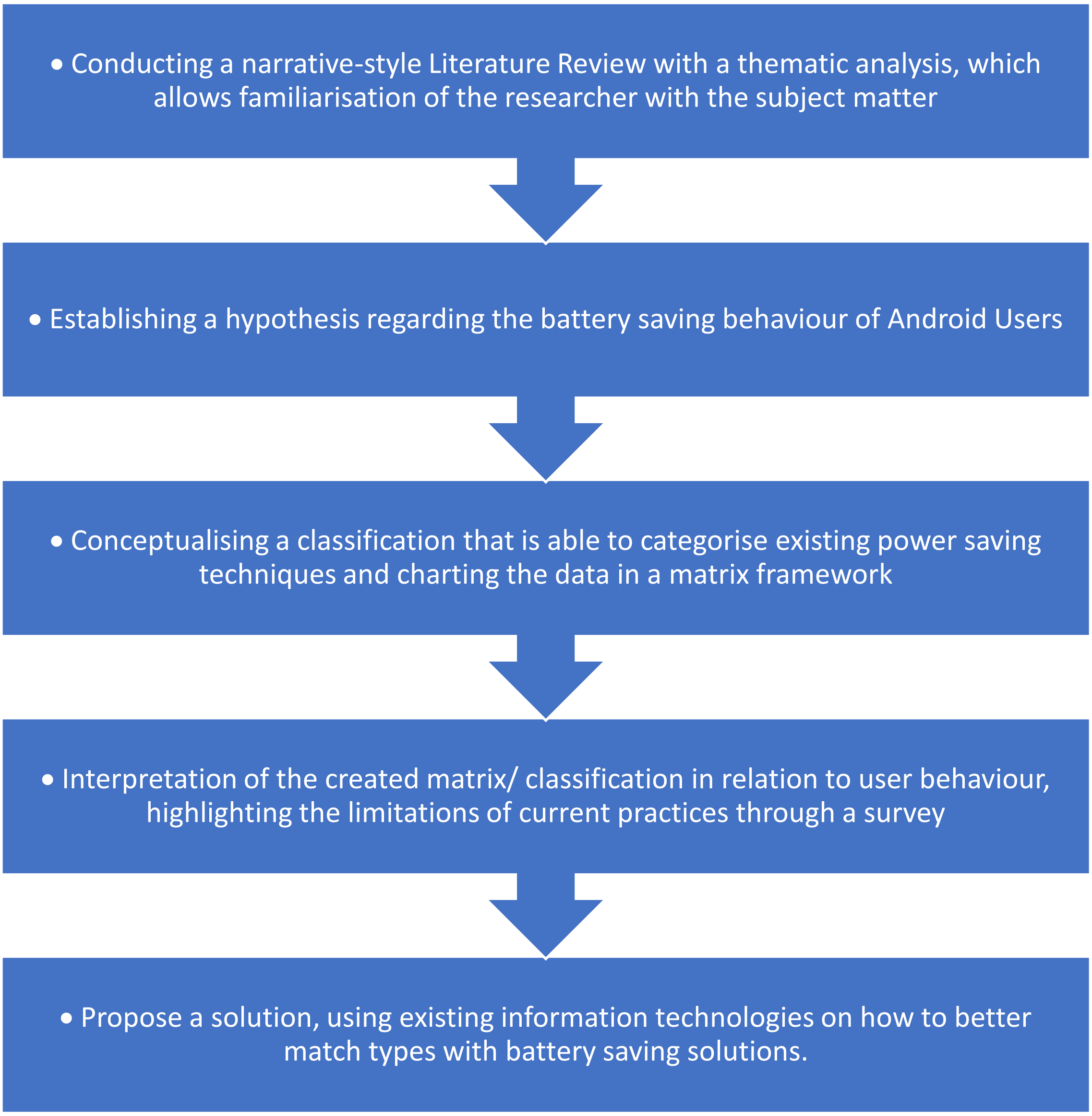


Figure 8.1 Procedural Model of Study

8.3 Summary of Findings

The literature review of this study demonstrated that user behavior impacts energy consumption, battery usage and charging duration. The current approaches of battery saving have been consistently demonstrated to be under-utilized by users. Thus, it was demonstrated that development of techniques for battery-saving is needed in both the medium and the long-term, with this being viewed as a potential aspect of global energy reduction as well, which will follow on from the reduced energy consumption from users no longer charging their smartphones so often. The other issue addressed through the current study is the importance of developing the mechanisms for guiding user to:

- Take advantage of the available battery saving settings;
- Develop habits and practices that spare the battery of their device; and
- Reduce the overcharging practices of their device's battery.

Through applying a classification approach, three main classifications of the current power saving approaches were identified, each with its unique limitations. Approach 1 (Simulate and Estimate) is informational, where app developers follow metric-based data of the user's consumption, with the aim of influencing the app behavior to consider the overall impact of their smartphone use on the battery. Approach 2 (Supervise, Detect and Control) is practice-based, where through a "detect and control" philosophy, a smartphone forcefully keeps monitoring the behavior of the installed apps and background processes then deems energy-hungry ones to the user at a certain time. Approach 3 diminishes many of the features of modern smartphones with the aim of maximizing battery performance alone. These classifications were of significant importance to the study as they demonstrated that any of the available power saving technique can be classified under any of the three classifications.

Through a combination of research approaches, the study demonstrated that there are six categories of Android users based on whether they care about technology or the battery life, namely: Housewives, Nature Scientists, Sailors, Heavy Gamers, Social Media Celebrities, and Media Reporters. These categories of users demonstrated vastly different behavior with regards to different methods of battery consumptions, with an example being the use of 'Ultra Power Saving Mode', thus affirming the hypothesis of the study that a 'One Size Fits All' approach is inefficient when it comes to addressing the battery-saving needs of users. Thus, a novel approach was introduced, which approaches the problem from a more layered standpoint in comparison to existing detective power-saving techniques. The suggested implementation is based on the grouping of smartphones users into categories based on various criteria in order to maximize power consumption for each category.

8.4 Triangulation of Results and Contextualisation of Study

The study demonstrated difference of usage of the phone based on lifestyle and demographic characteristics of the users, such as based on their age or occupation-type. These findings can be corroborated by Hamka study, where the study discuss how the use of the mobile device and mobile behavior changes on the basis of demographic and psychographic segmentation, enabling lifestyle categories to form (Hamka et al., 2014). In addition, the study also demonstrate that a big difference in smartphone usage emerges when the phone is used for work, which is also affirmed by the current research. Specifically, the study found that full-time outdoor male and female employees have the highest amount of power consumption, across all age groups. Thus, aligning with the findings of Hamka et al. (2014) study, the difference that using the smartphone for work does is that the battery consumption increases. However, the findings of the current study also demonstrated that not all groups are equally concerned with the battery level, as some have continuous access to charging resources. Such groups were typically those that were part-time occupied or working indoors. The latter trend is particularly concerning in consideration of the impact of battery overcharging on the environment, illustrated in chapter 1. While the urgent need for more efficient approaches to energy conservation is recognized as a global concern in the area of green computing by academics (Hu, 2012), the results demonstrate that it is not recognized by users. Previously illustrated research highlighted the benefits of improving battery performance from a user standpoint, such as improvement of the overall user experience, energy waste reduction, physical waste reduction and environmental conservation (Hu, 2012). Thus, individuals that spend the majority of their time indoors are recognized as being at a loss in terms of battery life expectancy and spending. This is due to the research demonstrating that when the phone is left charging for longer than needed on a regular basis, the battery is damaged, reducing its lifespan, while simultaneously the increased energy consumption leads to higher costs. This situation is not beneficial for both users in this group, as well as for the environment.

Previously, literature was presented, which proposed reasons why the battery of a smartphone is depleting at a faster than usual pace. Amongst those was slow connection Wi-Fi and Bluetooth being kept on search mode (Wagner et al., 2013). From an applications standpoint, the ‘battery killers’ identified were background services (Martins et al., 2015), dynamic Web components displayed in browsers (Thiagarajan et al., 2012), and location-aware applications running in the background (Liu et al., 2013). Applications with emerging technology integration also had a depleting effect on the battery (Cuervo et al., 2010). The study's findings validate the arguments illustrated in the literature review from other researchers, which have affirmed that the most battery-draining applications are those using a form of location-tracking service running in the background of the device. Referring to the study of Wang et al. (2016) illustrated in the literature review chapter, smartphone applications are used for a variety of aspects in our day-to-day lives, such as booking of the travel medium, to the check in process at the airport or at the hotel, through the navigation at the destination, etc. This was affirmed by the analysis of the applications on the smartphones of study participants, with the results demonstrating the prevalence of a variety of lifestyle applications, service applications, health and fitness applications and so on, many of which were operating in the background. Such power-intensive applications engage location detection by GPS (Man and Ngai, 2014), as illustrated previously. The prevalence of location detection applications on a variety of smartphones in individuals whose occupation leads them outdoors is thus, understandable, yet the high difference in power consumption of this group of individuals in comparison to those that spend their days predominantly indoors highlights the importance of developing technologies for location detection that are less power-intensive. This insight has been highlighted in academic research time and time again (Man and Ngai, 2014), as it is an issue commonly faced by smartphone users. Referring to the research related to Wi-Fi searching, it can be considered that outdoor users who have the habit of leaving their Wi-Fi button on whilst being away from home, further hinder their battery as it continues searching as they go about with their day. Also, amongst the study's less significant findings, yet one that affirms the findings of previous research is that through an analysis of the applications of user devices, the prevalence of social applications is evident, with a variety of social media applications being amongst the most downloaded apps. In this context, both indoor and outdoor users deplete their batteries through using media-intensive social media applications and messaging applications frequently. Nonetheless, loading social media applications (such as Facebook) on a smartphone through mobile data networks drains the battery of the user faster (Wyche et al., 2013) than if the content is accessed through a more stable connection, such as at-home Wi-Fi.

Occupations which lead individuals outdoors typically result in a shift in their attention towards battery level. Thus, a correlation is observed between the energy consumption amount per minute and the attention towards battery level, which applies to all age groups and genders. Therefore, as users become more actively impacted by the damaging effect that inefficient smartphone use has on their battery, they become more vigilant in terms of the level of their battery. Interestingly, though, the results have illustrated that both groups (indoor and outdoor) occupied individuals have behaviors, habits or applications that can benefit from their attention. Specifically in the former group, the disregard towards the frequency and duration of charging can be an issue, as illustrated previously, while in the latter group, the presence of a variety of location tracking applications and other battery-depleting services and tools, is an issue that creates a compounding effect on the battery, the charging habits and the overall battery performance management approach.

Through identifying the applications that were most used across the group of individuals that were occupied outdoors, an identification of power-hungry applications was made, which enabled suggestions to be made on the basis of app replacement for potential swaps that can be made. As a result of this approach, the study demonstrated that across the groups, there is potential for energy savings on average of upwards of 13%, with the highest energy savings achieved in the part-time students (aged 35-64) and part-time employees (aged 35-64), namely 23% saved energy after the swaps.

As illustrated at numerous instances throughout this research, battery saving increases the lifetime of both the battery and the smartphone (Hosio et al., 2016). Research also suggests that approximately 80% of all smartphone users can take measures to improve the lifetime of their smartphone devices (Hosio et al., 2016). Considering this research in context of the body of academic literature demonstrates that there are opportunities for presentation of novel approaches that can be implemented for improving the battery performance, which do not mandate that the user sacrifices the functionality of their device in any way, but benefit them substantially. While there are 'hard' approaches that can be undertaken, such as for optimization of technical components of devices, which can result in a greater efficiency of the battery (see Zaman and Almusalli, 2017), the current approach is based to some degree on behavioral changes. The approach asks users to make choices between having their preferred service or app on their device and having an extended life of their device. In a way, this can be expressed through a pleasure versus efficiency debate, or similarly through convenience versus device productivity. The results from the research demonstrate that while a certain balance can be struck, this is not without sacrifices from the user's behalf – be it their time in assessing, researching and contrasting the power usage of different applications or their psychological strength in replacing an app they have been using with a lower-impact duplicate. The prevalence of apps as service devices has resulted in development of a plethora of potential replacements of any given app, which arguably have no realistic impact on the functionality, as experienced by the user, yet it is recognized they can have a psychological impact, as will be further detailed in the Limitations section, below.

8.5 Validity of Findings

The results of the study demonstrate that the proposed model for rating has helped the end-users to save energy and extend their battery life. While there is numerical merit in the calculations performed and the results obtained have been demonstrated to be rigorous, it is recognized that the replication of findings is subject to a variety of factors. For example, it is required that longitudinal studies be also performed to ensure that the hypothesis proposed in this study can be affirmed continuously, highlighting the approach as suitable for wide use. While this study offers promising results in terms of potential battery savings, as well as positive recognition from participants that their perception of their applications' impact on their battery has improved, this research is a first-step in prototyping a complete solution to address the problem situation.

8.6 Implications of Findings

The implications of this research can be considered as relative importance for policy, practice, theory and further research. In terms of policy, the current research highlighted the rising tension between the field of technology and environmentalism, specifically how the rise in technology consumption negatively impacts the environment. The proposed approach arguably presents an opportunity for environmentalists to raise further awareness of the issues, related to over-charging batteries, premature battery depletion and battery disposal on the environment. From a practical standpoint, this research can be used by two groups of stakeholders – users and developers of energy-efficient apps. For users, this study demonstrates that aside from a personal psychological affirmation (such as loyalty-generating characteristics, illustrated above), there is no reason to continue using an application that is severely battery-depleting on a continuous basis, especially if leading a primarily-outdoor-based, busy lifestyle. The few of the hindrances of doing so are a faster battery life depletion, environmental impact, higher electricity bills, caused by unnecessary charging of the device, ultimately leading to a shorter lifespan of the device. The study affirms the benefits of switching to applications that do not automatically operate in the background or have an 'always-on' location tracking function. From an app developer standpoint, the results from this study can be used as a promotion technique, given that the apps developed fall into the category of applications, deemed as battery efficient.

The implications for further research, stemming from this research relate to examining the perceived importance of battery performance in comparison to psychological determinants of app use (as illustrated in the limitations section). Additionally, future research can examine the challenges and obstructions in making the proposed app swaps and applying this approach in practice, using a larger sample, as this can arguably demonstrate the barriers users face in engaging in more environmentally friendly battery-saving behaviors. Comparable to Hosio study, who reaches similar conclusions in relation to the variance with which people value their battery (being dependent on context, mobility and location), the current research recognizes that smartphones have become extensions of the self, with users being distraught when having their device 'die on them' due to lack of battery (Hosio et al.'s 2016). Thus, the study recognizes the importance of continuing the research initiative in both educating users of the importance of implementing a battery-saving strategy, as well as enabling them to implement their chosen approach in a manner that does not hinder the joy of using their device.

8.7 Significance of Study

This study benefits users and app developers, as it systematically demonstrates the importance of engaging in more efficient battery saving behaviors. From a user standpoint, this can be through using any of the listed methodologies in the three classes, defined earlier in the work and compromising the performance of the device in terms of functionality, or applying the proposed approach, sacrificing little in terms of comfort in the use of the device or device functions.

For developers, the study highlights the negative impact of 'always-on' features and app functionality in the background of the device, which could lead to a negative brand association of the user, who could relate the app to reduced battery performance, following the app's installation. Considering the illustrated findings in relation to the rising importance of smartphones in the lives of people, as well as the lagging advancements made in the technical development of higher battery capacity of smartphone devices, it can be speculated that the battery concerns of users will continue intensifying in the future, with more and more people paying attention to their battery performance. This trend, if observed, paired with the proposed approach to battery optimization, would give rise to app comparison platforms and services, which will favor developers and applications, which create apps that are battery-sparing.

8.8 Chapter Summary

The chapter discussed the findings of the work in the context of other academic research, highlighting important tensions between the insight generated from the work and the challenges that are recognized by researches in aspects such as environmental protection, green computing and battery performance. The study is considered successful in achieving the research objectives at the problem identified and remaining diligent to the created procedural model. The rating model of Android applications has helped the end-users to save energy and extend their battery life, with results demonstrating improved battery performance upwards of 13% on average across users that are occupied primarily outdoors in their day-to-day lives. These results demonstrate high potential for the development of a complete application that can be deployed as an assistance to users in navigating the app landscape through making choices that are responsible and beneficial for both themselves and the environment. Importantly, this chapter also highlighted the limitations of the current study, namely the lack of consideration of how brand attributes can influence app choice, potentially obstructing users to benefit from more battery-sparing applications and services on their devices. The illustrated limitations highlighted a variety of avenues for future research, which can examine the psychological or other barriers users have in engaging in battery-saving behavior. The study is considered significant for both users and app developers, with it being informative for the former group and potentially opportunistic for the latter, provided that they engage in behaviors that align with the principles of green computing and energy conservation.

Chapter 9. Conclusion and Future Work

9.1 Overview

From the above results, the efficiency of the solution was demonstrated clearly. A good amount of power will be saved if users from all selected users groups started using the solution to make their decision before continue to use or even installing a new application. After being able to give the end-users an indication about the level of energy efficiency for each application they are using, the amount of energy saved for each category is considered good where the main contribution of our solution is. This also contributes to the high-level goal towards improving the role of green computing.

These results are also considered as a good reference for applications developers and manufacturers. So even most trending applications that are listed on Google Play or used all around the globe will be given this star-rating label. The research believes that if a popular application was rated as a power-hungry application, this will encourage developers of this application to improve it more towards increasing its level of energy-efficiency. This will then lead to an area where both manufacturers and the end user are working together towards saving more battery life.

9.1.1 Current situation of power management systems for smartphones

Over the last ten years, any user of a mobile phone has been able to show a clear sense of compassion between the discharge times of the mobile phone used ten years ago and the discharge time of today's smartphones. Mobile phones were charged once every four days on average; on the other hand, today's smartphones need to be charged almost twice every 24 hours. Smartphones manufacturers have begun to invest more in technologies related to battery capacity and power storage technologies to address the two factors that are directly proportional to the capacity and physical size of any technology related to the battery. Added to this is the struggle with parallel increases in the intention of developers and programmers to take advantage of the increased power offered by new technologies. All of the above has caused the smartphone industry to fall into a situation that can be demonstrated by one statement: "More Technologies Offered by Smartphones, Less Battery Life of Same Smartphones". This has caused all smartphone manufacturers to run in closed loops against increasing power-saving technologies and increasing smartphone technology. As a result, smartphone manufacturers have begun to develop power-saving policies based on detective techniques for measuring and managing internal transactions on various key components of smartphones. Also, by monitoring user behavior with a view to minimizing power consumption from this point onwards. By the time users found out that this power-saving technique actually uses the same or more power that the user would have used.

Based on the review of the literature, solutions presented by prior studies in relation to the approach reveal that the average estimations that the proposed tools/techniques provide tend to conflict the actual usage habits of device and the accuracy of the power consumption measurements and simulators remain an issue of debate. Therefore, while the techniques presented herein provide some potential solutions for reducing energy consumption by mobile applications on Android-based smart-devices, they are limited in their usage. This study has gone through various areas of interest in order to answer all research questions asked on the introduction section. The study also has explored the literature and related works around power saving applications, the available approaches that have either not added or added a negative effect on the area of saving energy on smartphones. The study was able to classify the different levels of power-usage among different smartphone resources. That has helped us later to sort the smartphone components in terms of their level of power consumption. Based on the findings, a significant share of power consumption in these smart devices is largely caused by applications that are installed on the devices. Depending on the applications' functionality, they entail activities such as data downloading, content display, and use of built-in-sensors such as GPS (Global Positioning System) related sensors. There are various components of mobile smart devices that facilitate the above activities including; GPS sensors, device' display, the CPU, and network interfaces among others. Consequently, activities/functions of different Android smartphone applications increase the energy consumption of any of the above-mentioned components. As a result, there has been a lot of effort in the study geared towards identifying and investigating the underlying potential for energy savings in relation to these smartphone applications at applications layer and OS layer levels.

9.1.2 Guidelines of the European Commission

In reference to the guidelines of the European Commission regarding energy efficiency, huge improvements in energy efficiency are occurring across the European Union. Energy efficiency policies are delivering in terms of reducing consumption. Although much attention has been given to energy conservation, there are several issues that existing researchers need to devote more attention to. The European Union has successfully managed to decouple energy demand and economic growth. In short, this means reduction in energy use is not linked to a reduction in the economic or industrial activity (European Commission Directorate-General for Energy, 2017). The economy can now grow while energy is being saved. The primary motive for potential work is to stop following the statement that "waste any power from the mobile battery under the premise of saving the same power from the same device". At the end, more efforts are required to recognize the core flaws in the battery savings that are being built and introduced in potential smartphones. Today we are seeing so-called 'energy intensity' 1 levels fall. This fall is due to several factors, including structural changes to the economy and advances in technology. But it is also a result of new national and European energy efficiency policies that have played a key role in reducing energy consumption across the bloc.

9.1.3 Middle Solution between Extreme Constraints and Shorter Use

The current situation of smartphone batteries can be described simply by the following statement: "One Size Fits All". It is quite rare to hear from any of the top-famous smartphone manufacturers about the intention to produce different categories or smartphones for different classes of users based on the amount of power consumed by each class of users. Various versions and classifications for mobile phones were seen before the smartphone era when businesses were dealing with different variants of mobile operating systems such as Symbian and Java. Nokia used to make different types of phones for businessmen, gamers, sailors, etc. For example, the communicator, N-Gage, the same thing goes with LG, and Ericson. But after the MAC and Android booms, the world saw a massive upsurge in unifying the shapes and features of what's recently known as smartphones. At the same time as having this idea of unifying all smartphones, the smartphone industry was still faced with a real challenge in terms of increasing the capacity, time of use and reducing the time of discharge and the physical size or weight of smartphone batteries.

9.1.4 Preventive vs Detective Power-Saving Approach

Preventive power-saving strategies have actually been used recently in the form of a feature that is part of the phones operating system. What happens when the user activates this feature is that it simply activates a number of fixed commands that take over some of the main components of the smartphone. These components have been classified as the most energy-draining resources in previous studies, e.g. Screen, Wi - Fi, 3G, etc.. When this power-saving mode is activated by the user, most of these components must be provided with almost half the amount of power they used to be supplied without the power-saving mode being activated. This will cause these components to either work with half their efficiency or completely stop working as active components and go into standby mode, e.g. Screen brightness down to 50%, Wi-Fi on standby, 3 G Off, among many others possibilities. The whole idea behind this strategy is to prevent these components from consuming more energy on the basis of their previously studied reputation against other phone components and regardless of how and how much they are used for these components. By the time these techniques started giving positive feedback on saving more energy, on the other hand, what is known as detective power-saving strategies were all in the form of an add-on feature or application that the user installs or adds to the phone and then gives the newly added feature the power to act as a radar in order to detect and monitor the power consumption between different devices. This way of controlling categories involves handling phone applications and background commands, and all interactions and transactions between all phone components. The same techniques are also used to manage the overall power consumption, including by skipping the built-in smart power-saving fonts provided by the smartphone operating system and by enabling and disabling running and/or unused smartphone applications to save the battery as much as possible. One major disadvantage of this way of saving power is that it contradicts the main concept of saving power and this can simply be demonstrated. By recalling the previous results of this study in chapter three, Google Play classifies power-saving applications in the 'Productivity' category, which is classified in our analysis results as the 6th power-consuming category, which has made the user more relaxed with the Preventive Power-saving techniques, but has also not been satisfied to be controlled with certain restrictions that prevent him from using them. One of the latest Preventive solutions is Samsung's "Ultra Power Saving Mode", a power-saving mode that provides two weeks of standby mode. Table 39 shows the star rating of an application that follows the detective power saving technique after it has been exposed to our previously proposed scale of rating applications:

Category	Top 10 Popular Apps	Needed Permissions for the App	Application Average Energy Consumption Amount per minute for Indoor/Outdoor		Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)	
			Indoor (Wi-Fi)	Outdoor (Cellular)	Indoor (Wi-Fi)	Outdoor (Cellular)
Productivity	DU Battery Saver & Widgets	test access to protected storage	~ 19 mAh	~ 20 mAh	2.20 starts out of 6	2.00 starts out of 6
		view Wi-Fi connections				
		pair with Bluetooth devices				
		view network connections				
		full network access				
		Google Play billing service				
		Google Play license check				
		find accounts on the device				
		modify or delete the contents of your USB storage				
		read phone status and identity				
		control vibration				
		modify system settings				
		connect and disconnect from Wi-Fi				
		access Bluetooth settings				
		change network connectivity				
		read sync settings				
		toggle sync on and off				
		close other apps				
		run at startup				
		install shortcuts				
		draw over other apps				
		measure app storage space				
		retrieve running apps				
		prevent phone from sleeping				

Table 39 Star rating of an application that follows the detective power saving technique after exposing it stars rating scale

9.2 SREM a star-rating schema

As energy is critical for smartphones, increasing the charging time of the battery can greatly improve end-user experience. While end users have the option to choose from a limited number of power-saving solutions, app stores do not provide any indication of the energy behavior of the applications they sell. This energy related mystery causes end-users to arbitrarily select apps without knowing their energy consumption behavior. We introduced the SREM to address this issue, an approach that estimates the energy friendly level of Android apps and shows it in a star-rating scheme similar to the energy efficiency labels on home appliances. Our aim in this work is to generate the number of stars for each application from the difference between the amount of ordinary power consumption and the amount of power consumption after applying an energy conscious restructuring approach to the app. We relied on the refactoring approach as a previously tested effective approach to restructuring energy aware apps. Android app stores can use SREM to enhance the role of end users in deciding which apps meet their energy needs. SREM will also inspire developers and app providers to come up with multiple energy efficient versions of the same app to meet the needs of different categories of users and rate their own apps.

9.3 Extreme Power Saving Modes

Samsung, one of the leading smartphone manufacturers, has gone extreme with this power-saving strategy as it introduced its Ultra Power Saving Mode. As a powerful solution to take time as the key satisfaction factor for smartphone users, the Ultra Power saving mode as Samsung claims can operate a smartphone for up to two weeks without recharging. This is at the cost of the major changes that the consumer should be able to deal with. The main concept of ultra-power saving mode is to put the phone in standby mode until the user wakes it up by starting one of only six applications enabled. During these processes, no colors are permitted, no Wi-Fi, no cell data packets, and many items are not allowed, which potentially draws a valid point from a customer who may ask: “I don't pay X hundred dollars to have a smartphone that transforms to a black and white screen”. At the same time another user may ask “why I can't keep the colors only and disable all other stuff ”. Another may ask “I need the push notification, what's the use of a smartphone without a push notification service?”. All these questions and much more were the main motivation to our research of having a customized preventive power saving mode based on the results of the above two studies and to have a middle solution between enjoying long battery usage time by forcing users to coexist with extreme restrictions imposed by current Ultra Power Saving Mode and between sufferings from short battery usage time by giving the user the full freedom to use all phone features.

In order to begin with our proposed solution, it is essential to show the situation when using the Ultra Power Saving Mode. The list below shows the applications allowed under "Samsung Power Saving Mode". Features and/or components that are either disabled or reduced in Ultra Power Saving mode and phone settings that can be accessed in Ultra Power Saving Mode.

Applications or functions that may be used by the user in the Samsung Ultra Power Saving mode:

- Phone;
- Messages;
- Internet;
- Calculator;
- ChatOn;
- Clock;
- Google+;
- Memo;
- Voice Recorder.

Attributes or components that are either disabled or reduced in Ultra Power Saving mode:

- Screen Colors (Screen Turns to Black and White);
- Screen Brightness (Screen Brightness is decreased to 25%);
- Sounds levels (Sound levels are decreased to 25%);
- All Connections (Wi-Fi, Bluetooth, 2G, 3G and 4G are all forced to go into standby mode.

Settings that can be accessed under Ultra Power Saving Mode:

- Wi-Fi (ON/OFF);
- Bluetooth (ON/OFF);
- Airplane Mode (ON/OFF);
- Mobile Networks (Search/Select);
- Location (ON/OFF);
- Sound (Levels Control);
- Brightness (Levels Control).

9.4 User Tailored Power Saving Plan

The proposed solution focuses more on early "preventive" power savings, plus educating users about power consumption patterns and/or applications or categories, before taking any step towards any kind of interaction with their smartphone. It mainly starts from the step when the user purchases his/her smartphone, and during the process of configuring the smartphone, the operating system adjusts the power saving plan and shows the user a number of samples until he/she accepts the deal. Then the user can start using the smartphone under what is called the "tailored power saving plan". There will be no real-time or detective monitoring application to monitor power usage during the actual use of the smartphone. However, whenever the user attempts to install, add or change one of the pre-agreed factors and habits of use, he or she will be warned by an informative message about the impact of his or her planned step plus a recommendation to resolve it with an appropriate solution or even to change the tailored saving plan and tailor another one. The power savings plan is tailored to a number of factors, the user will be asked to provide information on his/her fields of interest, his/her age, the nature of his/her work, mostly using the "indoor" or "outdoor" smartphone, and then, under each field of interest, the user will receive short, direct information on the common reputation of each category of his/her interest in terms of p. Also, how the use of each category under different usage behaviors (indoor/outdoor) could affect its power saving plan. For example, if he/she were open field workers who have limited access to recharging resources. The user will be given a number of options to choose from which suite he/she needs and at the same time avoid using unified size power saving modes. The main reason for avoiding the use of unified power-saving modes is to give the user a much larger space of freedom from unified restrictions, which will cause the user to struggle with a smartphone that turns into a standby smartphone in order to increase the time of use of the battery. At the same time, it will set aside many unnecessary features or applications that would consume a lot of energy without any benefit to the user.

If users begin to have enough knowledge to define their main and common use(s) of their smartphones and also give the smartphone a clear idea of the nature of their day-to-day activities or the nature of their work, it will be much easier to achieve the main goal of saving power while, at the same time, enjoying the main intention of purchasing a smartphone. This will, of course, make it easier to control the type of application to be installed on your smartphone, plus it will be much easier to wisely divide the amount of energy between the different components of your smartphone.

From the above, the study was able to emphasize the importance of educating users about their own energy-consuming behaviors and/or applications or categories of power-consumption habits prior to their actual use of the smartphone. This can provide considerable help in developing 'proactive' power-saving techniques and can also increase user satisfaction. The following section proposes a new approach for the search and use of Wi-Fi connectivity on smartphones and how it can be enhanced under preventive power-saving strategies to achieve full energy savings.

9.5 Wi-Fi Energy-Aware Connectivity

Research also concluded that a smartphone surrounded by many nearby network connections consumes more power during the scanning phase and identifies each and every nearby network. The opposite is true of a smartphone surrounded by a few numbers of nearby networks where a smartphone won't have to use a lot of power trying to define a small number of nearby networks. As far as this is concerned, the research proposes to adjust the commands responsible for delivering the power voltage to the Wi-Fi antenna in order to minimize the range of wireless communication. This will have an effect on our goal of giving the phone the benefit of communicating only with what is close to its range. At the same time, end-users will be told that using this type of power-saving mode allows end-users to be close to the wireless network interface.

9.6 Limitations and Future Work

The study made some key assumptions about user behaviour. For example, it was generally assumed that users will use the most power efficient option, which was a fundamental aspect of the calculations performed for measuring the energy reduction of each group. This can potentially be considered a hindrance, as (as illustrated earlier in the chapter) some of the most energy-efficient battery saving applications on the market significantly hinder the user experience by stripping down the smartphone from the features and functionalities that defined it as such in the first place. Considering the previously illustrated observed debates regarding convenience and efficiency, this assumption could potentially result in different results being generated across different participant groups, if the current study is to be replicated. In addition, this assumption could have (to a small degree) influenced the results observed in the study.

Another limitation of this study is that it does not consider the impact of brand loyalty on app choice and app usage. There are several studies that examine the determinants of brand loyalty in mobile applications. For example, Kumar et al. (2018) highlight that holistic visual aesthetic dimensions can influence mobile app loyalty, demonstrating these findings through applying Kaplan's information processing model from environmental psychology and integrating it into the Technology Acceptance Model. Considering Kumir et al. (2018) findings, it can be presumed that switching applications might not be a chosen approach, if the proposed new apps differ significantly in terms of visual aesthetics dimensions. In addition, app satisfaction, the user's intention to continue using the app, and hedonic benefits obtained from using apps (such as consisting of app aesthetics and enjoyment – as well as, in some cases, social recognition) are the direct antecedents of intention to recommend the app to another user (Xu et al., 2015). This affirms the findings presented above regarding the importance of aesthetics and enjoyment of use, and illustrates that in terms of app use, battery performance has no observed impact on the user's intention to seize using an application, or recommend it to a friend. App usability, as demonstrated by Baek and Yoo's (2018) study is a multidimensional construct, consisting of 13 items in five factors: user-friendliness, personalization, speed, fun, and omnipresence, while extended brand use can also be a result of brand attributes of the developer corporation, such as its warmth and competence (Fang, 2019). Therefore, even if the user recognizes the value in making the recommended app swaps, they could continue using the battery-hungry applications, citing other in-app factors and features, which have ultimately led to them becoming loyal customers, or alternatively continue using the apps due to factors, related to the company, which has developed it. Overall, this demonstrates that while the proposed approach is logically-sound on the basis of efficiency of the battery, there are other determinants that influence app choice and user behaviour, which can obstruct the translation of the efficient savings, cited in the findings to a practical setting. As also previously highlighted, different users have vastly contrasting energy management behaviors, which relates to how battery-saving is approached and also how battery is discharged (Hosio et al., 2016).

The perceived importance of app loyalty and app choice versus battery performance improvement is also not well understood, with further research on this topic needed. While the present research findings suggest that the individuals from the group with the highest attention towards battery performance can benefit from switching to other applications, which can perform the same functions at a lesser expense to the phone's battery, it is unknown to what degree they would be willing to make the swap. In order words, while this coping strategy is considered by the authors least invasive to the lives of the individuals amongst the group, it is understood that other coping strategies exist, which might be preferred by different users as they consider them least invasive and most convenient. The recommended approach remains objectively the most efficient approach on the basis of environmental protection, battery performance optimization and personalization of the approach to the user's individual app use.

It is also recognized that energy savings do not always translate to extended battery life – an insight, affirmed within Kim et al. (2013) study. Specifically, the authors write: "*energy savings do not always translate to longer smartphone battery life and that evaluating any savings plan must be based on battery consumption, not energy used*" (p.59). In some cases, the manufacturers of batteries could have produced them with a certain lifetime in mind. In all cases though, the current research has demonstrated a reduction of battery consumption, which leads to less frequent charges required, thus generating a better behaviour in relation to green computing and energy use. Whether this translates to an extension of the lifetime of the device or the battery remains a point of debate in academic science.

Finally, it is recognized that there might be in some cases applications that cannot be replaced, even though there are more efficient, optimized applications doing the same service, with the issues going beyond the functional characteristics of the app. Referring back to the discussion illustrated as part of the literature review, regarding the recent pandemic, many users have now installed applications that support their day-to-day communications with their co-workers, the change of which is in most cases arguably impossible, as it is a decision, taken at a higher corporate level. This example serves to demonstrate that while users have ownership of their devices, due to the intertwined nature of smartphone devices, applications and services in our daily lives, there is sometimes an inability to manage the applications on the phones with complete ownership of the decision-making. Having certain applications, even if they are battery-damaging could be a means to sustain our roles as employees or individuals as part of a digital society.

The research proposes giving the chance to manufacturers and developers to improve their applications by asking Google Play store to provide the star-rating label instantly whenever a developer or a manufacturer uploads an application on Google Play. The rating will be provided to developers as a private report instead of showing it in a later stage as a published label. At this stage, such information will encourage developers to develop or improve their application. Furthermore, knowing that a label will be later shared by end users will give more encouragement to developers to come up with only energy-efficient applications.

Another improvement which can be added in a future stage is to use machine learning during the rating stage. Since machine learning were proven to give a positive output in different sectors starting from health, science, moving to applied science and industry, then machine learning will play a very good role in our proposed solution.

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Appendix I

Survey 2.A

Please Select Your Gender:

□ Male □ Female

Please Select Your Age Group:

□ 8 to 16

□ 16 to 24

□ 25 to 34

□ 35 to 64

□ 65+

Please Select Your Job Nature:

□ Full-time Students

□ Part-time Students

□ Part-time employee - Indoor

□ Part-time employee - Outdoor

□ Full-time Employee - Indoor

□ Full-time Employee - Outdoor

□ Businessman/ Businesswoman

□ Housewife

□ Retired

How much do you care about extending your battery life during the day? Please Select One Answer Only

□ I don't care, I can charge my phones battery anytime because I have wide access to recharging resources in my work or study environment also, I have enough time to wait for my phone to be charged.

□ I care about saving my phones battery because I have limited access to recharging resources in my work or study environment also, I have limited time to wait for my phone to be charged.

□ I extremally care about saving my phones battery because I have no access to recharging resources in my work or study environment also, I have no time to wait for my phone to be charged.

How often do you change your phone? Please Select One Answer Only

□ Around once a week

□ Every other day

□ Once a day

□ Twice a day

□ I keep it plugged to a recharging resource most of the day

When do you plug your phone to a charging resource? Please Select One Answer Only

□ When the phone is totally out of charge and it switches Off

□ When the phone gives a low battery alarm

□ When I'm in car or when I go to bed regardless of the battery level

□ I keep it plugged to a recharging resource most of the day.

Please list six or more applications you mostly use on daily basis:

1-

2-

3-

4-

5-

6-

7-

8-

9-

10-

End of Survey - Thank you

Appendix II

List of All Permissions an App May Need:

1. *access Bluetooth settings*
2. *access extra location provider commands*
3. *access mail information*
4. *access USB storage filesystem*
5. *add or modify calendar events and send email to guests without owners' knowledge*
6. *add or remove accounts*
7. *adjust your wallpaper size*
8. *allow Wi-Fi Multicast reception*
9. *approximate (network-based) location*
10. *Broadcast data messages to apps*
11. *change network connectivity*
12. *change system display settings*
13. *change your audio settings*
14. *change/intercept network settings and traffic*
15. *choose widgets*
16. *close other apps*
17. *connect and disconnect from Wi-Fi*
18. *control flashlight*
19. *control Near Field Communication*
20. *control vibration*
21. *create accounts and set passwords*
22. *delete all app cache data*
23. *directly call phone numbers*

24. disable your screen lock

25. download files without notification

26. draw over other apps

27. edit your text messages (SMS or MMS)

28. expand/collapse status bar

29. find accounts on the device

30. full network access

31. Google Play billing service

32. Google Play license check

33. install shortcuts

34. make app always run

35. measure app storage space

36. mock location sources for testing

37. modify or delete the contents of your USB storage

38. modify phone state

39. modify secure system settings

40. modify system settings

41. modify your contacts

42. modify your own contact card

43. modify/delete internal media storage contents

44. pair with Bluetooth devices

45. precise (GPS) location

46. prevent phone from sleeping

47. read calendar events plus confidential information

48. read call log

49. read call log, write call log

50. Read email attachments

51. *read Gmail*

52. *read Google service configuration*

53. *read Home settings and shortcuts*

54. *read instant messages*

55. *read owner data*

56. *read phone status and identity*

57. *read sensitive log data*

58. *read subscribed feeds*

59. *read sync settings*

60. *read sync statistics*

61. *read terms you added to the dictionary*

62. *read your contacts*

63. *read your contacts, choose widgets*

64. *read your contacts, read call log*

65. *read your own contact card*

66. *read your social stream*

67. *read your text messages (SMS or MMS)*

68. *read your Web bookmarks and history*

69. *receive data from Internet*

70. *receive text messages (MMS)*

71. *receive text messages (SMS)*

72. *receive text messages (WAP)*

73. *record audio*

74. *reorder running apps*

75. *reroute outgoing calls*

76. *retrieve running apps*

77. *run at startup*

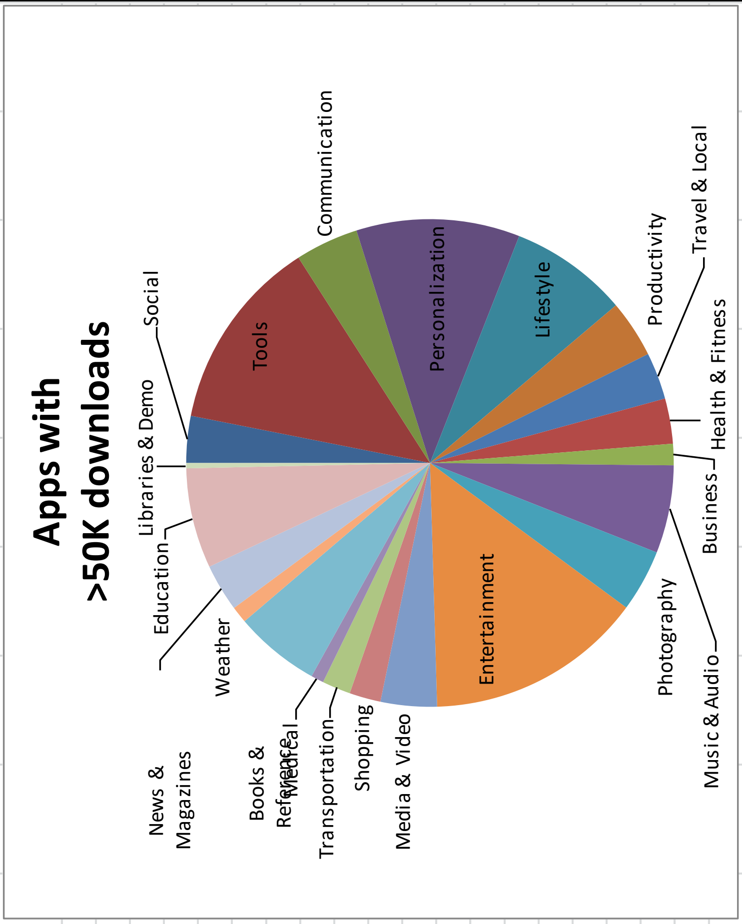
78. *send SMS messages*
79. *send sticky broadcast*
80. *set an alarm*
81. *set preferred apps*
82. *set wallpaper*
83. *take pictures and videos*
84. *take pictures and videos, record audio*
85. *test access to protected storage*
86. *toggle sync on and off*
87. *uninstall shortcuts*
88. *use accounts on the device*
89. *view configured accounts*
90. *view network connections*
91. *view Wi-Fi connections*
92. *write call log*
93. *write Home settings and shortcuts*
94. *write subscribed feeds*
95. *write to user-defined dictionary*
96. *write to your social stream*
97. *write web bookmarks and history*
98. *write web bookmarks and history, set an alarm*

List of 29 Permissions of Power Concern:

1. *access Bluetooth settings*
2. *allow Wi-Fi Multicast reception*
3. *Broadcast data messages to apps*
4. *change network connectivity*

5. *change system display settings*
6. *change your audio settings*
7. *change/intercept network settings and traffic*
8. *connect and disconnect from Wi-Fi*
9. *control flashlight*
10. *control vibration*
11. *directly call phone numbers*
12. *download files without notification*
13. *full network access*
14. *make app always run*
15. *modify phone state*
16. *modify secure system settings*
17. *modify system settings*
18. *pair with Bluetooth devices*
19. *precise (GPS) location*
20. *prevent phone from sleeping*
21. *read your social stream*
22. *record audio*
23. *run at startup*
24. *send sticky broadcast*
25. *take pictures and videos*
26. *take pictures and videos, record audio*
27. *toggle sync on and off*
28. *view Wi-Fi connections*
29. *write to your social stream*

Appendix III



Category	Apps with >50K download	Power Concern Permissions
Social	1834	22
Tools	7577	21
Communication	2476	21
Personalization	6405	17
Lifestyle	4634	17
Productivity	2256	17
Travel & Local	1839	16
Health & Fitness	1771	14
Business	836	14
Music & Audio	3441	13
Photography	2436	13
Entertainment	8525	12
Media & Video	2202	12
Shopping	1227	12
Transportation	1117	11
Medical	498	11
Books & Reference	3359	10
Weather	653	10
News & Magazines	1858	8
Education	3923	7
Libraries & Demo	207	3

Table 1A: Google Play Applications Categories Calculated Power Related Statistics

Category	Top 10 Popular Apps	Number of Permissions an App Needs	List of Permission Needed for this category Permission Description	Used amoung Top 10 Apps	Power Concern
Entertainment	**4shared**	10			
	Netflix	10			
	Talking Tom Cat 2 Free	12			
	Talking Ben The Dog Free	11	full network access	10	Yes
	Audiko Ringtones	16	view network connections	10	
	Twitch	7	read phone status and identity	9	
	MP3 Music Download	5	test access to protected storage	8	
	Talking Ginger	11	receive data from Internet	8	
	9GAG-Funny pics and videos	6	modify or delete the contents of your USB storage	8	
	Talking Tom & Ben News Free	12	prevent phone from sleeping	8	Yes
	Average	**10**	view Wi-Fi connections	6	Yes
			Google Play billing service	5	
			modify system settings	5	Yes
As per to 3rd August 2014			find accounts on the device	4	
http://www.appbrain.com			record audio	4	Yes
			run at startup	3	Yes
Avarage Number or Power Concern Permissions Used Under This Category			control vibration	2	Yes
			approximate (network-based) location	1	
			send sticky broadcast	1	Yes
12			pair with Bluetooth devices	1	Yes
			allow Wi-Fi Multicast reception	1	Yes
			retrieve running apps	1	
			read your contacts	1	
			modify your contacts	1	
			set an alarm	1	
			connect and disconnect from Wi-Fi	1	Yes
			take pictures and videos	1	Yes

Table 2A: Calculated Power Related Statistics For Entertainment Applications Category

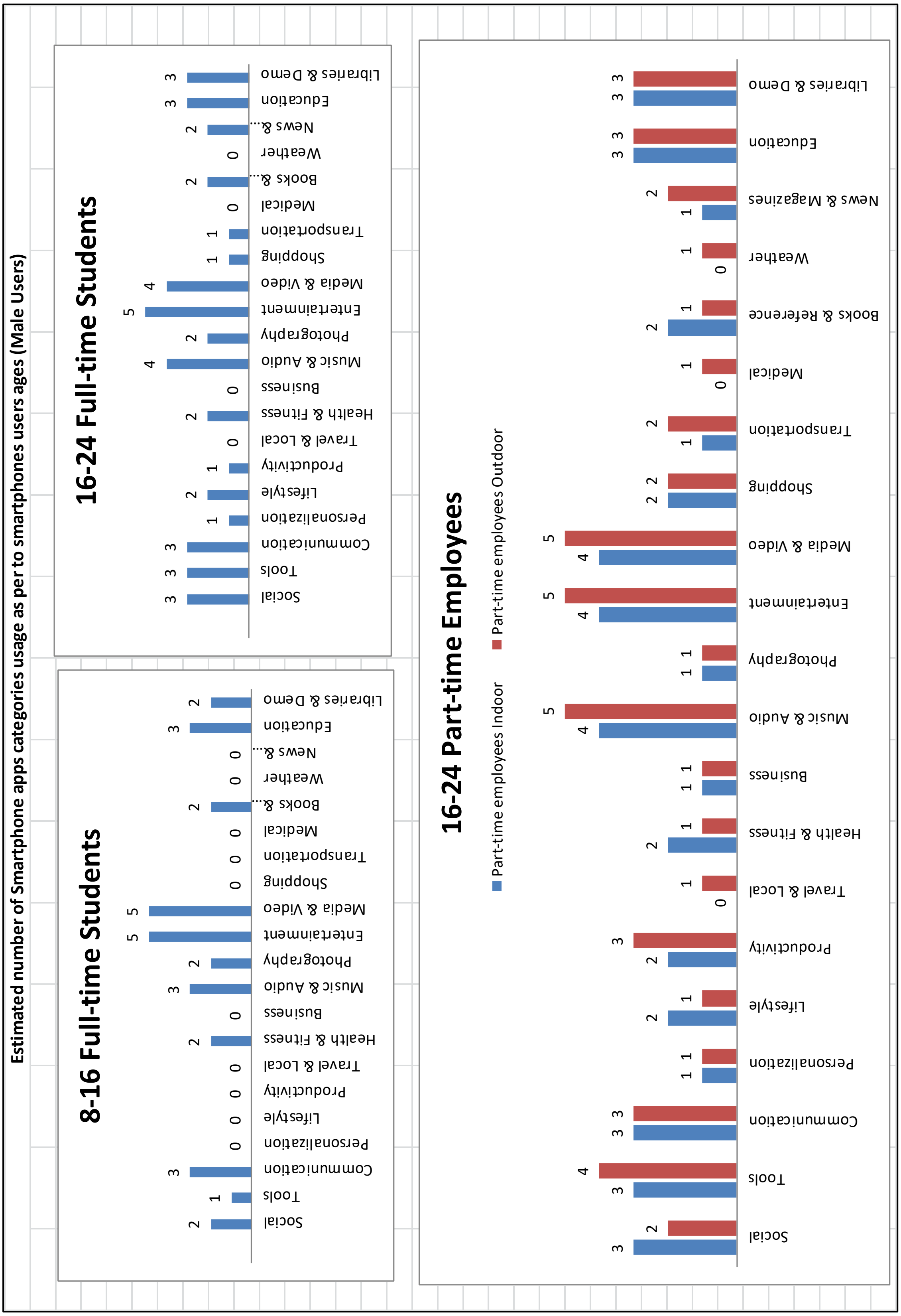
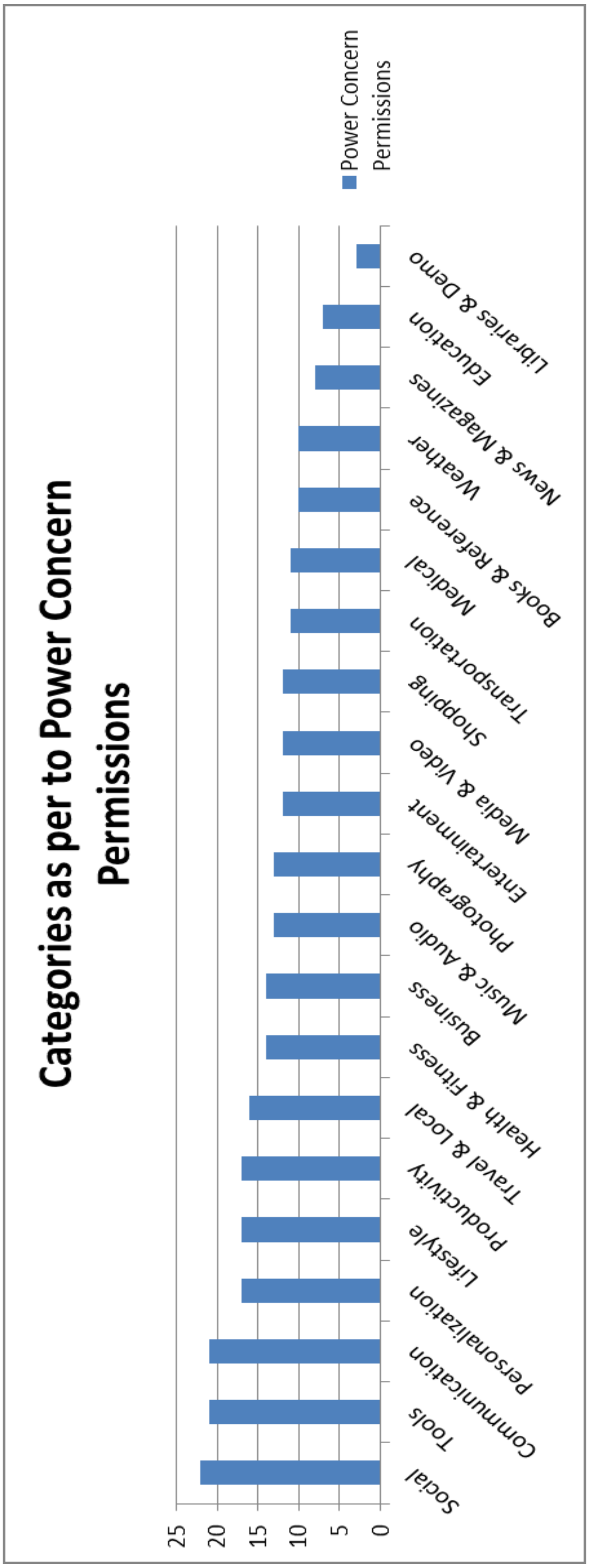


Table 3A: Estimated Number of Smartphone Applications Categories Usage as per to Smartphones Users Ages Groups



Categories as per to Power Concern Permissions
Power Concern Permissions
0
5
10
15
20
25
Social
Tools
Communication
Personalization
Lifestyle
Productivity
Travel & Local
Health & Fitness
Business
Music & Audio
Photography
Entertainment
Media & Video
Shopping
Transportation
Medical
Books & Reference
Weather
News & Magazines
Education
Libraries & Demo

Table 5A: Applications Categories as per to Power Concern Permissions

Users Age Range	Smartphone User Category		Social	Tools	Communication	Personalization	Lifestyle	Productivity	Travel & Local	Health & Fitness	Business	Music & Audio	Photography	Entertainment	Media & Video	Shopping	Transportation	Medical	Books & Reference	Weather	News & Magazines	Education	Libraries & Demo
8 to 16	Full-time Students		9%	3%	12%	0%	6%	0%	0%	3%	0%	12%	9%	15%	6%	0%	0%	0%	6%	0%	3%	9%	6%
16 to 24	Full-time Students		9%	7%	9%	2%	7%	2%	0%	2%	0%	11%	9%	9%	4%	2%	2%	0%	4%	0%	7%	7%	7%
	Part-time employees	Indoor	10%	7%	7%	2%	7%	5%	0%	2%	2%	12%	5%	7%	2%	5%	2%	0%	5%	0%	5%	7%	7%
		Outdoor	7%	9%	7%	2%	7%	7%	2%	4%	2%	9%	4%	4%	2%	4%	4%	2%	2%	2%	7%	7%	7%
	Full-time Employees	Indoor	8%	4%	6%	6%	8%	2%	0%	2%	2%	10%	6%	8%	10%	6%	6%	0%	2%	2%	6%	6%	4%
		Oudoor	9%	4%	7%	4%	9%	4%	2%	4%	2%	7%	6%	6%	7%	6%	4%	0%	0%	4%	7%	4%	6%
25 to 34	Part-time students		6%	4%	4%	2%	6%	8%	4%	4%	4%	6%	4%	6%	4%	4%	4%	2%	8%	2%	4%	8%	10%
	Full-time employees	Indoor	9%	3%	6%	3%	9%	9%	3%	6%	3%	9%	6%	6%	3%	3%	3%	3%	3%	3%	6%	3%	3%
		Outdoor	5%	2%	7%	2%	7%	5%	7%	10%	2%	7%	10%	2%	2%	2%	5%	2%	5%	5%	7%	2%	2%
	Buisenss women		4%	2%	6%	2%	6%	2%	6%	4%	10%	6%	4%	2%	2%	10%	10%	2%	4%	2%	10%	2%	2%
	Housewives		9%	2%	7%	2%	7%	0%	4%	9%	0%	7%	7%	9%	4%	11%	7%	2%	2%	2%	9%	2%	0%
35 to 64	Part-time students		4%	6%	4%	0%	6%	0%	4%	4%	4%	6%	6%	2%	2%	2%	6%	2%	10%	2%	6%	10%	10%
	Full-time employees	Indoor	6%	6%	6%	2%	6%	4%	4%	8%	4%	6%	6%	6%	4%	6%	6%	2%	4%	2%	6%	2%	2%
		Outdoor	6%	6%	9%	2%	6%	6%	4%	6%	4%	6%	4%	6%	2%	4%	6%	2%	2%	4%	6%	2%	2%
	Buisenss women		4%	2%	6%	2%	6%	2%	9%	6%	9%	6%	4%	2%	4%	9%	9%	2%	4%	4%	9%	2%	2%
	Housewives		8%	2%	6%	2%	6%	0%	4%	8%	2%	6%	6%	8%	4%	10%	6%	4%	2%	4%	6%	4%	4%
	Part-time employees	Indoor	9%	3%	7%	3%	7%	5%	3%	3%	3%	5%	7%	3%	7%	7%	3%	3%	3%	2%	7%	3%	3%
		Outdoor	7%	4%	5%	4%	5%	5%	2%	4%	5%	7%	5%	5%	5%	9%	4%	4%	2%	2%	9%	4%	4%
65+	Housewives		4%	2%	4%	0%	7%	0%	2%	9%	2%	7%	4%	2%	2%	2%	2%	9%	9%	4%	9%	9%	9%
	Retirees		4%	2%	4%	0%	6%	0%	4%	8%	2%	6%	4%	6%	6%	2%	2%	8%	4%	4%	8%	8%	8%

Appendix IV

1. Rating "Maps" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
precise location (GPS and network-based)	25	16	2.8
approximate location (network-based)			
take pictures and videos	14		
directly call phone numbers	10		
read sensitive log data			
change/intercept network settings and traffic	16		
read phone status and identity			
modify your contacts			
find accounts on the device			
read your contacts			
Photos/Media/Files			
access USB storage filesystem			
view Wi-Fi connections	12		
modify or delete the contents of your USB storage			
read the contents of your USB storage			
update component usage statistics			
close other apps			
modify app ops statistics			
modify/delete internal media storage contents			
read Home settings and shortcuts			
write Home settings and shortcuts			
receive data from Internet			
install shortcuts			
modify system settings	20		
control vibration	15		
prevent device from sleeping	18		
run at startup	20		
draw over other apps			
disable your screen lock			
uninstall shortcuts			
view network connections			
connect and disconnect from Wi-Fi	12		
full network access	16		

2. Rating "Hotspot Shield" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
retrieve running apps		14	3.3
take pictures and videos	14		
modify or delete the contents of your USB storage			
read the contents of your USB storage			
read calendar events plus confidential information			
precise location (GPS and network-based)	25		
approximate location (network-based)			
record audio	5		
view Wi-Fi connections	12		
directly call phone numbers	10		
read phone status and identity			
read your contacts			
receive data from Internet			
prevent device from sleeping	18		
read sync settings			
uninstall shortcuts			
pair with Bluetooth devices	10		
install shortcuts			
change your audio settings	9		
send sticky broadcast	16		
full network access	16		
reorder running apps			
draw over other apps			
toggle sync on and off	16		
view network connections			

3. Rating "BetterMe" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
precise location (GPS and network-based)	25	16	2.8
approximate location (network-based)			
take pictures and videos	14		
directly call phone numbers	10		
read sensitive log data			
change/intercept network settings and traffic	16		
read phone status and identity			
modify your contacts			
find accounts on the device			
read your contacts			
Photos/Media/Files			
access USB storage filesystem			
view Wi-Fi connections	12		
modify or delete the contents of your USB storage			
read the contents of your USB storage			
update component usage statistics			
close other apps			
modify app ops statistics			
modify/delete internal media storage contents			
read Home settings and shortcuts			
write Home settings and shortcuts			
receive data from Internet			
install shortcuts			
modify system settings	20		
control vibration	15		
prevent device from sleeping	18		
run at startup	20		
draw over other apps			
disable your screen lock			
uninstall shortcuts			
view network connections			
connect and disconnect from Wi-Fi	12		
full network access	16		
change network connectivity	15		

4. **Rating "Zoom Meeting" Application Using Power Consumption Stars Scale**

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
view Wi-Fi connections	12	14	3.1
directly call phone numbers	10		
read call log			
read phone status and identity			
read your own contact card			
add or remove accounts			
precise location (GPS and network-based)	25		
approximate location (network-based)			
record audio	5		
take pictures and videos	14		
read the contents of your USB storage			
modify or delete the contents of your USB storage			
modify your contacts			
find accounts on the device			
read your contacts			
download files without notification	16		
receive data from Internet			
create accounts and set passwords			
change your audio settings	9		
install shortcuts			
read Google service configuration			
draw over other apps			
full network access	16		
control vibration	15		
read sync settings			
prevent device from sleeping	18		
view network connections			
uninstall shortcuts			
pair with Bluetooth devices	10		
run at startup	20		
toggle sync on and off	16		

5. Rating "KineMaster – Video Editor" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
view Wi-Fi connections	12	14	3.1
read your Web bookmarks and history			
add or remove accounts			
precise location (GPS and network-based)	25		
approximate location (network-based)			
record audio	5		
take pictures and videos	14		
read the contents of your USB storage			
modify or delete the contents of your USB storage			
find accounts on the device			
read your contacts			
download files without notification	16		
read sync statistics			
receive data from Internet			
change your audio settings	9		
install shortcuts			
use accounts on the device			
write web bookmarks and history			
read Google service configuration			
access Bluetooth settings	10		
control Near Field Communication			
full network access	16		
control vibration	15		
read sync settings			
prevent device from sleeping	18		
view network connections			
pair with Bluetooth devices	10		
reorder running apps			
run at startup	20		
toggle sync on and off	16		

6. Rating "Cisco Webex" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
retrieve running apps		14	3.3
take pictures and videos	14		
modify or delete the contents of your USB storage			
read the contents of your USB storage			
read calendar events plus confidential information			
precise location (GPS and network-based)	25		
approximate location (network-based)			
record audio	5		
view Wi-Fi connections	12		
directly call phone numbers	10		
read phone status and identity			
read your contacts			
receive data from Internet			
prevent device from sleeping	18		
read sync settings			
uninstall shortcuts			
pair with Bluetooth devices	10		
install shortcuts			
change your audio settings	9		
send sticky broadcast	16		
full network access	16		
reorder running apps			
draw over other apps			
toggle sync on and off	16		
view network connections			

7. Rating "Imo free video calls and chat" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
take pictures and videos	14	14	3.1
retrieve running apps			
add or remove accounts			
record audio	5		
read your contacts			
view Wi-Fi connections	12		
modify or delete the contents of your USB storage			
read the contents of your USB storage			
read Home settings and shortcuts			
receive data from Internet			
change your audio settings	9		
install shortcuts			
control flashlight	19		
create accounts and set passwords			
prevent device from sleeping	18		
run at startup	20		
toggle sync on and off	16		
uninstall shortcuts			
expand/collapse status bar			
control vibration	15		
view network connections			
reorder running apps			
full network access	16		
use accounts on the device			

8. Rating "YouTube" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
retrieve running apps		14	3.3
take pictures and videos	14		
modify or delete the contents of your USB storage			
read the contents of your USB storage			
read calendar events plus confidential information			
precise location (GPS and network-based)	25		
approximate location (network-based)			
record audio	5		
view Wi-Fi connections	12		
directly call phone numbers	10		
read phone status and identity			
read your contacts			
receive data from Internet			
prevent device from sleeping	18		
read sync settings			
uninstall shortcuts			
pair with Bluetooth devices	10		
install shortcuts			
change your audio settings	9		
send sticky broadcast	16		
full network access	16		
reorder running apps			
draw over other apps			
toggle sync on and off	16		
view network connections			

9. Rating "WhatsApp Messenger" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
view Wi-Fi connections	12	14	3.1
directly call phone numbers	10		
read call log			
read phone status and identity			
read your own contact card			
add or remove accounts			
precise location (GPS and network-based)	25		
approximate location (network-based)			
record audio	5		
take pictures and videos	14		
read the contents of your USB storage			
modify or delete the contents of your USB storage			
modify your contacts			
find accounts on the device			
read your contacts			
download files without notification	16		
receive data from Internet			
create accounts and set passwords			
change your audio settings	9		
install shortcuts			
read Google service configuration			
draw over other apps			
full network access	16		
control vibration	15		
read sync settings			
prevent device from sleeping	18		
view network connections			
uninstall shortcuts			
pair with Bluetooth devices	10		
run at startup	20		
toggle sync on and off	16		

10. Rating "Udemy" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
view Wi-Fi connections	12	17	2.7
modify or delete the contents of your USB storage			
read the contents of your USB storage			
receive data from Internet			
view network connections			
full network access	16		
prevent device from sleeping	18		
read Google service configuration			
run at startup	20		

11. Rating "Telegram" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
view Wi-Fi connections	12	14	3.1
directly call phone numbers	10		
read call log			
read phone status and identity			
read your own contact card			
add or remove accounts			
precise location (GPS and network-based)	25		
approximate location (network-based)			
record audio	5		
take pictures and videos	14		
read the contents of your USB storage			
modify or delete the contents of your USB storage			
modify your contacts			
find accounts on the device			
read your contacts			
download files without notification	16		
receive data from Internet			
create accounts and set passwords			
change your audio settings	9		
install shortcuts			
read Google service configuration			
draw over other apps			
full network access	16		
control vibration	15		
read sync settings			
prevent device from sleeping	18		
view network connections			
uninstall shortcuts			
pair with Bluetooth devices	10		
run at startup	20		
toggle sync on and off	16		

12. Rating "Netflix" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
view Wi-Fi connections	12	12	3.7
record audio	5		
read phone status and identity			
modify or delete the contents of your USB storage			
read the contents of your USB storage			
receive data from Internet			
allow Wi-Fi Multicast reception	12		
view network connections			
full network access	16		
prevent device from sleeping	18		
change your audio settings	9		
pair with Bluetooth devices	10		

13. Rating "VLC for Android" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
record audio	5	14	3.2
modify or delete the contents of your USB storage			
read the contents of your USB storage			
read TV channel/program information			
write TV channel/program information			
change your audio settings	9		
modify system settings	20		
control vibration	15		
prevent device from sleeping	18		
run at startup	20		
draw over other apps			
view network connections			
pair with Bluetooth devices	10		
full network access	16		

14. Rating "Chrome" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
view Wi-Fi connections	12	14	3.1
read your Web bookmarks and history			
add or remove accounts			
precise location (GPS and network-based)	25		
approximate location (network-based)			
record audio	5		
take pictures and videos	14		
read the contents of your USB storage			
modify or delete the contents of your USB storage			
find accounts on the device			
read your contacts			
download files without notification	16		
read sync statistics			
receive data from Internet			
change your audio settings	9		
install shortcuts			
use accounts on the device			
write web bookmarks and history			
read Google service configuration			
access Bluetooth settings	10		
control Near Field Communication			
full network access	16		
control vibration	15		
read sync settings			
prevent device from sleeping	18		
view network connections			
pair with Bluetooth devices	10		
reorder running apps			
run at startup	20		
toggle sync on and off	16		

15. Rating "RainViewer" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
precise location (GPS and network-based)	25	20	2.1
approximate location (network-based)			
modify or delete the contents of your USB storage			
read the contents of your USB storage			
receive data from Internet			
view network connections			
full network access	16		
prevent device from sleeping	18		
run at startup	20		

16. Rating "Gmail" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
view Wi-Fi connections	12	13	3.3
read calendar events plus confidential information			
add or modify calendar events and send email			
directly call phone numbers	10		
write call log			
read your own contact card			
add or remove accounts			
record audio	5		
take pictures and videos	14		
read the contents of your USB storage			
modify or delete the contents of your USB storage			
modify your contacts			
find accounts on the device			
read your contacts			
download files without notification	16		
read sync statistics			
read subscribed feeds			
write subscribed feeds			
receive data from Internet			
view configured accounts			
create accounts and set passwords			
install shortcuts			
change your audio settings	9		
use accounts on the device			
read Google service configuration			
control Near Field Communication			
full network access	16		
control vibration	15		
measure app storage space			
read sync settings			
prevent device from sleeping	18		
view network connections			
pair with Bluetooth devices	10		
run at startup	20		
toggle sync on and off	16		

17. Rating "Twitter" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
take pictures and videos	14	15	3.0
read your contacts			
record audio	5		
find accounts on the device			
add or remove accounts			
read your own contact card			
Wi-Fi connection information			
view Wi-Fi connections	12		
approximate location (network-based)			
precise location (GPS and network-based)	25		
read phone status and identity			
read the contents of your USB storage			
modify or delete the contents of your USB storage			
receive data from Internet			
full network access	16		
run at startup	20		
draw over other apps			
control vibration	15		
measure app storage space			
change your audio settings	9		
use accounts on the device			
read Google service configuration			
create accounts and set passwords			
view network connections			
toggle sync on and off	16		
prevent device from sleeping	18		
install shortcuts			
read sync settings			

18. Rating "Instagram" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
take pictures and videos	14	14	3.3
receive text messages (SMS)			
read your contacts			
record audio	5		
find accounts on the device			
read your own contact card			
Wi-Fi connection information			
view Wi-Fi connections	12		
directly call phone numbers	10		
precise location (GPS and network-based)	25		
read phone status and identity			
read the contents of your USB storage			
modify or delete the contents of your USB storage			
retrieve running apps			
receive data from Internet			
read frame buffer			
change screen orientation			
full network access	16		
run at startup	20		
read battery statistics			
control vibration	15		
access Bluetooth settings	10		
change your audio settings	9		
use accounts on the device			
view network connections			
prevent device from sleeping	18		
uninstall shortcuts			
pair with Bluetooth devices	10		

19. Rating "Pinterest" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
read your contacts		16	2.9
read your own contact card			
find accounts on the device			
take pictures and videos	14		
view Wi-Fi connections	12		
record audio	5		
precise location (GPS and network-based)	25		
modify or delete the contents of your USB storage			
read the contents of your USB storage			
receive data from Internet			
prevent device from sleeping	18		
run at startup	20		
control Near Field Communication			
view network connections			
read Google service configuration			
full network access	16		
set wallpaper			
use accounts on the device			

20. Rating “Free VPN & Security” Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
view Wi-Fi connections	12	18	2.4
approximate location (network-based)			
precise location (GPS and network-based)	25		
read the contents of your USB storage			
modify or delete the contents of your USB storage			
receive data from Internet			
full network access	16		
prevent device from sleeping	18		
run at startup	20		
view network connections			

21. Rating "TikTok" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
take pictures and videos	14	14	3.1
retrieve running apps			
add or remove accounts			
record audio	5		
read your contacts			
view Wi-Fi connections	12		
modify or delete the contents of your USB storage			
read the contents of your USB storage			
read Home settings and shortcuts			
receive data from Internet			
change your audio settings	9		
install shortcuts			
control flashlight	19		
create accounts and set passwords			
prevent device from sleeping	18		
run at startup	20		
toggle sync on and off	16		
uninstall shortcuts			
expand/collapse status bar			
control vibration	15		
view network connections			
reorder running apps			
full network access	16		
use accounts on the device			

22. Rating "PicArt Photo Editor" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
take pictures and videos	14	18	2.5
modify or delete the contents of your USB storage			
read the contents of your USB storage			
precise location (GPS and network-based)	25		
approximate location (network-based)			
read your contacts			
view Wi-Fi connections	12		
bind to a wallpaper			
receive data from Internet			
set wallpaper			
view network connections			
full network access	16		
prevent device from sleeping	18		
read Google service configuration			
run at startup	20		

23. Rating "SkyScanner" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
view Wi-Fi connections	12	18	2.5
precise location (GPS and network-based)	25		
approximate location (network-based)			
receive data from Internet			
full network access	16		
prevent device from sleeping	18		
view network connections			

24. Rating "Uber" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
add or remove accounts		14	3.3
read your own contact card			
take pictures and videos	14		
view Wi-Fi connections	12		
read calendar events plus confidential information			
read your contacts			
find accounts on the device			
precise location (GPS and network-based)	25		
approximate location (network-based)			
read your text messages (SMS or MMS)			
receive text messages (SMS)			
send SMS messages			
record audio	5		
read phone status and identity			
directly call phone numbers	10		
Photos/Media/Files			
modify or delete the contents of your USB storage			
read the contents of your USB storage			
receive data from Internet			
prevent device from sleeping	18		
access Bluetooth settings	10		
change your audio settings	9		
draw over other apps			
run at startup	20		
full network access	16		
read Google service configuration			
change network connectivity	15		
use accounts on the device			
view network connections			
control vibration	15		
connect and disconnect from Wi-Fi	12		
pair with Bluetooth devices	10		

25. Rating "VIDAL" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
take pictures and videos	14	16	2.9
view Wi-Fi connections	12		
find accounts on the device			
read phone status and identity			
Photos/Media/Files			
modify or delete the contents of your USB storage			
read the contents of your USB storage			
receive data from Internet			
download files without notification	16		
view network connections			
control flashlight	19		
full network access	16		
prevent device from sleeping	18		
control vibration	15		

26. Rating "OfficeSuite" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
retrieve running apps		16	2.8
view Wi-Fi connections	12		
read the contents of your USB storage			
modify or delete the contents of your USB storage			
read phone status and identity			
add or remove accounts			
read your contacts			
manage document storage			
modify/delete internal media storage contents			
receive data from Internet			
install shortcuts			
use accounts on the device			
view network connections			
reorder running apps			
control vibration	15		
full network access	16		
add words to user-defined dictionary			
run at startup	20		
prevent device from sleeping	18		

27. Rating "Spotify" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
add or remove accounts		14	3.2
take pictures and videos	14		
view Wi-Fi connections	12		
find accounts on the device			
precise location (GPS and network-based)	25		
record audio	5		
read phone status and identity			
modify or delete the contents of your USB storage			
read the contents of your USB storage			
receive data from Internet			
prevent device from sleeping	18		
access Bluetooth settings	10		
change your audio settings	9		
run at startup	20		
full network access	16		
use accounts on the device			
view network connections			
control vibration	15		
control Near Field Communication			
allow Wi-Fi Multicast reception	12		
pair with Bluetooth devices	10		
send sticky broadcast	16		
install shortcuts			

28. Rating "Weather Live" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
approximate location (network-based)		20	2.1
precise location (GPS and network-based)	25		
read phone status and identity			
read the contents of your USB storage			
modify or delete the contents of your USB storage			
receive data from Internet			
full network access	16		
prevent device from sleeping	18		
run at startup	20		
view network connections			
read Google service configuration			

29. Rating “Be Closer” Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
read your contacts		17	2.6
Device & app history			
retrieve running apps			
read your own contact card			
take pictures and videos	14		
view Wi-Fi connections	12		
read phone status and identity			
precise location (GPS and network-based)	25		
access extra location provider commands			
approximate location (network-based)			
Photos/Media/Files			
modify or delete the contents of your USB storage			
read the contents of your USB storage			
receive data from Internet			
control vibration	15		
create accounts and set passwords			
prevent device from sleeping	18		
run at startup	20		
draw over other apps			
toggle sync on and off	16		
view network connections			
full network access	16		
read sync settings			

30. Rating "Jollychic" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
take pictures and videos	14	17	2.7
view Wi-Fi connections	12		
find accounts on the device			
precise location (GPS and network-based)	25		
approximate location (network-based)			
retrieve running apps			
modify or delete the contents of your USB storage			
read the contents of your USB storage			
receive data from Internet			
close other apps			
modify system settings	20		
view network connections			
prevent device from sleeping	18		
control vibration	15		
run at startup	20		
connect and disconnect from Wi-Fi	12		
full network access	16		
change network connectivity	15		

31. Rating "Screen Mirroring Cast To Tele" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
read the contents of your USB storage		15	3.1
modify or delete the contents of your USB storage			
view Wi-Fi connections	12		
view network connections			
change network connectivity	15		
connect and disconnect from Wi-Fi	12		
full network access	16		
prevent device from sleeping	18		

32. Rating "Amazon" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
add or remove accounts		14	3.3
take pictures and videos	14		
view Wi-Fi connections	12		
read your contacts			
find accounts on the device			
precise location (GPS and network-based)	25		
approximate location (network-based)			
record audio	5		
read phone status and identity			
modify or delete the contents of your USB storage			
read the contents of your USB storage			
read Home settings and shortcuts			
receive data from Internet			
view network connections			
control flashlight	19		
prevent device from sleeping	18		
access Bluetooth settings	10		
change your audio settings	9		
control vibration	15		
create accounts and set passwords			
connect and disconnect from Wi-Fi	12		
full network access	16		
pair with Bluetooth devices	10		
use accounts on the device			
install shortcuts			

33. Rating "TED" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
view Wi-Fi connections	12	15	3.0
read the contents of your USB storage			
modify or delete the contents of your USB storage			
receive data from Internet			
full network access	16		
change your audio settings	9		
prevent device from sleeping	18		
run at startup	20		
view network connections			

34. Rating "Zoom Cloud Meetings" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
view Wi-Fi connections	12	14	3.2
read calendar events plus confidential information			
add or modify calendar events and send email			
directly call phone numbers	10		
read phone status and identity			
Photos/Media/Files			
add or remove accounts			
precise location (GPS and network-based)	25		
approximate location (network-based)			
record audio	5		
take pictures and videos	14		
read the contents of your USB storage			
modify or delete the contents of your USB storage			
read your contacts			
find accounts on the device			
receive data from Internet			
full network access	16		
control vibration	15		
change your audio settings	9		
send sticky broadcast	16		
use accounts on the device			
prevent device from sleeping	18		
view network connections			
access Bluetooth settings	10		
modify system settings	20		
pair with Bluetooth devices	10		
draw over other apps			

35. Rating "CamScanner" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
take pictures and videos	14	15	3.0
view Wi-Fi connections	12		
read phone status and identity			
modify or delete the contents of your USB storage			
access USB storage filesystem			
read the contents of your USB storage			
receive data from Internet			
view network connections			
full network access	16		
prevent device from sleeping	18		
read Google service configuration			
install shortcuts			

36. Rating "NovelCat" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
view Wi-Fi connections	12	16	2.8
read the contents of your USB storage			
modify or delete the contents of your USB storage			
receive data from Internet			
full network access	16		
prevent device from sleeping	18		
view network connections			
control vibration	15		
run at startup	20		
read Google service configuration			

37. Rating "Davis's Drug Guide for Nurses" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
view Wi-Fi connections	12	15	2.9
read the contents of your USB storage			
modify or delete the contents of your USB storage			
receive data from Internet			
full network access	16		
prevent device from sleeping	18		
view network connections			

38. Rating "DuckDuckGo Privacy Browser" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
read the contents of your USB storage		18	2.4
modify or delete the contents of your USB storage			
view network connections			
full network access	16		
run at startup	20		
prevent device from sleeping	18		
install shortcuts			

39. Rating "Samsung Music" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
retrieve running apps		14	3.3
read sensitive log data			
read phone status and identity			
view Wi-Fi connections	12		
record audio	5		
modify or delete the contents of your USB storage			
read the contents of your USB storage			
configure Wifi displays			
power device on or off			
download files without notification	16		
press keys and control buttons			
interact across users			
display unauthorized windows			
manage activity stacks			
manage users			
control media playback and metadata access			
disable or modify status bar			
prevent app switches			
modify/delete internal media storage contents			
modify secure system settings			
receive data from Internet			
change your audio settings	9		
install shortcuts			
modify system settings	20		
prevent device from sleeping	18		
read terms you added to the dictionary			
view network connections			
reorder running apps			
full network access	16		
change network connectivity	15		
control vibration	15		
uninstall shortcuts			
pair with Bluetooth devices	10		
connect and disconnect from Wi-Fi	12		
send sticky broadcast	16		

40. Rating "IMdb" Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
Contacts		15	2.9
Identity			
find accounts on the device			
Wi-Fi connection information			
view Wi-Fi connections	12		
Location			
approximate location (network-based)			
Other			
receive data from Internet			
full network access	16		
prevent device from sleeping	18		
view network connections			
control vibration	15		
toggle sync on and off	16		
read sync settings			

41. Rating “Vault” Application Using Power Consumption Stars Scale

Needed Permissions	Permissions consumption rate	Application Average Energy Consumption Amount per Minute	Application Star Rating out of Six Stars (~ 1 to ~ 30 mAh)
precise location (GPS and network-based)	25	16	2.8
approximate location (network-based)			
take pictures and videos	14		
directly call phone numbers	10		
read sensitive log data			
change/intercept network settings and traffic	16		
read phone status and identity			
modify your contacts			
find accounts on the device			
read your contacts			
Photos/Media/Files			
access USB storage filesystem			
view Wi-Fi connections	12		
modify or delete the contents of your USB storage			
read the contents of your USB storage			
update component usage statistics			
close other apps			
modify app ops statistics			
modify/delete internal media storage contents			
read Home settings and shortcuts			
write Home settings and shortcuts			
receive data from Internet			
install shortcuts			
modify system settings	20		
control vibration	15		
prevent device from sleeping	18		
run at startup	20		
draw over other apps			
disable your screen lock			
uninstall shortcuts			
view network connections			
connect and disconnect from Wi-Fi	12		
full network access	16		
change network connectivity	15		