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Review of Energy Consumption and Measurement Management Techniques in Smartphones

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Abstract: Smartphones energy consumption and management have become a major issue all over the smartphones research and developing (R&D) centers. On smartphones, the researches must achieve the wide requirements of the power drawn by the smartphone components and its new huge applications as well as the revolutions with the new communication technologies. Based on the above, it is necessary to take the approach for energy consumption optimization and management of energy conservation into consideration. This will help to achieve the desired green environment technologies for optimizing energy use in smartphones. In this review paper, we reviewed many energy consumption concepts; the smartphone services and applications, the testbeds and platforms survey, recent methods for power measurements, the key metrics used, and the energy consumption optimization schemes.

Keywords: Review; Energy consumption; Measurement; Management; Techniques; Smartphones.

1. INTRODUCTION

With the increased network connectivity, recent smartphones considered to be ubiquitous or the aim of the Internet of Things (IoT) [1]. Practically, all network connected equipment such as tablets, and smartphones, have some form of wireless connectivity. Newly, operative smartphones are becoming low-cost and influential in its functionality, that causes a considerable growth in changes of innovative mobile users as well as their desired data transfer rates [2]. Smartphones consume the batteries energy required for their operation, which can be defined as battery capacity. The battery capacity is limited according to the condition of device size which specifies that the energy efficiency of the smartphone is vital to its suitability [3]. Later, the motivation is the best energy consumption management. At the meantime, the device formation, configuration, and functionality are growing rapidly [3]. Most smartphones are energized by a non-removable limited batteries energy and size [3]. For these reasons, designers cannot properly raise the energy generated from the limited sized batteries but focus to produce higher animated battery to elongate their life [4].

2. SMARTPHONES APPLICATION, SERVICES, AND THCHNOLOGIES

A few years ago, the markets witness an explosion in the smartphone services and applications. Recent smartphones are designed with very fast processors, extreme large capacity memory, very high-resolution wide displays, and a network interface. These capabilities permit smartphones to perform multimedia user tasks as video streaming, gamming, and images processing. Smartphone services and applications are closely deal with momently user interactions to his UE, which give an indication and reflection of the user's behavior to the service and application operation. Recently, a huge number of smartphone services and applications arise in the smartphone's markets. The authors in [5] investigated a wide-ranging measurement and experiments using characteristic smartphones. The measurement operation had been conducted with Samsung Galaxy S2 and S3 smartphones. These devices were uploaded and downloaded many files of different sizes (10, 20, and 50 MB), utilizing available wireless technologies (2G, 3G, and wireless fidelity (WiFi)). The authors automated the process (stop communications to others) to stop any interaction with the device under test any interaction with the device sets it out of power saving mode.

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To achieve this job, they established a new Android application that allowed the authors to start a measurement operation in a simple documented setup. In [6], the authors proposed a user interaction-based profiling method for a new Android application to overwhelmed the limits of development-level application debugging. They analyzed the device behavior under test and its components energy consumption with process-level application monitoring. Then, a new application was developed and tested in real environment. In [7], the authors inspected the activation and utilization of carrier aggregation (CA) and its effects on the UE consumption with different traffic protocols such as; web browsing, and file transport protocol (FTP) as presented in Figure 1. The authors provided the analysis which explain how CA affects UE performance in applicable scenario such as web browsing sessions.

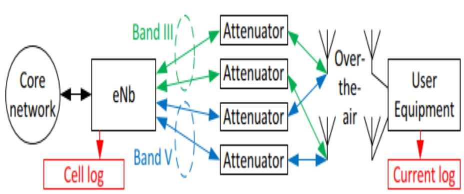
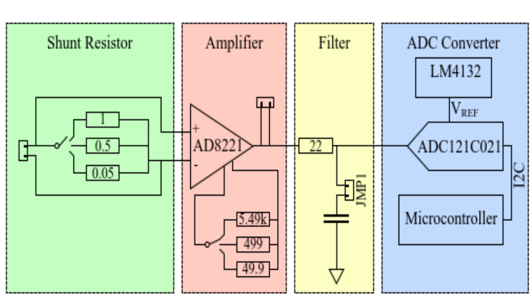


Figure 1: A block diagram of CA measurement setup

In [8], the authors evaluated the performance of the Android battery interface. They designed a power monitoring device that conducted any energy measurement tests for a set of most popular services with domestic calculations as well as 3G operation as shown in Figure 2. Their results showed that the device and battery interface can be depended to evaluate the energy consumption for any application consecutively on the device. In [9], the authors used the Samsung Note-4 as an Android platform to evaluate the parameters which cause energy consumption. They identified the battery drain in smartphone as the network, the device specifications, and the applications run by the user. The article [10] provided a methodical analysis of smartphone consumption in background audio recording setups.



.Figure 2. The architecture of the MCU-based measurement board

The authors testified inclusive measurement evaluations for many Android smartphone types with varied specifications, running with different types of Android operating systems (OS). They tested the smartphones which were connected to the high -resolution power supply programmed with power supply linked to a notebook personal computer (PC) via universal serial bus (USB) for logging subsequent data analysis. The block diagram of the setup is shown in Figure 3. They established a tradition Android application which performed the microphone audio recorded digitally at different levels of complexity.

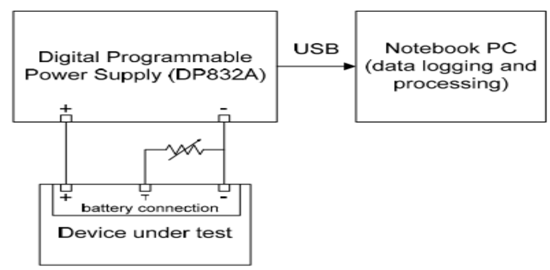


Figure 3: The connection diagram of the test environment.

In [11], the authors investigated the key considerations from the energy consumption attitude in the design of smartphone applications. They proposed diverse techniques, established at the operating system levels, have been anticipated to enhance energy efficiency in user device. In [12], the authors proposed an end-to-end efficient energy model to line up activity-based accounting principles which used to evaluate a range of SMS and video playback application to increased reality and simulated application. They conducted a sensitive analysis on different practice patterns to identify the basis causes of applications and services energy consumption.

3. Plateforms and its Specifications used in Smartphone

Some interesting novel architectures for wireless communication inspired by principles of cooperation have been introduced in the last few years. To evaluate the performance of any proposed architectures, it is needed to measure the performance; the throughput and delay in the communication, and the power consumption of the devices.

In many measurement campaigns, smartphones are placed in fixed referenced positions, and consequently, the evaluations differ from reality, where the topology of the network is constantly changing due to path loss and mobility of the users. All smartphone companies and research centers develop their equipment and core systems by testing and running platform experimentally.

In [13], the authors described the challenges, motivations, and identified the comparison of smartphone platforms and apps for energy efficiency. In [14], the authors provided an end-to-end energy model for IoT platforms. They have applied these models to an actual scenario: data stream analyzer which produced by cameras mounted in vehicles. In [15], the authors described the tasks and identified the methods how to compare the mobile platforms and applications for efficient energy consumption. Additionally, they discussed understandings to the main platform providers, the energy efficient applications design based on case studies that focused on energy comparison of different applications categories. In [16], the authors proposed a novel method that was lightweight in relations of the developing requirement which provided an accurate estimation for energy consumption at code level. In [17], the authors introduced an open testbed composed of more than 2500 wireless sensor nodes (WSN) and 115 mobile robots (MR) existing for experimenting with IoT technology, ranging from low-level protocols to advanced Internet services. The test bed was implemented to enhance the development of current IoT technology by offering an accurate multi-user scientific tool. In [18], the authors operated a PHONELAB as public smartphone platform testbed. The PHONELAB consisted of several-hundred UEs to run experimentally a platform image on their smartphone. The platform consisted of both instrumentational and experimental changes to platform components, including Linux and core Android services.

4. Measurement Methods

There are a lot of programs for energy measurements of the smartphones. However, these programs can't produce exact battery consumption measurements. Therefore, there are practical methods to measure and evaluate the results. In [19], the authors presented an LTE power model utilized with the industry to evaluate users' battery life. Their model was based on experimental measurements on LTE chipset. The model included functions for receiving and transmitting data rates with different power levels. The first complete Discontinuous Reception (DRX) and power consumption measurement setup were performed for the device under test for voltage and current for 30 seconds as shown in Figure 4. The measurement was reported together with cell bandwidth, display, and central processing unit (CPU) power consumption.

In [20], the authors analyzed how microsleep (MS) behaved with power discontinuity but with both, Reception and Transmission (DTX, DRX), combined with a wake-up receiver scheme to improve the battery life of the 5G UEs. In [21], the authors presented an empirical smartphone power model which covers the LTE subsystem based on DRX scheme. In [22] the authors reviewed a wide range of energy measurement models for UEs. They described a power measurement methodology which applied in the model-based energy profiles, as presented in Figure 5. The article classified the profilers according to their deployment strategies. They finally, pointed-out each profile limitation with the corresponding challenges.

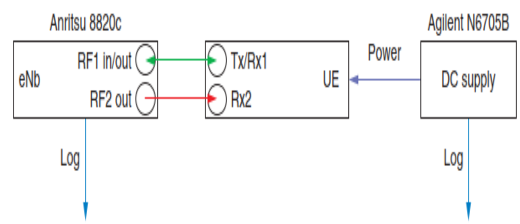


Figure 4. Measurement setup using base station emulator.

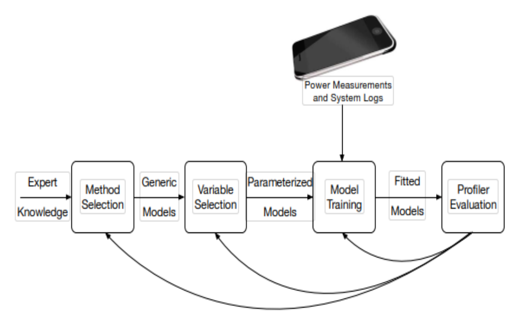


Figure 5. The process of power profiling, modeling, estimation, and a feedback to recalibrate the models.

In [23], the authors, by experiments, measured the power consumption for diverse elements of two kinds of smartphones. The measurements were done with applications that measure the power in each circuit and element of the smartphone. In [24], the authors analyzed several approaches for many previously energy saving proposed in a smartphone. They highlighted those schemes which dealt with the development of applications. They have included several strategies which designed, developed, and verified by research group which prevents consumed power thoughts from affecting other features of applications design, for example adaptable graphical user interface (GUI). In [25], the authors reviewed and defined many scenarios for device-to-device (D2D) scheme in 5G and future networks. They used a new model of WiFi and LTE-Advanced (LTE-A) interfaces to analyze the power consumed at UE. In [26], the authors analyzed how microsleep, stand-by, and DRX-DTX receiver schemes can be shared to elongate the battery life of UEs. They proofed, by measurements, that DRX and DTX schemes benefit from the new frame structure yield faster connection setup and up to 82 % lower energy consumption dependent on the traffic mode.

They proofed, also, that the stand-by receiver scheme can deliver 85 % lower energy consumption.

5. Evaluation Metrics Used in Measurements

There are a lot of methods and evaluation metrics used that can determine the energy consumption of the smartphone. However, these methods can't produce accurate battery consumption measurements. Therefore, there were some researches deal with new metrics to fulfill the required contribution, they are:

In [27], the authors defined the response time, the display-centric response time, which was known to be a metric for the quality of user experience (QoE) of the smartphone. The display-centric response time is defined as the period started by the beginning of user interaction and ended by the time when all interfaces for the next interaction is drawn. In [28], the authors investigated the impact of some development methods on the energy consumption of Android apps. Their study used a more than 30 testbed of different benchmarks and 3 applications on 5 different UEs to compare the energy efficiency and performance of the most commonly used approaches to develop apps on Android.

6. Consequences Evaluation

The mobile terminals are energy constrained because they depend on the limited power supply. Although development in battery technologies, hardware elements, and operating systems helped to improve these constrains, these improvements cannot avoid applications from inefficiently consuming a device's battery. Therefore, improving developers' capability to energy efficient applications is essential to diminish the impact of smartphones' energy limitations. In [29], the authors described a source-line energy consumption study of 400 real-world applications. They discovered several interesting observations by finding average apps which spent 60 % of their energy in idle state, network was the most energy consuming component, and only a few access point identifiers to control non-idle energy consumption. Their study revealed several observations that provided actionable guidance and motivate issues for future work for software engineers group. They found that some applications wasted 65 % of their power in an idle state. [30] the authors, using the Keysight Technologies, presented a power consumption model for the LTE UE. The model was useful when it was needed to examine the UE battery life in system-level simulation for smartphones adhering to the 3GPP LTE standard. In [31], the authors explored the impacts of the signal strength of WiFi environment on the energy consumption of UEs under good channel states, the category, and the protocol packets that are originated by WiFi APs to maintain basic network communications with the UEs. They constructed a time-based energy model which a signal strength-aware and packet/amount-aware energy models which corroborated the user experience on phone energy consumption. In [32], the authors proposed a power framework-based on user-perceived online response time optimization analyses. Their framework took clear account of the QoE into applying low-power technique.

7.Energy Consumption Optimization

In [33], the article addresses the challenge of minimizing the energy consumption of a wireless communication network by joint optimization of the base station (BS) transmit power and the cell activity. A mixed integer nonlinear optimization problem was formulated, for which a computationally tractable linear inner approximation algorithm is provided. The proposed method offered great flexibility in optimizing the network operation by considering multiple system parameters jointly, which mitigated a major drawback of existing state-of-the-art schemes that were mostly based on heuristics. The simulation results showed that the proposed method exhibited high performance in decreasing the energy consumption, and provided implicit load balancing in difficult high demand scenarios. In [34], the authors examined the power trade-offs in video transmission. They tested the display resolution and size along with the video schemes and quality through extensive experiments on different smartphones. They revealed throughout their study several interesting phenomena and tradeoffs. Their study identified, too, situations where the display size and resolution affect less power consumption than the different wireless communication technologies (Bluetooth, wifi, and radio). The extensive experiments showed a number of other useful insights such as the importance of the Wi-Fi chip in smartphones with same display size with different resolutions.

In [35], the authors proposed a user satisfaction-aware energy management approach, called "Perceptual Computer power management approach (Per-C PMA)", based on the technique of perceptual computing. Their proposed technique (Per-C PMA) minimized the energy consumption but maintained the user satisfied with the perceived system performance. The Per-C PMA achieved a power consumption reduction, and improvements in the overall satisfaction rating.

8.Energy Consumbtion Challenges And Some Solutions

Different researchers with different terminologies presented and proposed methods determined the energy consumption in mobile phones. The perception, the network and the application layer (middleware can be placed in between the last two layers) constitute what currently the Internet of Things relay, each one of them provides significant value to the whole system.

These segmentations provide modularity and helps systems to escalate more efficiently. However, it also allows malicious entities, in this context external attackers under the threat model defined, to exploit vulnerabilities intrinsic to each one of the IoT layers. Each one of the IoT components of the different layers can be run on top of separate technologies and, therefore, distinct weaknesses are found based on functionality and application. Such vulnerabilities have been exploited in a way that have required.

9. Conclusion

Researchers have been emphasizing that energy consumption optimization in smartphones should be considered while maintaining the quality of services and user applications as user. This paper reviewed, surveyed and classified the smartphones energy consumption and measurement management techniques used in smartphones. We reviewed and presented seven key energy consumption algorithms, schemes, and concepts; the smartphone services and applications, the testbeds and platforms survey, recent methods for power measurements, the key metrics used, and the energy consumption optimization schemes. This review explores each considered key management approach extensively by including many works improvements, or adjustments of the original proposal. Finally, we describe why computation offloading will become increasingly important for resource constrained devices in the future. Recent smartphones have power-saving features to dynamically adjust the power consumption of hardware components as per the required functionality but such improvements at hardware level are very slow as compared to the rapidly growing energy demands. Therefore, operating systems must exploit all the chances they have to reduce power consumption without diminishing the user experience. Therefore, as a future work we plan to design a novel key measurement management scheme utilizing the continues measurement with all applications and services or some of them being run simultaneously-based management approach.

References

[1] l. Carnevale, C. Antonio, A. Galletta, S. Dustdar, and M. Villari. "Osmotic computing as a distributed multi-agent system: The Body Area Network Scenario." Internet of Things: 130-139, (2019).

[2] A. Ali, N. Hatta, K. Tieng Wei, B. Anthony, M. Abdul Majid, "Literature review on energy consumption and conservation in mobile device." Journal of Theoretical and Applied Information Technology 95, no. 7 (2017).

[3] D. Yasser, F. Auger, E. Schaeffer, and M. Wahbeh. "Estimating lithium-ion battery state of charge and parameters using a continuous-discrete extended kalman filter." energies 10, no. 8, 2017.

[4] W. Hongjia, and M. Liu. "A Survey on Universal Design for Fitness Wearable Devices." arXiv preprint arXiv:2006.00823 (2020).

[5] S. Michele, B. Bloessl, C. Sommer, and F. Dressler. "Towards energy efficient smart phone applications: Energy models for offloading tasks into the cloud." In 2014 IEEE International Conference on Communications (ICC), pp. 2394-2399. IEEE, 2014.

[6] L., Seokjun, C. Yoon, and H. Cha. "User interaction-based profiling system for android application tuning." In Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing, pp. 289-299. 2014.

[7] S. Mejias, Y. Guo, M. Lauridsen, P. Mogensen, and L. Maestro. "Current consumption measurements with a carrier aggregation smartphone." In 2014 IEEE 80th Vehicular Technology Conference (VTC2014-Fall), pp. 1-5. IEEE, 2014.

[8] N. Quang-Huy, J. Blobel, and D. Falko "Energy Consumption Measurements as a Basis for Computational Offloading for Android Smartphones." In Computational Science and Engineering (CSE) and IEEE Intl Conference on Embedded and Ubiquitous Computing (EUC) and 15th Intl Symposium on Distributed Computing and Applications for Business Engineering (DCABES), 2016 IEEE Intl Conference on, pp. 24-31. IEEE, 2016.

[9] J. Elliott, A. Kor, and Oluwafemi Ashola Omotosho. "Energy Consumption in Smartphones: An Investigation of Battery and Energy Consumption of Media Related Applications on Android Smartphones.", 2018.

[10] S. Zhidkov, A. Sychev, A. Zhidkov, A. Petrov. On Smartphone Power Consumption in Acoustic Environment Monitoring Applications. Applied System Innovation;1(1):8, 2018

[11] A. Meneses-Viveros, E. Hernández-Rubio, S. Mendoza, J. Rodríguez, AB. Quintos. Energy saving strategies in the design of mobile device applications. Sustainable Computing: Informatics and Systems:86-95, 2018

[12] M. Yan, C. Chan, A. Gygax, J. Yan, L. Campbell, A. Nirmalathas, C. Leckie. Modeling the Total Energy Consumption of Mobile Network Services and Applications. Energies 12(1):184,2019

[13] G. Metri, W. Shi, M. Brockmeyer. Energy-efficiency comparison of mobile platforms and applications: A quantitative approach. InProceedings of the 16th International Workshop on Mobile Computing Systems and Applications (pp. 39-44). ACM. 2015

[14] Y. Li, O. Anne-Cécile, R. Ivan, B. Lemma Amersho, M. Parashar, and M. Jean-Marc. "End-to-end energy models for Edge Cloud-based IoT platforms: Application to data stream analysis in IoT." Future Generation Computer Systems 87: 667-678,(2018)

[15] M. Grace, W. Shi, and M. Brockmeyer. "Energy-efficiency comparison of mobile platforms and applications: A quantitative approach." In Proceedings of the 16th International Workshop on Mobile Computing Systems and Applications, pp. 39-44. ACM, 2015.

[16] H. Shuai, D. Li, W. GJ Halfond, and R. Govindan. "Estimating mobile application energy consumption using

program analysis." In Proceedings of the 2013 International Conference on Software Engineering, pp. 92-101. IEEE Press, 2013.

[17] C. Adjih, E. Baccelli, E. Fleury, G. Harter, N. Mitton, T. Noel, R. Pissard-Gibollet et al. "FIT IoT-LAB: A large scale open experimental IoT testbed." In Internet of Things (WF-IoT), 2015 IEEE 2nd World Forum on, pp. 459-464. IEEE, 2015.

[18] J. Shi, E. Santos, G. Challen. Lessons from Four Years of PHONELAB Experimentation. arXiv preprint arXiv:1902.01929. Jan 20, 2019

[19] M. Lauridsen, L. Noël, Sørensen TB, P. Mogensen. An Empirical LTE Smartphone Power Model with a view to Energy Efficiency Evolution. Intel Technology Journal;18(1), 2014

[20] L. Mads, G. Berardinelli, T. Fernando ML, F. Frederiksen, and E. Preben E. "Sleep Modes for Enhanced Battery Life of 5G Mobile Terminals." In VTC Spring, pp. 1-6. 2016.

[21] L. Mads, N. Laurent, T. Bundgaard Sorensen, and P. Mogensen. "An empirical LTE smartphone power model with a view to energy efficiency evolution." Intel Technology Journal 18, no. 1: 172-193, (2014)

[22] MA. Hoque, M. Siekkinen, KN. Khan, Y. Xiao, S. Tarkoma. Modeling, profiling, and debugging the energy consumption of mobile devices. ACM Computing Surveys (CSUR).;48(3):39, 2016

[23] T. Mohammad, and E. Alan. "Studying the energy consumption in mobile devices." Procedia Computer Science 94: 183-189, (2016)

[24] M. Viveros, E. Hernández-Rubio, S. Mendoza, J. Rodríguez, and A. Belem. "Energy saving strategies in the design of mobile device applications." Sustainable Computing: Informatics and Systems: 86-95, (2018)

[25] M. Höyhtyä, O. Apilo, M. Lasanen. Review of latest advances in 3GPP standardization: D2D communication in 5G systems and its energy consumption models. Future Internet.;10(1):3, 2018

[26] M. Lauridsen; B. Gilberto; F. Tavares, Fernando Menezes Leitão; Frederiksen, Frank; Mogensen, Preben Elgaard, "Sleep Modes for Enhanced Battery Life of 5G Mobile Terminals" Published in: IEEE 83rd Vehicular Technology Conference (VTC Spring), 2016

[27] W. Song, N. Sung, BG. Chun, J. Kim . Reducing energy consumption of smartphones using user-perceived response time analysis. In Proceedings of the 15th Workshop on Mobile Computing Systems and Applications (p. 20). ACM, 2014

[28] W. Oliveira, W. Torres, F. Castor, BH. Ximenes. Native or web? a preliminary study on the energy consumption of android development models. In2016 IEEE 23rd International Conference on Software Analysis, Evolution, and Reengineering (SANER) (Vol. 1, pp. 589-593). IEEE, 2016

[29] D. Li, S. Hao, Jiaping Gui, and H. William GJ. "An empirical study of the energy consumption of android applications." In Software Maintenance and Evolution (ICSME), 2014 IEEE International Conference on, pp. 121-130. IEEE, 2014.

[30] L. Mads. "Power-Consumption Measurements for LTE User Equipment: Agilent Application Note." , 2014.

[31] S. Yuxia, J. Chen, Y. Tang, and Y. Chen. "Energy Modeling of IoT Mobile Terminals on WiFi Environmental Impacts." Sensors 18, no. 6: 1728, 2018.

[32] W. Song, N. Sung, Chun BG, and J. Kim. Reducing energy consumption of smartphones using user-perceived response time analysis. In Proceedings of the 15th Workshop on Mobile Computing Systems and Applications (p. 20). ACM.,2015

[33] F. Bahlke, M. Pesavento. Energy Consumption Optimization in Mobile Communication Networks. arXiv preprint arXiv:1807.02651. 2018.

[34] P. Spachos, M. James, S. Gregori. Power tradeoffs in mobile video transmission for smartphones. Computer Communications.;118:163-70, 2018

[35] PK. Muhuri, PK. Gupta, JM. Mendel. User-Satisfaction-Aware Power Management in Mobile Devices Based on Perceptual Computing. IEEE Transactions on Fuzzy Systems. Aug;26(4):2311-23, 2018

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