Energy Management in Wireless Networks from the Mobile Devices Perspective

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***Resumo*— Pesquisas sobre o gerenciamento de energia em sistemas de comunicações sem fio estão geralmente focadas na configuração das estações bases (BTS), uma vez que estas são os principais consumidores de energia neste tipo de sistema. Contudo, um considerável percentual de energia pode ser também economizado se os dispositivos móveis fossem desenvolvidos de uma forma mais eficiente em termos de uso de energia. Este trabalho descreve nossos esforços (experimentos, medições e análises) em entender os aspectos de demanda de energia destes dispositivos, de modo que possamos propor novos métodos para o desenvolvimento de dispositivos mais ecológicos.**

Palavras-Chave*— Tecnologia verde, Gerenciamento de energia, Comunicação sem fio.

***Abstract*— Researches about the energy management of wireless communication systems are mostly focused on the base stations BTS side, once they are the main energy consumers of this kind of system. However, we can also save a considerable amount of energy if mobile devices could be developed in a more efficient way in terms of energy use. This work describes our efforts (experiments, measurements and analysis) in understand the aspects of energy demand in mobile devices, so that we can propose new methods for the development of energy saving or more "green" devices.**

Keywords*— Green technology, Energy management, Wireless communication.

I. INTRODUCTION

The current demand for wireless high-speed connections is becoming increasingly complex and requiring a better coverage strategy [1]. Meanwhile, there are recent worries about the increasing use of energy for the new generations of the wireless technology [2]. In this scenario, several works [3,4] are investigating the effect of small cell deployments in urban and dense urban areas from the energy consumption perspective. The main idea of such studies is to quantify the potential power reduction gain by deploying heterogeneous networks consisting of a mixture of both technologies (current BTS and small cells, such as *picocells* and *femtocells*).

From another perspective, mobile devices are also energy demand components. In fact, to attend the increasing consumers´ demand for new services and applications, the complexity of mobile devices is also rapidly increasing, so that more powerful, and consequently more energy demanding, hardware are required. In this way, it is also important to understand the energetic behavior or mobile devices, so that we can propose methods to decrease their energy demand.

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The aim of this work is to carry out several experiments, which represent mobile operations in different scenarios, so that we can stress configurations where the implementation of methods for energy saving are significantly viable. These scenarios include features of the software implementation, hardware engineering, user profile and network configuration.

The remainder of this work is structured as follows: Section II summarizes the main works related to the management and measurement of energy in the mobile platform. Section III describes the methodology that we have used in our experiments, so that such experiments can be replied and reevaluated in the same original conditions. Section IV describes the experiments and their results. Finally, Section V discusses the main remarks, limitations and future works.

II. RESEARCH ON ENERGY CONSUMPTION

The study on energy consumption in mobile devices can be carried out from different perspectives. In the computer architecture community, this issue is investigated at the level of computational instructions. Differently, in the network community, researches are focused on aspects related to wireless network protocols. Another approach focuses on the energy consumption at the level of applications [5], where measurements are related to the energy used during the execution of basic applications by devices. For example, transmission and reception of signals, emails services and web navigation. Next sections discussed each of these perspectives.

A. Consumption at the Level of Instructions

A first approach to analyze the energy consumption of mobile devices is from the perspective of instructions that are executed by the Central Processing Unit (CPU). In order, the CPU energy is consumed due to the execution of the instructions and their fetching from memory or caches [6]. Thus, the smaller the amount of code the system must fetch from the memory or cache, the less energy is consumed. An estimation of the energy, consumed in a processor for a given task, can be obtained by multiplying for each type of instruction, the total number of the executed instructions by the base consumption of the corresponding type. In the obtained result, we need to add the power consumed by program memory accesses in order to fetch the instructions [7].

Another dominant source of power consumption is the register file, which is an array of registers in the CPU. Although, many mechanisms that minimize the energy dissipation in other elements have been developed, we see a lack of research about power issues in this area [8]. Power loss in register file depends on the system configuration, with an emphasis on the number of integrated registers, the cache size and the existence of a branch predictor table. According to [8], having a large register set permits the temporary storage of intermediate results without the need of a main memory usage. Therefore, less memory accesses are performed and less load and store operations are needed. This results in a reduction of the power dissipation.

B. Consumption at the Level of Network

In general, the energy consumption does not only depend on the own device, but also on the configuration specified by mobile network operators and related applied technologies. According to [9], two factors determine the energy consumption due to network activity in a cellular device. First, the transmission energy that is proportional to the length of a transmission and the transmission power level. Second, the Radio Resource Control (RRC) protocol [9] that accounts for channel allocation and adjust of the power that is consumed by the radio, based on inactivity times. This protocol works for GSM/EDGE/GPRS (2.5G) as well as UMTS/WCDMA (3G) networks that follow the 3GPP [10] standard.

Even using the same protocol, the energy consumption also depends on the technology used by networks. Some works [11,12] have carried out comparative measures between 2G and 3G networks. It is notorious that 3G devices offers a better service if we compare to 2G devices, especially in downloading and uploading data operations. In addition, 3G devices are able to support voice and data traffic at the same time, enabling video calls, for example.

However, the use of data services is still not so popular, mainly in developing countries, and several users are still only using their devices to voice calls and messaging services (SMS – Short Message Service). Also, several areas currently present a limited 3G covering and devices need to carry out continuous handovers (change of connection between networks) when they move from a area with 3G to another area without this wireless covering. In this way, the connection in a 3G network, in particular when any kind of data transmission is required, has a high cost in terms of energy consumption. To illustrate such ideas and stress the difference between the energy use in 2G and 3G networks, consider the values below (Table I) extracted from the experiments in [11].

TABELA I. CONSUMPTION IN DIFFERENT NETWORKS TO VOICE SERVICES

Instruction	GSM	UMTS
Receiving a voice call	612.7 mW	1224.3 mW
Making a voice call	683.6 mW	1265.7 mW
Idle mode	15.1 mW	25.3 mW

This table shows values to energy consumption during voice calls in GMS (2G) and UMTS (3G) networks. The power values for the calls were obtained by making and receiving a phone call of five minutes and calculating the average of the power levels. The power consumption during the idle time was calculated averaging the power levels over eight hours of idle mode. The results show that making a call using GSM costs 46% less energy and receiving a call costs 50% less energy than using UMTS. In addition, to stay in the idle mode, while connected to a GSM network, costs 41% less than this same mode in UMTS.

Thus, if we use GSM instead of UMTS for voice call during one hour, we have an energy saving of 2095 J. For idle mode in GSM, we have a saving of 220 J during eight hours, comparing to the UMTS idle mode. Such examples show the total of energy that can be saved and used for other services. For example, making a one hour voice call with GSM instead of UMTS, could save energy to send more than 1000 text messages of 100 bytes.

From a user perspective, it makes more sense to be all the time connected to the GSM network and switch to 3G only if data connection is needed. In fact, the energy saved while using SMS or voice services can be used for other services offered by the 3G phones, such as Internet connection, VoIP, media and entertainment. Note, however, that the switch between networks (handovers) also has a cost in terms of energy consumption, as illustrated in Table II. Thus, a strategy to optimize the use of energy must consider all these factors.

TABELA II. CHARACTERIZATION OF HANDOVERS BETWEEN 2G AND 3G

Handover	Power (mW)	Time (s)	Energy (J)
GSM → UMTS	1389,5	1,7	2,4
UMTS → GSM	591,9	4,2	2,5

C. Consumption at the Level of Applications

Another approach to analyze the energy consumption of mobile devices is from the applications perspective. In this context, some works [13,14] have carried out measures on the consumption related to the use of applications such as Bluetooth and SMS service. Table III shows the consumption of a mobile device in different states regarding the use of Bluetooth.

TABELA III. AVERAGE CONSUMPTION OF BLUETOOTH TECHNOLOGY

Description of Bluetooth State	Consumption
Mobile device with Bluetooth Off	10,4 mW
Mobile device with Bluetooth On	12,52 mW
Mobile device with Bluetooth connected (idle)	62,44 mW
Mobile device performing a search	220,19 mW
Mobile device with Bluetooth receiving data	415,98 mW

This experiment was performed 15 times to each state in a closed environment, using the Bluetooth 2.0 technology. The devices of this experiment were placed at a distance of 12 meters. The two first values show that the use of Bluetooth increases the consumption in less than 3 mW. Differently, when the device is connected to another system, this consumption is about five times higher. A first idea could be to disconnect the Bluetooth after realizing a data transmission. However, the search for a new connection spends about 220 mW. This data about state and time could be used to create a model to optimize the connections, reducing the required energy.

The experiments carried out with SMS aimed to evaluate the relation between message size and energy consumption. The next graph (Figure 1) illustrates the behavior of the energy consumption, where each point in the graph represents the average of sending 20 messages with the same size.

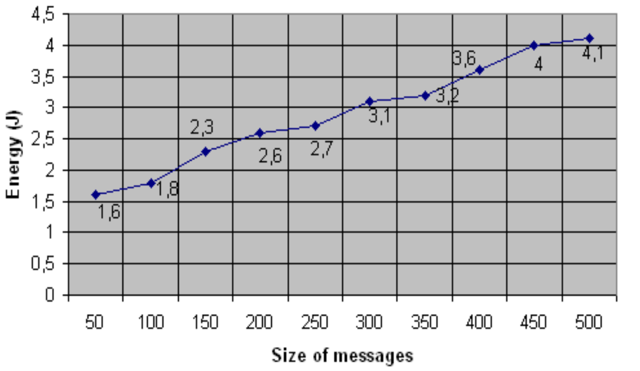

Fig. 1. Behavior of the energy consumption regarding the message sizes

To send a message with 160 characters (7-bit alphabet), the device requires about 2,35 J, so that two messages with the same time requires the energy of 4,7 J. If these messages were concatenated before the transmission, the cost of energy decreases to 3,12 J. Other experiments related to SMS were led to measure the energy consumption in 3G networks and their relations to the received signal power. For example, it is expected that if the power of the received signal decreases, the required time to sending messages increases and, thus, the energy consumption. All these aspects could be used as indicators to the development of strategies that decrease the energy consumption by devices that use SMS.

III. Methodology

Each experiment has a stage called "Preparation". In this stage, we configure the equipments, such as the network simulator and mobile device, so that they represent a particular scenario. After that, the experiment is executed 30 times, as follows: (1) active data collection, (2) wait 3 seconds for stabilization, (3) active the power source to energize the mobile device, (4) turn on the mobile device, (5) place the device inside the Faraday cage and close it, (6) wait for the register time and the end of the display turn off operation, (7) start the chronometer and wait for the time of the experiment, (8) open the Faraday cage and turn off the mobile device, (9) wait for its disconnection from the network, (10) wait while the display is turning off, (11) wait 3 seconds for stabilization, (12) turn off the power source, (13) wait 3 seconds for stabilization, and (14) deactivate the data collection.

We have used the SAS V.34.0.486 mobile network simulator, developed by Anite Telecom, to perform the experiments. The use of a simulator is justified because we have the total control of the experiment, differently of using a real network. We are also using a DC external programmable power supply from Agilent (E3640A), which energizes the mobile device and gives information about the consumption. Note that we are not using the battery, so that all the energy used by the mobile comes from the power supply. To provide an adequate connection between device and power supply, we are using an interface called Test JIG GH 80-01909A. The data collection is carried out via a Java program, which was developed by our team. This application is connected to the power supply via a serial interface. The sampling rate used to capture the points was 3/7 seconds. As we need an environment free of external network influences, we used a Faraday cage to isolate the mobile device in test. This is important to avoid that the mobile spends energy via the treatment of signals from outside of the experiment.

IV. Experiments

We have configured 5 scenarios related to different conceptual areas, such as Software Engineering, Hardware Engineering, Network Configuration and User Profile. The measures were carried out using a mobile device with default configuration, which can be restored via the mobile configuration menu. This is the initial condition of reference. From that condition, we can modify one particular variable (mobile feature), so that we can evaluate the influence of this variable in the device consumption. The amount of 30 samples was carried out for each scenario. Each sample had an average duration of 306 seconds.

A. *Scenario 1- simple network register (reference)*

This scenario is characterized by the simple activity of registering a device in the network (*Idle scenario*). The aim of this scenario is to create a reference to evaluate the consumption of other scenarios and also describe some important features of the standard curve. As the consumption curves for the 30 samples have the same behavior, we have isolated the curve of the first sample (Figure 2) to describe some features of this curve.

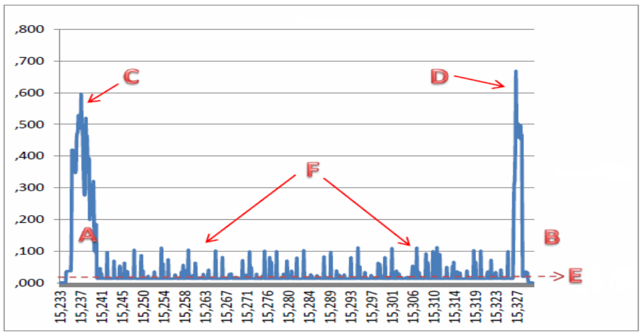

Fig. 2. Features of the consumption curve.

In this figure, we can identify six features, which are referred by the symbols A, B, C, D, E and F. The feature "A" is the moment when we turn on the device. At this moment the operating system is started, together with the display. During this process, the device starts its transceivers to register itself at the network, generating the peak "C", during "A". The feature "B" is the moment when we turn off the device. This action turns on again the display, so that we have an increasing in the curve. During this process, the transceivers are again used to inform the device disconnection to the network, generating the peak "D". The level of consumption "E" is characterized by the idle mode and this is the lower state of consumption. However we can note several small consumption peaks ("F"), which are related to the standard execution of the operating system. In this scenario, our focus is only related to the period when the device is already registered. Thus, the A and B part of the measure are not considered. From the resultant, we calculated the consumption of the 30 experiments, each of them with duration of 306,725 seconds. The average consumption was 13,139 J.

B. *Scenario 2 - simple network register, with ratified consumption*

We observed, in the previous experiment, that ever when any user request is sent to a device, such a device presents a high amount of consumption peaks. At a first moment we guessed that such peaks could be answers to network requests. However we have analyzed the message changing between network and device, and this communication was null during this period. We concluded that the operating system and basic applications could be the sources of this consumption. In this context, we observed a potential opportunity to improve the energy consumption, which is associated with the software engineering area.

To this experiment, we consider that an ideal improvement in the code was carried out to eliminate these peaks. However, the consumption must still consider the operating system needs, which are related to the internal routines that cannot be turned off. For this experiment, we estimated a value considering the curve's median, so that we had an average consumption of 9,149 J. The reasons to use the median are: it is a value higher than the idle state of the device and it represents half of the sample population.

C. Scenario 3- Bluetooth activation

The aim of this scenario is to quantify the energy consumption by the Bluetooth hardware when it is active, however without use. In this way, we simulate the execution of an intelligent agent that could identify that this module is active, but not providing services, so that it could be deactivated until some new user request. Then we measure the potential energy saving for this case.

During the experiment, we have identified a new curve in a sinusoidal format, which is related to the Bluetooth activation. This feature is shown in Figure 3 and indicated by the symbol "G". The average consumption of the 30 samples was 14,48 J.

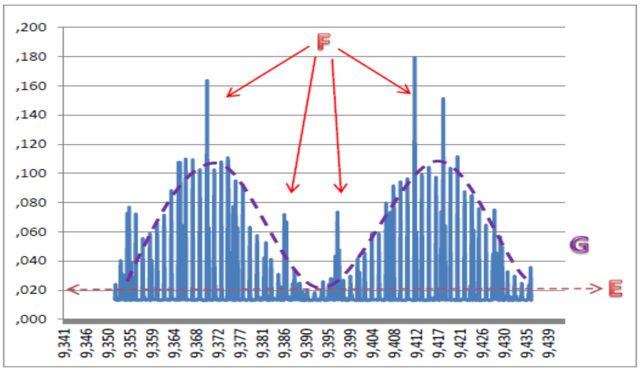

Fig. 3. Curve of consumption in the registered mode.

D. Scenario 4 - Error in the mobile network configuration

The coverage of a network is provided via the use of several cells, which are distributed inside a space. Such cells provide the radio frequency signal to mobile communication, so that devices are all the time on influence of one or more cells. When a device is on influence of two or more cells, the received signal power (P) of each cell is generally different and the device should be connected to the cell with the higher power. We are interested in the scenario where the device is at a position on influence of two cells, X and Y, with the same power.

To avoid the situation where a device tries to infinitively change the connection from a cell to another, the network defines a value of difference between the signals, what is called *hysteresis* (H). So, we have: if $(P_Y - P_X) > H$, then (select tower Y). Consider now that the network is erroneously configured with a small or null H value. In this situation, any minimal difference between the signals will result in reselection of cells. The aim of this experiment is to analyze the amount of energy that could be saved if the device could analyze the network configuration, identify this failure and avoid continuous reconnections.

This experiment presents a consumption behavior that is associated with the energy spent to reselect cells for connection. This behavior is indicated by the symbol "H" (Figure 4).

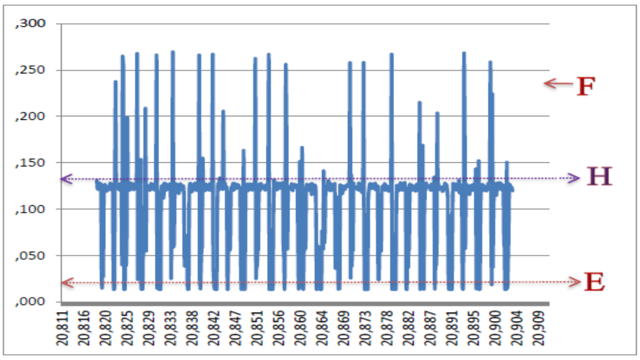

Fig. 4. Curve of consumption with hysteresis failure.

As we can observe, the device is periodically consuming energy due to the reselection activity of different cells, but without benefits to its user. This is common when the hysteresis parameter of a mobile network is not adequately configured. Thus, this is an opportunity to save energy. In order, the average consumption of the 30 samples was 73,038 J.

E. Scenario 5- Display configuration

In several situations, users modify the devices configuration to situations that result in a higher consumption, but without benefits to usability. As example, we have used a scenario where the illumination of the display is set to stay on with 100% of its intensity during three minutes and with 50% of intensity during one minute.

The aim of this experiment is to evaluate the amount of energy saved if a device could identify the time that its display needs to be on. A software agent could, for example, decrease the illumination period until a new request to use the display. This new request may be a warning that this human user requires a longer illumination time in the next use. Note the adaptable feature of this kind of approach. In fact, the agent should identify particular conditions of use because some applications, such as games, need a continuous use of the display. For this experiment we adopted an initial time during which the display stays on with a 100% of intensity. After that, we decrease the intensity for 50% of total.

This scenario considers the mobile device in the idle status, however with the display on. At a first moment ("I"), the display has 100% of luminosity during 3 minutes. At a second moment ("J"), the display has 50% of luminosity during 1 minute. After that, the device is turned off. These features are illustrated in the graph below (Figure 5). The average consumption in this case was 129,368 J.

F. Discussion

The reference for our analysis is the first scenario. From this reference, we have changed just one feature in each experiment. After the data collection, we identified opportunities for energy saving if specific solutions could be applied to each scenario. It is important to stress that such solutions cannot affect the quality of mobile services.

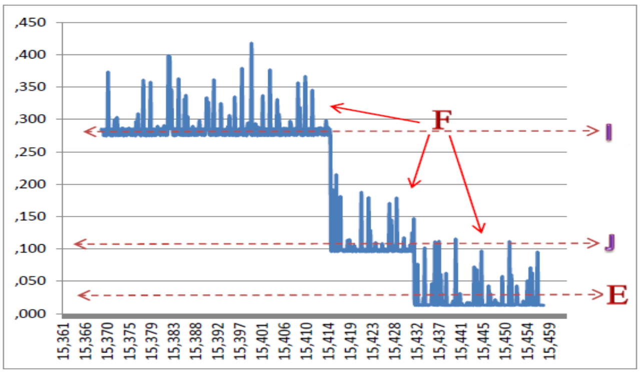

Fig. 5. Curve of consumption with display on.

According to our first experiment, the reference average consumption was 13,139 Joules. If we improve the implementation of the operating system and basic applications, we could decrease this consumption to 9,149 Joules. Thus, we could have an energy saving of about 30,36%. For this optimization, compiler optimization techniques could be used to reduce, for example, the use of the internal registers, avoiding as many as possible memory access and repaginations.

In the *Bluetooth Activation* scenario, the average consumption was 14,482 Joules. Thus, we have an consumption increase of 10,21% when the Bluetooth is activated and without use. This percentage could be the level of energy saving if an intelligent process could detect this scenario and deactivate the Bluetooth module until it is actually required. In the *Hysteresis Failure* scenario, the average consumption was 73,038 Joules. Thus, we could have an increase of 455,87% in the consumption in case of a network configuration failure. This is also the percentage of energy saving if this scenario could be avoided via a smart detection and treatment, which could avoid periodic connections and disconnections. In the *Display Configuration* scenario, the average consumption was 129,368 Joules. Its comparison to the first scenario gives an consumption increase of 884,58%. This could be reduced via the adaptation of the display parameters in accordance with the user profile.

V. Conclusions and Research Directions

This work analyzed different scenarios where we could apply methods to improve the mobile device consumption. Works like that are currently associated with the *Green* Technology [15] term and we see a significant increasing in discussions and scientific studies about energy efficiency, mainly related to mobile devices whose autonomy is dependent of batteries. In this context, we stressed the significance in the use of display regarding the energy consumption. Thus, the optimization of such resource could bring a considerable energy saving percentage. Based on this result, we have introduced a first prototype that uses an intelligent strategy to adapt the display illumination time in accordance with the profile or usual behavior of final users. Independently of the strategy that is used to save energy, it is important to stress that the implementation of this strategy must consider the energy that such strategy will need. This means, once this implementation will run inside the device, it consumes part of the energy of such device.

As future works, we intend to increase the number of evaluation scenarios, so that we can find new opportunities for energy saving implementations. An initial study is also considering the definition of a configurable API for energy management, so that developers could consult and modify the operational modes of system components. Another important research direction is associated with the study of profile of use and context as source of information that may support the implementation of energy saving strategies. In the context of Software Engineering, we identified the need of consumption evaluation related to good programming practices. This means, the energy saving should be considered as an important no-functional requirement, such as reliability or security.

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