Energy Impact of Heterogeneous Wireless Networks on Mobile Devices

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Abstract. The last decades are characterized by a rapid development in the area of wireless communications, including both Radio Access Technologies (RATs) and mobile terminals. Mobile terminals are equipped with multiple interfaces, while there is a variety of heterogeneous wireless networks that users can be connected to. However, the continuous switching of interfaces or the adhesion to a single interface, can result in the depletion of a mobile phone's battery. In the current work, we study the problem of energy depletion in smartphones under various access technologies and applications. In particular, a testbed was implemented and real measurements were collected concerning the energy efficiency of different access technologies and different users' applications. The experimental results enlighten the impact of the access network and the mobile applications on the battery life of mobile devices.

Keywords: Heterogeneous wireless networks · Mobile devices · Energy efficiency

1 Introduction

Given the rapid growth of the wireless networks and the trend of mobile users to always seek the "best available connection" (Always Best Connected) [1] the need for provisioning more than one RAT at any single location has raised during the last decades. For example, in a large city like Athens, the population coverage for 3G and 4G is greater than 97 % and 46 % respectively [2], while there are hundreds of access points for connecting to Wi-Fi. On the other hand, recent studies suggest that after seven years since Apple launched the iPhone, creating a new market, the number of smartphones surpassed one billion worldwide and is estimated to double by 2015. More than 89 % of the smartphones that are sold in the market, are used in a daily bases. Smartphones are carrying on average more than 450 Mbytes per month either through cellular networks, such as HSPA, HSPA + , LTE and WiMAX networks or via WLAN.

It is widely known that the battery life of smartphones is one of the major concerns of the users. This is why there are many studies in the literature that concentrate on the optimization of the operation time of mobile phones [3–5]. This work, following the above trend, focuses on the battery life of mobile terminals, by measuring the power

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consumed in a smartphone. Specifically a testbed was implemented and real measurements were collected concerning the power consumption of mobile devices, which were connected to different RATs, serving different user's applications. The mobile devices were equipped with Android OS, and they run an implemented application that measures the consumed power, based on the interface used for the connection.

The rest of this paper is organized as follows. In Sect. 2, we briefly outline the available tools and methods that are used for this study as well as the proposed systems' architecture. In Sect. 3 we present the test scenarios that were followed to retrieve measurements from mobile devices, while in Sect. 4 we present our results. The paper is concluded in Sect. 5.

2 Methods and Tools

As mentioned above, mobile phones market is rapidly developing, while modern smartphones are equipped with multiple interfaces, allowing the connection to different RATs. In addition, users have access to different kinds of technologies regarding wireless technologies, satisfying their need for voice, video and data applications. One of the predominant operating systems is the Android OS.

Androids' architecture is based on conventional versions of the Linux kernel, with many improvements to facilitate inter-process communication (IPS), memory and energy management (see Fig. 1) [6]. Lower layers, connected with the core (hardware), are written in C and C++ and include a large number of open-source libraries such as WebKit, libpng and libsqlite.

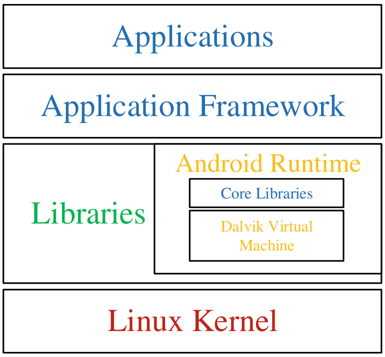

Fig. 1. Androids' architecture.

Android is an open source project and provides a flexible software development kit (SDK), allowing developers to make customizations. Most applications are implemented in Java, while through the provided SDK, developers can have access to core libraries and variables, such as the devices' battery level or the amount of power that is consumed.

As a Linux distribution, Android provides an event mechanism which relies on runtime events generated by the kernel, recording changes on the hardware of the system. These events are handled by the *uevent* daemon [7]. The data that are generated from the *uevent* daemon and are related to power measurements, can be accessed in the */sys/class/power_supply/battery* folder of the users' device. The available events may vary from device to device. A list with the most common available data that are produced from the uevent is presented in Table 1.

Table 1. Available events gathered from *uevent* daemon.

uevent variables
POWER_SUPPLY_PRESENT
POWER_SUPPLY_NAME
POWER_SUPPLY_STATUS
POWER_SUPPLY_CHARGE_TYPE
POWER_SUPPLY_HEALTH
POWER_SUPPLY_PRESENT
POWER_SYPPLY_ONLINE
POWER_SUPPLY_TECHNOLOGY
POWER_SUPPLY_VOLTAGE_NOW
POWER_SUPPLY_VOLTAGE_AVG
POWER_SUPPLY_CURRENT_NOW

In this paper, we are interested for the power that is consumed when the device is connected to one of the available RATs. From the above list, the events that can extract this information are the POWER_SUPPLY_VOLTAGE_AVG and the POWER_SUPPLY_CURRENT_AVG. Using these data, the power consumption can be computed as follows:

$$Power = Voltage * Current \tag{1}$$

A representation of the testbed architecture involved in the scope of this paper is depicted in Fig. 2. The architecture is designed using ArchiMate® [8] showing the application layer entities (application functions) and their relationship.

As shown, the application layer of the architecture consists of one product related to the mobile device and one product representing the platform. For the mobile device, the following functions have been identified for the application layer:

- *Connect to available RAT:* this application function connects the mobile device to one of the available heterogeneous RATs.
- *Gather information related to RAT:* this application function retrieves the available information regarding the RAT e.g. sim operator, cell id.
- *Gather information related to application:* this application function gathers the available information related to the application that the user is using each time, namely voice, video, data.

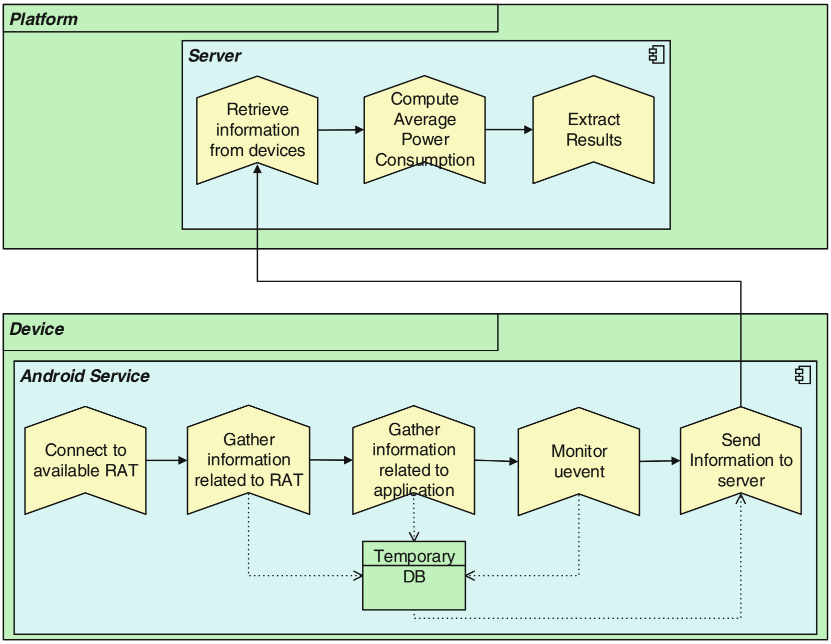

Fig. 2. Testbed's architecture.

- *Monitor uevent:* this application function monitors the uevent daemon and whenever the location of the user, or the cell id, or any variable related to power consumption is changed, it retrieves data for the voltage and the current of the device.
- *Send information to server:* this application function, once the measurements are over, it sends the gathered information to the platform server, in order to be processed.

Similarly, for the platform we recognize the following functions for the application layer:

- *Retrieve information from devices:* this application function retrieves the measurements from the mobile devices.
- *Compute Average Power Consumption:* this application function is responsible for computing the power that was consumed, using the retrieved data from the mobile devices.
- *Extract results:* this application function extracts the final results regarding a mobile device's power consumption, in order to be graphically represented.

The *Android Service* component is running on the background of the Android device, collecting necessary data for the estimation of the power consumption of the device, while it is connected to a RAT, serving one of the available applications (voice, video, data). Once the measurements are taken, they are uploaded to the platform server.

On the other hand, the *Platform* component is responsible for processing the collected measurements and for extracting the results related to the power consumption of the device.

3 Measuring Scenarios

For the test scenarios we used two different devices with the ability to connect to different modern RATs, while they are also capable of providing the services that we are studying in this paper (voice, video, data). Specifically, the devices are presented in Table 2 along with their main specifications. Both devices enable the connection to WiFi, UMTS, HSDPA, and LTE RATs.

Table 2. Smartphones technical specifications.

Device	Samsung I9190 Galaxy S4 mini	LG Nexus 5
Operating system	Android v4.3	Android v4.4
Processor	Dual-core 1.7 GHz Krait	Quad-core 2.3 GHz Krait 400
RAM	1.5 GB	2 GB
Battery capacity	1900 mAh	2300 mAh
Interfaces	WiFi, GPRS, HSDPA, LTE	WiFi, GPRS, HSDPA, LTE

For the RATs that needed outdoors measurements, the test scenarios were taken in a residential area, where the network coverage for all three RATs (UMTS, HSDPA, LTE) was satisfying (see Fig. 3). Test scenarios related to the WiFi technology, were made inside the university campus of the National Technical University of Athens.

Fig. 3. Residential area for test scenarios (GPRS, HSDPA, LTE).

The scenarios for each RAT can be categorized according to the three offered services namely voice, video and data, as described in Table 3. Each category represents a set of services that are provided to users through their mobile devices.

Table 3. Test scenarios.

	Voice	Video	Data
Services	voice call, VoIP	video call, video streaming	FTP, web browsing

4 Results

In this section we present the results obtained from the test scenarios as described above. Figure 4 demonstrates, for the voice scenario, the power that is consumed on a mobile device, when it is connected to one of the available RATs, compared to the RSS integrator (RSSI). Similarly, Figs. 5 and 6 show the results for the video and the data test scenarios respectively.

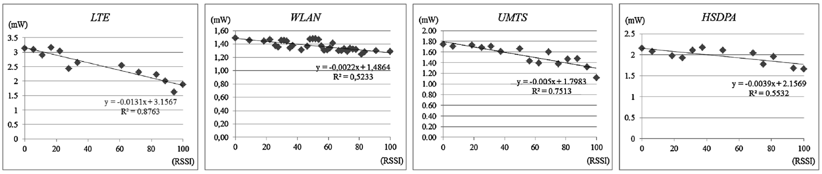

Fig. 4. Power consumption per RAT for voice application.

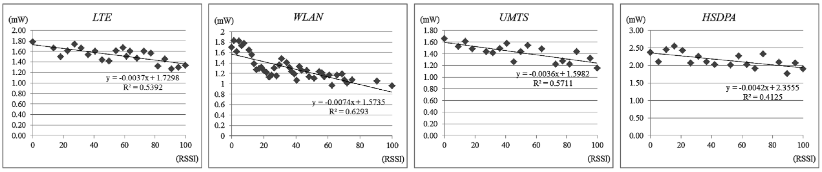

Fig. 5. Power consumption per RAT for video application.

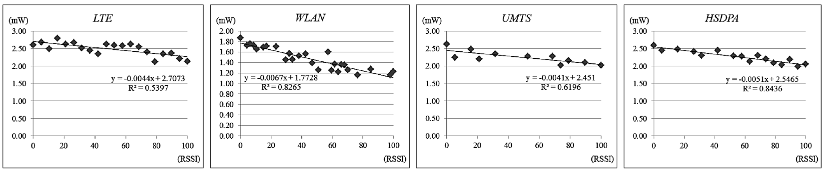

Fig. 6. Power consumption per RAT for data application.

In general, as the signal strength gets higher, the power that is consumed on the mobile device is getting lower. This can be justified because when the signal strength is strong, the mobile device doesn't need to increase the transmit power in order to communicate with the BS. On the other hand, when the signal strength is low, in order to achieve connectivity the mobile device consumes more battery power.

Studying the power consumption per RAT, as we can see for the voice scenario in Fig. 4, LTE consumes more power on the mobile device, while HSDPA, UMTS and WiFi (in descending order) consume less. A similar behaviour can be observed in Fig. 6 for the data scenario but to a lesser extent, where LTE again consumes more power than the other RATs. According to [9] this is well expected since LTE is much less power efficient, and the key contributor is the tail energy, controlled by Ttail.

On the contrary, for the video scenario (Fig. 5) HSDPA is the RAT that gives higher power consumption compared to the other studied RATs. Although LTE was expected to produce higher values, due to the high speed that it provides, data are buffered very quickly resulting to having periods with minimum data transactions.

5 Conclusions

In this paper we presented our work on the study of the energy impact of heterogeneous wireless networks on mobile devices. Specifically, our research focused on Android devices and we presented the testbed architecture that was implemented in order to retrieve real measurements from mobile devices. The results concerning the energy efficiency of different access technologies, show how each access network and mobile application influence battery's life of mobile devices. The RAT that was usually leading to higher power consumption was LTE. However, for services like video streaming, LTE was more power efficient since the required data for the video were buffered in a short time.

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