Community RF Sensing

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I. *Introduction*

Cellular mobile telephony (GSM or newer UMTS) is currently used by over 4 billions users, indicating great success of the relevant technologies. The received signal power levels at each geographical region are very important since they define the quality of service. Thus, received signal strength (RSS) recording networks have emerged the last few years, such as those in the Hermes [1], [2] or Android's OpenSignalMaps [3] projects. However, the Hermes project deploys measuring stations at fixed locations only, uses expensive scientific RF signal strength readers [4]. On the other hand OpenSignalMaps does not offer recordings of user transmission power levels or other important details such as channel frequencies usage in cellular bands. Detailed network information as well as a vast amount of real data must be available to the researchers for experimentation. Furthermore, the former work does not focus on the time variant nature of RSS due to scattering, fading and the GSM Power Control, which is performed by Base Station Transceivers (BTS) for power saving [5].

This work develops community RF sensing using as sensors the mobile phones of users; cellular telephony coverage maps are created by user measurements with the iPhone (3G, 3GS, 4) platform. A community Geographical Information System (GIS) is implemented, consisting of the MySignals iPhone application running at each participating user, a central MySQL database (DB) and a website that displays the acquired coverage maps. Over one million RSS measurements have been collected within seven months in an automated and user-transparent way. In Figure 1 the big picture (coverage Maps & iPhone App) of this work is demonstrated. A time/space analysis was performed demonstrating, in terms of the real world, the RSS variance over time and additionally particular areas with very poor signal were discovered. The collected dataset can be used in a wide range of research applications. Currently, the collected measurements have been exploited for developing localization techniques for Cell Tower Localization with no a-priori information. The system is designed to support a large number of user-sensors and could assist in city-wide evaluations of existing cellular telephony network deployments.

II. *Background and Motivation*

Cellular Mobile Telephony is without doubt the most successful technological product ever made, since is used by over 4 billion users. Especially in Greece everybody uses a Mobile Phone, nevertheless only a minority knows the basic principles of its operation and this was a strong source of motivation. Unfortunately, users cannot understand how important it is to have good RSS for both their health and for quality of mobile services. Most of the people does not understand that the Cellular Tower's Network should become more dense in order to achieve better RSS which consequently leads to better Quality of Service (QoS) in their phone services and at the same time the transmission power of the mobile phones will be reduced. It is easier for a mobile to "reach" a Cell Tower when the distance becomes shorter. It must be emphasized, that even close to the BTS, the reception power (that is RSS) is million times smaller than the transmition power. Reception power is at the

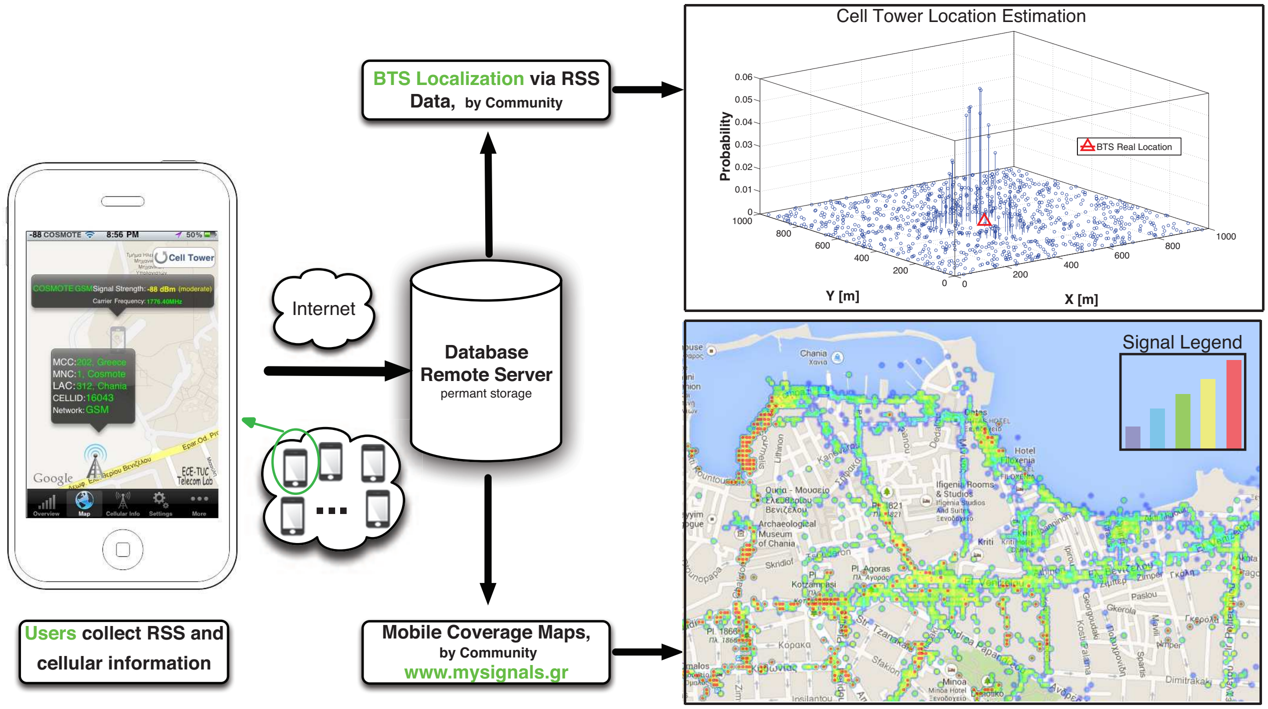

Fig. 1. Community GIS Overview.

best case, -45 dBm [1] ($10^{-4.5}mW$) which is over 100 million lower than the mobile's transmition power. Thus, the main problem is the transmition levels of the mobile phones, which occur next to the user's head, not the Cell Towers. Users must use handsfree or a bluetooth headset and not have the mobile transmitting 30 dBm (1 watt) next to their head.

The RSS from a mobile cellular network in a fixed location may differ from time to time. It may be affected by scattering, reflections, thermal noise in electronics, changes in the environment or additionally by BTS's trasnmitted power which is not constant (BTS transmitted power is dependent on network's status). Therefore the accurate modeling of the received signal strength (RSS) is extremely difficult.

On the other hand, the cellular mobile telephony coverage -i.e., the RSS level per region- is very important parameter which any carrier and user would like to know, for the following reasons:

- The best network carrier for the user can be chosen.
- The cellular network coverage, performance and range can be determined.
- Service's evaluation per region can be done. If e.g. mobile Internet is needed by users, the 3G signal's quality would be checked at workplace or home.
- Specific regions with poor signal can be discovered. This data is vital for network carriers in order to do a better network planning and probably add new Cell Towers.
- Network upgrades can be scheduled. For example, if a detailed mobile coverage map is available, the network carrier can determine where 2G signal is available but 3G is not.

How can a RSS-reading network be implemented in order to construct a Mobile Coverage map? The answer is extremely simple. The RSS readings can be obtained from the mobile phone itself, since the mobile phone calculates an estimation of the RSS. This is called Receive Signal Strength *Indicator* (RSSI, always expressed

[1] $y(dBm) = 10\log_{10}(z/1mW)$

in dBm) and it is implemented by the hardware of the mobile. RSSI is displayed roughly on the mobiles via the well known five bars and indicates the quality of the mobile services to the users. Smartphone capabilities (powerful SDKs ((Software Development Kit)), internet connectivity, location awareness through GPS etc) were also a big source of motivation in order to build a RSS-reading network and a community mobile Coverage Map.

Finally, the last few years years localization techniques using RSS measurements have emerged. GPS is used everywhere, but consumes tones of energy, affecting at a big level the battery life. RSS data contains information about emitter and receiver distance at the cost of extremely high noise for the aforementioned reasons that have been mentioned above. Thus, RSS measurements can be used in a multitude of research applications. For example RSS measurements from many users shared by a fixed Base Station could be used to infer the Base Station locations.

III. *Contribution, innovation-originality and differentiation.*

The contribution of the MySignals revealed from the motivation chapter, and is summarized on the following:

1) Social, Informational and Educational Tool.
   - A Mobile Coverage Map by users themselves.
   - Users Understand Cellular Mobile Telephony Principles.
   - Users are informed for the Mobile network coverage and quality.
2) A Scientific, Engineering and Research Tool.
3) Most Important: The First RF Sensing Community from iPhone Users.

OpenSignalMaps was launched at 2011 in Android Platform, while MySignals was under development. It has already discussed that OpenSignaMaps does not records user's transmitted power levels or other important details such as frequency channels allocation and does not focus on the time variant nature of RSS. Recently, OpenSignalMaps released on App Store but with limited functionality due to Apple's restrictions for private APIs.

The MySignals App, in comparison with OpenSignalMaps, aims to be adopted widely in order to combine the informational and educational aspect, with the social aspect as well as exploit user measurements for a wide range of research applications such as the Cell Tower Localization. Also, emphasis will be given at transmitted power levels which are not recorded by OpenSignalMaps.

IV. *Application and Platform functionallity, Implementation technology and architecture*

A. *Iphone Application*

Apple's iPhone was chosen as the platform to implement this project. Implementing MySignals in iPhone was really challenging, since iPhone's *official* SDK and APIs (Application Programming Interfaces) do not provide access to RSSI (Received Signal Strength Indicator) neither to Cellular Network information, which is necessary for creating the coverage maps.

The basic software components and GIS architecture of this work as well as the data flow, are shown in Figure 1. Users of the MySignals App can be informed for various cellular network parameters, their cellular network performance and basic principles of mobile phone operation. Measurements which contain RSSI -i.e., the signal quality-, the serving cell tower, the network type (RAT), the neighbouring cells and a lot more technical information for the mobile network are observed by the MySignals App. These measurements are saved locally

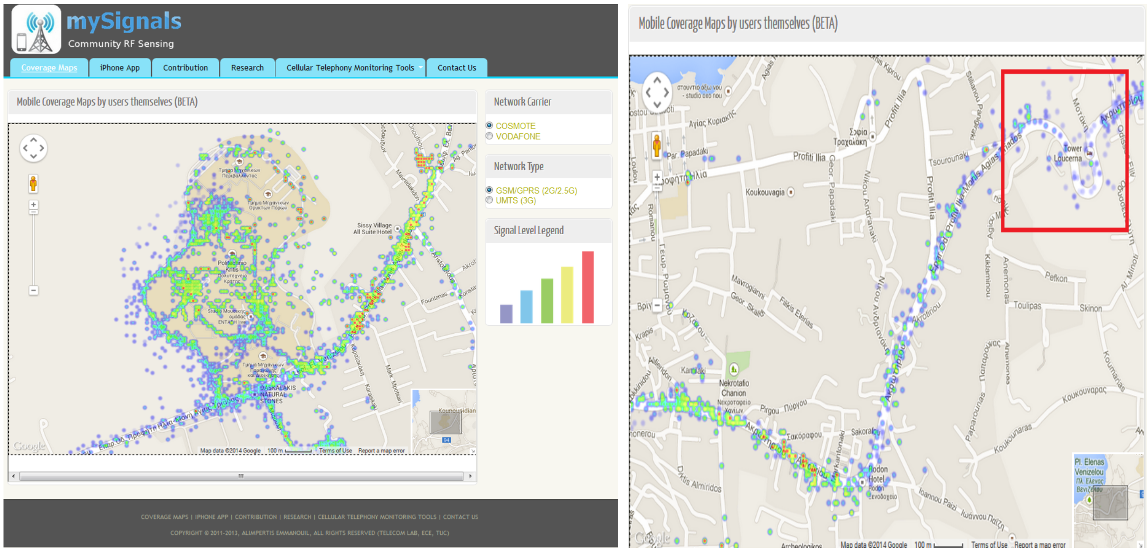

Fig. 2. MySignals website demonstration. User can choose from filters the Network Carrier and Network Type.(left) Poor signal region discovered, at Akrotiriou turns where road is between two hills , by community mobile coverage maps, weak purple indicates very weak signal(right).

in iPhone and more specifically to a SQLite database. At regular time intervals, assuming that Internet connection is available, all these measurements are packetized using JSON [1] (JavaScript Object Notation) format and they are sent to a central web server through HTTP protocol (using POST variable). At the central web server, the measurements are unpacked and saved permanently to a MySQL database. The final result of this work is a mobile coverage map displaying the collected RSSI data to their corresponding location. The Mobile coverage map is implemented using a heatmap engine. Each RSSI measurement is displayed using a color code which is depends on RSSI level. The mobile coverage maps constructed through to the cooperation of the iPhone users, is hosted on the website http://www.mysignals.gr [2].

For accessing RSSI and cellular information, jailbreaking the iPhone is necessary in order to gain access to the iPhone's baseband (modem). Then, MySignals App is able to submit AT Commands to the baseband's socket thus gathering the RSSI and cellular Information (Network Carrier Name, Network Type, Location Area Code, Absolute Radio Frequency Channel -ARFCN-, Cell Global Identity, neighbouring cell tower information, transmit power level, and several other GSM technical parameters etc). The MySignals displays and connects all the cellular information to their corresponding mobile's location (provided by GPS). Cellular Tower position, is displayed on randomly positions in map for demonstration purposes.

Since the most of the mobile phone internal variables and parameters are encoded, a data interpretation library was implemented by MySignals, following the official GSM Technical Specification Sheets [6]. For example, transmition power levels of GSM are converted to dBm as well as uplink and downlink carrier frequency are calculated in absolute MHz values using ARFCN.

B. Local Meausurements Storage

The local iPhone cache is implemented using the Core Data framework, a SQLite wrapper provided by the iPhone SDK. In addition, MySignals saves the coordinates provided by iPhone's a-GPS with the respective

[1] JSON is a lightweight data-interchange format, commonly used by web services.

[2] Site is in beta version and under development. Web Browser supporting HTML 5 is required.

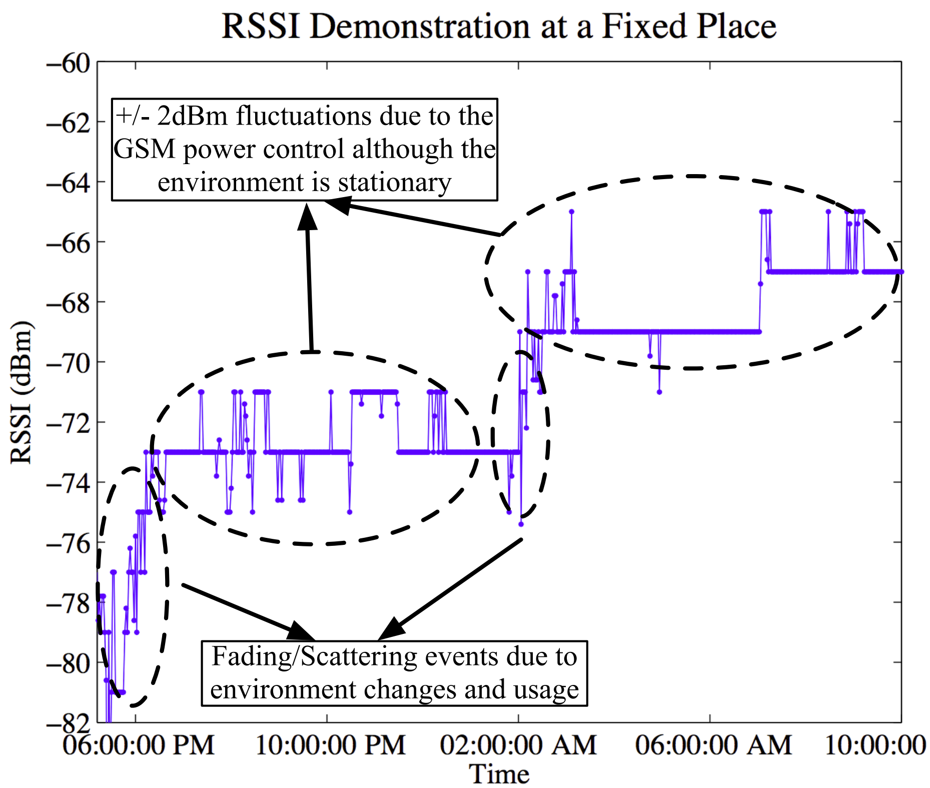

Fig. 3. RSSI VS. TIME in a specific indoor location (a user's home): GSM Control Power demonstration.

accuracy and the timestamp of the collected measurement, in order to be able to perform time analysis on collected data. Periodically, collected measurements are packed in JSON format and are being uploaded to the central MySignals web server for storage.

C. Web Server: Global Measurements storage and demonstration of MySignals Mobile Coverage Map

The Web Server database is encapsulated, for security reasons, by an appropriate Web Service written in PHP. The Web Server is hosted by the Network Operation Center (NOC) at TUC on a Ubuntu Server machine. The server is on-line 24h/7d since it is installed on a UPS supported Data Center. A Apache 5.0 HTTP server, a PHP server and a MySQL server database system were installed for supporting MySignals Web Service. Global Database system gathers the collected measurements in order to edit and display them.

A custom conversion from Core Data Object graph to JSON format was implemented in MySignals App for uploading measurements to central database. The website heatmap engine is a modified version of an opensource heatmap engine [7], which is implemented using HMTL 5 Canvas.

V. *Supported Devices*

In Table I a synopsis of supported iPhone models as also supported methods for retrieving cellular information from iPhone, are presented. MySignals Beta is available at Cydia Store (Sources/Add Source / http://www.mysignals.gr/MySignalsRepository).

	iPhone 3G	iPhone 3GS	iPhone 4	iPhone 4S/5
Baseband Chip	Infineon X-Gold 608	Infineon X-Gold 608	Infineon X-Gold 618	Qualcom MDM6610
Supported RAT	GSM/EDGE (850,900,1800,1900MHz) UMTS/HSDPA/HSUPA(4S) (850,900,1900,2100 MHz) LTE (4G) iPhone 5, CDMA models@USA			
Supported iOS	4.0 - 4.2.1	4.0 - 6.1.2		5.0.1 - 6.1.2
Field Test Mode (AT Commands)	**SUPPORTED**			*Not Supported*
CoreTelephony Private Callbacks	i)RSSI ii)cell-ID iii)MNC, MCC, LAC iv)RAT **supported**, iPhone 4S is currently under development			
Notes (socket etc.)	/dev/tty.debug		/dev/dlci.spi-baseband.extra_0	*Not Supported*

TABLE I
SUPPORTED IPHONE MODELS BY MYSIGNALS AND A SYNOPSIS OF ACCESSING CELLULAR INFO METHODS.

VI. *MySignals Adoption and Business Model*

Currently MySignals is in a beta testing. Beta testing users were asked to leave MySignals open while they driving or being at home or walking into town. Thus, the mobile coverage maps were created and hundred of thousand of measurements from fixed points (user's home), which are used in Cell Tower Localization, was collected.

As it is presented in Table I, iPhone's baseband chip has been changed at iPhone 4S and iPhone 5 model. New Qualcom's baseband cannot be accessed through At Commands, since they have been designed with a completely new architecture. Thus, access to Cellular Information can be obtained only from private APIs callbacks. Considering also the Apple's restrictions (jailbreak is needed, hardware and access method changes all the time and does not always be known), a port to Android platform would be vital for the adoption of the whole platform. The focus will not be on how to bypass Apple's software restriction, but in platform adoption and research applications with the collected dataset.

Clearly one major drawback is that MySignals drains the battery.I n order to achieve a wide adoption of MySignals, we must introduce a social game with rewards. This will be a great source of motivation for the users, because applications such as MySignals, drains user's battery by using GPS (e.g. MySignals uses over 7-8% per operational hour) and definitely this would discourage users in real life. In addition, ways of switching off the GPS must be considered. Recently, iOS 7 was introduced by Apple and one of the new feature was the true multitasking for all the applications. So in iOS 7, switching off GPS without being killed by iOS, as currently happens, may be possible.

VII. *Results*

In Figure 3 RSSI values from the above locations, are plotted during 20:00 PM and 14:00 PM of the next day. Since the user was in a fixed position and the measurements are overnight, the iPhone is surely stationary and also connected continuously to the same Cell Tower, GSM Power Control effect can be observed as well as scattering, fading and shadowing effectes while the user is active. In Figure 2 MySignals website is demonstrated, as also a zoomed region where very poor signal was discovered.

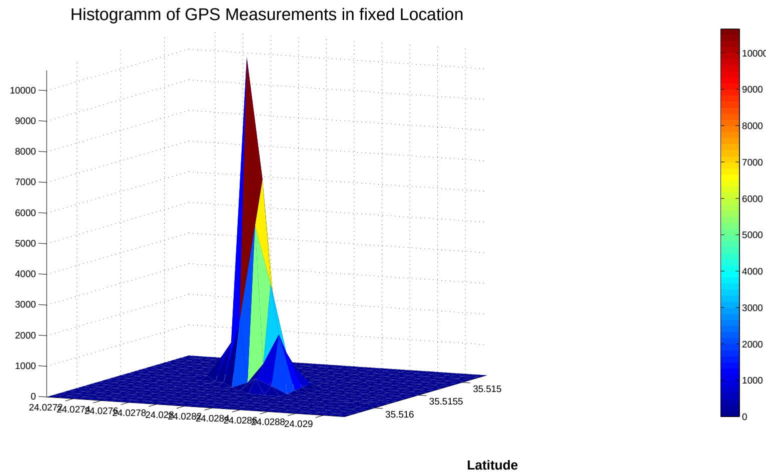

Fig. 4. Experimental Error Sensor Model of GPS at a fix location. It follows a conical distribution.

VIII. *Research Application: Discover a Cell Tower Location*

This work is currently under development with co-worker Mr. Nikos Fasarakis (colleague at the ECE Department, TUC). Our work blindly, without training, (only users fixed positions is known) detects the Cell Tower Location. This work is under extensively testing in several envirnoments. Another example of research application, is to determine experimentally, the error sensor model of the GPS at fixed locations (e.g. in our home). Experimental measurements shows that the theoretical conical distribution, which is assumed in bibliography, is followed.

IX. *Conclusion And Future Work*

Throughout this work, a fully functional Community Geographical Information System providing Mobile Coverage Maps was designed and implemented. To the best of our knowledge is the first community of RF Sensing in iPhone platform. Performance and time analysis of the Cellular Mobile Network was done demonstrating in practice the GSM Power Control and discovering regions with very poor signal. MySignals aims to be adopted widely by users and create a version for the newer iPhone 4S and iPhone 5 as well as aims to be introduced to Android. Widgets to iOS as well as several additions and improvements in MySignals Application and web site are considered. Also our future work contains the usage of the collected RSS and cellular information dataset at new research applications. Our currently work on Cell Tower Localization indicates that collected RSS and user's cellular information can be used in practice for a wide range of research applications.

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