Spectrum Monitoring. An Approach Based on People-Centric Sensing (SMOPEC)

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***Abstract*— Spectrum monitoring is a key factor in the spectrum management strategy implemented by government entities. It is of enormous importance to evaluate the spectrum use and its overall performance. Spectrum monitoring, with inspection and law enforcement provide useful tools to maintain the integrity of the spectrum management process. The infrastructure and equipment necessary to get a complete monitoring system require a huge investment, about money, time and human resources. Using People-Centric sensing it is possible to develop a monitoring system using the users' mobile devices. An app installed in the mobile device allows to manage all the information obtained by the device sensors. The monitoring system based on mobile devices, would reduce the mentioned investment. Also, the system updates could be cheaper and easier. In this paper we present a Spectrum Monitoring approach using a People-Centric sensing (SMOPEC) approach; the system elements are described, the operation are detailed, a pilot test results are showed and the feasibility are exposed.**

Keywords*— *Spectrum Monitoring; People-Centric; Spectrum Management.

I. INTRODUCTION

Actually, technological advances in electronics, computation and telecommunications will turn the near ubiquitous smart phones into a global mobile sensing device, integrating an extensive sensors network for all the base station coverage area. These devices are able to measure some parameters like temperature, acceleration or user localization; also the smart phones can obtain other technical data, like reception power, transmission frequency, Signal to Noise ratio (SNR), data rate, etc. In Figure 1 some sensors and technical information obtained from smart phones are identified.

The cell network could be seen as a people-centric system, where the users' devices become the focal point of sensing and the sensor-based information is used for get a more elaborate analysis [1]. People using their mobile phones integrate sensing networks called people-centric sensing networks that sense what we are doing and support our daily activities. Most of the sensing applications depend on the ability to monitor statistics including max, average, ranking, rather than raw sensor readings [2]. These sensor networks are proposed to be used to spectrum monitoring.

Otherwise, and as a consequence of increased demand for mobile services around the world, the International Mobile Technology (IMT) spectrum has been defined as a very precious commodity. The demand for more spectrum is increasing every day. This higher demand could generate some spectrum scarcity in these bands; however, some authors mentioned that this could be just an "apparent scarcity"; they stablish that this scarcity is due to inefficient spectrum management strategies [4].

To fulfill this increased demand the government entities and operators have the commitment to integrate an efficient spectrum management strategy in order to optimize the spectrum use; this spectrum management strategy must be based on spectrum monitoring system. The monitoring system will provide an accurate and actualized information about the spectrum use. The provided information will be fundamental to integrate an efficient spectrum management strategy [3].

The information provided by the spectrum monitoring system contain the assigned bands, the interference levels, the coverage area, quality of service, etc. All these parameters will be useful for the management entities of the spectrum radio, including governments and operators. Actually, to get these information, they spent a lot of resources integrating monitoring spectrum systems, including investment in measurement equipment, human resources and time.

In this paper we present a Spectrum Monitoring approach based on a People Centric sensing (SMOPEC) system, to inventorying the spectrum utilization while this is occupied by mobile users.

This paper is organized as follows: In Section II spectrum monitoring concept are described, detailing its importance as key issue for spectrum management, in order to get more spectrum efficiency. In Section III the SMOPEC system is detailed, identifying its elements and basic operation is explained. The monitoring process based on the SMOPEC system is explained in Section IV by describing some technical issues. Some results, conclusions and future works are mentioned in Sections V and VI.

II. SPECTRUM MONITORING AND MANAGEMENT

Spectrum management is the combination of administrative, scientific and technical procedures necessary to ensure the efficient operation of radio communication equipment and services without causing interference. Simply stated, spectrum management is the overall process of regulating and administering use of the radio frequency spectrum [5]. The goal of spectrum management is to maximize spectrum efficiency, minimize interference and eliminate unauthorized

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Figure 1. Mobile sensor network using the mobile phones. The SMOPEC concept.

and improper use of the spectrum. Rules and regulations, based on relevant legislation, form a regulatory and legal databases facilitates the spectrum management process resulting in decisions for spectrum allocations, frequency assignments, and licensing. Spectrum monitoring, inspection, and law enforcement provide the necessary means to maintain the integrity of the spectrum management process.

For government managers and mobile operators the spectrum monitoring is a key factor in order to achieve a more efficient use of this commodity. The employment of an infrastructure and organization to monitoring the spectrum operational issues could be a very expensive assignment.

For governments, the assigned frequency bands to the operators for IMT services are based on national and/or international directives; in these advices are defined technical requirements regarding to coverage area, interference level, power transmission, etc. Moreover, these directions include fines and others punitive actions; these recommendations should be applied when the operator has an omission / failure in the operation over the assigned frequency band. However, if there is not a mechanism to monitoring the spectrum performance, the operator assessment could be a so problematic mission.

Otherwise, for mobile operators, the spectrum monitoring allow them identify opportunities and “holes” in the used bandwidth (inefficient use); with this information the operator can implement new shared spectrum algorithm to increase spectrum efficiency, evaluate the Quality of Service (QoS) delivered or rate provided to users; information about coverage area and power reception could be useful to integrate plans about marketing strategies too.

For this project, the key sensors are the accelerometer (to detect user movements), Global Position System (GPS) and the information obtained from the RF signal captured by the mobile. In this first stage, we focus to get a first approach to evaluate the SMOPEC feasibility to monitoring spectrum use.

According to the above mentioned facts, the spectrum monitoring is a valuable tool in order to increase the spectrum efficiency and benefits. Monitoring is closely associated with inspection and compliance in that it enable the identification and measurement of interference sources, the verification of proper technical and operational characteristics of radiated signals, and detection and identification of illegal transmitters. Monitoring further supports the overall spectrum management effort by providing general measurement of channel and band usage, including channel availability statistics and the effectiveness of spectrum management procedures. It obtains statistical information of a technical and operational nature on spectrum occupancy. Monitoring is also useful for planning, in that it can assist spectrum managers in understanding the

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level of spectrum use as compared with the assignments signed [7].

As the demand for mobile communication systems grows, the needs for radio spectrum increases too. In order to generate an effective and efficient spectrum management, it is imperative to possess a full understanding about how the IMT spectrum behaves over time, frequency and space. Then, the spectrum monitoring issue is a key factor in order to achieve an efficient spectrum use.

III. SMOPEC. GENERAL CONCEPT

The spectrum monitoring by people-centric strategies using the mobile devices provide a less expensive alternative to obtain the spectrum parameters performance, inside the huge investment required for the traditional approach. Moreover, due that the monitoring operation using the mobile phones are based on an app installed on the mobile device, the system is flexible, allowing that new characteristics could be added just with a software update.

The smart-phones around the world are increasing every day. Using these devices the users can receive a lot of information from practically anywhere around the world. At the beginning, the users were defined primarily just as information receivers, however this condition have been changing due to the increased connectivity available in many places and a better quality in these links. Moreover, in the smart phones are integrated a numerous sensors that can obtain a lot of the environmental information, also operational and technical data. The information collected for the sensors could be saved, processed and sent by the device to other specific user or shared in some social network. Some of these information could be sent without the user intervention, in an automatic mode. Mobile phones sending data automatically from their location integrate a sensor mobile network, and this scenario open a lot of possibilities. This is the main concept behind the SMOPEC system: thousands of mobile sensors collecting and providing information about the IMT spectrum performance. The mobile devices situated in the base station coverage area, are generating information about the spectrum performance; these spectrum information are sending to a central data processing where a more specific analysis is done.

In order to the mobile phone send just the key information, an app is installed on the device. This app manage the information obtained by the sensor, saving the data sensed, pre-processing it and sending the relevant data. The information sent from each user are: reception power (dB), location, SNR, reception frequency, standard used, call duration and data rate (bps). The pre-process and analysis are explained in the next sections. The data protection issue is not analyzed in this paper.

IV. MONITORING USING SMOPEC

As mentioned before, the installed app on the smart phone manages the collected information. These data are collected and sent by the cell phone throw the cell network to the data center, where all the information are processed. A system overview is showed in the Figure 2. The system operation is as follows:

a) Using the installed app, the device save the parameters values obtained by the cell phone sensors.
b) To avoid send redundant information to the data center processing, an algorithm compute the data correlation to select the data to be sent. This algorithm economize the operations volume performed in the device (saving energy and time).
c) The selected information is sent throw the cell net toward the processing data center; the data are analyzed and processed, using some statistical algorithms. Localization, data rate, call duration, operation frequency and power received were reported.
d) An information report is integrated and sent to the operator, indicating coverage area, average rate, users, technology, etc.

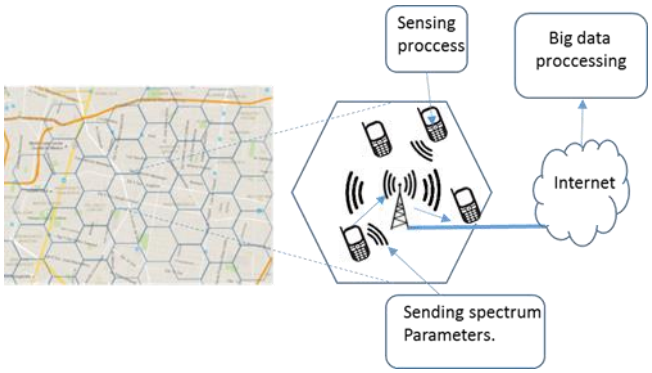

Figure 2. Spectrum Monitoring System

In the monitoring process, there are some particulars concerns to be considered to avoid that the monitoring process interfere with the device overall performance. Among others, we consider:

- Store capacity.
- Energy consume.
- Bandwidth used.

TABLE I RESULTS FROM MONITORING PROCESS

Users	Location (Lat, Long)	Power Rx (dBW)	Rate (mbps)	Call duration (secs).
1	19.398936, -99.171843	-82.7	6.2	4.27
2	19.583247, -99.236731	-75.89	1.3	1.8
3	19.266798, -99.266567	-92.25	0.8	4.9
4	19.599682, -99.227647	-88.9	5.7	8.96
5	19.398517, -99.156978	-72.49	9.2	7.02
6	19.520446, -96.92688	-89.92	3.7	2.95
7	19.479021, -96.871948	-94.26	2.9	3.76

The monitoring process is integrated for 5 stages: sensing data, pre-processing, save selected information, send the saved information and erase the sent data.

To avoid affectations on the device store capacity, the app installed in the mobile phone will send the selected data just a few seconds after the data were saved; once the information be sent to the data center processing, this information will be eliminated from the device memory, to achieve a more efficient memory use.

The operations committed with the spectrum monitoring assignment will consume extra energy; the goal is to get that this extra consumption be minimum. To get this reduction in the energy consumption, an algorithm is implemented to compute the data correlation between two consecutive samples obtained by each sensor, named as x(t) and x(t-1). In the Figure 3 is showed the flow diagram for this algorithm.

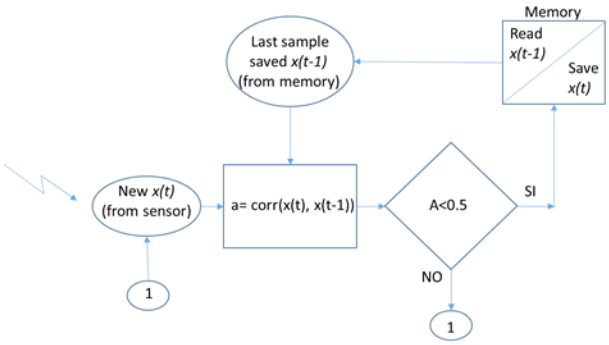

Figure 3. Monitoring process algorithm

In the monitoring process, and to optimize the memory occupancy is needed to determine if the obtained information, x(t), is different compared with the previous saved saved, x(t-1) (to avoid redundancy). To implement this evaluation, the correlation coefficient between these samples is calculated. If the correlation coefficient between the two samples is bigger than 0.5, then the system assume that the conditions in which the device are operating are the same and there are not changes about spectrum operation (i.e. same rate or same location); in this case, not new information is generated and just an update procedure is execute in the data center processing using the last information available (last sample saved). Otherwise, if the correlation coefficient is less than 0.5, then the sensed data in x(t) is defined as different compared with the previous sample saved in x(t-1), then the value in x(t) will be considered as new information as a consequence of a some changes in the operation conditions; therefore, x(t) will be saved and sent, in order to actualize the data base in the data center processing. Once the data was sent, it will be eliminated from memory as be stated before.

Considering the before explanation, just new information will be collocated over the channel. With these scheme, there is a considerable reduction in the information amount sent by the wireless channel, achieving an improved in the spectrum efficiency. In the case for GPS sensor, the app read the accelerometer values, taking a sample each 5 seconds to determine if the user is in movement or not. If there is some acceleration detected by the sensor, then it assume that the user is moving and a new location will be detected.

One advantage of the spectrum monitoring using the app installed on the mobile device is that all the parameters defined to perform the monitoring process can be changed to obtain more or less sample rate for the data collected, in order to find the ideal values to get accurate measurements.

To get a higher coverage area levels (more user using the app), the users must to obtain some benefits using it. Due that the system would provide valuable information for operators and Government, the business model must be contemplate an investment to offer some benefits to users. These paybacks could be free calls, others apps, new devices, etc. This is a key issue for the project.

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V. RESULTS

For the pilot test, the app was installed in several smart phones and the users were monitoring while they were using their devices (voice or data). The data collected were: geographical location, power reception, data rate, and call duration. In Table 1 some results are showed. The mobile phones transmission were done using the GSM and LTE bands (800 and 1700 MHz), reporting an average rate of 3.3 Mbps. The information showed correspond a sample taken from the overall users registered in the data base; it means that the information was pre-processed and just the relevant data were sent and saved in the data base. The users in the test were distributed mainly in the metropolitan Mexican area (DF and Mexico State) and the Veracruz state. In the first case, there is metropolitan area, with a high user per area density; otherwise, for the second scenario we consider a low user density. The devices were identified by their IP (Internet Protocol) and their Mobile Identification Number (MIN). The test were running for about one week with a user average number of 150 users randomly distributed. The mobile users did not report any malfunction or some affectation over the device performance.

With collected information by the GPS system, a report with coverage area are generated; in the Figure 5 are showed two users position in one minute interval, using the available samples in the data center processing.

The final report can integrate the users per area and user per base station, among others data.

The power reception is an average power over the time that the mobile is receiving information. The power reception and the data rate are important issues to evaluate the quality of service (QoS) offered.

The sensors quality and the environmental interference could affect the information accuracy. To get a system error margin, the data collected and processed by the SMOPEC system, could be compared with the information obtained from past measurement campaigns stored in data bases.

VI. CONCLUSIONS AND FUTURE WORK

The SMOPEC project offer several opportunities. Regarding to the SMOPEC implementation, the software that manage the collected information can be installed with the operative system from factory. In this way, all the mobile phones will be able to be added to the mobile sensors network and consequently, more information will be obtained.

For governments, this alternative brings some opportunities. An application can be developed to monitor the frequency bands dedicated to official and public services. Moreover, the application will send only the parameters that the authority decides. Thus, to prevent the key and sensitive information was exposed.

Big Data algorithms can be used to process all the information and new opportunities can be developed. For example, in marketing areas, the user behavior and consumer habits would be predicted.

In some cases, some interference signals were detected. In order to determine if these transmissions were done by a license transmitter, the information could be saved and compared with other interference signals captured before in the same geographical area. When these signals were highly correlated, the system could report as a probable illegal transmitter. The authority might compare the signal reported (magnitude and time), with the legal communications done in that area to determine if it was a license transmission or not.

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