RADMAP: A Computational Proposal for Electromagnetic Field Pollution Maps in Colombia

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***Abstract*—In this paper we propose a first version for a computational proposal for Electromagnetic Field (EMF) Pollution for the construction of calculated maps, as a visualization tool for estimating the levels of human exposure to potentially harmful levels of electromagnetic radiation. The computational model includes the necessary mathematics for estimating levels of exposure in any two dimension space point in a map, given a massive set of emitters and its relevant parameters, but also contains adjust considerations using a data set of field measures that would allow the model to adapt to real environmental conditions. This combination of mathematical model and field data also will allow us to skip the use of interpolations an other statistical methods typically used in maps based exclusively on measures. The proposal also specifies the system main features and development methodology in order to achieve an interactive and flexible tool.**

I. Introduction

The study of the risks excessive electromagnetic radiation exposure on humans is a topic of research interest in health and environment institutions. More than 1500 studies on those risks have been made or are currently working on them [1] and [2], including considerations by the World Health Organization [3]. This field of research can be separated in two main categories: effects on human body of electromagnetic radiations, and environmental levels of exposure. The later comprises the analysis of levels and distribution of artificial electromagnetic radiation emissions in populated areas due high concentration of antennas for radio communications and broadcasting.

A. Pollution Maps

Pollution maps are very useful analysis tools for regulatory institutions and epidemiology research. We can find temperature, $C0_2$ emissions, air and water quality maps available worldwide. On the other hand, EMF exposure maps are not as easy to find. Powerful tools are available for Radio frequency propagation analysis, such as Radio Mobile and ICS Telecom [4], that offer coverage mapping, and many other features based on simulations, and can be used as input for exposure analysis. However, the specific effort for exposure risk analysis has become a matter of field measuring as the main tool for mapping, given the wide range of radio frequency sources and, some times, the lack of information about all the sources installed. After a representative set of measures have been made, gaps between measures are usually filled using statistical analysis, like interpolation and other techniques, as in [5], in Spain, [6] in Colombia and [7] in The Netherlands.

B. Regulatory Context

According to the World Health Organization, in [8], there is no data regarding regulations for electromagnetic radiation emissions in Colombia. Nevertheless, the Colombian Spectrum National Agency (ANE, for *Agencia Nacional del Espectro*), has made a couple of efforts in [9] and [10], to establish mechanisms for measuring electromagnetic propagation patterns and potential risks, in order to test whether Colombia complies with safety recommendations by IEEE in [11] and [12], and by the UIT in [13] and [14].

C. The RADMAP Project

The aim of this proposal is to create an specific EMF exposure mapping tool for Colombian cities, based on a combination of mathematical modeling and specific field adjusting measures, called RADMAP (Radiation Map). This has the advantage of skipping the statistical gap filling, adding precision to the simulation. The RADMAP tool will consist of an application with mobile and desktop capacities that works with a dedicated server for the massive amount of mathematical calculations, working side by side with available geo-localization and mapping on-line tools. It not only will give static, previously calculated results, but also will be interactive, so an authorized user can add a new radiation source and see the results promptly. The project is an independent multidisciplinary academic effort, but open to future collaboration with any interested public or private organization for which all the results and tools will be available.

II. Mathematical Model

The main sources of non-ionizing electromagnetic radiation in our urban environment are telecommunication and broadcasting antennas, so we focus on them. In a radiation system we have a sinusoidal voltage source connected to a conductor, whose energy produces a charge distribution of electric field and magnetic field. When these fields arrive by the conductor to the antenna, the radiation will occur and the

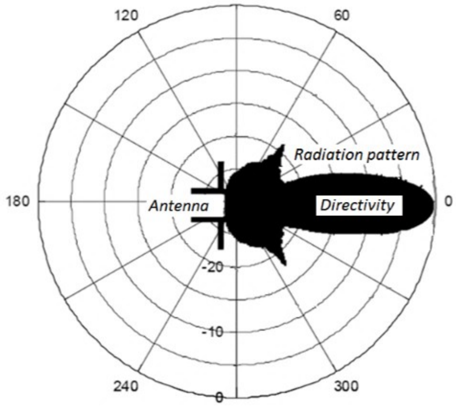

Fig. 1. Radiation pattern example.

electric field and the magnetic field propagate through the air. In this propagation by the antenna, three relevant parameters are important to analyze:

- Directivity
- Radiation Pattern
- Bandwidth

These parameter are the key to determine how much energy an antenna can irradiate and where in space that energy is sent to by a single antenna. Figure 1 is an example of radiation pattern, showing the directivity and distribution of irradiated energy. From this parameters we can compute the transferred energy per area unit, power density or Poynting vector that is defined like 1.

$$\vec{P} = \vec{E} \times \vec{H} = \frac{P_t}{4\pi d^2} \tag{1}$$

Where 1 E is electric field intensity in V/m, and H is magnetic field intensity in A/m [15]. This power density can also be calculated for any point in space too, in terms of power and distance, where P_t is the antenna terminal power, d is the distance between the antenna and the desired point, and P is the power density expressed in W/m^2 [16].

In this work we will deal with multiple antenna types, so, to analyze a specific antenna in an area depends heavily on characterization measures of magnetic and electric field at place of observation with equipments of radio-frequency exposimeters, but, the big problem are the multiple contributions of energy by the antennas in an urban area. So, additionally to the measurements of field or power density, is necessary works in a model to found how is the variation of energy by different antennas at one specific point of the space, and estimated the contributions of each antenna around it.

A. Propagation Model by Path Loss

When the signal is propagate at the space by the antenna, attending its directivity and radiation pattern, a average signal level can be received and measured at a specific location

TABLE I
ELECTROMAGNETIC SPECTRUM AREAS

Region	Sub-region	Frequency	Wavelength
Radio	High Frequency	3MHz-30MHz	>10m
	Very High Frequency	30MHz-300MHz	>1m
Microwaves	Ultra High Frequency	300MHz-3GHz	>0.1m
	Super high Frequency	3GHz-30GHz	>0.01m
	Extra high Frequency	30GHz-300GHz	>1mm
Infrared		300GHz-348THz	>780nm
Visible Light		384THz-789THz	>380nm

TABLE II
CELLULAR TECHNOLOGY FREQUENCIES

System	Frequency
2G/GSM	900MHz-1800MHz
3G/WCDMA	900MHz-2100MHz
4G/LTE	800MHz-2600MHz

respect to the antenna, if different average signal levels are recorded at the space graphically, in terms of dB respected to the distance between the antenna transmitter and receiver point, a model can be generate [17] . This model is generally called Path Loss, and its describe how the propagation can be founded from the attenuation of propagation and its measure of at a specific location relative to space reference. This measurements to assemble path loss model is given by 2, [18], [19].

$$\overline{PL}[dB] = PL(d_0) + 10Blog_{10}\left(\frac{d}{d_0}\right) \tag{2}$$

Where $\overline{PL}$ is the mean path loss at the distance from the emitter and the point of receiver separation in d meters, $PL(d_0)$ is the path loss reference at distance d_0, and B is a path loss exponent that describe how mean path loss increases with distance. Respect to this model and its application, other path loss models with empirical adjustments are been developed given the geometry and irregularity of geographical terrain or urban and rural area, within this models exist [17]: Longley-Rice's [20] model that calculate transmission loss relative to free space loss over irregular terrain, Edwards-durkin's model [21] that only predicts irregular terrain and losses caused by obstacles, Okumura's model [22] that predicts taking into station antenna heights, Hata's model [23] that is a graphical extension of loss data provided by Okumura's and Walfisch-Bertoni's model [24] that consider the impact of rooftops and building height. This work focused on Okomura's model because is largely used in our application context.

B. Algorithmic Approach

Knowing the quantity of antennas by nearby towers, and considering, at first, omni directional arrays for each technology and also features as its Gain and path loss, we can found the total amount of EMF radiation using the contributions of each antenna in a specific point of reference, allowing

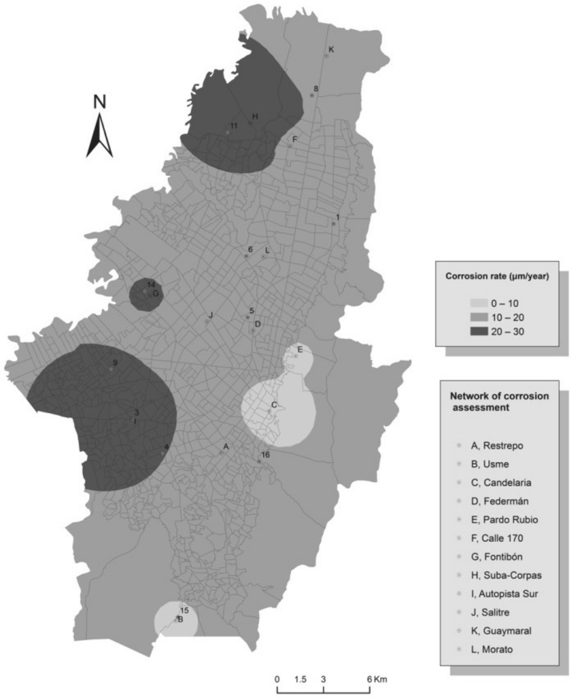

Fig. 2. Example of a pollution map. In this case a Corrosion index for Bogotá [26]

estimated the level of field o power density on it. So, then after it will be corroborate the measurements on the point of reference with calibrate exposimeters. With this information, RADMAP will be able to compare with the standards and recommendations and feed the graphical computational application visualization of EMF pollution.

III. Regulatory Component

This work is focused on cellular antenna base stations, radiation sources of electromagnetic waves. To obtain the exposition level values, we use commercial instruments or exposimeter devices, to verify the maximum levels accepted by norms and international rules, and to analyzing this values of power density using computed path loss model and physical measurements, at proximities of cellular antenna base stations. So, is important to analyze the results against reference regulatory manuals; in this sense IEEE C95.1-1991 (IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3kHz to 300GHz) [12] and norms of the ICNIRP such as 1999/519/CE [25]. Attending to this standards, our work is focused in validating power density inside accepted limits of maximum exposition.

Table I shows the main areas of the electromagnetic spectrum. However, cellular base stations only cover the microwave range, as shown in table II. Any cellular base station comprises one or more antennas that concentrate their emissions to frontal-horizontal directions from its structure, and low emissions to all other directions, as in figure 1, constructing an array of electromagnetic sources.

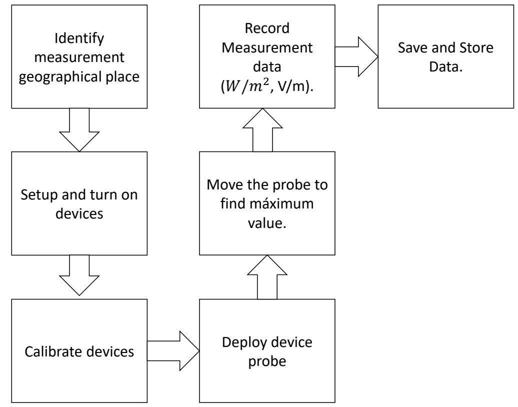

Fig. 3. Field Measurement Protocol

IV. Measurement Component

A. Measurement Technology and Tools

The measure component is key to validate the mathematical path loss model and adjust own parameters. For each tower of antennas, we must find the path loss model, to be able to estimate a good first solution for power density. In this point we will count with different commercial devices to measure quantities of field or density power like: EME-140, EME SPY 200, EME SPY 120 and ESM-140 which have been tested, certified and used in other works [27], [5] of radio frequency or electromagnetic field exposure.

B. Field Measurement Protocol and Feeding Model

In order to initiate analyze the contributions of propagation and its measurement process, we will use the following protocol:

1) Identify valid areas for measurement of power density. These areas are close to sources base-stations antennas, to ensure initials conditions.
2) Identify directions of radiations and quantity of antennas by towers respect to a reference point of study.
3) Identify specific key hours for measuring relevant fluctuations during the day.
4) Ensure the availability of measuring and recording instruments.
5) Implement and programing the geographical towers in the computational application and prepare the model of path loss.

V. Computational Component

The first RADMAP Project product is an electromagnetic exposure 2D map, implemented as a web and mobile Application.This application will show a color mesh of geolocation points. An example of this kind of pollution map can be seen in Figure 2, and also in the on line Bogotá air pollution index[1].

[1]http://aqicn.org/map/colombia/bogota/

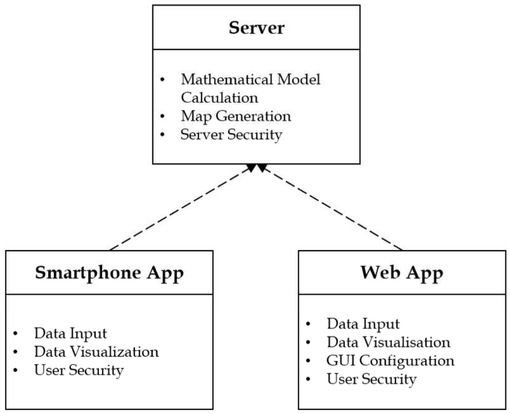

Fig. 4. RADMAP System Client-Server Configuration.

A. Functional Generalities

The main functionalities of the RADMAP System are the following:

1) **Mobile and Desktop:** The map is an application for the web and mobile devices.
2) **Graphical User Interface:** It's a graphical tool. While delivering a number of technical calculations, it also shows that information in an easy to understand graphical way. This is important in order to achieve impact on the user. Basic Things like zooming, navigation and graphic data input is considered.
3) **Interactive:** It's an interactive application. It allows filtering of specific information for any point of the map. For instance, select frequencies and geographic points, adding new sources and measures.
4) **Configurable:** The application can be configured in order to adapt to new data and new geographic areas and technologies.
5) **Server Supported:** The main process is executed by its dedicated calculation server, due to the massive amount of numeric data being processed.

B. System Model

When computing our massive amount of electromagnetic exposure points for a city map, and doing so on demand or in a background process scheme, those calculations should not be local. Therefore a client-server model is proposed, as in figure 4.

1) Client: The client side of the system (figure 4), is the user application implementation. Clients do not calculate the points of the map. Clients only request information calculated by the server, and provides geolocation information and allow the user to add several kinds of input, like new EMF sources or new measures for mathematical model adjust settings. This way the application can be user to visualize data, but also ask for new calculations in the server, whenever necessary.

2) Server: The Server side of the system (figure 4), is a dedicated calculation server. Even though the system can use an on line available system to generate maps, the mathematical model calculation is based on raw EMF propagation exposure on each point of the map, so the use of a dedicated server is necessary in order to make web and mobile clients light and reliable. The server calculates the points, and maintains the EMF exposure map, but also can update the maps whenever a client send new EMF sources like new antennas, or new adjusting parameters for the mathematical model.

C. Data Management

The system has special features, which make its navigation usable: Online Access to a dedicated hosting under cloud computing technology and services, for instance Google Firebase for prototyping stage, and MySQL Server 5.5 databases will be implemented also. Application Service Glassfish 4.1 will be used in order to provide access to data, and Web services as Restful and Soap will be responsible for integrating applications consuming Resources of another application. Mobile Devices, responsible for consuming services and resources of the system.

D. User Interface

For the implementation of the system and with the objective that the application has Usability and accessibility, we will consider environments: JEE, IONIC, HTML5, Android, Ireport and JSP, and as a means of communication between the System: Web App, Mobile App and End User.

VI. Methodology

A. Information Gathering

In order to make all the mathematical model computation possible, RADMAP needs a large amount of data input regarding every relevant EMF source geolocation and characterization. This information can be obtained using public crowd sourced databases like OpenCellId [28], OpenSignal [29], RadioCells [30], CellMapper [31] and others. These provide free API access and services for developers. However, field work is also needed in order to achieve close to real accuracy. Colombian public institutions can provide regulatory information and enterprise antennas data, and more detailed antenna information will be obtained using on site visual inspection.

1) Field Measurements: A special case for information gathering and validation are on site EMF measurement. On the information gathering stage, measurement allow us to characterize antenna parameters like directivity and Power density, when no official information is available. On validation stage, EMF exposure are made so we can validate the mathematical model, and also adjust its parameters.

B. Software Product Development

From the product development stand point, international software standards will be used, which are flexible and sustainable, as Scrum [32], [33] and [34]. Scrum allow us to work in cycles of iterative development. The first version will have basic working functionalities and in every new iteration new ones shall be added. Nevertheless, fixed development stages as requirement analysis, product launch and others will be fulfilled.

VII. Conclusion

In this work we have outlined a detailed proposal for a Mathematical model based electromagnetic field exposure Map tool called RADMAP, emphasizing that field measurements will be used to feed the model algorithm and benefits its accuracy and adaptation. The multidisciplinary team have taken into account epidemiological and regulatory impact to define the objectives, and a serious review of current state of related issues and possibilities have been performed, resulting on the selection of theoretical techniques, development tools and appropriated methodologies. Given the resulting study and proposal, we consider it is feasible as a low cost development and relevant. Finally, the aim of this article is to gain traction in the Colombian academic community, about the necessity of a complete platform development of this kind of low cost tool as a permanent and independent effort in order to contributing effectively to public institutions and the progress of social impact technology in Colombia.

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