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Analytical Computation Method of Electric Field based on Free Space Model

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Abstract—**The multiplication of the number of GSM base stations raises the issue of the harmfulness of the electromagnetic waves radio frequencies. In such a context, evaluation methods of the quantity of energy absorbed (SAR-Specific Absorption Rate) by human tissues during an exposition exist: dosimetry for cellular phone and in-situ measurement for base station. However, the in-situ methods require devices for measuring electric fields (spectrum analyzer, personal dosimeter and probe, etc…) that are characterized by high financial and temporal costs. In this paper, we propose an analytical calculation method of electric fields emitted by the GSM base station (BS). It relies on a propagation model of electromagnetic wave. The simulation of our model with MATLAB tools shows a lot of similarities with real measures obtained with in-situ measurements. The advantage of our model is that it doesn't require equipments but only a prior study of the base station vicinity.**

Index Terms—Base stations, Electromagnetic fields, Biological interactions, In vitro, In vivo, Dosimetry, Free Space Model, Path loss.

I. INTRODUCTION

In 2011, the number of subscribers to the mobile telephony reached 4.6 billion, which is almost 50 percent of the world population. All the forecasts show that this number will increase in the next years. The number of BS increases parallel to the number of subscribers and obstacles. This leads to real public health problems which require to be taken into account. Indeed, studies in vivo, in vitro, and epidemiologic [1] showed a possible correlation between the carcinogenic appearance of tumors and the use of cell phones on the one hand, and the proximity of the base stations on the other hand.

For this purpose, evaluation methods of the quantity of electromagnetic field absorbed have been proposed.

Dosimetric methods exist in case of exposure to a cell phone. They are divided into two complementary groups: experimental methods and numerical methods. Experimental methods are done using a bench of filters made from a homogeneous liquid-filled phantom. The phantom simulates the physiological properties of a real head [2]. More than experimental methods, numerical methods have the advantage of considering heterogeneous tissues, with a consideration of reality better than an experimental dosimetry. Instead of homogeneous liquid, they use a model of head conceived using MRI images (Magnetic Resonance Imagery) [3] [4] [5].

The Specific Absorption Rate (SAR) is the most indicated parameter to measure the interaction of the electromagnetic waves with the biological tissues.

The exposure to a BTS is evaluated using methods known as in-situ. Indeed, dosimetry is very difficult to apply because the energy absorbed becomes weak for long distances. This gives infinitesimal DAS. Measurement equipments such as probes, spectra analyzers and personal dosimeters are necessary to measure the electric field emitted by a BTS. In a concern of guaranteeing the reproductibility and the reliability of measures, certain countries have defined measurement protocols. In this context, ANFR (National agency of Frequencies) defined a complete measurement protocol based on the European recommendations relating to the exposure limitation of the public in the electromagnetic field [6]. The measures carried out according to the ANFR protocol are representative of the exposure in a fixed point and at a given time, while extrapolating with the maximum traffic for the transmitters of the mobile telephony. Thus these measures are not representative of the real exposure of a person who moves and can be exposed with various radioelectric transmitters according to the moments of the day. On this point, personal dosimeters (EME Spy 120 of SATIMO/Antennessa, EME GUARD of SATIMO) exist and allow to know the evolution of the exposure level for various wavebands at real time, and according to the mobility and the activities of the person.

The problems involved in equipments are financial and temporal. The price of a high efficiency portable-spectrum analyzer is around €34,995 and a measurement campaign can cost €1,500. Otherwise, the price of a personal dosimeter is estimated on average to €450. The measurement duration is a handicap because it lasts several hours. In this context, we propose an analytic method of electric field based on an electromagnetic waves propagation model.

II. CHARACTERISTICS OF A BASE STATION

A BTS is a small cabinet (see figure1) generally placed in the immediate surroundings of an antenna. It contains a certain number of radioelectric transmitters called TRX (Transmission/Reception Unit). The number of TRX depends on the population density of the coverage area and obstacles. With each TRX, an emission frequency and a maximum power out Ptx are associated. The total power transmitted to the various antennas of the BTS is calculated by using (1):

$$P_{Trans} = NP_{tx}10^{-L/10} \quad (1)$$

N represents the number of transmitters and L the losses (dB) created by the cables. These losses are estimated between 4 and 6dB.

The power density around the BTS is function of the distance to the BTS and the radiated power around. It is calculated by using (2):

$$S = \frac{P_{Trans} * 10^{G/10}}{4\pi d^2} = \frac{P_{Ray}}{4\pi d^2} \quad (2)$$

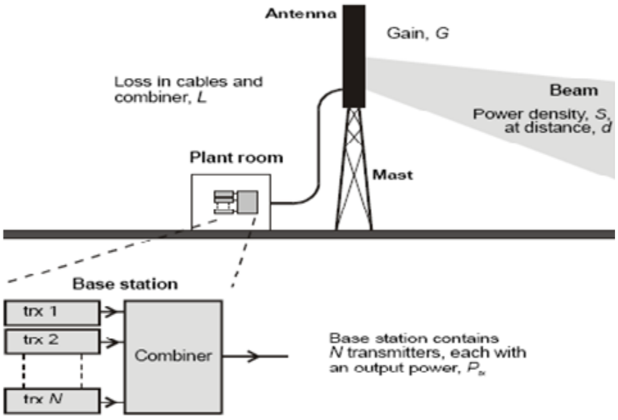

Fig. 1. Various components of a base station

III. OUR PROPOSITION

Our proposition is based on real measurement results which we compared with the results of a theoretical model. We used as entry parameters of the propagation wave model, the parameters obtained during measurement.

A. *case of study and description*

Electric fields measurements were obtained in a Belgian locality [7], in order to have data on the exposure to the electromagnetic fields. The environment around the base station antenna, of type macro cellular, is a well clear semi rural area. A football field occupies the essential of the sector 1 where the measures are carried out. Each sector is swept by an antenna. The measures are taken on the axis of the principal bisectrix of the sector n°1 (figure 2).

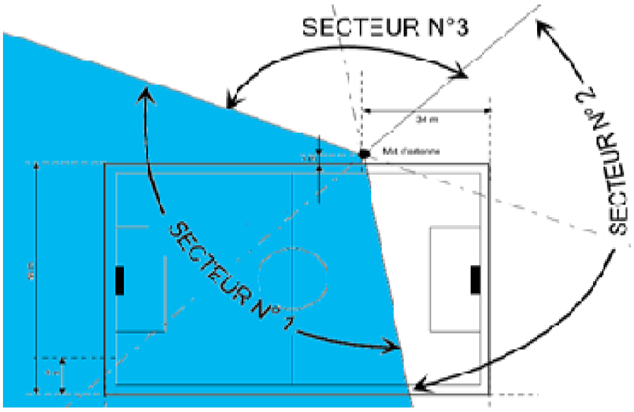

Fig. 2. Plan of site

The measurement parameters are consigned in the table below:

TABLE 1
MEASUREMENT PARAMETERS

Type of landscape	Frequency used	Measurement step	BTS Heigh	Cellphone Heigh	P_{trans}
Suburbain	954.0MHz	6m à 76m	28.5m	1.80m	52.5dBm

B. *Choice of the propagation model*

In the literature, there exist several electromagnetic field propagation models. Among these models, we can quote Okumura HATA model, Cost231 HATA models, and Cost231 Walfisch IKEGAMI [8]-[9]-[10]. Our choice related to the model whose values of parameters respect more or less the conditions of the measurement parameters described in table 1. For that, we establish a comparative table of different models by showing the application domain from each one of them (table 2).

TABLE 2
COMPARISON TABLE OF DIFFERENTS MODELS STUDIED

Model	Parameters	characteristics	Type of landscape
Free space	d : distance between BS and mobile f : carrier frequency	Basic model, line of sight	Suburbain, rural
Okumura-hata	Hm : mobile antenna height Hb : BS antenna height d, f	f=[150-1500MHz] Hm=[1 - 10m] Hb= [30- 200m] d = [1 - 20km]	Suburbain rural
Cost-231 Hata	hm, hb, d, f	f=[500- 2000MHz] Improvement of Okumura Hata.	Urbain Suburbain, Rural
Cost-231 WI-LOS	hr : building height w : street width b : building separation ϴ : street orientation angle	f between 800MHz and 2000MHz Hb = [4- 50m] Hm = [1- 3m] d= [20 - 5000m]	Urbain Suburbain Rural

Then, using the MATLAB tool, we calculated the Mean Square Error (MSE) between measured path loss value and those predicted by theoretical model by using (3) [9]:

$$MSE = \sqrt{\frac{\sum_i \left(A_{i,measured} + A_{i,predicted}\right)^2}{N-1}} \quad (3)$$

where N is the number of samples of measurement.

The MSE represents the losses undergone by the radioelectric signal. For each model, the MSE is calculated and the results are consigned in the table below:

TABLE 3
MSE VALUES FOR DIFFERENTS MODELS

Models	Free space	COST231-Hata	COST231-WI
MSE (dB)	41.1790	53.9296	42.9943

According to table 2, free space model is the only model which permits to take into account the whole of the measurement parameters into table 1. OKUMURA HATA and COST 231 HATA models are empirical and are conceived for specific geographical locations [9]. Besides that, their reliability is proven only for important distances (beyond 1km). Concerning COST 231 Walfisch IKEGAMI model, it is too complex because it takes into account not only the obstacles present but also their disposition in space. In addition, the MSE calculated on free space model is weaker. All this leads us to choose free space model as basic model.

IV. RESULTS AND DISCUSSIONS

A. Free Space Model

Free space Model applies in far field, in line of sight and in the principal beam of the antenna.

By assimilating the power received by a mobile station with that which an individual could be exposed, the expression of path loss undergone by the signal between the base station and the exposure point is calculated by (4) [9]:

$$L_p(dB) = Transmitted\_power - received\_power \quad (4)$$

Equation (5) represents the expression of path loss for free space model:

$$L_p(dB) = 20\log(d) + 20\log(f) + 32.5 \quad (5)$$

where d and f are respectively the distance and the frequency.

From the plot, the comparison between the path loss calculated with the free model and those obtained by measurement on site according to the distance to the base station, show clearly that the measured path loss is less than the predicted path loss. The difference is 41,1790dB (fig 3).

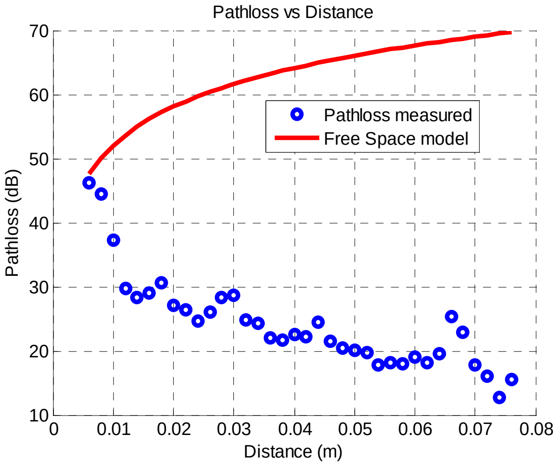

Fig. 3. Comparison between path loss calculated and those measured

Indeed, most of measurements are carried out below the principal beam. The power density, in vicinity close to the BTS, is low compared to the power density in the principal beam. Thus, the measured powers grow while moving away from the BTS, of this fact the path loss decrease.

B. Our model

The precision of a model is considered to be good if it is centered (its MSE is lower than 3,5dB in absolute value), and the standard deviation weakest possible (6 to 7 dB for the radiomobiles).

The MSE found with free space model is too high, thus it does not take account of the measures taken. From this model, our proposition adds to the MSE the half of the error made between path loss measured and the path loss calculated on free space model. The equation (6) allows us to calculate our Model:

$$Our\_Model = MSE + (pathloss\_measured - free\_space\_model)/2 \quad (6)$$

Knowing the group of point relating to the path loss measured, the expression of its regression curve is given by using (7):

$$Path\_loss\_measured = -9.85\log(d) + 13.9 \quad (7)$$

Finally the final equation of our model is calculated by using (8):

$$Our\_model(dB) = -14.925\log(d) - 10\log(f) + 31.879 \quad (8)$$

The below table gives the values of the statistical parameters of the prediction error:

TABLE 4
STATISTICAL PARAMETERS OF THE PREDICTION ERROR

Model	Our model	Acceptables values
MSE (dB)	3.6050	3.5 dB
σ (dB)	3.6025	6 to 7dB

The MSE calculated (3.6050) is slightly larger than the acceptable range (3.5dB). This is explained by the insufficiency amongst samples which influences the precision of the regression equation. On the other hand the standard deviation is largely lower than the acceptable range (6 to 7 dB).

The figure below watches that our model sticks closely the group of point representing the measured path loss.

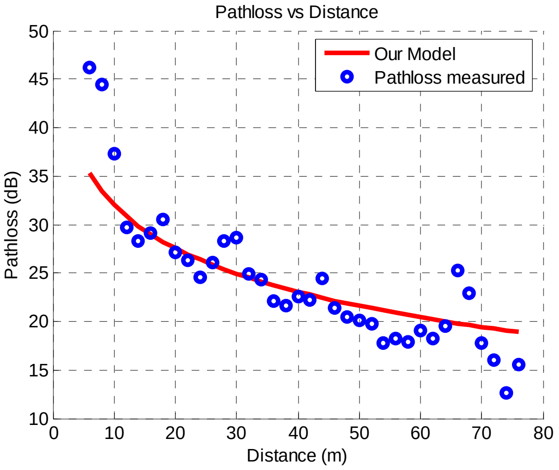

Fig. 4. Comparison between our model and path loss measured

The finality, within the framework of the exposure to the electromagnetic fields, is to compute the electric field in a point given in the vicinity of the base station and to compare it with the exposure limit value defined by the ICNIRP (International Commission on Non-Ionizing Radiation Protection) [12]. The above figure watch calculated electric fields compared with the electric fields measured on the site.

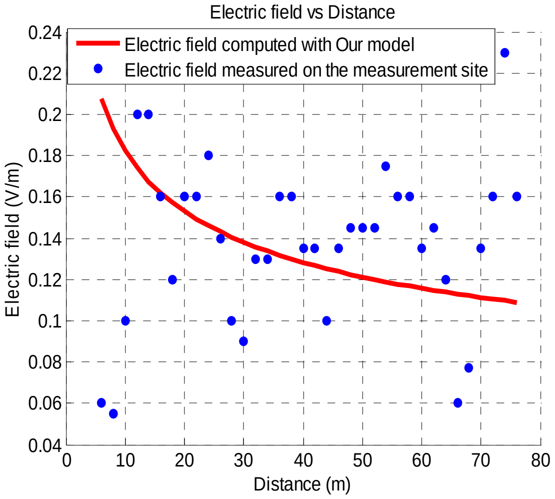

Fig. 5. Comparison between electric field measured on site and electric field calculated with our model

On the curve, we notice that the electric field increases exponentially in the immediate vicinity of the base station. Indeed, this vicinity is apart from the principal beam which is part of the limits of our model.

CONCLUSION

This paper deals with analytical computation method of electric field based on a propagation model of electromagnetic wave. At the origin, such a model was used to evaluate path loss between transmitter and receiver. The electric field measurement requires expensive equipments of measurement and a very strict measurement protocol. The financial costs and temporal can become very high. We proposed an analytical method whose results are compared with those obtained by measurement. A MSE of 3.6050 (the acceptable range is 3,5 dB) enables us to say that our model is precise and, is thus an alternative to the in-situ measurement method. However our model can apply only in the principal beam of the antenna and an environment without obstacles.

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