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# On the Applicability of Pathloss Model to Predict RF Human Exposure

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**Abstract**—An experimental setup for measuring the electric field distribution in indoor environment is presented. Measurements are performed with an isotropic electric field probe and compared with a classical dipole antenna. Results are used to evaluate performances and applicability of usual engineering pathloss models in the prediction of human exposure to electromagnetic fields.

**Index Terms**—propagation model, measurement, isotropic electric field probe.

## I. INTRODUCTION

Development of wireless technologies in recent years has induced new general concerns into the information technology community. First, power consumption has become an important design criteria for wireless devices, putting large efforts to optimize their consumed energy. Second, electromagnetic (EM) emissions produced by these wireless devices must be characterized, respecting radiation levels established to limit human exposition.

This work is part of the GREENCoMM project, which handles these two main topics. First, the project aims to propose some novel techniques to reduce energy consumption in Home Networks. Second, techniques to estimate radiated EM fields are developed for constantly monitoring human exposition levels and optimizing indoor signal coverage.

This paper deals with the aspect of human exposure to electromagnetic fields, in the aim of generating continuous real time cartography of electric fields for an indoor home environment. The procedure consists in measuring the electric field using an isotropic electric field probe and then calculating the field distribution using a prediction pathloss model. Environmental undetermined conditions (like material electric properties) impose a calibration phase of the propagation model based on measurement results, in order to obtain correct model parameters and therefore correct prediction results.

In this paper, a measurement setup using an isotropic E-field probe usually employed to determine human exposure is presented. Applicability of measurements made with isotropic probes for calibrating usual path loss models is discussed. Measurements are also made using a standard dipole antenna for comparing with isotropic probe results. The procedure to calibrate the propagation model is also introduced. The performance of different obtained models is finally compared.

## II. PROPAGATION MODELS

### A. Context

Propagation models in indoor scenarios are currently used in planning and modeling wireless networks. These models allow to predict signal coverage in room or buildings and to calculate some other parameters like channel capacity. There are many different models for indoor propagation calculation. They are generally classified in empirical and deterministic models [1]. Empirical models use formulas containing empirical parameters to estimate path loss requesting measurement data for adjusting model parameters. They provide rapid prediction, but accuracy is highly dependent on the quality of measurements (representativity, precision, volume). Deterministic models, such as ray tracing, use complex mathematical expressions and a full environmental database to compute channel prediction. The rigorous description of propagation environment makes these models very long and high computer consuming. However, it is possible to obtain more advanced channel parameter such as temporal dispersion or MIMO channel capacity.

For a real time application, fast calculation and computational simplicity are required, preferring the utilization of a COST 231 empirical path loss model [2]. In this model, a direct path between transmitter and receiver is computed, using number and properties of each material. As previously mentioned, for adequately calibrating this model a set of measurements is needed. The measurement procedure consists in setting a transmitter and placing a receiver through some previously defined points in the working area. Narrowband measurements are usually used. In general, the antenna receiver is a monopole or dipole type. To simplify the measurement setup, it is also possible to use a real commutation system in survey mode [3] - [5].

### B. Simulations

Accuracy of measurement results depends on the correct characterization of all devices used for performing these measurements (radiation pattern of antennas, cable losses). For instance, if radiation pattern of an internal laptop antenna is assumed to be isotropic, high errors could result in predicted field distribution. For estimating error committed when assuming ideal isotropic antennas instead of omnidirectional or “real” antennas, simulations of an indoor scenario have been made. Using wave propagation software WinProp, a

simulation environment was defined (3D representation of building and material properties) and complete ray information was extracted from several fixed locations (reception points). Then, data was post-processed in Matlab, in order to compare pathloss results for multiple scenarios using different transmitting and receiving devices.

Simulations are defined as follows: in transmission, an isotropic antenna is used. Furthermore, multiple receiving antennas have been considered: isotropic, 3 omnidirectional antennas having different polarizations and the radiation pattern of a real monopole antenna. Isotropic probe antenna used for measurements is modeled as the quadratic addition of the 3 omnidirectional antennas.

Fig. 1 shows the difference in dB between considering an isotropic reception antenna compared to the other types of reception antennas for each simulation point. We observe how computed pathloss depends on antenna type, polarization and location, resulting in differences until 30 dB. In fact, computational errors are committed when ideal isotropic antennas are assumed in simulations instead of omnidirectional or real antennas used in measurements.

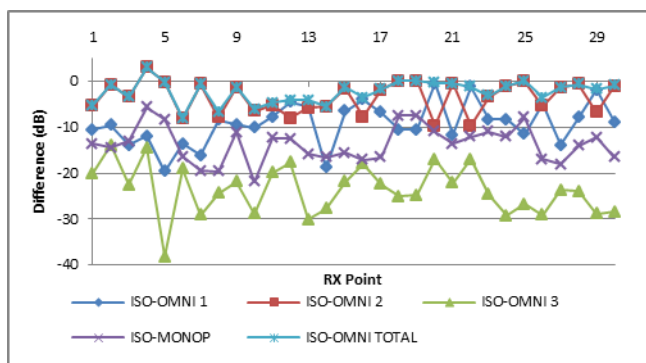


Fig. 1. Pathloss calculation for different antenna configuration (difference dB).

We observe also that the minimum error is produced when using the isotropic antenna resulting from the addition of 3 orthogonally disposed monopoles, which is analogous to the isotropic probe (blue line). Using measurements from an isotropic probe will highly increment accuracy of the model allowing to obtain better prediction results. Complexity of the model is also reduced, avoiding necessity of including complex radiation patterns of reception antennas.

### III. MEASUREMENTS

#### A. Measurement system

The measurement system is divided in a reception and a transmission section. Reception is composed by an isotropic electric field probe, a dipole antenna, a controlling system (laptop), a bi-band Wi-Fi adapter working in 2.4 and 5 GHz and an 8 port RF switch. The isotropic probe is provided by SATIMO [6] consisting of a 3 axis isotropic antenna working from 700 MHz to 6 GHz frequency band. The Wi-Fi adapter is connected alternatively to each axis (antenna) of the probe measuring one of the 3 electric field components. It can also be

connected to the additional dipole antenna for making simple measurements. Switch allows us to control which antenna is associated to the Wi-Fi adapter. This card is connected to the laptop, collecting RSSI levels for each component of the tri-axis probe and dipole antenna.

Isotropic electric field is then calculated knowing the antennas characteristics and switch and cable loss. Using a Wi-Fi adapter allows to identify several additional network parameters such as Wi-Fi channel number and AP identification which is useful to fully characterize the propagation environment. Fig. 2 shows the architecture of the entire system.

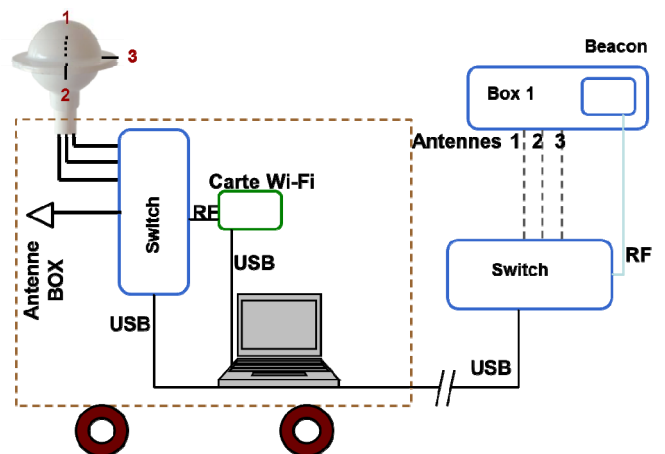


Fig. 2. Measurement set-up using an isotropic E-field probe

Concerning transmission section, antennas from a commercial SAGEMCOM access point are used. The selected AP has 3 antennas with different polarization, providing polarization and spatial diversity. Each antenna has been characterized using the Satimo Stargate™ equipment. These radiation patterns were considered in the prediction model for increasing accuracy of the model.

Transmission and reception switches are controlled by a Matlab™ script, which also stores information and makes calculation of total electric field. Transmitting and receiving section are separated by a USB cable, attending distances up to 30 m.

#### B. Wi-Fi adapter calibration

Wi-Fi adapter will receive Wi-Fi signals using one of the 3 axis probe antenna and send them to the laptop for calculating the RSSI values. In order to obtain accurate measurements results it is necessary to characterize the Wi-Fi adapter to “calibrate” the RSSI received values. Measurements at 2.4 were performed to characterize the Wi-Fi adapter, representing measured RSSI level in function of received power. In order to do that, one RF output of an access point has been connected to the Wi-Fi adapter controlling power level with a variable attenuator. Input power has been measured with a spectrum analyzer for 1 MHz Resolution Bandwidth (RBW) at 2.42 GHz frequency and transmitting power of 16 dBm.

Calibration results are shown in Fig. 3. Received RSSI levels are given in function of power levels at the input of the Wi-Fi card. RSSI values from 3 different Wi-Fi monitoring programs are compared. We observe that RSSI behavior is mostly linear; however, some additional corrections are required for obtaining actual power values. We observe also dynamic range of the dongle, between -45 and -75 dBm. Measurements of the different monitoring programs show similar RSSI values. However, they present different sampling and response time. In some cases, stable results are found after 10 seconds, while other programs provide almost instantaneous results. Concerning sampling time, in order to obtain representative Wi-Fi power levels continuous and more frequent measurements are needed. We have selected Vistlumber software which provides almost instantaneous response and a variable sampling time (above 50 ms).

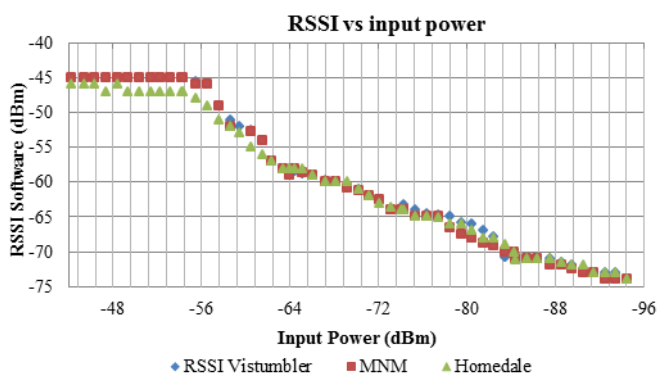


Fig. 3. Wi-Fi dongle calibration

### C. Measurement set-up

Measurements were performed in indoor environment at Télécom Bretagne premises. Fig. 4 shows selected corridor of the building, composed by rooms separated by brick walls, containing offices and laboratory furniture. Transmitter was set at the middle of the hall at 1.5 meters height and measurements had been performed for 15 reception points.

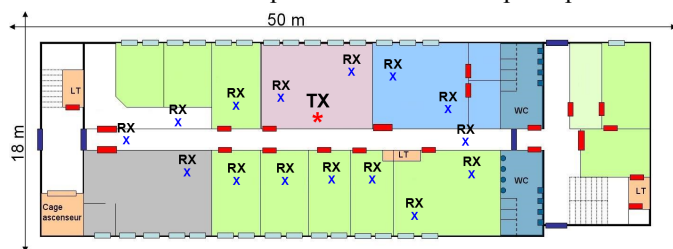


Fig. 4. Telecom Bretagne building.

For each reception point 2 set of measurements were made: static and dynamic measurements. For dynamic measurements, the system was moving 10 cm around for taking into account spatial variation of propagating signals and averaging power. Measurement duration for each point was 15s at intervals of 0.3s. Transmitting power from the AP was 16 dBm working in 2.4 GHz frequency band.

## IV. PROPAGATION MODEL CALIBRATION

### A. Propagation model calibration

Cost model is represented by the following expression:

$$Path\ loss: PL = \sum_{k=1}^w n_{wk} \alpha_{wk} + b_0 \log d + b_1$$

Where  $n_k$ : is the number of  $k$  type materials,  $\alpha$  is attenuation,  $w$  is the number of materials,  $b_0$  and  $b_1$  are constants and  $d$  is the distance between Tx and Rx points.

Measurement data was used to adjust the unknown parameters of the propagation model (material attenuation and constants). Pathloss was computed from measurements of the 15 reception points considering separation walls as the only unknown material. A matrix system of 15 equations and 3 unknown was solved using these measurement results.

### B. Results

Comparison between model parameters for static and dynamic measurements is shown in Table I for two transmitting antennas (TX1 and TX2).

TABLE I. STATIC AND DYNAMIC MEASUREMENTS

	TX1		TX2	
	Static	Dynamic	Static	Dynamic
$a0$	-2,04	-1,7	-2,1	-1,9
$b0$	-12,3	-13,2	-14,4	-14,8
$b1$	-20,4	-20,3	-18,1	-18
<i>Std. measurements</i>	4,94	4,6	5,6	5,3
<i>Std. model</i>	2,4	1,93	2,8	2,5
<i>Static model std.</i>	1.95		2.52	
<i>Static error</i>	-0.1		0.13	

We observe how static and dynamic measurements give very similar model parameters even if static and moving measurements were made at different times. In both cases standard deviation error of the model is small, improving the results respect to measurements.

However, better results are obtained in dynamic case, showing less standard deviation values. It is possible to validate static model parameters by taking dynamic measurements and applying static the model parameters. Results are shown in the last two rows. We observe that model performance is not reduced (standard deviation of 1.95 and 0.1 dB of error) if parameters obtained with static measurements are used.

Finally we observe that changing transmitting antenna does not substantially affect final model parameters.

## V. CONCLUSION

A measurement system for obtaining the isotropic electric field is presented. Measuring 3 components of the electric field provide more accurate results taking into account different polarization and arrival directions of the incident fields.

These measurement results are used to properly calibrate a propagation model for generating field cartography of an indoor residential zone.

## ACKNOWLEDGMENT

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