COMITÉ NATIONAL
FRANÇAIS DE
RADIOÉLECTRICITÉ
SCIENTIFIQUE

Management of electromagnetic fields in the environment

Albert CORTEL-CARRASCO, Yahya OULD ISSELMOU, Man-Faï WONG et Joe WIART *

(*): France Télécom R&D, 38, rue du Général Leclerc, 92794 ISSY les MOULINEAUX

(E-mail: prénom.nom@orange-ftgroup.com)

Abstract. This paper presents a method of creating cartographies of the electromagnetic environment from time measurements on fixed points.

I. INTRODUCTION

Exposure to electromagnetic fields raises questions not only from the point of view of compliance with existing limits, but also from an environmental point of view. The trends on personal communication systems without license, which contribute to the electromagnetic environment with mobile transmitters or broadcasting, raise questions about the exposure of individuals.

With the expansion of mobile communications some years ago, institutions and general public have been concerned by the possible impact of radiofrequency electromagnetic fields on health. Military and health institutions had already lead some studies on the effect of non-ionising radiation on the human body. However, from the early nineties with the mobile phones and nowadays, with short-range devices, electromagnetic fields seem to get closer and closer to the immediate environment of every person. Radio emitting sources can be easily spotted at any moment. Sometimes they may cause some community rejection; most times they raise many questions up.

In this context, measurements of electromagnetic fields are mostly done in order to check the compliance of a specific place with national regulations. Such measurements are usually done by independent institutions following official standards. Therefore, in this study we have gone beyond the problem of compliance of a single point to give an overall informative representation of the electromagnetic environment.

In this paper, a method to interpolate of the exposure from isolated measurements of electromagnetic field is presented. Temporal frequency selective measurements were carried out over an area of interest. The interpolation of the whole set allows mapping the electromagnetic environment of this area of interest. Also, the temporal aspect of the measure and its interpolation allows the determination of the variation of the environment over the period measured.

Some measurement protocols to determine human exposure to electromagnetic fields exist. However, the determination of the site where the measurements are done is given only by the demand of the measurement itself or by visual inspection of the emitters. The interpolation of a sufficient number of consecutive measurements over a site avoids the prior investigation of the site and its emitters. Measurements are frequency selective following the protocol defined by the ANFR (Agence Nationale des Fréquences). A broadband probe 80 MHz to 3 GHz is used and each band is filtered. The objective is to determine the contribution to the exposure of each radio service separately.

The assets of this protocol are several. The most important one is that measurements are done by frequency band. The final objective of the protocol is to compare the measurement results with the exposure limits and this is not possible with wide band measurements. The exposure limits being defined for each frequency band, exposure measurements must be done accordingly.

Another strong point is the consideration of the maximum exposure conditions in the final assessment. Exposure to electromagnetic fields is not constant. While considering a single static evaluation point, measured fields can change due to the surrounding environment, weather conditions and especially, the traffic charge of the different measured emissions. Some radio services, such as mobile fixed stations, show time-variant power characteristics. Differently from other services, where power variations in time are due to modulation characteristics, variations due to traffic charges appear smoothly over much longer periods of time. With time averaged measurements, fast variations of the measured emissions are compensated. That is not the case for traffic dependent variations. The ANFR protocol considers the maximum deviation of a measurement due to traffic issues by the extrapolation to its maximum theoretical value. Although being unrealistic, this approach ensures that none of the exposure results will be exceeded. Moreover, a high level of repeatability is achieved by this procedure.

For all the measurements done, a geostatistical interpolation method is applied. This approach aims to minimize the error committed in the estimation of the electric field as a function of its variation. Finally, the estimation of the field is represented on a map on the area of interest.

II. MEASUREMENTS

III.1 Material

Two measurement devices [1] are used for the experimentation. Four personal dosimeters EME Spy 120 were used to assess exposure on four different points simultaneously over a period of one day. For the measurement of fixed points and to record statistics of exposure, the frequency selective fixed station INSITE Box was used. The choice of the measuring device is based on the sensitivity and location for the measurement.

III.2 Protocol

Measurements are performed in indoor environment, the goal is to establish the quality of the interpolation in a complex propagation environment. The devices have made continuous measurements from 9 am to 18 pm every day, depending on the use and occupancy of the buildings covered by the study. Each measure was sampled every 4 seconds in order to reduce the total burden of data. At the end of the measurement period, the data package has been identified and located geographically.

III. INTERPOLATION GEOSTATISTIQUE

Kriging is a spatial interpolation method, which allows the estimation based on the linear mathematical expected value and the variance of the measurements. This method differs from other methods of interpolation by the fact that it is the only one to take account of the spatial variation of the data. Thus, it does not only generate spatial estimations, but the estimation of errors it produces is more reliable than those produced by conventional regression. The reason is that the assumptions of Kriging are closer to reality for spatial reference data [2].

IV.1 Variogramme

In order to study the correlation of measurements as a function of distance, geostatistics use a function $\gamma(h)$ called variogram. The variogram is a function that quantifies the correlation between measurements separated by a distance *h* [2]. Pour chaque distance *h*, il représente la moitié de la valeur moyenne du carré de la différence des expositions.

$$\gamma(h) = \frac{1}{2}E\left(\left[Z(s+h) - Z(s)\right]^2\right) \quad (1)$$

E is the mathematical expected value. The process of the analysis of the correlation is:

- Calculate an experimental variogram with the measured data.
- Adjust the experimental variogram by a theoretical model.

The experimental variogram is deducted from the variographic cloud which represents the variance between each pair of points [2]. It is written:

$$\gamma(h) = \frac{1}{2N_h}\sum_{s_i - s_j = h}\left(Z(s_i) - Z(s_j)\right)^2 \quad (2)$$

N_h : number of pairs of points spaced separated by a distance h
$Z(s_i)$: the degree of exposure at the point s_i

Once the experimental variogram has been built, the theoretical model of the variogram points, obtained by optimizing the model by counter-verification, is adapted[2]. The variogram is investigated by means of theoretical models using a known function of the variographic cloud. The objective is to find the theoretical curve that best fits the experimental curve. In the case of our study, we adjusted it by the Cauchy model [5].

$$\gamma(h) = 1 - \left(1 + \frac{|h|^2}{a^2}\right)^{-p} \quad a > 0;\ p > 0; \quad (3)$$

Power *p*, range *a*.

IV.2 Kriging

Kriging method was developed by [3]. In this method, the average is unknown but it is supposed invariant in the surroundings of the estimation. This method does not require that the hypothesis of intrinsic stationarity. With this assumption, the ordinary kriging technique has become the most used one according to [4]. The basic model of this method is written::

$$Z(s) = \mu + \delta(s) \quad (4)$$

With μ invariant unknown and $\delta(\cdot)$ an intrinsic stationary random function, null expected value, and structure of dependency known. The estimator $\hat{Z}(s_0)$ at a point s_0, is therefore written :

$$\hat{Z}(s_0) = \sum_{i=1}^{N}\lambda_i Z(s_i) \quad (5)$$

For the estimator is unbiased :

$$E\left[\hat{Z}(s_0) - Z(s_0)\right] = E\left[\sum_{i=1}^{N}\lambda_i Z(s_i) - Z(s_0)\right] = \mu\left(\sum_{i=1}^{N}\lambda_i - 1\right) = 0 \quad (6)$$

So the estimator at a point s_0 takes the following shape :

$$\hat{Z}(s_0)=\sum_{i=1}^{N}\lambda_i Z(s_i) \qquad \text{Avec} \qquad \sum_{i=1}^{N}\lambda_i = 1 \quad (7)$$

The aim is to minimize the estimation of the variance under this constraint. This stage will be carried out using the Lagrange function.

IV. RESULTS

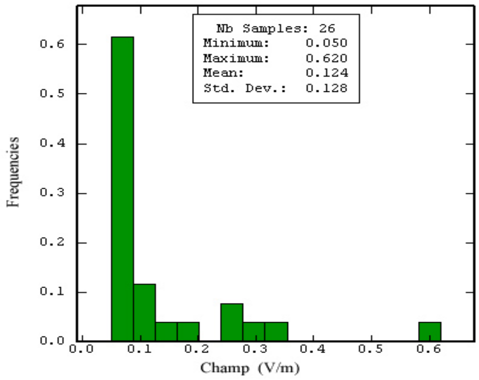

Fig.1 – Departure of the algorithm

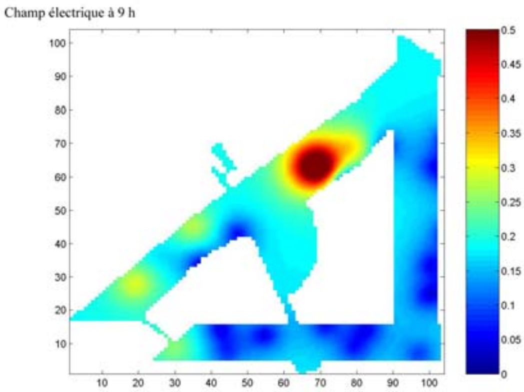

Fig.2 – Cartography

Figure 2 shows the result of the final map of interpolation issued from measured electromagnetic fields, all frequency bands combined.

Many different types of results have been obtained from the study. The electromagnetic environment is never static. On one hand, propagation of electromagnetic waves depends on the physical environment. The physical environment consists of static elements such as buildings, ground surfaces and other minor objects. It also consists of moving elements like cars or other vehicles. On the other hand, the human activity between the electromagnetic source and the measurement in terms of utilisation of the radio resources induces the biggest variations on a measurement. Therefore, by measuring continuously over a given period, the correlation between the activity and the measurement can be retrieved. Moreover, statistics on the influence between the utilisation of radio resources and its associated exposure can be drawn.

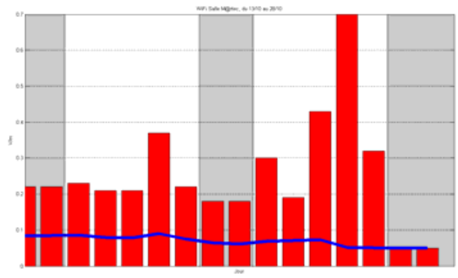

Fig.3 – Exposure to WiFi. Mean and maximum exposure values over two weeks

Figure 3 shows the mean and maximum values of the exposure due to WiFi. The measurements were done over two weeks in a meeting room equipped with a wireless access point. It can be seen that, even if the maximum levels can be relatively

The exposure to electromagnetic fields at the FTR&D has been measure over defined periods of time. The period of interest has been chosen as a working day, so the normal 8 hours were the workers are exposed, but at the same time contribute, to the electromagnetic environment. Interesting results are retrieved from the measurements over different periods of interest. Over an 8-hour day, oscillations of the exposure level due to GSM neighbouring base stations are observed. Generally, there's a slight increase of the traffic at the end of the morning and the departure time. In shorter periods of time, the amount of activity on WiFi Access Points can be observed from the measured exposure. Access Points work on burst mode by sending periodic beacons even if there's no traffic. The exposure level increases with the traffic. In meeting room areas or offices where WiFi is used, this can be observed by an increase of the level due to WiFi. Other areas have almost no exposure due to WiFi.

Weekends and periods of vacation are also observed from the electromagnetic environment measurements. The oscillations of the GSM exposure are smoother and WiFi levels almost disappear whenever there's no activity on the Access Points.

A statistical representation of the measurement results has been done. For relevant measured services, the probability density function of the exposure has been calculated. However, since the measurements have been done over large areas, the probability of exposure is weighted towards the lowest measured values. The analysis of the different probability functions shows that only GSM and DCS bands have a reproducible probability density function. In both cases, the PDF is a Gaussian distribution. The measurement of WiFi exposure shows a more uniform probability distribution. However, since the number of the lowest measured values is high, the PDF is weighted to its minimum.

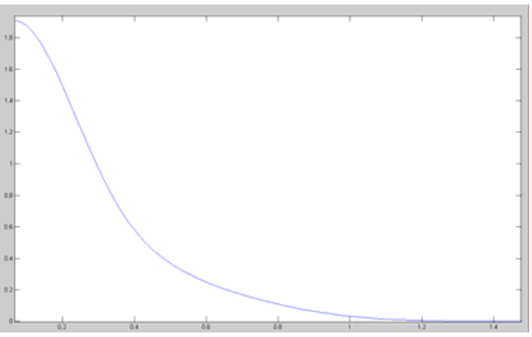

Fig.4 – Probability distribution function of the exposure levels to WiFi

The probability density function of the exposure due to a WiFi access point is shown in Figure 4. The PDF follows a normal distribution with its mean equal to to minimum measurable level. The reason is that, most of the time, an access point does not transmit over the channel.

V. CONCLUSION

This tool brings the measurement of the exposure beyond the problem of compliance to limits. As an informative tool, where the user has the decision on what is being measured and its condition, a target could be public organisms such as districts or other urban councils. However, any organism concerned about the electromagnetic environment at large scale is expected to show interest in such a tool.

Nowadays, public involvement in environment problems is a major issue. Hand-to-hand with environmental pollution, sustained development or energy, questions regarding the electromagnetic environment are appearing periodically on Medias. A tool which is meant to deliver information on the electromagnetic environment covering wider areas is expected to give rise to much interest. From July to October 2007, Le Grenelle de l'Environnement has brought together representatives of the civil society and the Government in France in order to establish a roadmap in favour of environmental issues. From the environment and health round table, the link between radiofrequency radiation and health was labelled as being an emerging risk. In the French law that will issue from the Grenelle de l'Environnement, a chapter will be dedicated to electromagnetism.

REFERENCES

[1] SATIMO Bretagne www.antennessa.com
[2] H. Wackernagel, Multivariate Geostatistics: an Introduction with Applications, Springer-Verlag, Berlin, 3rd edition, 2003.
[3] G. Matheron, La théorie des variables régionalisées, et ses applications. Les cahiers du Centre de morphologie mathématique de Fontainebleau, Fascicule 5. Ecole des Mines de Paris, Fontainebleau. 1970.
[4] Y. Gratton, Le krigeage : La méthode optimale d'interpolation spatiale. Les Articles de l'Institut d'Analyse Géographique. 2002.
[5] J.-P. Chilès, P. Delfiner; "Geostatistics modelling spatial uncertainty", A Wiley-Interscience Publication.