Exposure index of EU project LEXNET: principles and simulation-based computation

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***Abstract*— The EU project LEXNET is defining a new metric to evaluate the exposure induced by a wireless network communication at a whole. Exposure induced by base station antennas but also exposure induced by wireless devices are taken into account to evaluate the average global exposure of the population in a specific geographical area. The paper first explains the concept and gives the formulation of the Exposure Index (EI). Then the EI computation is illustrated, based on simulation, showing how radio-planning predictions, realistic population statistics, user traffic data and Specific Absorption Rate (SAR) calculations can be combined to assess the index.**

***Index Terms*—EMF population exposure, Exposure index, Simulation**

I. INTRODUCTION

Exposure induced by electromagnetic fields (EMF) emitted by wireless telecommunication systems is limited by exposure limits recommended by international authorities as ICNIRP [1]. Existing metrics to evaluate EMF exposure are well adapted to check the compliance with limits but not at all to evaluate a global exposure of a population. In the context of high concern about possible health effect of EMF, the European Commission DG CONNECT (Directorate General Communications Networks, Content and Technology) asks for studying future networks minimizing the human exposure to radiofrequency electromagnetic waves. The LEXNET project is a European project that started in November, 2012 in response to this demand.

The strategic goal of LEXNET is to take into account the public concern about possible health effects of electromagnetic fields and to improve the acceptability of existing and future wireless systems through low exposure systems without compromising the user's perceived quality.

One of the objectives of LEXNET is to define a new metric to evaluate the exposure of a population induced by a given wireless telecommunication network. The so-called Exposure Index (EI) is changing the exposure's paradigm by evaluating simultaneously the contribution of the personal devices (as mobile phone) and the contribution of the infrastructures of the network (as base station antennas) to the global exposure.

In section II, the concept of the Exposure Index is described. Its computation is illustrated in section III, based on radio-planning predictions, while section IV gives some conclusions.

II. THE EXPOSURE INDEX (EI): CONCEPT AND FORMULATION

A. Concept

In the daily life, exposure is partly induced by the fixed network installations and partly induced by the use of personal devices. Both these components are strongly linked [2] [3].

The metric proposed by the project LEXNET, named Exposure Index, merges the exposure incurred by personal devices with that attributable to base stations and access points of a given wireless telecommunication network (or set of networks), without taking into account the background exposure induced by other RF sources such as FM radio or DTT transmitters. The purpose of this new metric is many-fold. First, it provides a way to fairly characterize the exposure generated by a given wireless network on a whole population. Second, this unique metric allows for the introduction of a simple EMF target in the network design optimization process. Third, it can also be integrated in the evaluation of new network topologies, technologies, equipment or management techniques, in the same way as more usual QoS (Quality of Service) or energy efficiency metrics, helping in the design of future low-EMF networks.

In a nutshell, the LEXNET Exposure Index is a function transforming a highly complex set of data into a single parameter which has two key benefits: it is understandable and acceptable for all the stakeholders, from general public to regulatory bodies; and it is linked in a tangible way to the network operating parameters. The Exposure Index is the mean exposure of the people located into a given area, over a given time period (e.g. during a typical day time) and from a given set of networks (e.g. together from all 2G / 3G / 4G / WLAN networks operating in the area). It is basically the average of doses (SAR x exposure duration) experienced by all individuals present in the target area over the considered time period. In that perspective, the EI computation takes into account:

- The whole population living, working and travelling in the area of interest modeled by different people categories (both connected and non-connected people).
- All kinds of environments into the area of interest, typically outdoor and indoor environments.
- All radio access technologies (RAT) of interest and for those target RATs, all cellular layers (macro, micro, pico and femto).
- All specific time sub-periods, having particular network usage, traffic load and even network configuration (low-load at night-time vs. heavily loaded peak-hours);
- The user device and its posture; making a phone call in a sitting posture will not lead to the same exposure as downloading data in a standing position.

B. *Formulation*

The building block in the exposure assessment remains the Specific Absorption Rate (SAR expressed in W/kg). The SAR will depend on the morphology and the posture of the user and on the far-field and near-field sources.

Summing over different type of parameters, the exposure index can be formulated as the following averaged dose:

$$\mathrm{EI} = \sum_{t}^{N_T} \sum_{p}^{N_P} \sum_{e}^{N_E} \sum_{r}^{N_R} \sum_{c}^{N_C} \sum_{u}^{N_U} \Big[\sum_{l}^{N_L} \Big(f^{users}_{t,p,l,e,r,c,u[\%]} d^{UL}_{t,p,l,e,r,c,u} \left(\tfrac{s}{kg}\right) \bar{P}_{TX[\mathrm{W}]} \Big) + f^{pop}_{t,p,e,r,c,u[\%]} d^{DL}_{t,p,e,r,c,u} \left(\tfrac{s}{kg}\right) \bar{S}_{RX[\mathrm{W/m^2}]} \Big] \qquad \text{(Eq.1)}$$

where:

- N_T is the number of Time periods of the day;
- N_P is the number of Population categories;
- N_E is the number of Environments;
- N_R is the number of Radio access technologies (RAT);
- N_C is the number of Cell types;
- N_U is the number of Usages with devices;
- N_L is the number of user Load profiles;
- $\bar{P}_{TX}\ (W)$ is the mean TX power by the users' devices during the period t, for the category of population p, in usage mode u, connected to RAT r, in condition e.
- $\bar{S}_{RX}\ (W/m^2)$ is the mean power density incident on the body during the period t, for the category of population p, connected to RAT r, in condition e.
- $d^{UL}_{t,p,l,e,r,c,u}\ \left(\frac{s}{kg}\right)$ and $d^{DL}_{t,p,e,r,c,u}\ \left(\frac{s}{kg}\right)$ are the normalised raw SAR values for UL and DL, respectively weighted by the time spent in emission in the configuration
- $f^{users}_{t,p,l,e,r,c,u[\%]}$ and $f^{pop}_{t,p,e,r,c,u[\%]}$ are the percentages of the users during the period t among population p, in usage mode u, connected to RAT r, in condition e the pop

In terms of units the EI can be considered as an average dose per day, expressed in J/kg/day.

The choice of different degrees of segmentation in time, people, environments, RAT, cell layers, usages and users profiles will depend on the scenario and on the future solutions to minimize EI. One example is given in the next section.

III. COMPUTATION OF THE EXPOSURE INDEX: AN EXAMPLE

The assessment of the Exposure Index may follow various methodologies depending on the application and context, for instance: evaluation of a new technology implemented in a real testbed; pre-deployment optimization of the network design; optimization of a network configuration based on network monitoring data and user device measurements; assessment of the EMF exposure from a sensor network; etc. While LEXNET will experience different assessment methods, one based on radio-planning techniques is used here to illustrate the EI computation and clarify the role of the different involved components (people categories, user traffic models, transmit UL powers, DL received powers, reference SAR values, etc).

A. *Description of the scenario*

The exposure index is computed in a real urban area – part of the 7th district of Paris - represented by a High Resolution (HR) map data. For simplicity of the demonstration, only a 1-RAT macro-cell network is considered, based on LTE technology.

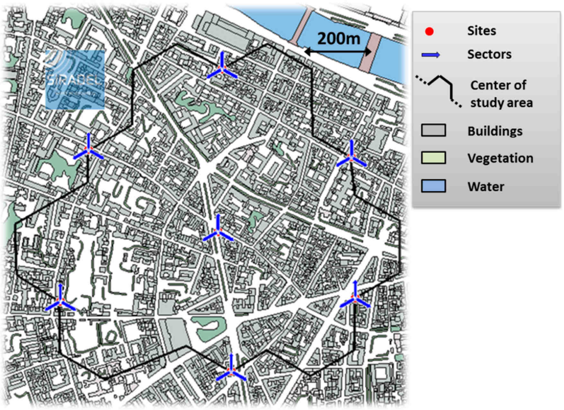

Figure 1: Macro deployment and study area in Paris 7th district

Macro Base Stations (BS) are deployed in a hexagonal manner with an inter-site distance of 450 m. The positions, heights and transmitted powers of the base stations have been selected to be representative of a typical macro deployment in an urban environment. The area covered by the 12 central macro sectors defines the study area, as shown in Figure 1. Note that base stations outside this study area are also included in the simulations to generate an accurate interference pattern.

We consider an LTE FDD 2 x 10 MHz system that operates in the 2600 MHz frequency band. Additional parameters such as BS and UE (User Equipment) transmit powers, antenna parameters etc. will be detailed in the final version of this paper. Users are assumed to be uniformly distributed in the study area; an indoor ratio sets the percentage of users located inside buildings.

B. EI equation terms

- In the following, each term of Eq.1 is properly defined and explained. A quite simple segmentation has been chosen in this example to illustrate the feasibility of EI end-to-end computation. Time Periods: $N_T = 2$

Two time periods are considered ($N_T = 2$): the day from 8 am to 6 pm (10 hours in total) and the night from 6 pm to 8 am (14 hours in total).

- Population Categories: $N_P = 3$

In this example, we are only considering the population above 15 years old. The population density of the 7th District of Paris was estimated at 14 360.50 inhabitants per km² in 2009 [4].

Usage profiles are set depending on the age: for example young people are using mostly messaging when older people are using more voice calls. To represent the different usage profiles depending on the age, the population has been segmented into 3 categories: young people (between 15 and 29 years), adults (between 30 and 59 years) and seniors (over 60 years). Table 1 shows the percentages of people in each category.

Population category	**Percentage** ($\propto_{category}$)
***p*=Young people (15-29 yo)**	26 %
***p*=Adults (30-59 yo)**	45 %
***p*=Seniors (+60 yo)**	29 %

Table 1: Repartition of Paris 7th population depending on age

- Environments: $N_E = 2$

Activities of everyday life for each population category have been analyzed in European time surveys as in [5-7]. We derived from these analyses the time spent indoor (***e = in***) or outdoor (***e = out***) for each category on an average day (averaged over one year, considering weekdays, weekends and holidays) as summarized in Table 2.

	***t*=day**		***t*=night**	
	$e = in$	$e = out$	$e = in$	$e = out$
***p*= young people**	8h (80%)	2h (20%)	13h18 min (95%)	42 min (5%)
***p*= adults**	8h (80%)	2h (20%)	13h18 min (95%)	42 min (5%)
***p*= seniors**	7h (70%)	3h (30%)	13h18 min (95%)	42 min (5%)

Table 2: Repartition of the each category of population *p* by environment *e* and time slot *t*

- Network typology $N_R = 1$ and $N_C = 1$

We consider a LTE network with a macro deployment as described in section III.A.

- Usage and devices: $N_U = 2$

Two different network usages are considered: voice and data. For both of them, the device is assumed to be a mobile phone, while the user is in a standing posture.

- Users profiles $N_L = 2$

In this example, we consider only one profile: moderate users. We assume different moderate user profile for the different categories of population detailed in Table 4 and focusing on the mobile.

	Voice		Data	
	t_{indoor}^{com}	$t_{outdoor}^{com}$	t_{indoor}^{data}	$t_{outdoor}^{data}$
Adults				
Day	4 min 2s	4 min 2s	22 min 50s	8 min 44s
Night	2 min 1s	2 min 1s	38 min 55s	5 min 6s
Young people				
Day	1 min	1 min	11 min 24s	4 min 22s
Night	30s	30s	19 min 27s	2 min 33s
Seniors				
Day	2 min 1s	2 min 1s	5 min 42s	2 min 11s
Night	1 min	1 min	9 min 58s	1 min 16s

Table 3: Duration of usage u for moderate profile of users depending on their profile *l*

We are considering 158 MB of data traffic per day for moderate users (estimate for 2013 derived from IDATE table and considering full mobile traffic from LTE network [8]) and we are considering a classical ratio of 90% DL and 10% UL.

Based on all these figures, averaged user throughputs are used.

- $d_{t,p,l,e,r,c,u}^{UL}$ and $d_{t,p,e,r,c,u}^{DL}$

These weighting coefficients will be calculated on the basis of a table detailing the different durations of use and typical values of whole-body SAR induced by mobile phones and by macro base stations. These values are derived from numerical dosimetric simulations, as part of LEXNET project, at several frequencies and for different devices and human postures.

- Received $\bar{S}_{RX}$ and transmitted $\bar{P}_{TX}$ powers

A crucial point is the calculation of the received and transmitted powers for voice traffic and data traffic over all the area of interest.

The SIRADEL software based on the VOLCANO technology [9] has been used to perform the calculations with the assumptions detailed in previous sections. Rx power computation is not depending on the type of traffic, so there are only 2 cartographies of Rx power computed for day and night periods (see Figure 2).

But the Tx power is depending on the type of traffic. Figure 3 illustrates the cartographies for the voice and data traffic during the day and Figure 4 during the night.

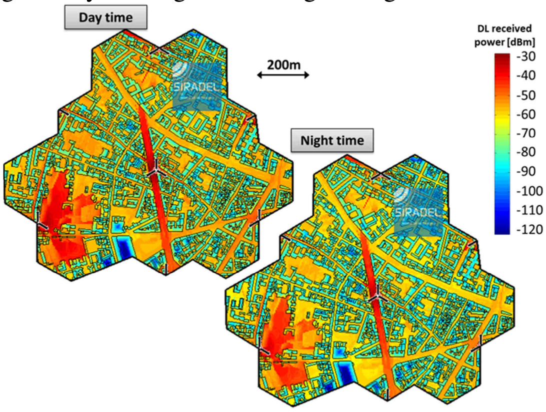

Figure 2: Rx power (dBm) calculated indoor at ground floor and outdoor in day and night configurations

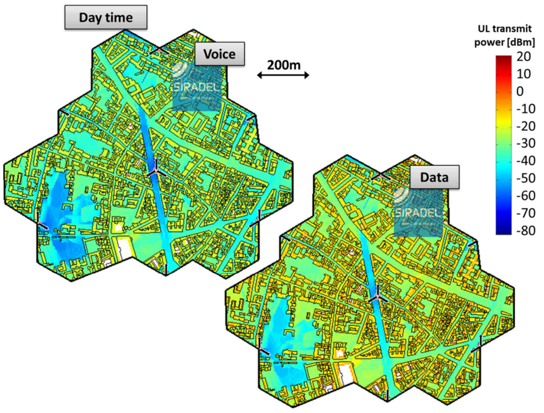

Figure 3: Tx power (dBm) calculated indoor at ground floor and outdoor during the day for voice and data traffic

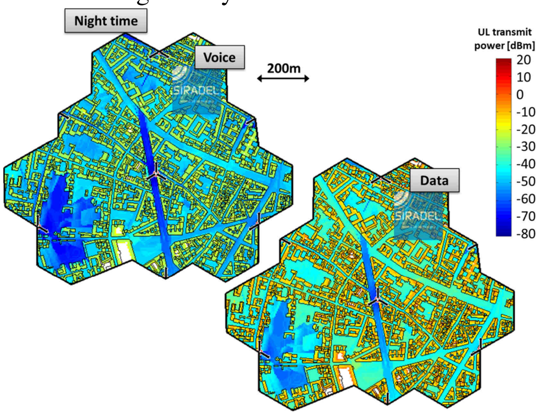

Figure 4: Tx power (dBm) calculated indoor at ground floor and outdoor during the night for voice and data traffic

C. Results

Aggregating everything we obtain the following value for the exposure index of the over 15 years old population of the 7th district of Paris, considering a macrocell LTE network:

EI **=1.24e-05 J/kg/day**

IV. CONCLUSION

In this paper, a new metric to evaluate the EMF exposure induced by a wireless telecommunication network has been introduced. This metric called Exposure Index (EI) aims at evaluating the averaged exposure of a population in a given area induced by both user devices and network equipment. The exposure index is built on segmentations in time, people, environments, RAT, cell layers, usages and users profiles. In this paper, a simple scenario of a macro urban LTE environment illustrated the feasibility of an end-to-end calculation of EI. In the future, different solutions will be studied to minimize EI both at architecture and technological levels.

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