LEXNET
Low EMF Exposure Future Networks

D3.1 Exposure Index assessment v1

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Abstract	LEXNET aims at assessing the exposure in a network by taking into account the uplink (UL) exposure besides the downlink (DL) exposure. Electromagnetic field exposure data will be available from EMF measurements with dosimeters, narrowband and broadband measurement systems, 3D EMF simulations (e.g. based on ray tracing methods) and receive and transmit data obtained from the user's mobile device and base stations / access points. Task 3.2 on the assessment of the exposure index is still at an early stage. Hence, this deliverable is a preliminary version of D3.3 due in month 24 of the project. It provides an		

	overview of the EMF data available for assessing (calculating) the EI and the concept to combine the heterogeneous sets of EMF data.
Key words	Exposure index, exposure metric, electromagnetic fields

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Joe Wiart	Coordinator	Orange	15/11/2013	

Document history

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V0.1	23/09/2013	Initial draft	Sam Aerts, Günter Vermeeren
V0.2	4/11/2013	Updated missing references and reviewing of text Version for internal review	All
V0.31	14/11/2013	Revision of document after internal review, including minor correction on the location of the fixed dosimeter batteries	All
V1	15/11/2013	Final version	Günter Vermeeren, F. Bourdel

Executive Summary

LEXNET aims at assessing the exposure in a network by taking into account the uplink (UL) exposure combined with the downlink (DL) exposure, as embodied in the LEXNET-conceived Exposure Index. Electromagnetic field exposure data will be available from a varied set of sources, including EMF dosimeters, narrowband and broadband measurement systems, 3D EMF simulations (e.g., based on ray tracing methods) and transmission parameters obtained from the user's mobile device and base stations / access points.
In this deliverable "D3.1 Index Exposure Assessment v1", we provide an overview of the EMF data available for computing the Exposure Index and the methods for combining the heterogeneous EMF data. The methods will be elaborated and extended in deliverable "D3.3 Index Exposure Assessment v2".

1 INTRODUCTION

Current Radio Frequency (RF) exposure metrics mainly deal with assessing compliance with exposure limits. These metrics are discussed in LEXNET deliverable D2.1 [1]. Most of these metrics are either uplink-only or downlink-only focused. Recent studies also looked at the combined exposure of uplink and downlink, but on an individual user basis [2], [3]. Within the LEXNET project, a metric that quantifies the global exposure in an environment or area is defined and is called the Exposure Index (EI). This index combines the uplink and downlink exposure to assess average exposure of all people in an environment. If all the data concerning the network are known then the usual planning tools and systems simulations can be used to determine the exposure induced by uplink and downlink. Usually some bits of information are missing and there is some uncertainty about the available data. Because of that and also to allow independent EI estimation, LEXNET has to specify methods able to combine measurements and simulations. Currently, Task 3.2 of the LEXNET project on the methods for assessing the exposure index is still at an early stage and this deliverable is a preliminary version of an updated version due in month 24 of the project.

The present Deliverable 3.1 is the first deliverable of two on the methods for assessing the Exposure Index (EI). This deliverable provides in Section 2 an overview of the exposure and network data available for determining the EI. Section 3 discusses some concepts on how to combine the heterogeneous exposure and network data in order to calculate the EI. Section 4 discusses challenges and constraints of the EI and the usage of it. Finally, Section **Erreur ! Source du renvoi introuvable.** concludes this deliverable.

2 DATA

The EI defined by the LEXNET consortium in D2.4 [4] quantifies the global exposure in an environment induced by uplink and downlink wireless communications. This index aggregates all the available exposure data in an environment and relevant network data in order to assess the global exposure in the considered environment.

This section provides a brief overview of the exposure and network data available for assessing the global exposure.

2.1 Exposure data

Data on the exposure in an environment or area can be obtained from various devices and simulation tools. These measurement devices and simulation tools expresses the exposure in different ways: directly in terms of incident power density (e.g., from dosimeter measurements), incident field strengths (e.g., narrowband and broadband measurements) or specific absorption rate (SAR) (e.g., simulated with numerical tools or measured with the body phantoms); or, indirectly from exposure proxies, such as transmitted and received power by a mobile device (i.e., smartphone, tablet, or laptop), as well as the type of application running on the device and the location of the device with respect to the user.

2.1.1 Broadband and narrowband exposure measurements

Far-field incident electric fields or power density (usually downlink signals from base stations) are typically measured using a broadband or narrowband setup. A broadband measurement setup comprises a broadband probe connected to a broadband field meter. Narrowband exposure measurements are band- or frequency-selective measurements using a combination of an antenna (e.g., conical dipole or tri-axial isotropic antenna) and spectrum analyzer. An exposure value is obtained for all the considered frequency bands. Frequency-selective measurements allow identifying the importance of a specific communication technology in the total exposure.

Statistics on the exposure in terms of incident field levels and temporal behavior of exposure can be derived from past, comprehensive measurement campaigns [5–9] (see also deliverable D2.1 [1]) and depend on the environment. These statistics characterize the exposure in an environment and can be used to estimate the exposure in an environment when no (measurement) data is available.

2.1.2 Personal dosimeter measurements

The personal dosimeter, or exposimeter, measures the electric-field values (*E*, in V/m) (on the body, if worn on the body) for different frequency bands, including downlink and uplink bands of various Radio Access Technologies (RATs) such as GSM900, GSM1800, UMTS, and LTE. Samples in every frequency band are taken at regular time intervals, which can be tuned depending on the (*e.g., the fastest acquisition time of current dosimeters is 2 seconds*).

- In combination with GPS coordinates, the exposure along a path can be visualized (*graphical guidance for public information*).
- In combination with an activity diary, the exposure during certain activities can be determined.

Dosimeter measurements offer us information about non-self-induced or involuntary exposure: downlink, and uplink from other users' devices (assuming the carrier of the dosimeter does not use his/her user equipment).

2.1.3 Fixed point dosimeter measurements

As opposed to the wearable device that has been presented before, a number of fixed dosimeters will be deployed on a larger testbed, exploiting the possibilities of an available smart city platform. Since the number of devices to be deployed needs to be rather large, their cost shall be reduced. A detailed description of their characteristics is given in [10]. In particular, they will be integrated within the SmartSantander platform as Internet of Things (IoT) nodes and will allow taking measurements of the electromagnetic fields (in V/m) over a real large scale scenario.

As described in [10] the corresponding deployment embraces a repeater and the dosimeter itself. The repeater is the element which facilitates the integration of new sensing devices (dosimeters in the LEXNET case) to the SmartSantander architecture. At the time of writing, there is not a final decision on whether we will use the ones which are installed or we will deploy new ones (the decision does not have any impact over the operation of the system or the integration process, and therefore it will be taken based on cost considerations). Regardless of which option is finally selected, the integration with the overall platform is guaranteed by the use of this element. In order to integrate the dosimeter (new sensor) with the repeater two constraints have been considered, as described below.

The first one refers to the potential interferences coming from the repeaters, which work on the 2.4 GHz band, and thus they could jeopardize the measurements. In order to avoid this, it has been decided to place the dosimeters in a separated box from that used by the repeater, and thus a physical connection between the two boxes will be necessary.
The second issue that needs to be addressed is the additional supply required by the dosimeters to work properly. As described in [10] the repeater board is not able to provide enough power supply to the dosimeter. Hence, the deployment must ensure that the dosimeters are connected to additional energy sources.
All in all, the dosimeters will be deployed on lamp-posts and traffic lights throughout the city. In order to avoid harmful interferences, the dosimeter boxes shall be placed as far from the repeater as possible. As can be seen in Figure 1, repeaters are currently placed at mid-height, which would allow placing the dosimeter at the top of the lamp-posts (this would also depend on the lamp shape).

Figure 1 – Current repeater installation

Regarding the energy issue, the current plans are to provide the dosimeter with an additional battery (to be placed inside the IoT node or the repeater node). This battery, as it currently happens to the repeaters, will be connected to the lamp-posts supply to re-charge. This scheme has the drawback that the city lights are just switched-on during the night, so it needs to be tested whether the batteries life-time is enough to supply the dosimeter during the day period. In order to avoid battery problems, and the additional costs of integrating them, the dosimeters will be located in traffic lights whenever possible, as those lights are continuously supplied.

2.1.4 3D EMF maps

Coverage-based simulators (or radio-planning techniques) are envisaged to predict Tx/Rx powers and user Quality of Service (QoS) metrics over large pixel grids (or maps). The prediction that relies on the modelling of access network, environment, user traffic, propagation and network performance, is merged with measurements. The purpose of the merge is three-fold:

- Calibrate predictions;
- Dynamically adjust prediction to a specific time period (for continuous EMF assessment);
- Extrapolate measurements from a limited set of sounder locations to 3D maps.

Coverage-based simulators allow for the simulation of the coverage and key indicator metrics (e.g. cell load, spectral efficiency, user and cell throughput, etc) from large-scale real network (possibly multi-RAT or multi-layer networks).

- The network environment is represented by digital geographical map data, with preferably high-resolution in urban areas.
- The propagation is based on deterministic approaches: multiple-knife-edge diffraction, ray-tracing.
- The resource allocation in MAC layer is simulated by simple abstraction models (required for fast and large-scale predictions).
- The inter-cell interference on both DL and UL are computed from average user traffic.

The main outputs for EMF computations are DL average received-power maps and UL average transmit-power maps. The simulator has to generate one DL map per time period and frequency band; it must produce one UL map per time period, frequency band and type of service (voice, streaming, etc). A map is composed of several pixel grids: the outdoor grid calculated at street level; and indoor grids calculated at different floors. Figure 2 shows one example from a macro LTE network operating at 2.6 GHz (detailed scenario is described in D2.4 [4]).

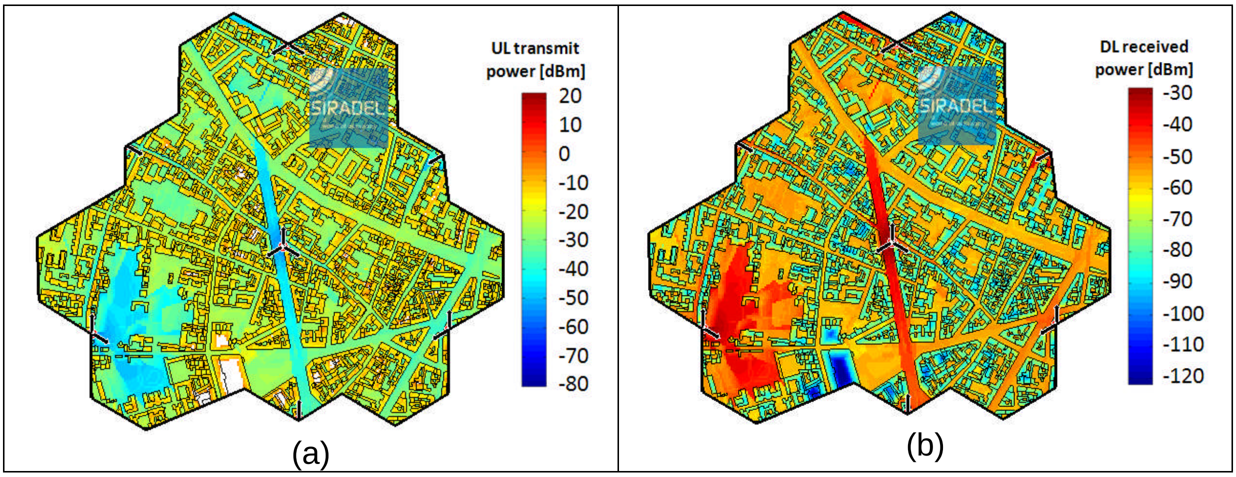

Figure 2: Example of (a) UL transmit power ground-floor map and (b) DL received power ground-floor map.

The accuracy of the simulations strongly depend on the precision we can reach on the access network description (location of base stations, maximum transmit powers, etc), the environment modelling (geographical map data) and the user traffic modelling (user density, user profile, variation along the day).
Interaction with measurements is essential, and may occur at three different levels:

- Impacting the prediction models, for instance:
  - Calibration of the propagation model from drive-test measurements;
  - Calibration of the UL transmit power prediction model from mobile device measurements.
- Impacting the simulation inputs, for instance:
  - Derivation of an average user traffic model from analysis of a large amount of network monitoring data;
  - Time variation of the DL user traffic estimated from continuous measurement by a sounder network.
- Generating output maps: merging the received power measurements and the simulated maps to get mixed output maps.

2.1.5 Wireless Heuristic Indoor Propagation Tool

The WiCa Heuristic Indoor Propagation Prediction (WHIPP) tool [11] is a heuristic network predictor and planner, developed and validated for indoor environments, and suitable for WiFi, Zigbee, and/or 3G/4G. It takes into account the effect of the environment on the wireless propagation channel and its calculations are based on the establishment of the dominant path between transmitter and receiver, i.e., the path along which the signal encounters the lowest obstruction.
Besides throughput and path loss predictions of a given wireless network configuration, the tool also enables a quick automatic network design, where user-defined coverage requirements in the different rooms of the building are achieved with the smallest number of access points. Finally, the tool allows the reduction of the number of access points in over dimensioned networks without affecting the coverage. The used algorithms can serve as a basis for future developments and extensions. An exposure index calculation module will be added. This will allow the assessment of different scenarios with respect to exposure (SAR and incident power densities).

2.1.6 Position of a mobile device close to the body

The available sensors that exist in smartphones (accelerometer and magnetometer) can be used to determine the exact position of the phone but the relative position of the user is not at present time possible. Only proximity sensors can be used to determine if the system is close to the body. Such methods are nowadays used in epidemiological study to analyze the laterality of the use as for example the application XMobiSense used in the study Mobi-Expo [12] whose aim is to characterize the young people's usage of the mobile phones.

2.2 Network data

Besides exposure data obtained from measurements and simulations, the network itself also contains data of interest in assessing the EI in an environment. This data can be obtained from network management and monitoring systems available at base stations and access points. Using these tools in operational network will provide realistic values and realistic distributions of extracted parameters to be combined for calculating the total exposure. Main parameters that will be extracted are:

- The average transmitted (TX) power of user equipment per user or per cell.
- The average received (RX) power or power density of user equipment per user or per cell.
- The TX of base stations and access points.
- The traffic load per cell during the day.

In addition, we can statistically determine user profiles from the live network.
We distinguish between data available at the mobile devices and data available at the base stations and access points.

2.2.1 Data available at the mobile devices

Using Software Modified Phones (SMP) or a mobile application, it’s possible to log the TX and the RX powers of some mobile devices. Hence, we are able to obtain statistical knowledge about the TX-RX distributions of different networks, and during different usage (voice vs. data, various data usages, etc.).

- The logged TX values offer valuable information about the near-field exposure to the user's own devices (*user equipment*).
- RX measurements alongside dosimeter measurements of downlink signals → gain knowledge about RX measurement uncertainty. (typical SMP RX parameters are the RSSI or some other indicator of the downlink signal's intensity; (dosimeter) measurements of the downlink signal's power density are needed to calibrate these RX measurements)

2.2.2 Data available at base stations and access points

The data available at base stations and access points can be share in two categories. On the one hand, there is the information on the base station antennas: location, tilt, type of antenna and power emitted. Information about external ICT base station antennas can be collected through agency database such as Cartoradio from Agence Nationale des Frequence (ANFR) in France, Sitefinder from the Office of Communication (OFCOM) in the UK, funksender from Bundesamt für Kommunikation (BAKOM) in Switzerland or cadaster from Belgian Institute for Postal services and Telecommunications (BIPT) in Belgium. Not all European countries have such information tools, and the information available is not standardized. In some cases it is possible to get the type of emission (2G 900-1800 MHz, 3G…), the position and height of the antennas with uncertainties that we have to take in account but most of the time the exact power emitted and tilt are not given. Dealing with the indoor antennas, it depends on the power emitted, for example the WiFi box is not listed. Table 1 lists the public information on base station antennas available through national agencies in some European countries.

Table 1: Summary of the public information on external base station antennas in some European countries.

	OFCOM UK[1]	ANFR France[2]	BIPT Belgium[3]	BAKOM Swiss[4]	Eire[5]	Minister of Industry Spain[6]
Operator	X	X	X		X	X
Position	approx	address	address	X	X	X
Macro/Micro	X		X			
GSM/UMTS/LTE	X	X	X	X	X	X
Frequency	X	X	X			
Height	X	X	X			
Power/EIRP	X		X		X	
Azimuth	X	X	X			X
Tilt			X			
Antenna gain			X		X	
Technical file			X			
Simulation			X			

[1] www.sitefinder.ofcom.org.uk; [2] www.cartoradio.fr; [3] www.sites.bipt.be; [4] map.geo.admin.ch;
[5] www.askcomreg.ie; [6] Infoantenas

On the other hand, the data available at base stations and access points can also be the result of a survey of the power emitted and received by mobiles connected at the bases station under analysis. Such a survey requires a program in the base station system to collect the very large amount of data. Because of that such implementation is complex on operating system and a report on event is usually preferred in real network.

2.3 SAR simulations

The frequency of the wireless signal, the usage of the mobile devices, and the posture of the user all influence the induced exposure. Whole-body and/or localized SAR simulations are needed for each combination *frequency-usage-posture*, using reference values for TX (e.g., 1 W) and RX (e.g., 1 W/m^2). Combining exposure data, network data and dosimetric simulations (see Section 2) allows to calculate the real (statistical or individual) exposure (see Section 3).

3 METHOD FOR DATA COMBINATION

One of the challenges for the assessment of the EI is to combine the heterogeneous data from measurements (narrowband, dosimeter, and broad-band measurements) and simulations (3D field maps). Currently, interpolation techniques are designed to deal efficiently with the variety of exposure data.

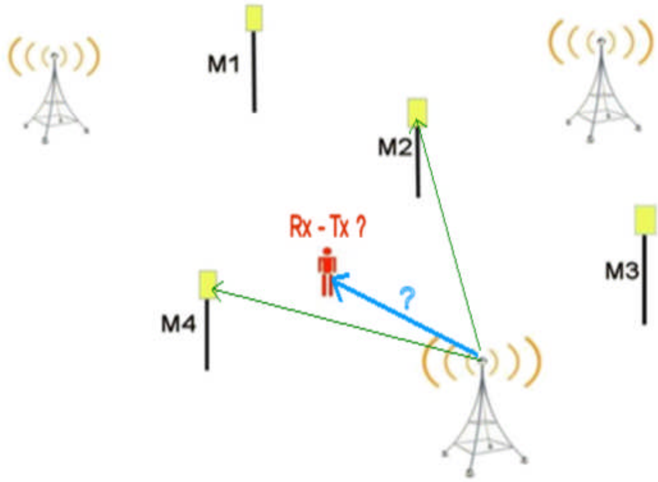

Figure 3: Measurement points (M_i) and antenna locations.

The downlink assessment can be done using interpolation technique such as Kriging [13] in geo-statistical methods. The challenge is to assess the uplink. Broadband measurement performed at specific location (see Figure 3) can be compared to simulations based on public available database (antenna type, tilt, location power…). If enough information is available some input parameter of the simulation can be tuned to fit the measurement. After such optimization the uplink can be assessed.
A high-level flow-chart on the assessment of the EI is shown in Figure 4. The EI for an exposure scenario is calculated based on the available simulated dosimetric, network and exposure data for the considered scenario. The uplink and downlink dosimetric data is simulated for selected human body models and for typical usages of mobile devices at wireless communication frequencies.

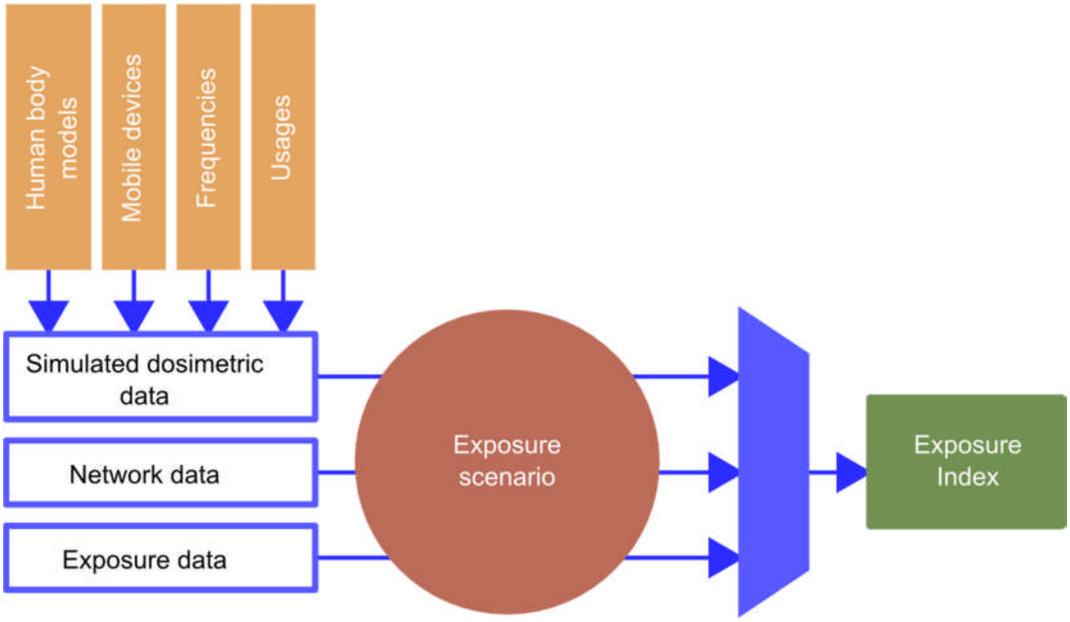

Figure 4: Flowchart of the assessment of the Exposure Index.

4 DISCUSSION AND CONCLUSIONS

This deliverable is a preliminary version of D3.3 due in month 24 and provides an overview of the EMF data available for assessing (calculating) the EI and the concept to combine the heterogeneous sets of EMF data.

The EI quantifies the global exposure in an environment aiming at assessing and optimizing the exposure in an environment by combining data from exposure assessment, network data, and dosimetric data. Optimizing a communication network can be performed during the design stage of the network or can be integrated in the network management tools.

One of the main challenges is the combination of these data and assessing the corresponding uncertainty. In addition, a main issue is the availability of accurate information on the network. If not, the optimization is very difficult due to the many degrees of freedom. Other issues are how to deal with the large amount of (live, real-time) data, sounding one specific channel or all channels, etc.

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6 APPENDIX 1: INTERNAL REVIEW

	Reviewer 1: Emmanuelle Conil			Reviewer 2: Milos Tesanovic		
	Answer	Comments	Type*	Answer	Comments	Type*
1. Is the deliverable in accordance with						
(i) the Description of Work?	☒ Yes ☐ No		☐ M ☐ m ☐ a	☒ Yes ☐ No		☐ M ☐ m ☐ a
(ii) the international State of the Art?	☒ Yes ☐ No		☐ M ☐ m ☐ a	☒Yes ☐ No		☐ M ☐ m ☐ a
2. Is the quality of the deliverable in a status						
(i) that allows to send it to EC?	☐ Yes ☒ No		☐ M ☐ m ☐ a	☒ Yes ☐ No		☐ M ☐ m ☐ a
(ii) that needs improvement of the writing by the editor of the deliverable?	☒ Yes ☐ No	Please see my comments in the text	☐ M ☐ m ☒ m ☐ a	☒ Yes ☐ No	Please see my comments above.	☐ M ☒ m ☐ a
(iii) that needs further work by the partners responsible for the deliverable?	☐ Yes ☒ No		☐ M ☐ m ☐ a	☐ Yes ☒ No		☐ M ☐ m ☐ a

* Type of comments: M = Major comment; m = minor comment; a = advice