Ref. Ares(2015)5347928 - 25/11/2015

LEXNET
Low EMF Exposure Future Networks

D2.8 Global Wireless Exposure Metric Definition

Contractual delivery date: M36
Actual delivery date: M36

Document Information

Version	V1	**Dissemination level**	PU
Editor	Nadège Varsier (Orange)		
Other authors	Yuanyuan Huang, Anis Krayni, Abdelhamid Hadjem, Joe Wiart (Orange) Günter Vermeeren, David Plets, Wout Joseph, Luc Martens (iMinds) Carla Oliveira, Daniel Sebastião, Manuel Ferreira, Filipe Cardoso, Luis Correia (INOV) Mladen Koprivica, Milica Popović (TKS) Enis Kocan, Milica Pejanovic-Djurisic (University of Montenegro)		

PROPRIETARY RIGHTS STATEMENT
This document contains information, which is proprietary to the LEXNET Consortium. Neither this document nor the information contained herein shall be used, duplicated or communicated by any means to any third party, in whole or in parts, except with prior written consent of the LEXNET consortium.

Abstract	This deliverable puts an end to the global EMF exposure metric built in the framework of the LEXNET project. It described this new metric defined in order to evaluate the averaged exposure of a population in a given area induced by a wireless communication network including base stations, access points but also the personal devices of the population. First, the concept of the new metric called Exposure Index (EI) is detailed. The EI is an average of the population exposure; it consequently results from the aggregation of all exposure sources and exposure situations met in the exposed area. The computation of EI is based on a chain of exposure where each branch represents a specific exposure source and situation. The index is a weighted sum of the individual exposures from all the branches in this chain. Then, the concept is formalized through an analytical model with multiple input variables. Each input variable needed for the EI computation is described and detailed. In section 4 the EI integration methodology is described on a dense urban macro 3G scenario. Finally the uncertainties and the variability are discussed and ICT usage data variability is detailed and propagated into the analytical model to evaluate the variability of the EI.
Key words	Metric, exposure index

Project Information

Grant Agreement n°	318273
Dates	1^{st} November 2012 – 31th October 2015

Document approval

Name	Position in project	Organisation	Date	Visa
Joe Wiart	Coordinator	Orange	18/11/2015	OK

Document history

Version	Date	Modifications	Authors
V0	19/10/2015	First draft version for internal review	Nadège Varsier
V1	09/11/2015	Version after taking into account internal reviewer comments	Nadège Varsier

TABLE OF CONTENTS

Executive Summary

This deliverable is focused on a global wireless exposure metric defined in order to evaluate the averaged exposure of a population in a given area induced by all the networks deployed in the considered area including base stations, access points but also the personal devices of the population. The project LEXNET aims at reducing this averaged exposure.

The concept of this new metric is to take into account the global EMF exposure of a population to wireless telecommunication networks.

It covers the exposure of a population during a given time frame in a given area incurred by a wireless telecommunication network as a whole, combining the downlink exposure induced all day long by base stations and access points and the uplink exposure incurred by individual wireless communication devices.

The way to build the new metric called Exposure Index (EI) is based on a chain of exposure covering all the configurations of exposure we are dealing with. Individual exposure is integrated over different radio access technologies (GSM, UMTS…), layers (macro-cells, micro-cells, femto-cells), types of used devices (mobile, tablet…), usages of these devices (voice calls or data sessions) and profiles of users (heavy users, non-users…). Finally, the EI is a weighted sum of all the branches of the chain of exposure.

The first chapter of the deliverable provides a reminder of the need to define a new metric. The second chapter details the new concept of EI and its formalization through an analytical model with multiple input variables.

The third chapter introduces data sources used to compute the EI.

Then the EI integration methodology is described on a complete macro 3G scenario.

Finally the uncertainties and the variability are discussed and ICT usage data variability is detailed and propagated into the analytical model to evaluate the variability of the EI.

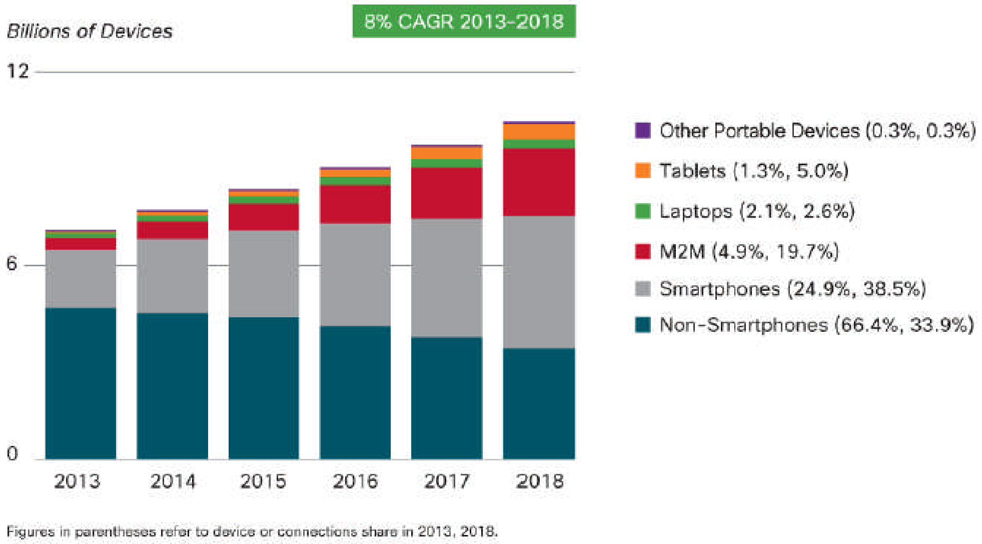
List of Acronyms and Abbreviations

AIC	Akaike Information Criterion
ANR	Agence Nationale de la Recherche (French National Agency of Research)
BS	Base Station
CAD	Computer-Aided Design
GSM	Global System for Mobile
DL	Down-Link
EI	Exposure Index
EM	ElectroMagnetic
EMF	ElectroMagnetic Field
EPRE	Energy Per Resource Element
ISD	Inter Site Distance
FDD	Frequency Division Duplexing
FP7	7th Framework Program of the European Commission
GPU	Graphics Processing Unit
ICT	Information and Communication Technology
KPI	Key Performance Indicator
LOS	Line Of Sight
LTE	Long Term Evolution
MLW	Maximum number of Lines per Wavelength
NLOS	Non Line Of Sight
PEC	Perfect Electrical Conductor
QoS	Quality of Service
RAT	Radio Access Technology
RX	Received
RF	Radio-frequency
SAR	Specific Absorption Rate
SAS	Statistical Analysis System
SINR	Signal to Interference plus Noise Ratio
TX	Transmitted
UE	User Equipment
UL	Up-Link
UMTS	Universal Mobile Telecommunication System
WiFi	Wireless Fidelity

1 INTRODUCTION

Wireless communications are being used in almost every aspect of daily life. The extremely rapid technological evolution results in dramatic changes in the usage of the wireless devices but not in the perception of the exposure induced by these networks.

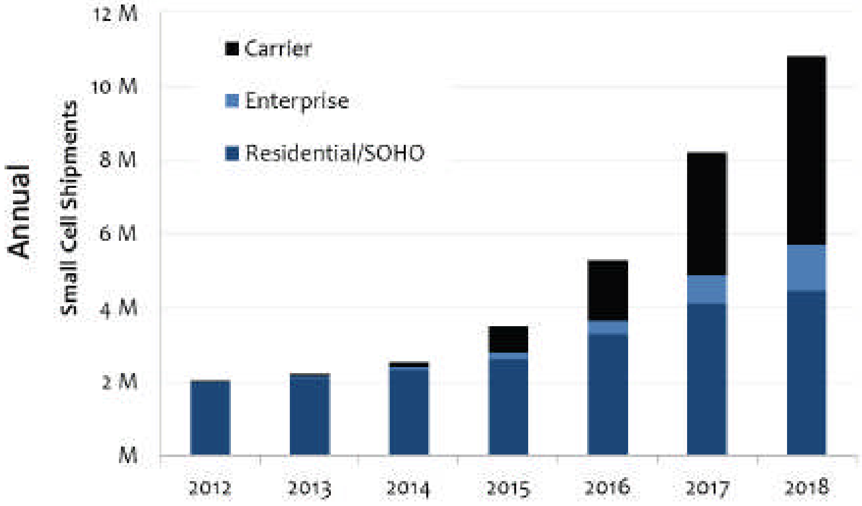
On the one hand, new devices and new generations of wireless networks have made a multitude of new applications popular. These applications (used mainly with smartphones) are consuming more and more data as illustrated in Figure 1 [CISCO14].



Figures in parentheses refer to device or connections share in 2013, 2018.
Source: Cisco VNI Mobile, 2014

Figure 1: Global mobile data per month traffic forecast by type of device.
Source: Cisco VPN Mobile Forecast 2014

To support this increasing demand, traditional macro-cellular networks are not well dimensioned anymore and new types of networks based on heterogeneous topologies (including small cells) must be used to offload the data traffic.
The deployment of new frequency bands and new technologies as LTE, as well as the growth of WiFi usage will help to support this demand.
As illustrated on Figure 2, a massive small-cells deployment is forecast in the next few years.



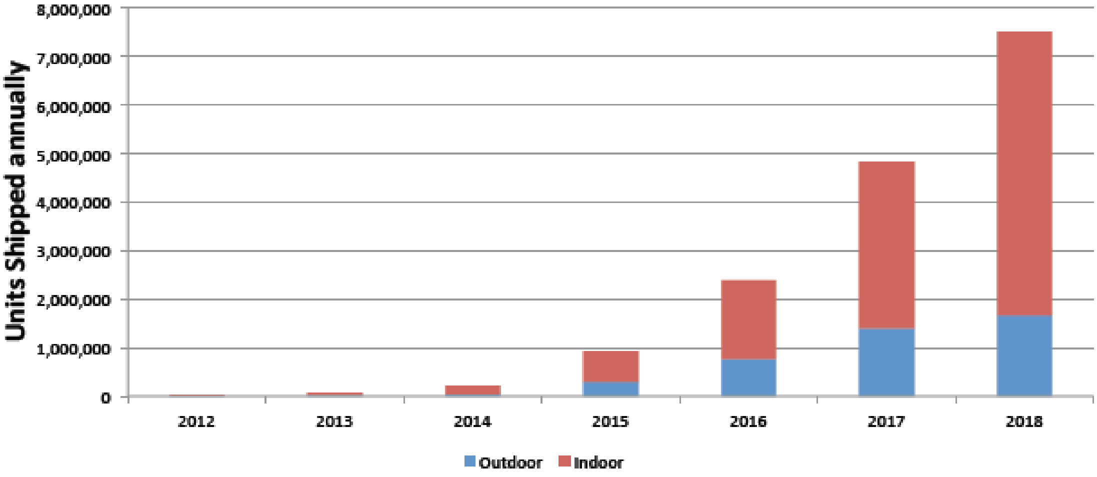


Figure 2: Worldwide small cells deployment forecast (figure on top) and public access metrocells deployment forecast (bottom figure) - Source: Maravedis-Rethink RAN Research Service

But paradoxically, as the role of wireless communications in the daily life quickly expanded, the public concern around EMF health risk grows just as much. An in-depth survey has been conducted in the framework of LEXNET. Data was collected from April to June 2013 in France, Germany, Portugal, Spain, Romania, Montenegro and Serbia using an online survey tool. A total of 2392 respondents participated in this survey (mean age: 34.82 years; gender distribution: 40% female and 60% male).
The first part of the survey focused on the perceived sources of daily RF-EMF exposure of the respondents. Additionally, we were interested in the factors which determine, in their view, the degree of EMF exposure. Another part of the survey regarded risk perception and health concerns.
Only key findings are reported here but detailed description of the survey and of the results is in the deliverable entitled “D2.2 Risk and exposure perception” [LEXNET D2.2 2013].

Regarding the perceived health hazards of various usage scenarios, our respondents evaluated base stations on a school roof as the most dangerous. Using mobile phone for calls is perceived as less dangerous, a somewhat lower score characterizes the laptop used on the lap. The results of this survey indicate that risk perceptions of the general public and the underlying health concerns are guided by subjective models of EMF impact, which underestimate near-field exposure and overestimate far-field exposure. People are more concerned about base stations than about all other RF-EMF sources.

Currently, different metrics are used to deal with exposure induced by sources close to the users as mobile phones and with exposure induced by far away sources as base station antennas.

The current state of existing metrics to evaluate the exposure induced by RF-EMF sources has been reviewed in the deliverable “D2.1 Current metrics for EMF exposure evaluation” [LEXNET D2.1 2013].

Basically, two types of metrics are distinguished, the ones dedicated to the exposure induced by sources close to the users, as personal devices, and expressed in terms of Specific Absorption Rate (SAR) and the ones focusing on the exposure induced by far field sources as access points or base station antennas and currently expressed in Electric/Magnetic fields or Power Density.

Personal devices and base stations are too often represented as two separate worlds when dealing with exposure issue. But the connection between exposure induced by personal devices and base stations is indisputable. Measurements on real networks illustrate a strong correlation (Figure 3) between the power emitted by personal devices and the power received by personal devices from the base station antennas [GCWW10]. The higher is the received power by the device the lower is the emitter power by the device as illustrated by Figure 3.

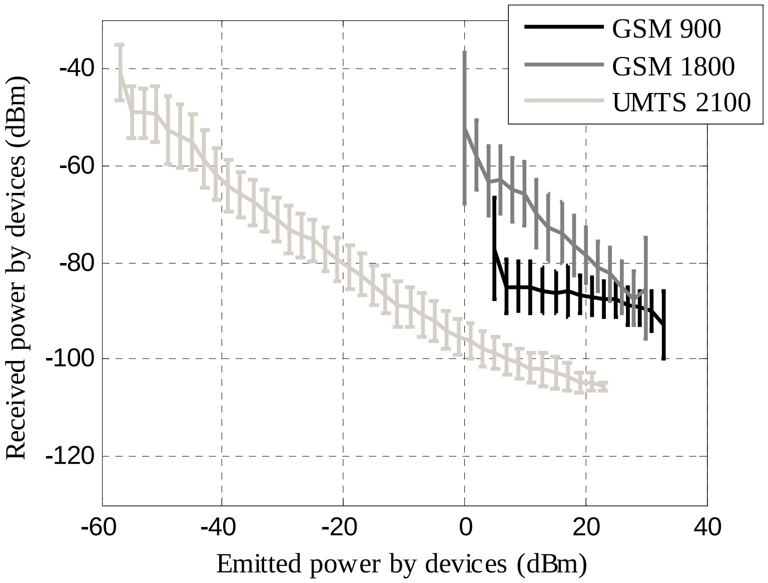


Figure 3: Duality between mobile phones emitted and received powers measured during voice calls on the 3G Orange France network - source [GCWW10]

The project LEXNET aims at filling the gap between these two separate ways of dealing with exposure by proposing a new exposure metric named Exposure Index (EI). The EI is assessing the average exposure of a population induced by both personal devices and base stations (or access points). The concept is to average this global exposure over space by assessing the EI in a given area and average it over time by considering a given time frame. Therefore an important question that the

project must absolutely address is about the understandability and acceptability of this new exposure metric by the general public.
A second survey has been therefore conducted in the framework of LEXNET. Data were collected from July to September 2014 in France, Germany, United Kingdom, Portugal, Spain, Romania and Serbia among a representative sample of the general population. A total of 1809 respondents participated in this second survey.
An important part of the survey focused on how people are considering strategies proposed in the framework of the LEXNET project to define and minimize the population's exposure to electromagnetic fields.
Only key findings are reported here but detailed description of the survey and of the results is in the deliverable entitled "D2.5 Risk and exposure perception" [LEXNET D2.5 2014].

When asked about adding up the exposure from personal wireless devices and the exposure from base stations when evaluating the exposure of people to EMF, more than 90% of respondents agreed on the fact that both downlink and uplink exposures should be considered when evaluating the population exposure to EMF.
A large percentage of respondents also agreed when asked if it makes sense to characterize the day-to-day exposure to EMF by averaging it over time or if they think that an individual exposure to EMF can be approximated by measuring the exposure over a large population.

The next chapter of this deliverable describes the Exposure Index proposed by the project LEXNET.

2 THE EXPOSURE INDEX

2.1 Key concept

The Exposure Index (EI) takes into account the global EMF exposure of a population to a given wireless telecommunication network (or a set of networks). The EI, in the framework of LEXNET project, does not take into account the exposure induced by other RF sources such as Frequency Modulation (FM) radio or digital terrestrial television transmitters. However the EI was designed as a future-proof metric and other RF sources could completely be taken into account if needed.

It covers the exposure of a population during a given time frame in a given area incurred by a wireless telecommunication network as a whole, aggregating the downlink exposure induced all day long by base stations and access points and the uplink exposure incurred by individual wireless communication devices. The uplink exposure can be subdivided in exposure due to the uplink of the user's own device and the uplink of devices operated by other users nearby.

In order to assess the realistic exposure of a population many parameters influencing the exposure need to be taken into account in the Exposure Index: age (adult and child exposure are different [CHLWW08] [WIART08]), posture [NAGAOKA08], usage, technology, environment etc.

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, acceptable and usable for all the stakeholders, from general public to regulatory bodies; and it is linked in a tangible way to the network operating parameters.

The EI is built from the aggregation of individual exposure contributions generated by a specific exposure source in specific exposure situations. For instance, an averaged individual exposure generated by WiFi 2.4 GHz can be calculated at day time for an adult heavy-user located indoors, sitting, and with a tablet. The same kind of individual exposure is estimated for other time periods, RATs, populations, environments, usages and postures to get complete elements that compose the EI. The individual exposure contributions are weighted according to their representativeness before aggregation. A complete example of EI integration is given in section 4.3.

The individual exposure is the sum of a down-link (DL – generated by surrounding base stations and access points) and up-link (UL – generated from personal mobile devices) components, as explained with more details in section 2.2.1.

The EI is computed in a given area from the aggregation of individual exposure contributions in a chain of exposure (see Figure 4). The nodes in this chain are related to different exposure sources or exposure situations:

- time periods, as the configuration of the network and type of usage depend on the time of day (low-load night-time vs. heavily loaded peak-hour);
- population category, as different population categories will have different life segmentations and different usages of wireless devices;
- user profile;

- location, as the exposure configurations will be different in different environments, typically indoors and outdoors;
- radio access technologies RATs (GSM / UMTS / LTE / WiFi etc.), frequency bands and deployment layers (macro, micro and femto cells) that users connect to;
- posture, as different body postures will lead to different absorption rates in the human body;
- device usage, as for example making a phone call does not lead to the same exposure as downloading data.

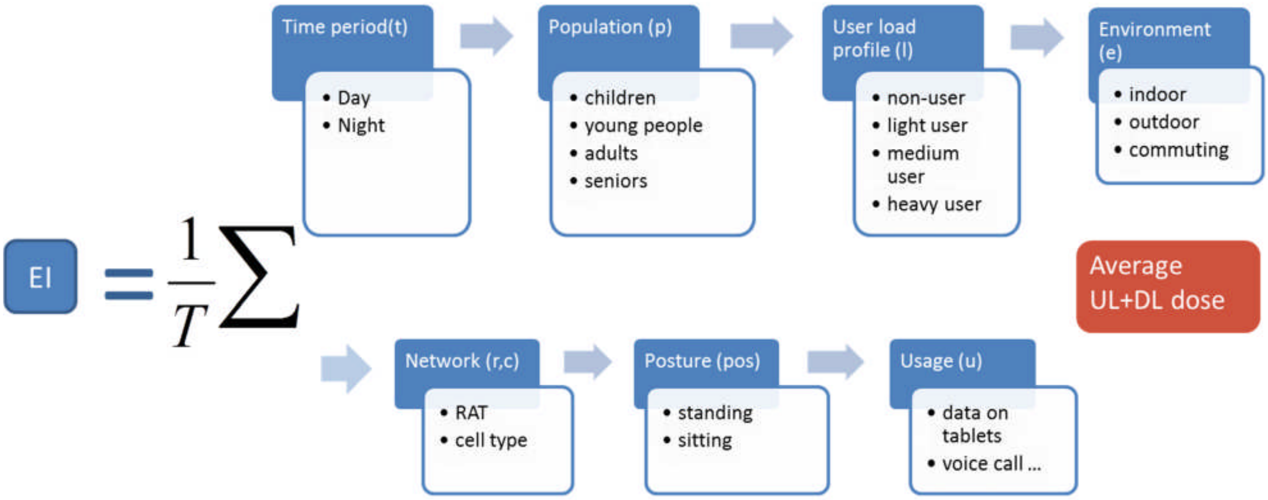


Figure 4: the LEXNET chain of exposure

Different exposure scenarios [LEXNET D2.3 2013] are considered and aggregated by putting weights on each configuration, thereby determining the EI. A partial EI can be, for example, computed for a scenario that considers only a subset of RATs, population, environment, etc... Then several partial EI can be aggregated with a weight related to their representativeness.

EI takes into account different parameters coming both from the telecom world to describe the accessible network environment and from data on how people segment their life to describe how people are using this network.

2.2 Mathematical formalization

2.2.1 Exposure Index Equation

The Exposure Index is calculated for a finite geographical area that must preferably be homogeneous in terms of population and network usage; it can be of urban, suburban or rural type for instance.

The general formulation of the Exposure Index contains a set of technical parameters, as described below. The number of values, classes or settings of each parameter depends on the level of detail of the available data and on the level of achievable complexity in terms of calculation. For a given geographical area, the EI takes the following into account (see also Table 1):

- time period (t): e.g., day and night;
- population (p) segmented into different categories: e.g., children (under 15 y.o), young people (15-29 y.o), adults (30-59 y.o) and seniors (60 y.o and over);
- user load profiles (l): e.g., heavy, medium, light or non-users;
- environment (e): e.g., indoor (office, home), outdoor, and in commuting (bus, car, subway etc…);
- different available Radio Access Technologies (RATs) (r): e.g., 2G (900 MHz and 1800 MHz), 3G, 4G, WiFi; the number of RATs depends on the scenario;
- different cell types (c): e.g., macro, micro, pico and femto cells; the accessibility to the different cell types depends on the scenario;
- posture (pos): e.g., sitting, standing;
- usage (u) is described by the device (e.g., mobile, PC, laptop) and the service (e.g., voice call, data);

Time	Population	User Profile	Environment	RAT	Cell Type	Posture	Usage
Day	Children	Heavy	Indoor	2G	Macro	Standing	Voice, mobile
Night	Young people	Medium	Outdoor	3G	Micro	Sitting	Data, mobile
	Adults	Light	Commuting	4G	Pico		Data, Tablet
	Seniors	Non user		WiFi	Femto		Data, Laptop on the laps
							Data, Laptop on the desk

Table 1: input variables in the modelling of the EI

The individual exposure contributions rely on the SAR expressed in W/kg. The SAR depends on the device, the frequency band, the morphology and the posture of the user as well as on the position and distance of the source with respect to the user. As part of LEXNET, a set of numerical dosimetric simulations have been performed in order to fill out a comprehensive matrix of raw normalized SAR values, calculated for a reference transmitted power (near-field exposure) or a reference received power density (far-field exposure). These SAR values can be whole-body or localized SAR values. Whole-body SAR values are evaluated by averaging SAR over the whole-body whereas localized SAR values are values focusing on a body volume, specific organ or tissue. Different EI can be evaluated depending on the value of interest (whole-body or localized value).

Network measurements or simulation tools are expected to provide transmitted and received power density average values to apply to the raw SAR matrix.

Information and Communication Technologies (ICT) usage data obtained through sensors inside the network and segmentation life data will finally provide the levels to apply for the evaluation of the EI.

It was decided to build the EI based on the dose (SAR x duration of exposure) even if there is no evidence today of a higher correlation between the dose and any hypothetical health effect than with instantaneous peak SAR.

$$EI^{\mathrm{SAR}} = \frac{1}{\mathrm{T}} \sum_{t}^{N_T}\sum_{p}^{N_P}\sum_{e}^{N_E}\sum_{r}^{N_R}\sum_{c}^{N_C}\sum_{l}^{N_L}\sum_{pos}^{N_{pos}} f_{\mathrm{t,p,e,r,l,c,pos}} \left[\sum_{u}^{N_U}\left(d^{UL}\,\bar{P}_{TX}\right) + d^{DL}\,\bar{S}_{\mathrm{RXinc}} + d^{DL,close\ devices} S_{RXinc}^{DL,close\ devices}\right] \quad \left[\frac{\mathrm{W}}{\mathrm{kg}}\right]$$

(1)

where:

- EI^{SAR} is the Exposure Index value, the average exposure of the population of the considered geographical area over the considered time frame T. SAR refers to whole-body SAR, organ-specific SAR or localized SAR.
- N_T is the number of considered periods within the considered time frame (e.g., single day);
- N_P is the number of considered Population categories;
- N_E is the number of considered Environments;
- N_R is the number of considered Radio Access Technologies;
- N_C is the number of considered Cell types;
- N_L is the number of considered user Load profiles;
- N_{pos} is the number of considered Postures;
- N_U is the number of considered Usages with devices
- $\bar{P}_{TX}$ is the mean TX power transmitted by the users' devices during the period t, in usage mode u, connected to RAT r, in environment e. For example, when EI is computed from simulation tools, the TX power can be predicted over a map that covers the whole considered geographical area and the average value is extracted for the EI evaluation. See details in section 2.2.3.
- $\bar{S}_{RXinc}$is the mean incident power density on the human body during the period t, induced by RAT r, in environment e. A distribution of the incident power density for the whole considered geographical area is considered and the average value over this area is taken into account for the EI evaluation.
- $S_{RXinc}^{DL,close\ devices}$ is the incident power density on the human body during the period *t*, induced by a wireless device connected to RAT r of a user in the proximity, in environment *e*. This term is important when the exposed person is the user itself; it can also be significant for persons in the proximity of users of a wireless device, for instance in a crowded meeting room, in public transportation, etc. In the applications discussed in this paper, this term is neglected. We also remark that $S_{RXinc}^{DL,close\ devices}$ depends on the orientation of the user of the wireless device with respect to the body of the people in its proximity. See details in section 2.2.3.
- d^{UL} $(\frac{\mathrm{Ws}}{\mathrm{kg}}/\mathrm{W})$, $d^{DL,close\ devices}$ $(\frac{\mathrm{Ws}}{\mathrm{kg}}/\frac{\mathrm{W}}{\mathrm{m^2}})$, and d^{DL} $(\frac{\mathrm{Ws}}{\mathrm{kg}}/\frac{\mathrm{W}}{\mathrm{m^2}})$ are the normalised raw dose values for UL, the DL from the user in the proximity, and DL from base stations and access points, respectively, all multiplied by the time spent in the configuration. See details in section 2.2.2.

- $f_{t,p,e,r,l,c,pos}$ is the fraction of the total population that corresponds to population category *p*, user load profile *l*, in posture *pos*, connected to RAT *r*, for a cell type *c*, in environment *e*, during the time period *t*.

In the following, we explain the different terms used in the EI formula in more detail.

2.2.2 Coefficients d^{UL} and d^{DL}

The coefficient d^{UL} is associated to the exposure induced by the uplink and expressed as an absorbed dose normalised to a transmitted power of 1 W:

$$d^{UL}_{[\frac{\mathrm{s}}{\mathrm{kg}}]} = \frac{TD^{UL}_{t,p,l,e,r,c,u,pos[\mathrm{s}]} SAR^{UL}_{p,r,u,pos[\mathrm{W/kg}]}}{P^{ref}_{TX[\mathrm{W}]}} \qquad \left[\frac{\mathrm{Ws}}{\mathrm{kg}}/\mathrm{W}\right] \tag{2}$$

where:

- $TD^{UL}_{t,p,l,e,r,c,u,pos}$ is the time duration of usage u, and a user profile load l, when connected to the RAT r, operating in cell type c, in the environment e, for the population category p, in the posture *pos*, during the time period of the day t.

- $\frac{SAR^{UL}_{p,r,u,pos}}{P^{ref}_{TX}}$ can be the whole body or an organ-specific or tissue-specific SAR value for the usage u and the posture *pos*, in the frequency band of the RAT r, and the population category p, calculated for an incident emitted power of P^{ref}_{TX} and normalized to this power.

The coefficient d^{DL} is associated to the exposure induced by the downlink and also expressed as an absorbed dose normalised to an incident power density of 1 W/m^2:

$$d^{DL}_{[\frac{\mathrm{s}}{\mathrm{kg}}]} = \frac{TD^{DL}_{t,p,e,r,c,pos[\mathrm{s}]} SAR^{DL}_{p,r,pos[\mathrm{W/kg}]}}{S^{ref}_{\mathrm{RX[W]inc}}} \qquad \left[\frac{\mathrm{Ws}}{\mathrm{kg}}/\frac{\mathrm{W}}{\mathrm{m}^2}\right] \tag{3}$$

where:

- $TD^{DL}_{t,p,e,r,c,pos}$ is the time duration of posture pos, when connected to the RAT r, operating in cell type c, in the environment e, for the population p, during the time period of the day t.

- $\frac{SAR^{DL}_{p,r,pos}}{S^{ref}_{RXinc}}$ can be the whole body or an organ-specific or tissue-specific SAR value induced by the base station or access points of the RAT r, in the population p, for the posture pos, normalized to the received power density S^{ref}_{RXinc}.

2.2.3 Transmitted power $\bar{P}_{TX}$ and received power density $\bar{S}_{\mathrm{RXinc}}$

$\bar{P}_{TX}$ is the average power transmitted by the device in busy mode (in active communication). It should be noted that, even in idle mode (not for active communication), the devices transmit from time to time some power (to stay synchronized with the network for example) but the exposure induced by the device in idle mode is negligible as it is based on rare events.

$\bar{S}_{inc}$ is the average power density incident on the human body from the base stations or access points of the RAT. The incident power density is assessed not only for users of mobile devices, but also for non-users. It is assumed that the usage pattern of the user considered in the EI formula does not influence the average incident power density. From a theoretical point of view, $\bar{S}_{inc}$ is the average incident power density integrated over all the frequency bands of the RAT and cell type considered. From a practical point of view, $\bar{S}_{inc}$ can be assessed directly from spectrum analyzer (SA) measurements, dosimeters, simulations and indirectly from the received power on a user device or in a drive test measurement.

$\bar{P}_{TX}$ and $\bar{\mathrm{S}}_{\mathrm{inc}}$ average out the instantaneous variations of the transmitted power and incident power density that arise during a communication. These variations occur when the user is static or moving over a very small distance and are caused by different phenomenas (power regulation, small-scale fading, resource allocation, user traffic variations, etc.). Values that will be used in the EI evaluation are averaged values over the whole considered geographical area.

For both the evaluation of the DL incident power density and UL transmitted power, the ressource allocation or duty cycle of the system has to be taken into account. The EI computation does not rely on maximum allowed power values (as in existing EMF exposure procedures) but on the incident and transmitted powers that respectively depend on the DL network and UL user resource load. This definition leads to an estimate of the UL transmitted power that necessarily depend on the type of user traffic (e.g. voice, web browsing, file upload, etc); the higher is the instantaneous UL throughput during the communication, the higher is generally the UL transmitted power.

2.2.4 Exposure from close users

To account for all possible exposure situations in the EI equation (1), we also have to include the exposure induced in persons close to an active device operated by a third person. This happens for instance in crowded places, public transportation, and meeting rooms. The exposure is typically induced by a mobile phone, laptop or tablet. The exposure induced by nearby active devices can be viewed as a downlink exposure at the persons in the proximity (see 3rd term in the EI equation (1)), even if generated by an uplink transmission, since it would be treated as a far-field exposure. The contribution of radio-frequency radiation originating from other people's devices has been studied in [PLETS15]. This contribution has been compared to the total personal absorption in a train environment. They found that the absorption from nearby active mobile devices cannot always be neglected: in a GSM macrocell connection scenario, UL of 15 other users can cause up to 19% of total absorption for users having themselves a call and up to 100% for non-active persons. In an UMTS femtocell connection scenario, UL of 15 other users contributes to total absorption of a non-active person for no more than 1.5%. Hence, in exposure situations, where mobile devices are operated in close proximity of other persons or users, the 3rd term in the EI equation might be non-negligible.

3 EXPOSURE INDEX COMPUTATION: DATA SOURCES

The EI evaluation relies on the collection of a wide range of data, from simulation tools, literature, models and measurement equipment that have been demonstrated in the LEXNET technical work-packages. All the input data that were collected and were used in the framework of the project are detailed below.

3.1 Life segmentation data

Life segmentation data were extracted from up-to-date life segmentation surveys performed in the countries involved in LEXNET.

In order to evaluate the Exposure Index we needed data for each of the considered population categories: children (under 15 y.o), young people (15-29 y.o), adults (30-59 y.o) and seniors (60 y.o and over).

How young people, adults and seniors spend their time in Europe was extracted from the HETUS survey [HETUS], the French INSEE survey [INSEE] and the time use survey in Republic of Serbia [Survey-Serbia] (see Table 2).

	Adults	Young people	Seniors
Gainful work, study	5:00	4:40	0:05
Domestic work	3:00	1:15	4:00
Travel	1:30	1:20	00:50
Sleep	8:15	9:00	8:45
Meals, personal care	2:15	2:45	3:30
Free time indoor (TV, socializing, reading, internet surfing...)	3:00	4:00	4:30
Free time outdoor (sports, gardening, hiking...)	1:00	1:00	2:20
Total	24:00	24:00	24:00

Table 2 How young people, adults and seniors spend their time in Europe

How children spend their time in Europe was extracted from [HOFFERTH01] [LARSON01], [LARSON11] and [COOPER10] (see Table 3). Average daily time spent at school or day care, for domestic work, sleeping, eating and personal care were deduced from [HOFFERTH01] and [LARSON01]. Then it was difficult to extract the free time indoor and outdoor as categories in [HOFFERTH01] do not precise if activities such as “other passive leisure” are outdoor or indoor activities. From [LARSON11] we could extract that American children spend in average 2h per day doing outdoor activities. From [COOPER10] we could deduce that UK children spend in average 45 min per day outdoor between 3.30 and 8.30 PM.

	Children
School-Day care	3:45
Domestic work	0:45
Travel	0:30
Sleep	10:40
Meals, personal care	2 :30
Free time indoor (TV, playing, reading, internet surfing...)	4:35
Free time outdoor	1:30
Total	24:00

Table 3 How children spend their time in Europe

Extracted from Table 2 and Table 3, the data required in EI equation is reported in Table 4.

Population category	**Day (8 AM-6 PM)**			**Night (6 PM- 8AM)**		
	Indoor (office-school-home)	**Outdoor**	**Transportation (bus, car, subway etc...)**	**Indoor (home)**	**Outdoor**	**Transportation (bus, car, subway etc...)**
Adults	8h15 (82.5%)	1h10 (11.5%)	35 min (6%)	13h05 min (93.5%)	20 min (2.5%)	35 min (4%)
Young people/students	8h20 (83%)	1h10 (11.5%)	30 min (5.5%)	13h10 min (94%)	20 min (2.5%)	30 min (3.5%)
Children	8h15 (82.5%)	1h30 (15 %)	15 min (2.5%)	13h45 min (98.5%)	0 min (0 %)	15 min (1.5%)
Seniors	7h35 (75.8%)	2h10 (21.7%)	15 min (2.5%)	13h05 min (93.5%)	40 min (5%)	15 min (1.5%)

Table 4 Life segmentation inputs for evaluation of the Exposure Index

3.2 ICT usage data

3.2.1 When and where

Figure 5 and Figure 6 show that we are generally using different wireless devices at different time of the day and in different locations. Laptops are used in indoor locations, whether at the office or at home. Tablets are preferred at home at night whereas mobile phones are used throughout the day, with a high usage during commuting.

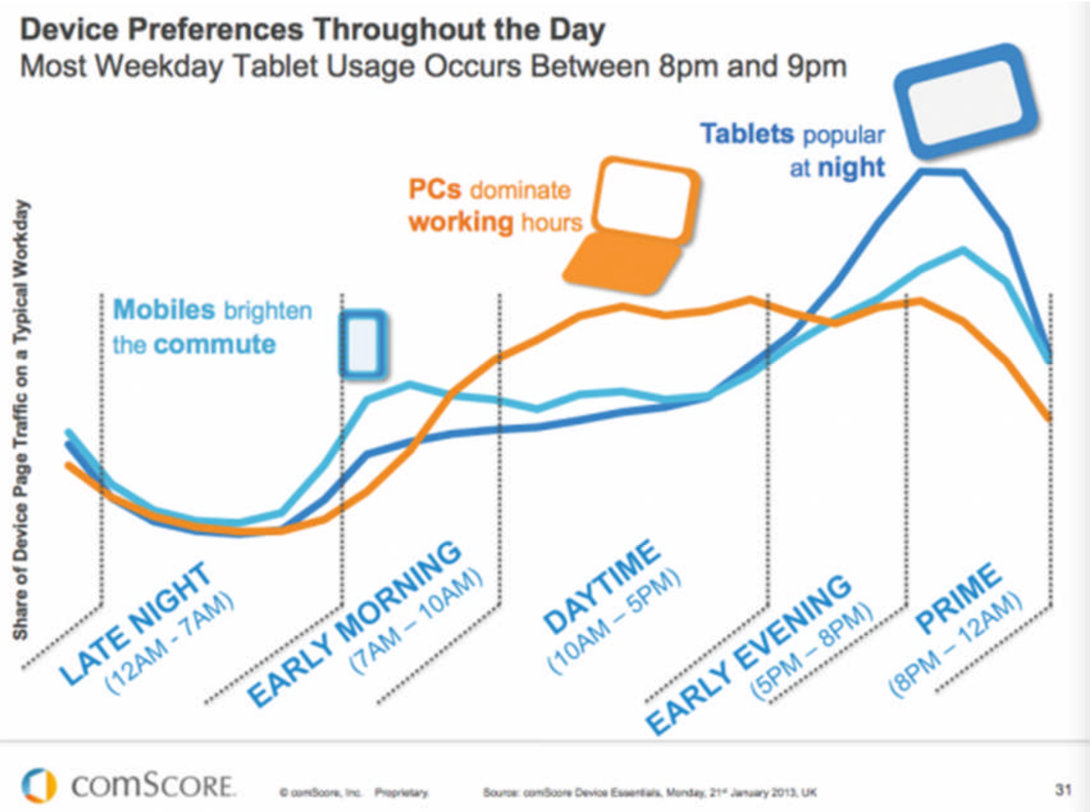


Figure 5: Devices preferences throughout the day (Source: comScore devices Essentials, January 2013)

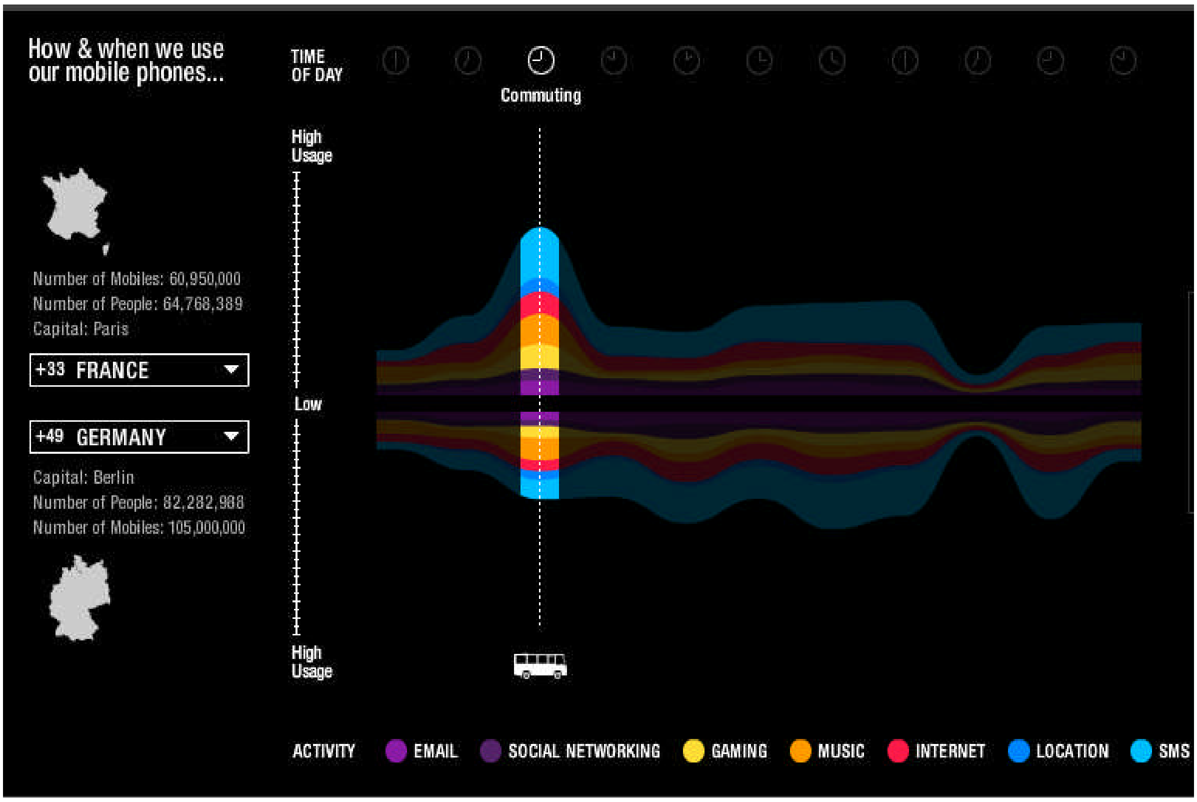


Figure 6: How and when we use our mobile phones (Source: TNS Mobile Life survey)

Crossing this kind of information extracted from survey and life segmentation data, we can assume that about 100 % of laptop or tablet usages happens indoors; 70 % of phone usages is indoors, 20 % when commuting and 10 % outdoors.

We also draw the conclusion that 50 % of laptop usage happens during the day (from 8 AM to 6 PM) and 50 % during the night (from 6 PM to 8 AM). For tablet usage we consider that 20 % of the usage happens during the day and 80 % during the night.

For WiFi usage, we make the hypothesis that 100 % of wireless device usages happen indoors.

3.2.2 Connections per RAT

As shown in Figure 7 (from [CISCO14]), it is forecasted that in 2016 the 4G connections will represent 8 % of the mobile connections whereas 2G and 3G will respectively represent 48 % and 44% of the connections.

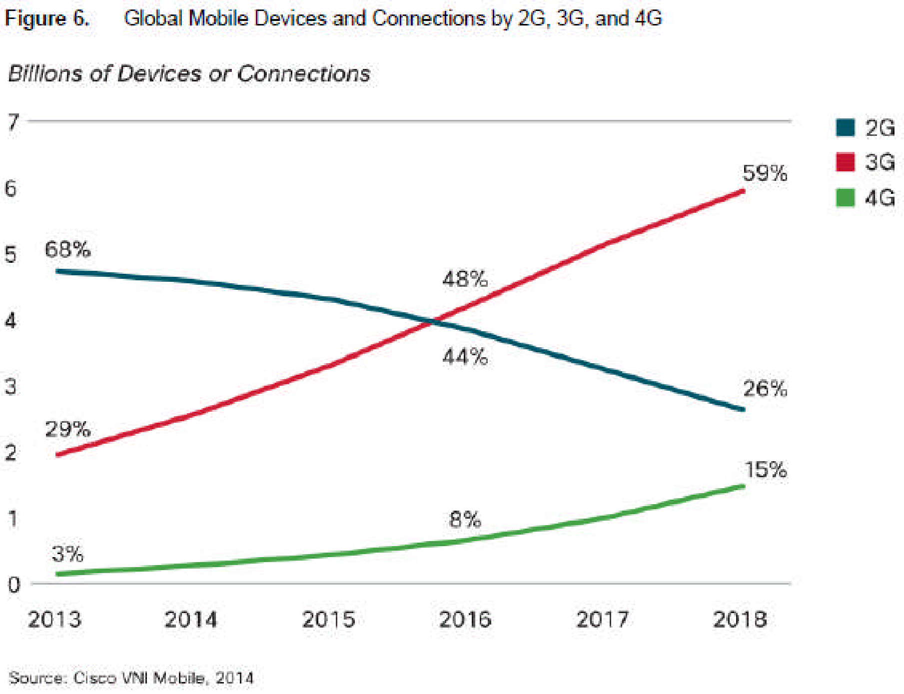
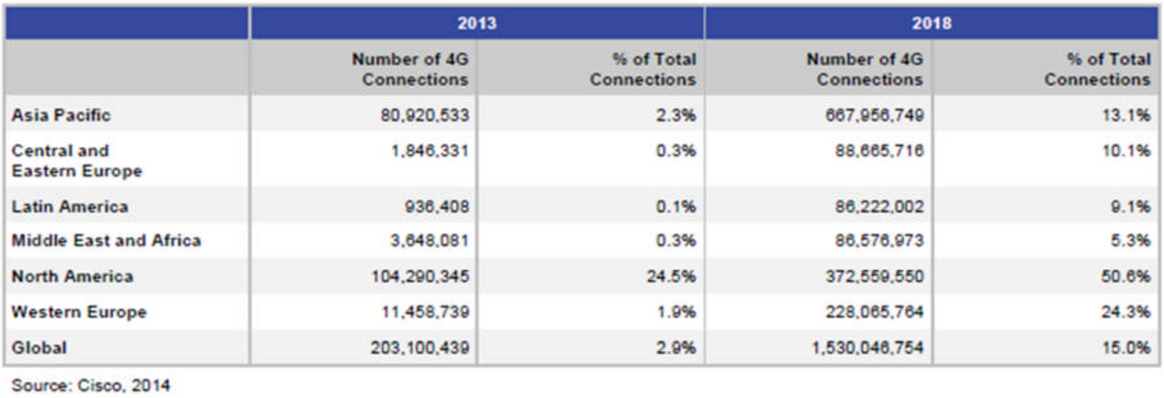


Figure 7: Connections by RAT forecast

Figures are a bit different, depending on regions. As shown on the table below, extracted from [CISCO14] the 4G connections are expected to represent 24 % of mobile connections in 2018 in Western Europe whereas they will represent only 10 % of the connections in Central and Eastern Europe.



	2013		2018	
	Number of 4G Connections	% of Total Connections	Number of 4G Connections	% of Total Connections
Asia Pacific	80,920,533	2.3%	667,956,749	13.1%
Central and Eastern Europe	1,846,331	0.3%	88,665,716	10.1%
Latin America	936,408	0.1%	86,222,002	9.1%
Middle East and Africa	3,648,081	0.3%	86,576,973	5.3%
North America	104,290,345	24.5%	372,559,550	50.6%
Western Europe	11,458,739	1.9%	228,065,764	24.3%
Global	203,100,439	2.9%	1,530,046,754	15.0%

Source: Cisco, 2014

Table 5 Life segmentation inputs for evaluation of the Exposure Index

This forecast is used as a baseline scenario in some of our studies. Then promoting changes in the RAT percentages can be envisaged as a way to reduce the EI.

3.2.3 Users/non-users per population category

Using 2013 data on the equipment rates of classical mobile phones and smartphones and proportions of the French population using a mobile phone for websurfing extracted from the 2013 CREDOC (Centre de Recherche pour l'Etude et l'Observation des Conditions de vie) report [CREDOC13] and data extracted from a March 2014 Ipsos survey entitled "Les nouveaux usages des moins de 20 ans", we evaluated the proportions of users and non-users of mobile phones for voice communications and data traffic per population category (see Table 6). For children under 8 years old we make the assumption that they are not wireless device users.

Mobile phone usage		Children (under 8 y.o)	Children (8-12 y.o)	Children (12-15 y.o)	Young people (15-29 y.o)	Adults (30-59 y.o)	Seniors (over 60 y.o)
Voice communication	Non-users	100 %	60 %	10%	4%	5%	30%
	Users	0 %	40 %	90%	96%	95%	70%
Data traffic	Non-users	100 %	90 %	45%	33%	59%	90%
	Users	0 %	10 %	55%	67%	41%	10%

Table 6 Proportions of users and non-users of mobile phones per population category

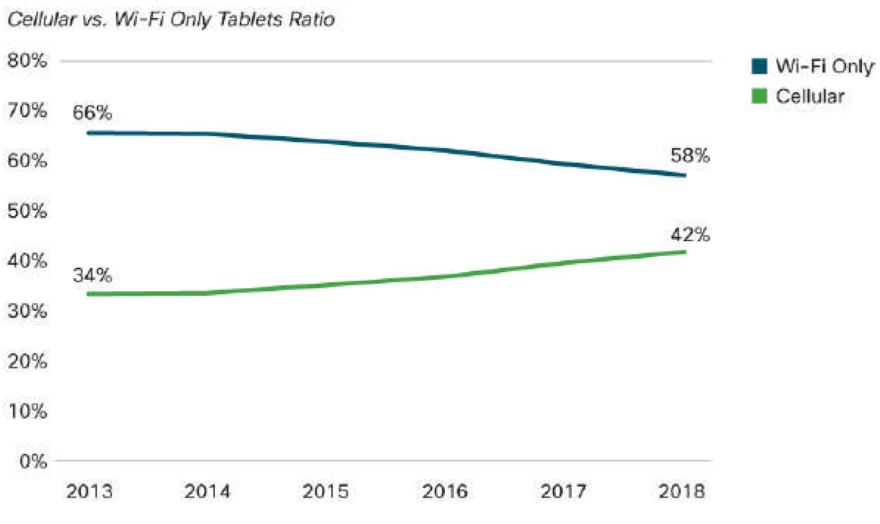
Using data on the equipment rates of tablets, 3G dongles and laptops from [CREDOC] and the March 2014 Ipsos survey we deduced the proportions of users and non-users of tablets, 3G dongles and laptops per population category (see Table 7).

		Children (under 8 y.o)	Children (8-12 y.o)	Children (12-15 y.o)	Young people (15-29 y.o)	Adults (30-59 y.o)	Seniors (over 60 y.o)
Tablets	Non-users	92 %	81 %	78%	77%	79%	94%
	Users	8 %	19 %	22%	23%	21%	6%
3G dongles	Non-users	100 %	100 %	92%	90%	90%	93%
	Users	0 %	0 %	8%	10%	10%	7%
Laptops	Non-users	100 %	100 %	21%	22%	34%	67%
	Users	0 %	0 %	79%	78%	66%	33%

Table 7 Proportions of users and non-users of tablets, 3G dongles and laptops per population category

3.2.4 Tablets and laptops usage data

From [CISCO14], in 2013, the average worldwide mobile data traffic per tablet (from 3G and 4G tablets) was 1.37 GB per month and 2.4 GB per month for a 4G tablet.
From subscribers billing data collected in January 2014 in Serbia we could derive an average monthly traffic per tablet of 0.83 GB.
Figure 8, extracted from [CISCO14], gives cellular vs. WiFi only tablets ratios.



Source: Cisco VNI Mobile, 2014

Figure 8: Cellular vs. WiFi tablets ratio

From [CISCO14], in 2013, the average mobile data traffic per laptop was 2.45 GB per month.
From subscribers billing data collected in January 2014 in Serbia we could derive an average monthly traffic per laptop of 3.4 GB in Serbia.

Finally we took the hypothesis that the UL traffic for tablets and laptops represents 15 % of the total mobile data traffic.

3.2.5 Mobile phone usage data

3.2.5.1 3G data from Orange

Mobile phone usage data were collected through an access network probe localized at the RNC (Radio Network Controller) level in the 3G Orange France network. Three areas have been monitored: one urban area in a district of Paris, one suburban area in the region of Clermont-Ferrand and one rural area in the region of Nancy.

Extracted data gives per-user and per-hour measurements during one week:

- total duration of voice calls
- number of voice calls
- total duration of UL data sessions
- number of UL data sessions
- total volume of UL data sessions
- total duration of DL data sessions
- number of DL data sessions
- total volume of DL data sessions

Averaged daily profiles have been extracted for voice and data services (Figure 9).

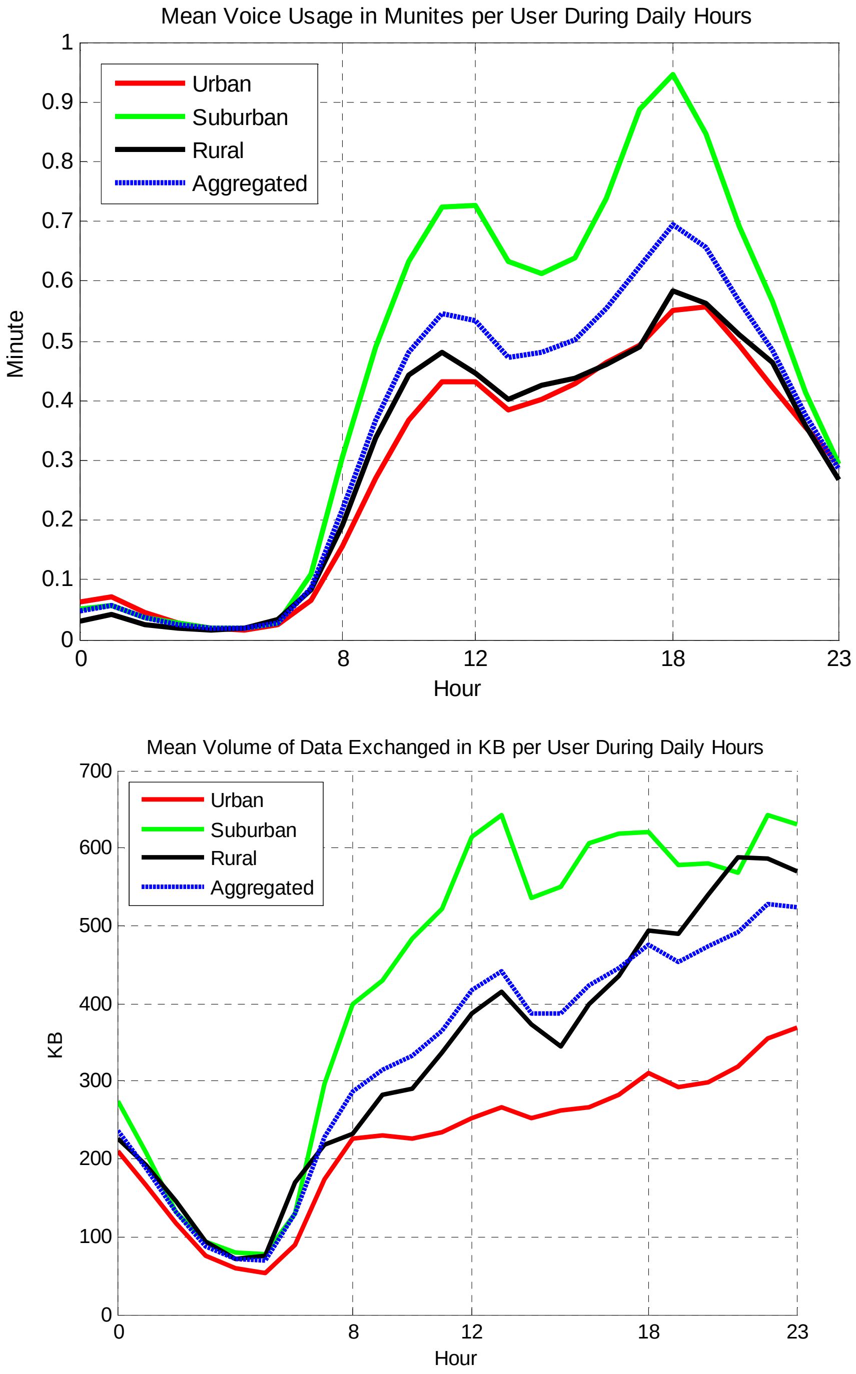
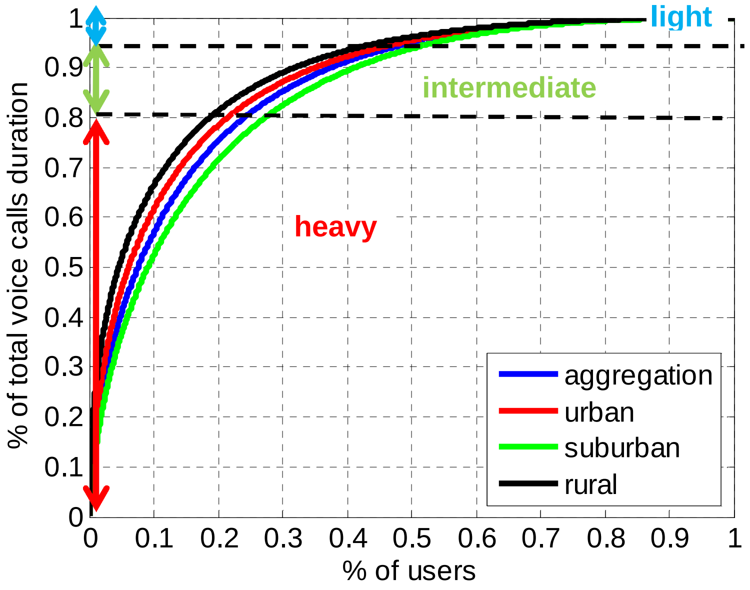


Figure 9 : Illustration on time variation of mean voice (top figure) and data (bottom figure) usage per user over a day. Data have been collected in urban, suburban and rural areas during a week in November 2013 on the 3G Orange France network.

The usage is also completely unbalanced among all the users. A small number of users are consuming a large part of traffic whatever the type of area as illustrated on Figure 10.



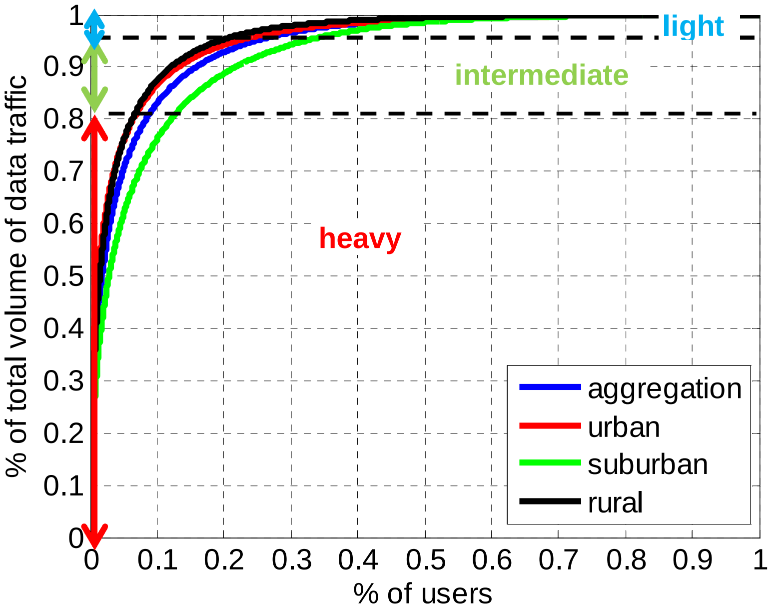


Figure 10 : Distribution of the voice (top figure) and data (bottom figure) traffic for urban (red line), suburban (green line), and rural (black line) areas and aggregated over the 3 types of areas (blue line)

Three types of profiles were defined for voice and data service:

- heavy users: top users consuming 80% of the total data
- moderate users: users consuming 15% of the total data
- light users: users consuming 5% of the total data.

Based on the data recorded in the network, the user profiles are defined in Table 8. As expected there are not so much differences quantitatively between rural, suburban and urban. All the data have been pooled to define the mean user profiles. Table 9, Table 10 and Table 11 detail for different geographical areas the average voice communication durations and data traffic volumes per user profile. Table 12 summarizes the repartition of user profiles for Orange 3G voice and data usages.

3G network								
	Rural		**Suburban**		**Urban**		**Global**	
	t_{com} [s]	vol_{data} [kB]	t_{com} [s]	vol_{data} [kB]	t_{com} [s]	vol_{data} [kB]	**t_{com} [s]**	**vol_{data} [kB]**
Heavy users	1972	103635	1899	70711	1610	67875	**1762**	**73065**
Moderate users	249	9210	361	7915	233	5242	**305**	**6940**
Light users	42	492	71	753	41	345	**53**	**504**

Table 8 User profiles defined in rural, suburban and urban areas

3G (Orange network)	Voice	Data (82 % DL 18% UL)	
Urban	**t_{com} (s)**	**vol_{ULdata}** [kB]	**vol_{DLdata}** [kB]
Heavy user			
Day	841	4948	25124
Night	689	5879	31922
Moderate user			
Day	147	464	2390
Night	86	387	2001
Light user			
Day	26	35	158
Night	16	28	124

Table 9 Average voice communication durations and data traffic volumes per user profile for a 3G Orange dense urban network

3G (Orange network)	Voice	Data (81 % DL, 19% UL)	
Suburban	**t_{com} (s)**	**vol_{ULdata}** [kB]	**vol_{DLdata}** [kB]
Heavy user			
Day	1081	5393	30199
Night	743	5175	29941
Moderate user			
Day	242	739	3930
Night	119	505	2740
Light user			
Day	49	90	382
Night	22	55	226

Table 10 Average voice communication durations and data traffic volumes per user profile for a 3G Orange suburban network

3G (Orange network)	Voice	Data (79 % DL, 21% UL)	
Rural	**t_{com} (s)**	**vol_{ULdata}** [kB]	**vol_{DLdata}** [kB]
Heavy user			
Day	928	7013	36925
Night	723	9379	50314
Moderate user			
Day	164	735	3716
Night	85	754	4005
Light user			
Day	28	54	208
Night	14	48	182

Table 11 Average voice communication durations and data traffic volumes per user profile for a 3G Orange rural network

	% Heavy users	% Moderate users	% Light users
Voice	20%	30%	50%
Data	10%	20%	70%

Table 12 Repartition of user profiles for Orange 3G voice and data usages

3.2.5.2 2G and 3G data from Telekom Srbja

Telekom Srbja combined data coming from different sources, mainly:

- Customer analytics system
- Network management system

On one hand, data that could be retrieved from the customer analytics system SAS contains personal information on subscriber as:

- age
- gender
- address
- account type (voice and/or data)
- device type (mobile, dongle, tablet)

Traffic statistics of these subscribers were also collected through the customer analytics system.

On the other hand, cell statistics were obtained from the network management system on an hourly basis as:

- number of voice calls
- duration in Erlang
- number of data sessions
- duration of all data sessions (min)
- volume of UL / DL data transfers (kB)

Analyzing data about customer personal information revealed that these data correspond mainly to those who pay the bills at the end. Employees and children have been usually hiding respectively behind companies and parents who pay the bills but do not use many of those subscriptions personally.

Data used for LEXNET were collected from the customer analytics system SAS and were based on users' billing data for the month of January 2014. A LEXNET test area consisted of a few representative cells of different types of environment: Urban, Suburban and Rural. Subscribers who were located in the test area and did generate at least voice or data traffic have been taken into account. Traffic data consisted of 2G and 3G networks usage all together.

Telekom Srbja LEXNET test area (2G and 3G)								
User profile	Geographical area							
	Rural		Suburban		Urban		**Global**	
	t_{com} (s)	vol_{data} (kB)	t_{com} (s)	vol_{data} (kB)	t_{com} (s)	vol_{data} (kB)	**t_{com} (s)**	**vol_{data} (kB)**
Heavy user	1176	40072	1230	46410	1372	47315	**1313**	**46777**
Moderate user	107	4929	120	11208	187	11367	**153**	**11214**
Light user	11	735	15	1186	28	1120	**21**	**1181**

Table 13 User profiles defined in rural, suburban and urban areas from TKS usage data

Specific 2G and 3G data were extrapolated considering, for voice communications, that 72 % of communications were made through the 2G network and 28 % through the 3G. For data traffic 91 % of the traffic was assigned to 3G and 9 % to 2G. UL and DL data traffic proportions were respectively assumed to be 17 % and 83 %. Those ratios were calculated based on cell statistics that were obtained from the network management system on an hourly basis for same period of time. Cells were same as those used for identifying subscribers. Finally, three types of user profiles were defined for voice and data service (see Figure 11 and Figure 12):

- heavy users: top users consuming 80% of the total data
- moderate users: users consuming 15% of the total data
- light users: users consuming 5% of the total data.

Table 13 details for different geographical areas the average voice communication durations and data traffic volumes per user profile.

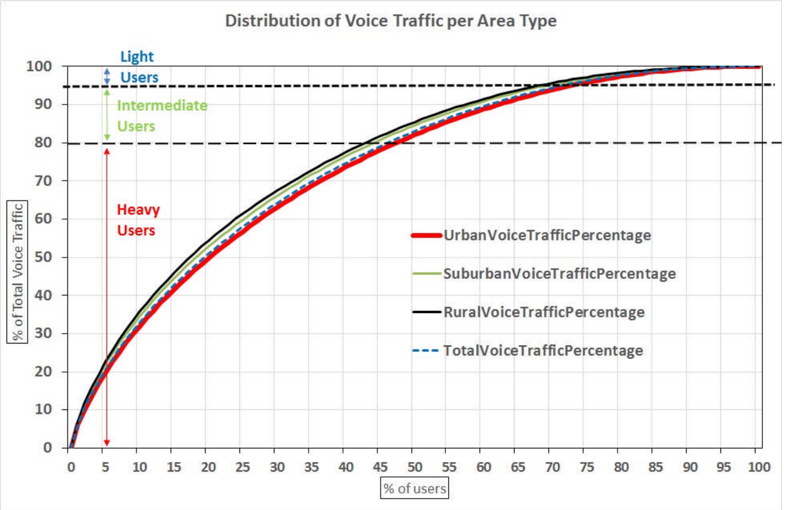


Figure 11: Distribution of the voice traffic for urban (red line), suburban (green line), and rural (black line) areas and aggregated over the 3 types of areas (blue line)

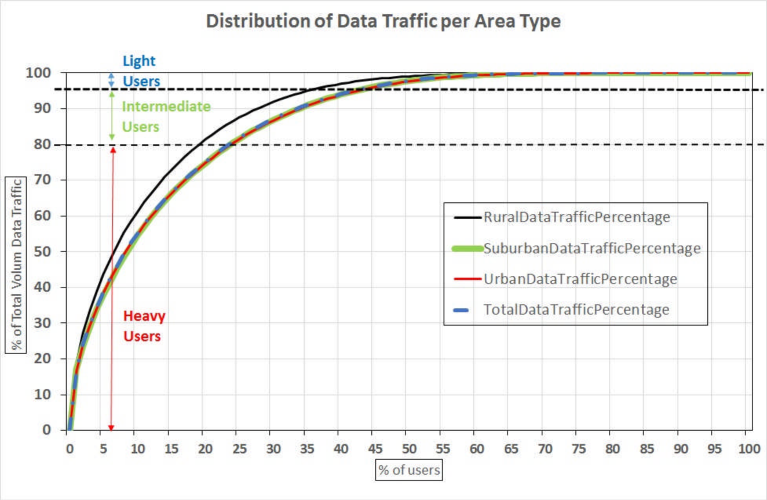


Figure 12 Distribution of the data traffic for urban (red line), suburban (green line), and rural (black line) areas and aggregated over the 3 types of areas (blue line)

The repartition of voice communications and data traffic over the two periods, day and night, was extracted from the type of call statistics, over 24h (see Figure 13 and Figure 14).

The voice hourly extrapolation was based on outgoing calls; and data extrapolation was based on prepaid traffic, due to limitations on the customer analytics system.

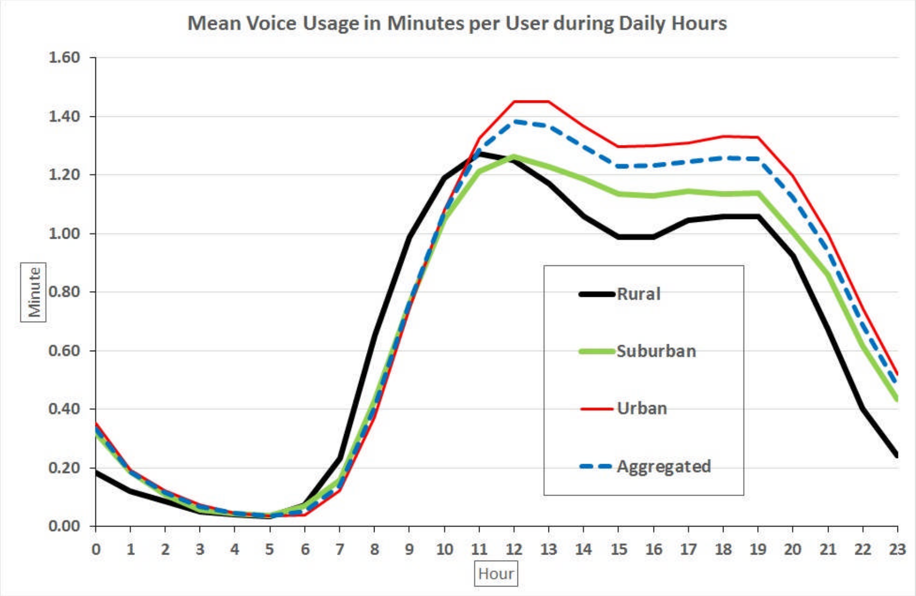


Figure 13 : Mobile phone voice communications hourly distribution over 24h

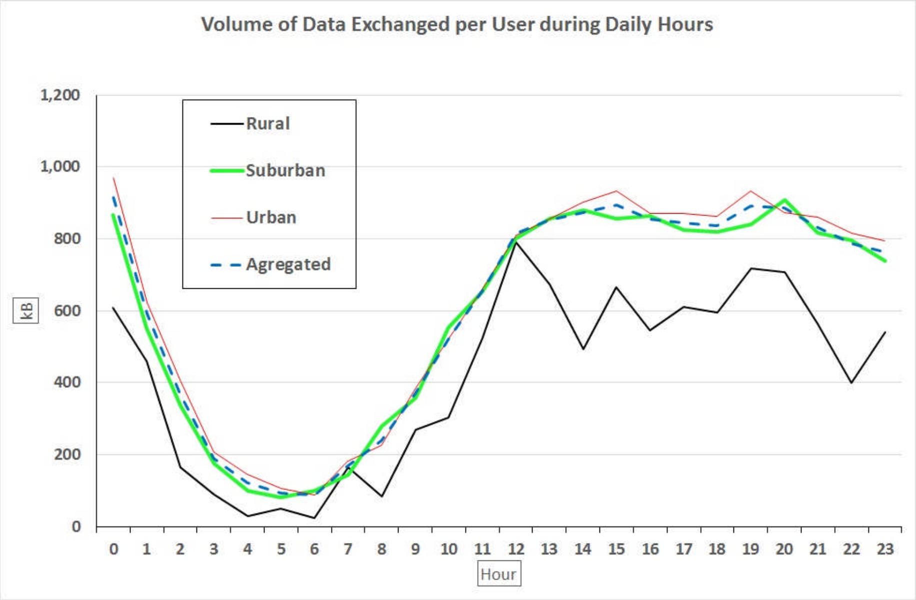


Figure 14: Mobile phone data traffic hourly distribution over 24h

63 % of mobile phone voice and 48 % data traffic were made during the day period (8 AM – 6 PM) and 37 % and 52 % respectively during the night period (6 PM – 8 AM).

Finally, we could extract the average communication times and data traffic volumes per user profile for different geographical areas for 2G and 3G Telekom Srbja networks (see tables from 13 to 18).

2G (Telekom Srbja)	Voice	Data (83 % DL, 17% UL)	
Urban	**t_{com} (s)**	**vol_{ULdata}** [kB]	**vol_{DLdata}** [kB]
Heavy user			
Day	619	342	1660
Night	368	373	1807
Moderate user			
Day	84	82	399
Night	50	90	434
Light user			
Day	12	9	43
Night	7	10	47

Table 14 Average voice communication durations and data traffic volumes per user profile for a 2G Telekom Srbja dense urban network

2G (Telekom Srbja)	Voice	Data (83 % DL, 17% UL)	
Suburban	**t_{com} (s)**	**vol_{ULdata}** [kB]	**vol_{DLdata}** [kB]
Heavy user			
Day	554	336	1828
Night	330	365	1773
Moderate user			
Day	54	81	393
Night	32	88	428
Light user			
Day	7	9	42
Night	4	9	45

Table 15 Average voice communication durations and data traffic volumes per user profile for a 2G Telekom Srbja suburban network

2G (Telekom Srbja)	Voice	Data (83 % DL, 17% UL)	
Rural	**t_{com} (s)**	**vol_{ULdata}** [kB]	**vol_{DLdata}** [kB]
Heavy user			
Day	530	290	1406
Night	316	316	1531
Moderate user			
Day	48	36	173
Night	29	39	188
Light user			
Day	5	5	26
Night	3	6	28

Table 16 Average voice communication durations and data traffic volumes per user profile for a 2G Telekom Srbja rural network

3G (Telekom Srbja)	Voice	Data (83 % DL, 17% UL)	
Urban	**t_{com} (s)**	**vol_{ULdata}** [kB]	**vol_{DLdata}** [kB]
Heavy user			
Day	242	3529	17119
Night	144	3843	18642
Moderate user			
Day	33	848	4113
Night	20	923	4479
Light user			
Day	5	91	441
Night	3	99	481

Table 17 Average voice communication durations and data traffic volumes per user profile for a 3G Telekom Srbja dense urban network

3G (Telekom Srbja)	Voice	Data (83 % DL, 17% UL)	
Suburban	**t_{com} (s)**	**vol_{ULdata}** [kB]	**vol_{DLdata}** [kB]
Heavy user			
Day	216	3461	16791
Night	129	3769	18286
Moderate user			
Day	21	836	4055
Night	13	910	4416
Light user			
Day	3	88	429
Night	2	96	467

Table 18 Average voice communication durations and data traffic volumes per user profile for a 3G Telekom Srbja suburban network

3G (Telekom Srbja)	Voice	Data (83 % DL, 17% UL)	
Rural	**t_{com} (s)**	**vol_{ULdata}** [kB]	**vol_{DLdata}** [kB]
Heavy user			
Day	207	2989	14498
Night	123	3255	15789
Moderate user			
Day	19	368	1783
Night	11	400	1942
Light user			
Day	2	55	266
Night	1	60	290

Table 19 Average voice communication durations and data traffic volumes per user profile for a 3G Telekom Srbja rural network

	% Heavy users	% Moderate users	% Light users
Voice	47%	25%	28%
Data	24%	18%	58%

Table 20 Repartition of user profiles for Telekom Serbia 2G and 3G voice and data usages

We can see that majority of voice communications at the test area in Serbia is done over 2G, contrary to what has been observed in Orange network. Due to that reason voice communication is significantly lower on 3G than in the test area in France. Average data traffic volumes per user in France are a bit different than average data traffic volumes at the test area in Serbia, depending on the considered geographical area. The repartitions of user profiles are also very different for voice usages between Orange data and Telekom Serbia data. A larger percentage of users are heavy users at Telekom Srbja while at Orange France there are more light users in the test areas.

3.2.5.3 Extrapolation of 3G data to LTE

LTE data were collected from Orange network probes installed in Orange LTE network. For different geographical areas (urban, suburban and rural) in the North of France, we could collect, for some time periods during June 2014, the number of LTE users and the total volumes of DL and UL data traffic. Proceeding like we did for 3G data, we extracted average user profiles (see Figure 15).

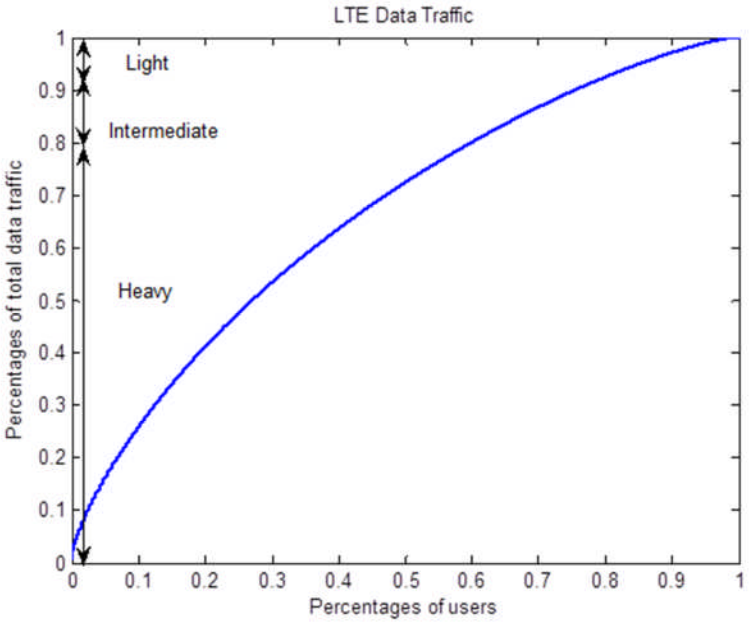


Figure 15: Distribution of data traffic aggregated over the 3 types of geographical areas for LTE network

Then we evaluated the average volumes of LTE data traffic per day and per user profile (see Table 21).

LTE network	vol_{data} [KB]
Heavy users	160639
Moderate users	60396
Light users	31003

Table 21 Average volumes of LTE data traffic per day per user profile

Comparing these data with data in Table 8 in the Global column, we extract the following 3G to LTE extrapolation ratios:

- Heavy user: 2.2
- Moderate user: 8.7
- Light user: 61.5

The repartition of user profiles for Orange LTE data usages, based on Figure 15, is summarized in Table 22.

% Heavy users	% Moderate users	% Light users
60 %	15 %	25 %

Table 22 Repartition of user profiles for Orange LTE data usages

This repartition is completely different compared to the repartition of user profiles for Orange 3G data usages. The ratio between heavy usage and moderate usage is only 2.5 for LTE while it is a factor 10 for 3G.

3.2.6 IP traffic through WiFi

From [CISCO14], in 2014, 9739 PB per month of IP traffic were generated by Western Europeans and 4416 PB per month by Central and Eastern Europeans.
2.2 % of the IP traffic was generated by tablets, 3.5 % by smartphones and 67.2 % by PCs. And about 41 % of the total IP traffic was transmitted from Fixed/WiFi access.

Considering that in Western Europe tablets were accounting for 6 % (56.6 M) of all networked devices, smartphones for 14 % (223.9 M) and PCs for 17 % (271.8 M), we can evaluate the average IP traffic through WiFi per user per month for Western Europe. The same calculation was performed for Central and Eastern Europe (Table 23).

Device	Western Europe	Central and Eastern Europe
smartphone	623 MB	410 MB
tablet	1.55 GB	2.2 GB
PC	9.9 GB	9.6 GB

Table 23 Average IP traffic volumes through WiFi per device per user per month for Western Europe and Central and Eastern Europe

We took the hypothesis that the UL traffic for WiFi represents 17 % of the total data traffic.

3.2.7 Usage differences between the population categories

ICT usages are different, depending on the age category of people. The numbers in the previous sections were extracted without distinction of the age category of users.
We are able nevertheless to play with the user profiles repartition. For example, considering a high school survey performed in Portugal between 2010 and 2014 [SBOC12] teenagers were reported to use their mobile phone for voice communication an average of 30 minutes per day, which corresponds to a heavy user profile (see Figure 16). We could then consider a higher heavy user profile percentage among young people.
In [BYUN13] they assessed mobile phone usages in terms of number of calls per day and average duration per call amongst Korean children and teenagers. They have shown that Korean children are on average using less than 5 minutes per day their mobile phones for calling, which would correspond to the usage, for voice calls, of a moderate user.
Besides, in absence of any known study on the topic, we are making the hypothesis that a large percentage of seniors are light users.

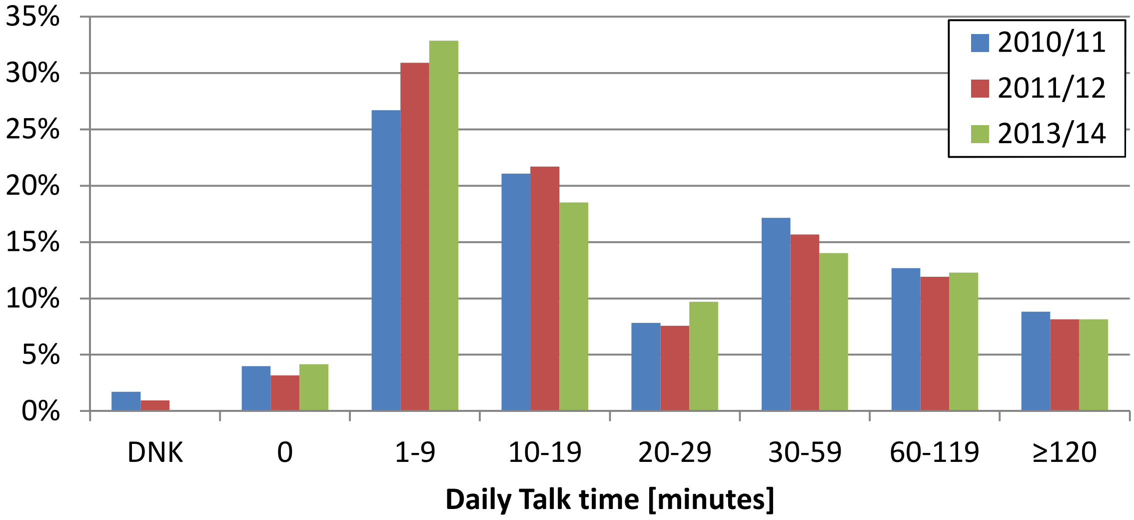


Figure 16 : Distribution of Daily talk time by teenagers in Portugal (2378, 3320, and 597 answers, in 2010/11, 2011/12, and 2013/14, respectively).

We were obliged in the LEXNET project to fix precise numbers in order that to build a reference scenario for EI assessment technical workpackages. As explained above, some result from statistical studies, some others have been defined from basic assumptions:

2G/3G Telekom Srbja		% Heavy users	% Moderate users	% Light users
Children	Voice	25 %	50 %	25 %
	Data	60 %	20 %	20 %
Young people	Voice	47 %	25 %	28 %
	Data	60 %	20 %	20 %
Adults	Voice	47 %	25 %	28 %
	Data	24 %	18 %	58 %
Seniors	Voice	47 %	25 %	28 %
	Data	5 %	25 %	70 %

Table 24 Repartition of user profiles for Telekom Serbia 2G and 3G usages for each population category

3G Orange		% Heavy users	% Moderate users	% Light users
Children	Voice	20%	30%	50%
	Data	50%	40%	10%
Young people	Voice	50%	30%	20%
	Data	50%	40%	10%
Adults	Voice	20%	30%	50%
	Data	10%	20%	70%
Seniors	Voice	20%	30%	50%
	Data	5%	25%	70%

Table 25 Repartition of user profiles for Orange 3G usages for each population category

LTE Orange	% Heavy users	% Moderate users	% Light users
Children	30 %	40 %	30 %
Young people	80 %	10 %	10 %
Adults	60%	15%	25%
Seniors	10 %	40 %	50 %

Table 26 Repartition of user profiles for Orange LTE usages for each population category

3.3 SAR data

Reference SAR data were computed using 3D electromagnetic simulation platforms based on the Finite Difference Time Domain (FDTD) [TAFLOVE00] and Finite Integration Technique (FIT) [WEIL77] methods. SAR values were calculated for far-field and near-field exposure for two anatomical human body models of the Virtual Family [CHRIST10], Duke, a 34-year-old male and Eartha, an 8-year-old girl. Two postures (standing and sitting) and three usages (mobile phone close to the head, mobile phone or tablet for data and laptop usage) were selected. More details on numerical simulations can be found in [LEXNET IR2.1 2013].

Table 27 shows reference Whole-body SAR (WBSAR) values calculated for far-field and near-field exposure of the adult and the child models at four different frequency bands (see deliverable D2.6 Appendix 1 for specifications of frequency bands). Table 28 shows reference WBSAR values calculated for exposure of the adult and the child models at 2100 MHz, relevant for a human model standing or sitting close to the access point (this access point can be a femtocell or a WLAN access point).

WBSAR		Frequency band			
		400 MHz	900 MHz	1940 MHz	2600 MHz
Child - voice sitting	DOWN	0.0088	0.0082	0.0071	0.0066
	UP	X	0.029	0.011	0.014
Adult - voice sitting	DOWN	0.0050	0.0056	0.0043	0.0039
	UP	X	0.012	0.0052	0.0047
Child - voice standing	DOWN	0.0082	0.0084	0.0077	0.0071
	UP	X	0.029	0.01	0.015
Adult - voice standing	DOWN	0.0064	0.0052	0.0046	0.0042
	UP	X	0.012	0.0052	0.0053
Child - data sitting	DOWN	0.0090	0.0088	0.0071	0.0065
	UP	0.011	0.011	0.0135	0.0094
Adult - data sitting	DOWN	0.0054	0.0046	0.0043	0.0038
	UP	0.0078	0.0056	0.0081	0.0037
Child - data standing	DOWN	0.0088	0.0090	0.0077	0.0072
	UP	0.013	0.01	0.0109	0.0083
Adult - data standing	DOWN	0.006	0.0052	0.0047	0.0042
	UP	0.0064	0.0049	0.0039	0.0029
Child – laptop on the lap	DOWN	X	X	0.0069	0.0066
	UP	X	X	0.0035	0.0038
Adult – laptop	DOWN	X	X	0.0053	0.0049

on the lap	UP	X	X	0.0027	0.003
Child – laptop on a desk	DOWN	X	X	0.0069	0.0066
	UP	X	X	0.0025	0.0031
Adult – laptop on a desk	DOWN	X	X	0.0053	0.0049
	UP	X	X	0.0035	0.0027

Table 27 Whole-body SAR data in W/kg for child and adult models for different devices, in different postures at different frequencies

WBSAR	Femtocell (2100 MHz)
Child – voice sitting	0.000190
Adult – voice sitting	0.00014
Child – voice standing	0.00023
Adult – voice standing	0.00013

Table 28 Whole-body SAR data in W/kg for child and adult models for a femtocell, for different postures (reference transmitted power of 1 W)

UP stands for Uplink exposure to device). Values are normalized to a reference transmitted power of 1 W.
DOWN stands for Downlink exposure to base-stations. Values are normalized to a reference received power density of 1 W.m^{-2}

For the future we could imagine performing new SAR simulations for new new types of wireless device. For instance, Appendix 1 presents the results of dosimetric simulations performed with Google glasses [GLAS15].

4 EI INTEGRATION METHODOLOGY ON A MACRO 3G DENSE URBAN SCENARIO

4.1 Scenario

We are showing in this section the EI integration methodology over 24 hours for a macro urban Orange 3G scenario.

Time	Population	Environment	RAT	Cell Type	User Profile	Posture	Usage
Day	Children	Indoor	3G	Macro	Heavy	Standing	Data, mobile
Night	Young people	Outdoor			Moderate	Sitting	Voice, mobile
	Adults				Light		Data, tablet
	Seniors				Non user		Data, laptop

Table 29 Input parameters for the macro urban Orange 3G scenario

The considered urban area is located into a typical European urban area in the centre of Lyon (3rd largest city in France) (see Figure 17).

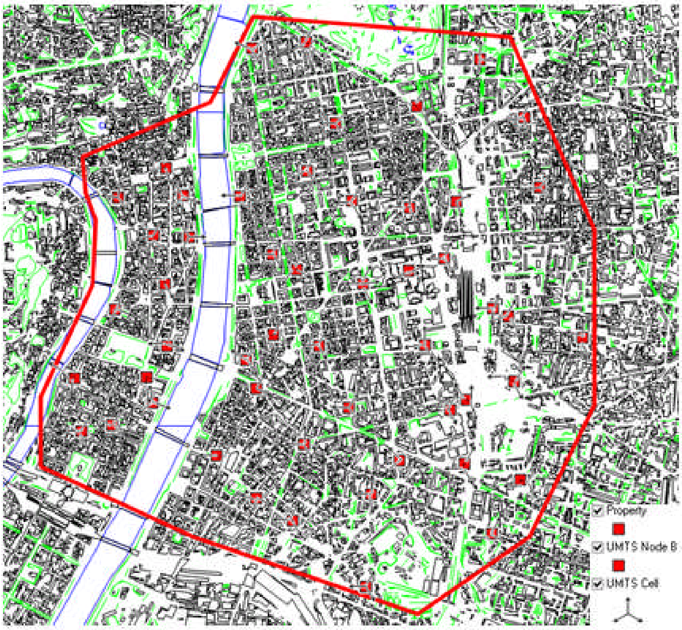


Figure 17 Urban area in Lyon

4.2 Input data

- Time period N_T

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

- Population categories N_P

4 population categories are considered: Children (below 15 years), young people (between 15 and 29 years), adults (between 30 and 59 years) and seniors (over 60 years).

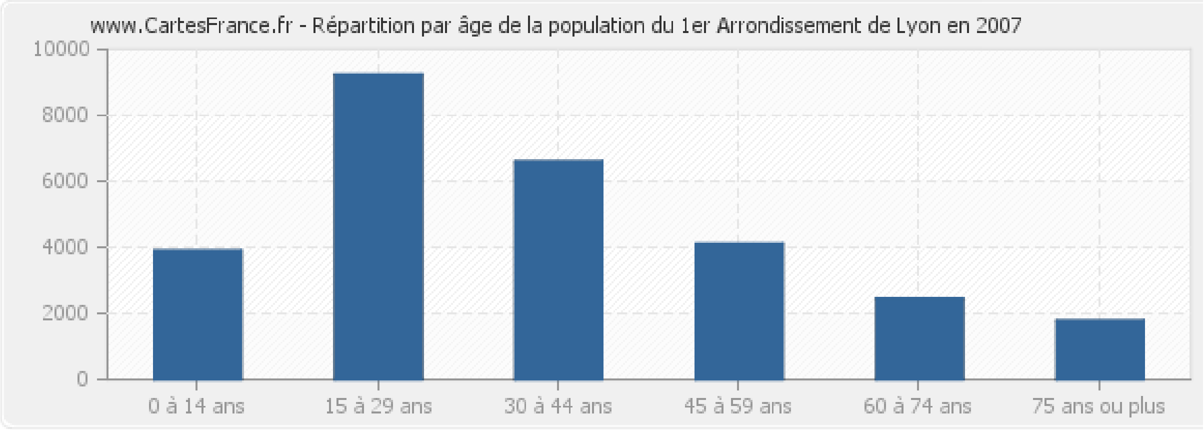


Figure 18 Repartition by age of the population in the first district of Lyon in 2007 (from http:// http://www.cartesfrance.fr)

From Figure 18 we extracted the repartition of the four population categories in the first district of Lyon:

Population category	**Percentage**
Children	13.9 %
Young people	32.8 %
Adults	38.2 %
Seniors	15.1 %

Table 30 Repartition of the population in the centre of Lyon

- Environment N_E

Two environments are considered, indoor and outdoor environments. Table 31 is derived from Table 4 considering that the time spent commuting is spent outdoor in our scenario.

	Day (from 8am to 6pm)		**Night (from 6pm to 8am)**	
	Indoor	**Outdoor**	**Indoor**	**Outdoor**
Children	8h15 (82.5%)	1h45 (17.5%)	13h45 (98.2%)	15 min (1.8%)
Young people	8h20 (83%)	1h40 (17%)	13h10 (94%)	50 min (6%)
Adults	8h15 (82.5%)	1h45 (17.5%)	13h05 (93.5%)	55 min (6.5%)
Seniors	7h35 (70%)	2h25(30%)	13h05 (93.5%)	55 min (6.5%)

Table 31 Repartition of each category of population by environment and time period

Consequently we are considering that 70 % of mobile phone usages happen indoors and 30 % outdoors. 100 % of tablet and laptop usages are indoor usages.

- Macro 3G network N_R N_C

- User Profiles N_L

Three user profiles (heavy, moderate and light profiles) are used for mobile phone users and one moderate user profile for tablet and laptop users.

- Posture N_{pos} and Usage N_U

Two network usages for the mobile phone are considered: voice and data traffic usage. If the mobile phone is used in indoor environment, we consider that the user is in a sitting posture. And if the mobile phone is used in outdoor environment, we consider that the user is in a standing posture. For each population category, we derived from Table 6 and Table 7 the proportions of users and non-users of mobile phones, 3G tablets and 3G dongles (Table 32). Table 33 and Table 34 give respectively average voice communication durations and data traffic volumes per mobile phone user profile and the repartition of user profiles per population category.

		Children (under 15 y.o)	Young people (15-29 y.o)	Adults (30-59 y.o)	Seniors (over 60 y.o)
Mobile phone usage Voice communication	Non-users	68%	4%	5%	30%
	Users	32%	96%	95%	70%
Mobile phone usage Data traffic	Non-users	84%	33%	59%	90%
	Users	16%	67%	41%	10%
3G Tablet usage	Non-users	95%	92%	93%	98%
	Users	5%	8%	7%	2%
3G dongle usage	Non-users	98%	90%	90%	93%
	Users	2%	10%	10%	7%

Table 32 Proportions of users and non-users of mobile phones, 3G tablets and 3G dongles per population category

3G	Voice	Data (82 % DL, 18% UL)	
Urban	**t_{com} (s)**	**vol_{ULdata}** [kB]	**vol_{DLdata}** [kB]
Heavy user			
Day	841	4948	25124
Night	689	5879	31922
Medium user			
Day	147	464	2390
Night	86	387	2001
Light user			
Day	26	35	158
Night	16	28	124

Table 33 Average voice communication durations and data traffic volumes per mobile phone user profile

3G Orange		% Heavy users	% Moderate users	% Light users
Children	Voice	20%	30%	50%
	Data	50%	40%	10%
Young people	Voice	50%	30%	20%
	Data	50%	40%	10%
Adults	Voice	20%	30%	50%
	Data	10%	20%	70%
Seniors	Voice	20%	30%	50%
	Data	5%	25%	70%

Table 34 Repartition of mobile phone user profiles for Orange 3G usages for each population category

For 3G tablet usage we consider an average data traffic volume of 45.7 MB per day per user, whatever the population category, 20 % (9.1 MB) during day time and 80 % (36.6 MB) during night time. We are making the assumption that 15 % of this traffic is on UL.

For 3G dongle usage we consider an average data traffic volume of 81.6 MB per day per user, whatever the population category, 50 % (40.8 MB) during day time and 50 % during night time. As for the tablet we are making the assumption that 15 % of this traffic is on UL.

- Reference SAR values

SAR values are those extracted from Table 27 for the 1940 MHz frequency band. We use adult values for young people, adult and senior population categories and child values for child category.

- Received $\bar{S}_{RX}$,transmitted $\bar{P}_{TX}$ powers and UL data throughputs

Received $\bar{S}_{RX}$ transmitted $\bar{P}_{TX}$ powers and UL data throughputs can be derived from network simulation or from drive-test measurements in Lyon, e.g. dosimeter measurements for the DL power and TRACE mobile measurements for the UL power.
Mean values indoor, outdoor, during the day and during the night are needed.

4.3 EI integration

Considering Figure 7 we made the hypothesis that, in 2016, 48 % of the population of the 1st district of Lyon is using a 3G network. And considering the existence of four telecom operators in France we assumed that only 25 % of these 48 % 3G users are subscribers of the Orange 3G network.

$$EI_{global} = 0.139 * EI_{children} + 0.328 * EI_{youngpeople} + 0.382 * EI_{adults} + 0.151 * EI_{seniors} \quad (4)$$

We propose to detail the calculation for one population category, i.e. the adult one. Table 35 details the different macro urban 3G input parameters.

Variable	Abbreviation	value
Time spent indoor during the day	$t_{dayindoor}$	29700 s
Time spent outdoor during the day	$t_{dayoutdoor}$	6300 s
Time spent indoor during the night	$t_{nightindoor}$	47100 s
Time spent outdoor during the night	$t_{nightoutdoor}$	3300 s
Mobile phone usage		
Percentage of 3G connections	$percentage_{3G_{connections}}$	0.48
Percentage of mobile phone users for voice calls	$percentage_{uservoice}$	0.95
Percentage of mobile phone users for data traffic	$percentage_{userdata}$	0.41
Average duration of mobile phone use indoor for voice calls during the day	$t_{dayindoorvoice}$	157.71 s
Average duration of mobile phone use outdoor for voice calls during the day	$t_{dayoutdoorvoice}$	67.59 s
Average duration of mobile phone use indoor for voice calls during the night	$t_{nightindoorvoice}$	120.12 s
Average duration of mobile phone use outdoor for voice calls during the night	$t_{nightoutdoorvoice}$	51.48 s
Average UL volume of mobile phone data traffic indoor during the day	$vol_{datadayindoor}$	428.47 kB
Average UL volume of mobile phone data traffic during the day	$vol_{datadayoutdoor}$	183.63 kB
Average UL volume of mobile phone data traffic indoor during the night	$vol_{datanightindoor}$	479.43 kB
Average UL volume of mobile phone data traffic during the night	$vol_{datanightoutdoor}$	205.47 kB
3G Tablet usage		
Percentage of 3G tablet users	$percentage_{user3Gtablet}$	0.07
Average UL volume of tablet data traffic during the day	$vol_{tabletday}$	1365 kB
Average UL volume of tablet data traffic during the night	$vol_{tabletnight}$	5490 kB
3G dongle usage		
Percentage of 3G dongle users	$percentage_{user3Gdongle}$	0.10
Average UL volume of laptop data traffic during the day	$vol_{laptopday}$	6120 kB
Average UL volume of laptop data traffic during the night	$vol_{laptopnight}$	6120 kB
Reference SAR values		
UL WBSAR for a phone call in voice mode indoor	$WBSAR_{ULvoicein}$	0.0052 W/kg
UL WBSAR for a phone call in voice mode outdoor	$WBSAR_{ULvoiceout}$	0.0052 W/kg
UL WBSAR for a phone call in data mode	$WBSAR_{ULdatain}$	0.0081 W/kg

indoor		
UL WBSAR for a phone call in data mode outdoor	$WBSAR_{ULdataout}$	0.0039 W/kg
UL WBSAR for a laptop usage	$WBSAR_{ULlaptop}$	0.0035 W/kg
DL WBSAR indoor	$WBSAR_{DLin}$	0.0043 W/kg
DL WBSAR outdoor	$WBSAR_{DLout}$	0.0047 W/kg

Table 35 Macro urban 3G scenario input data

$$EI_{adults} = EI_{in_{day}} + EI_{out_{day}} + EI_{in_{night}} + EI_{out_{night}} \tag{5}$$

$$EI_{adults} = k_1 * \bar{P}_{TXindoordayvoice} + k_2 * \bar{P}_{TXoutdoordayvoice} + k_3 * \bar{P}_{TXindoornightvoice} + k_4 * \bar{P}_{TXoutdoornightvoice} + k_5 * \frac{\bar{P}_{TXindoordaydata}}{Th_{indoordaydata}} + k_6 * \frac{\bar{P}_{TXoutdoordaydata}}{Th_{outdoordaydata}} + k_7 * \frac{\bar{P}_{TXindoornightdata}}{Th_{indoornightdata}} + k_8 * \frac{\bar{P}_{TXoutdoornightdata}}{Th_{outdoornightdata}} + k_9 * \bar{S}_{\mathrm{RXindoorday}} + k_{10} * \bar{S}_{\mathrm{RXoutdoorday}} + k_{11} * \bar{S}_{\mathrm{RXindoornight}} + k_{12} * \bar{S}_{\mathrm{RXoutdoornight}} \tag{6}$$

Where
$\bar{P}_{TX}$, $\bar{S}_{\mathrm{RX}}$, and Th represent respectively mean transmitted power values, mean received power density values and average UL throughputs.

k_1 to k_4 are constant coefficients characterizing UL exposure for voice call usage:

$$k_1 = \frac{0.25 * percentage_{3G_{connections}}}{24 * 3600} * [t_{dayindoorvoice} * WBSAR_{ULvoicein} * percentage_{uservoice}]$$

$$k_2 = \frac{0.25 * percentage_{3G_{connections}}}{24 * 3600} * [t_{dayoutdoorvoice} * WBSAR_{ULvoiceout} * percentage_{uservoice}]$$

$$k_3 = \frac{0.25 * percentage_{3G_{connections}}}{24 * 3600} * [t_{nightindoorvoice} * WBSAR_{ULvoicein} * percentage_{uservoice}]$$

$$k_1 = \frac{0.25 * percentage_{3G_{connections}}}{24 * 3600} * [t_{nightoutdoorvoice} * WBSAR_{ULvoiceout} * percentage_{uservoice}]$$

k_5 to k_8 are constant coefficients characterizing UL exposure for data usage:

$$k_5 = \frac{0.25}{24 * 3600} * \left[\left(percentage_{3G_{connections}} * percentage_{userdata} * vol_{datadayindoor} + percentage_{user3Gtablet} * vol_{tabletday}\right) * WBSAR_{ULdatain} + percentage_{user3Gdongle} * vol_{laptopday} * WB_{ULlaptop}\right]$$

$$k_6 = \frac{0.25 * percentage_{3G_{connections}}}{24 * 3600} * percentage_{userdata} * vol_{datadayoutdoor} * WBSAR_{ULdataout}$$

$$k_7 = \frac{0.25}{24 * 3600} * \left[\left(percentage_{3G_{connections}} * percentage_{userdata} * vol_{datanightindoor} + percentage_{user3Gtablet} * vol_{tabletnight}\right) * WBSAR_{ULdatain} + percentage_{user3Gdongle} * vol_{laptopnight} * WB_{ULlaptop}\right]$$

$$k_8 = \frac{0.25 * percentage_{3G_{connections}}}{24 * 3600 * WBSAR_{ULdataout}} * percentage_{userdata} * vol_{datanightoutdoor}$$

k_9 to k_{12} are constant coefficients characterizing DL exposure:

$$k_9 = \frac{t_{dayindoor} * WBSAR_{DLin}}{24 * 3600}$$

$$k_{10} = \frac{t_{dayoutdoor} * WBSAR_{DLout}}{24 * 3600}$$

$$k_{11} = \frac{t_{nightindoor} * WBSAR_{DLin}}{24 * 3600}$$

$$k_{12} = \frac{t_{nightoutdoor} * WBSAR_{DLout}}{24 * 3600}$$

5 VARIABILITY AND UNCERTAINTIES

The EI is the output of an analytical model expressed by the equation (1) with a number of uncertain input variables. To propagate the uncertainty associated to the input variables in the model, the first step consists in characterizing the distribution of input variables. Each uncertain variable input has to be described by a statistical distribution.

Average DL power density and UL transmitted power are estimated using specific configurations, environments and usages. The downlink power absorbed by the user and the uplink power emitted by the device (and so partially absorbed by the user) depend on these configurations, environments and usages. Their statistical distributions have to be characterized in order to be incorporated in the total EI statistical uncertainty.

The uncertainties of ICT usage data have been analyzed and modelled using computable functions such as Gamma, Gaussian or uniform distributions and a sensitivity analysis has been carried out in order to determine the most important parameters in the EI equation and how we could simplify the EI formula.

5.1 Variability of the power transmitted by wireless personal devices

In this subsection, a methodology dedicated to characterize the variability of the power radiated by wireless personal devices under specific propagation assumptions is introduced.

Studies focusing on SAR variability induced by sources generally did not take into consideration the impact of the propagation channel especially for an uplink transmission. In the framework of numerical dosimetric simulations for the LEXNET project we analyzed the variability of the power radiated by wireless personal devices under specific propagation assumptions. Interactions between the human body and the antenna remain a complicated subject, due to the high variability of these parameters, such as the type of antenna and the body shape. These interactions have been often investigated toward two disjoint objectives. One is dedicated to analyze the effect of the antenna radiation on the human body whereas the second is devoted to study the effects of human body on the antenna performance. In wireless communications, devices are usually placed close to the human body and, as a consequence, part of the energy is necessarily absorbed. The averaged SAR over the whole body depends on many parameters, such as the design of the antenna and its position with respect to the human body. In our study we focused on both the quantification of the SAR and the statistical characterization of the variability of the radiated power. We analyzed the influence of the positioning of the personal device against the human body on the SAR and the variability of the power radiated in both LOS and NLOS (Non-line of Sight) scenarios.

During the communication, the power radiated by the transmitter system depends fundamentally on the gain in the *LOS* direction. Since an antenna radiation pattern is usually anisotropic, this parameter varies after each change in the transmitter orientation with respect to the base station. For interference limitation reasons, the transmitted power is commonly adjusted to a minimum level, consistent with a predetermined link quality. Then, the power radiated P_r must be simultaneously changed with the gain $G_e\,(\phi_{LOS}, \theta_{LOS},)$ in order to meet the requirements of receiver in terms of signal to noise ratio (SNR). In practice, assuming a constant noise power, the received power (at the base station) must be such that, the same SNR is maintained in order to ensure a successful decoding. This means that the product of the power radiated by the transmitting antenna (P_r) and of its power gain (G_e) in the *LOS* direction should be constant:

$$P_r\, G_e\,(\phi_{LOS}, \theta_{LOS}) = \alpha \qquad (7)$$

At first, the personal device was assumed to be placed in a fixed position with respect to the user's body. Thus, the user's body and the personal device compose an invariant transmitter system ***S***. The sphere surrounding the system ***S*** represents the sphere on which the various parts of a radiation pattern are calculated. It is assumed to be fixed with respect to the base station, while the system ***S*** can rotate along azimuth and elevation angles. The orientation of the system ***S*** with respect to the base station axes is given by a random variable $\Omega_S(\phi_S, \theta_S)$, where ϕ_S and θ_S are respectively the angles of rotation of ***S*** around the vertical axis *z'Oz* and the horizontal plane *xOy* (Figure 19).

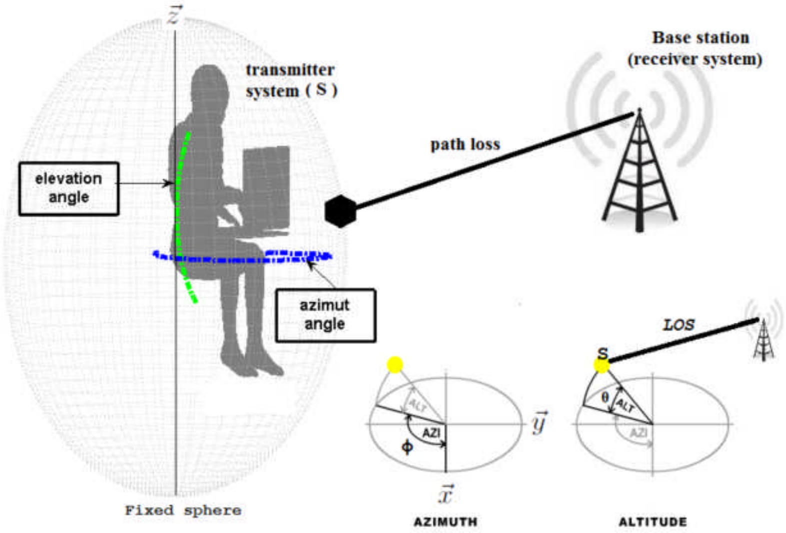


Figure 19 Design concept

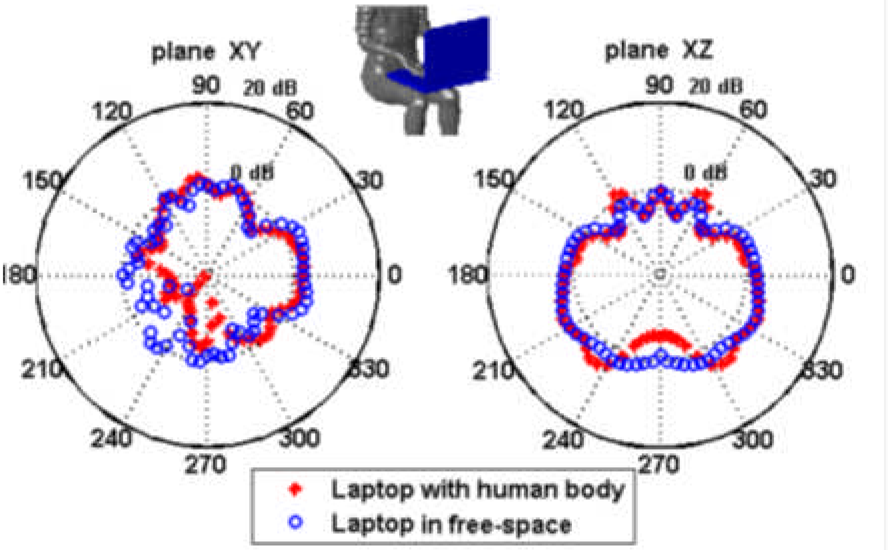


Figure 20 Comparison of radiation patterns of the laptop in free space and in the presence of human body

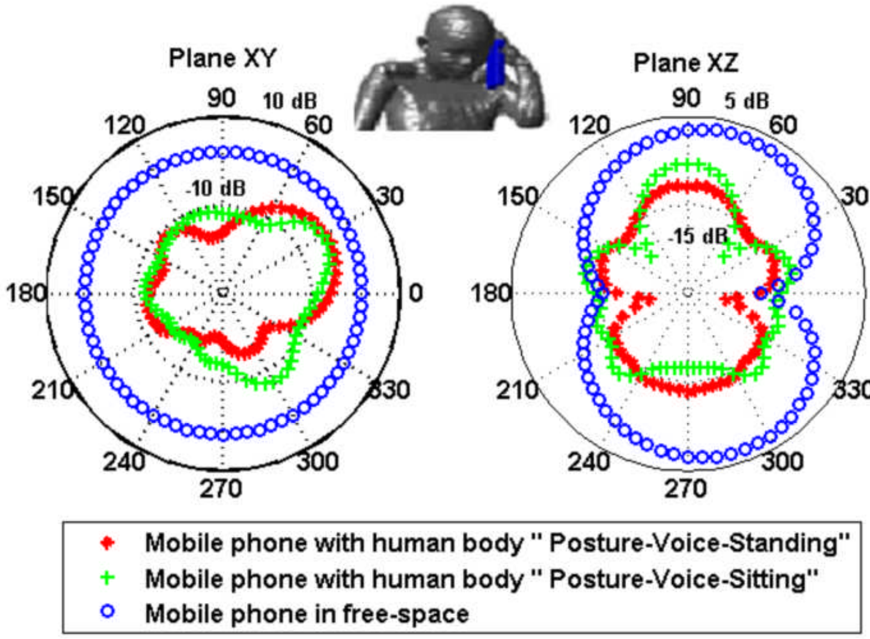


Figure 21 Comparison of radiation patterns of the mobile phone in free space and in the presence of human body

In the case of the laptop (Figure 20), the gain variation is smaller than the one obtained in the mobile phone case (Figure 21). This can be explained by the farther distance between the 3G USB dongle and the human body. The gain pattern is actually almost identical to the free space pattern, as shown in the two planes. The small difference between both stems is due to reflection of waves by the body. In the xz plane, the effect of the left leg is observable around the direction θ = 270°.
Since the exposure is proportional to the power radiated by the device, which depends on many parameters, a statistical analysis of this physical quantity is required in the modeling of the exposure. Based on relationship (7), the power radiated can be written in the following form:

$$\mathrm{Pr} = \frac{\alpha}{\mathrm{Ge}\ (\Omega_s,\ \phi_{LOS},\ \theta_{LOS})} \qquad (8)$$

where α is arbitrarily chosen equal to 1mW. The gain $\mathrm{Ge}\ (\Omega_s, \phi_{LOS}, \theta_{LOS})$ depends on the relative orientation ($\Omega_S(\phi_S,\ \theta_S)$) of the transmitter system with respect to the base station. To simplify computations, ϕ_S and θ_S are assumed to follow a discrete uniform distribution over [0°; 360°] and [-45°; +45°], respectively.

- Voice posture case

Figure 22 and Figure 23 show that the radiated power depends strongly on the local attenuation caused by the body shadowing effects. It is very clear that it increases logarithmically with the attenuation level. In this respect, the quasi lognormal character of the distribution is not surprising. This statistical behavior remains typical of Body Area Networks.

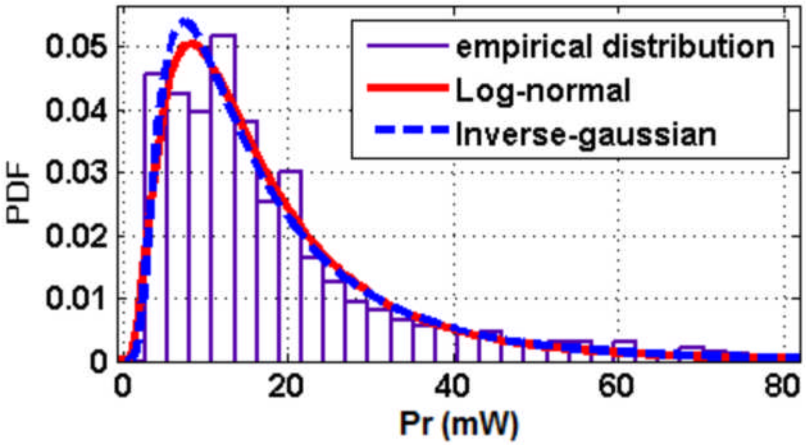


Figure 22 Comparison between the empirical and the analytical distribution function obtained with the standing voice communication posture at 900 MHz

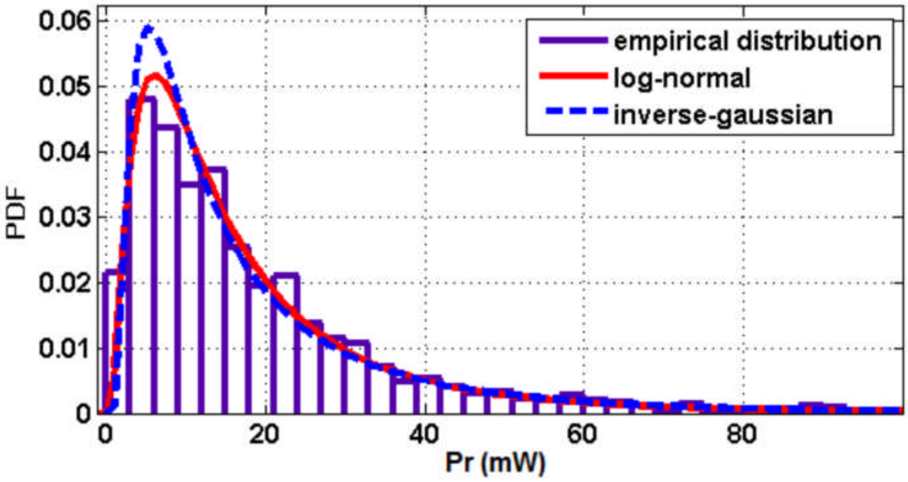


Figure 23 Comparison between the empirical and the analytical distributions function obtained with the sitting voice communication posture at 900 MHz

Between the two voice postures (standing and sitting), a small variation in the parameters of the distributions is noticed. This is due to the fact that the antenna gain is mainly affected by the upper body portion. The latter is not perfectly identical in both postures, in spite of the identical positions of the hand and the hand + head with respect to the mobile phone. This is due to a few constraints in building the computerized body models.

- Laptop posture case

In the case of laptop, the variability of the radiated power is not very large. The high peaks of radiated power are up to 20mW, which is smaller than those noticed with the mobile phone. These results can be explained by the fact that the 3G USB dongle is localized away from the human body (Figure 24).

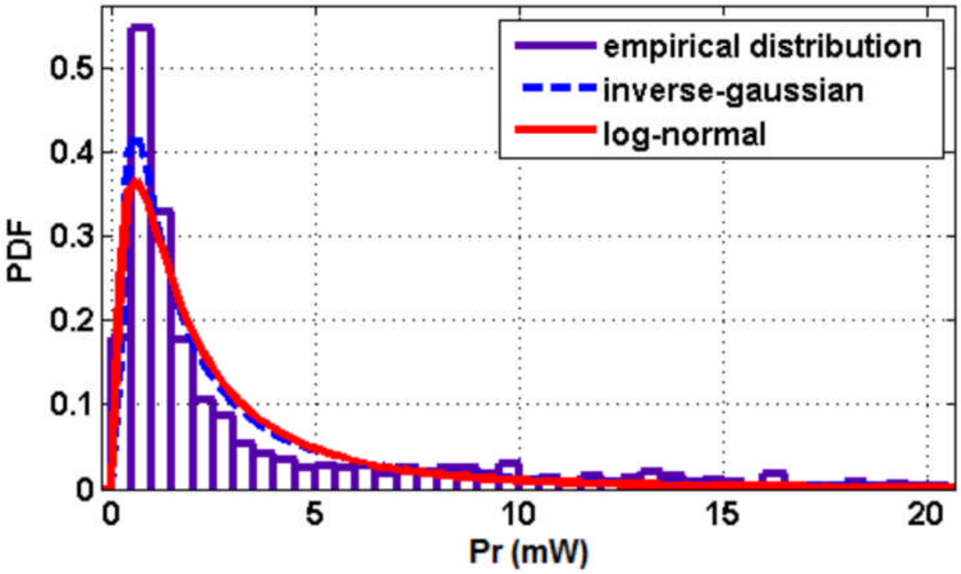


Figure 24 Comparison between the empirical and the analytical distribution functions obtained with the laptop posture at 1940 MHz

During the post-processing, a particular attention was given to the limitation of the maximum power that can be radiated by the mobile phone. Particularly, in the case of GSM 900 MHz, the average power radiated by the mobile antenna is always limited to a threshold power of 250 mW.

The results show that the performance of the antenna is significantly affected in terms of radiation efficiency as well as shape of the radiation patterns, especially in the case of a mobile phone use for voice calls. This observation is reflected by the absorption of a huge amount of radiated power by the head and the hand and also by the partial reflection of the waves by the body. Furthermore, the degradation of the radiation efficiency and the level of exposure level showed a (moderate) sensitivity to the change in the position of the personal device with respect to the human body, particularly in the case of the laptop.
In a wireless network context, the exposure has been found to be strongly dependent on the local propagation environment, owing to the power control enforced by most wireless communications standards. This was addressed by combining the Whole-body SAR value (calculated for a constant power) with a statistical distribution of the radiated power, for various user positions, expressing the dependence on the position of the device with respect to the body and the impact of the propagation channel (e.g., the number of paths, their attenuation and the departure angles).

5.2 EI variability

The assessment of the EI is based on input parameters collected from surveys, simulations and measurements. These input parameters can be divided into several groups as presented in section 3. ICT usage data have a great and direct impact on the exposure duration. And due to the complexity, variability as well as confidentiality, ICT usage data are not easy to obtain and therefore to characterize. Using the data collected in the framework of LEXNET project a statistical analysis was performed in order to characterize this variability. Then a random sampling from probability distributions of ICT usage data was realized in order to characterize the EI variability and uncertainty with respect to ICT usage data (we considered other groups of data as constant values) by using Monte Carlo method.

5.2.1 Statistical analysis of ICT usage data

We considered ICT usage data as twelve different input parameters summarized in Table 36. Based on daily traffic consumption recorded on the 3G network of Orange, each parameter was well defined in order to characterize its statistical distribution.

Input parameter	**Description**
Ht_{day}	Total voice call duration during the day for heavy users
Mt_{day}	Total voice call duration during the day for moderate users
Lt_{day}	Total voice call duration during the day for light users
Ht_{night}	Total voice call duration during the night for heavy users
Mt_{night}	Total voice call duration during the night for moderate users
Lt_{night}	Total voice call duration during the night for light users
$Hvol_{day}$	Data traffic volume during the day for heavy users
$Mvol_{day}$	Data traffic volume during the day for moderate users
$Lvol_{day}$	Data traffic volume during the day for light users
$Hvol_{night}$	Data traffic volume during the night for heavy users
$Mvol_{night}$	Data traffic volume during the night for moderate users
$Lvol_{night}$	Data traffic volume during the night for light users

Table 36 ICT usage data represented by twelve different input parameters

In our study we used Akaike Information Criterion (AIC) in order to determinate the distributions followed by the different input parameters. This measurement is developed using information theory for model selection. It offers an estimation of the relative quality among some given statistical models for a set of data by evaluating AIC value of each model. From the equation below, we can see that AIC depends on L (value of likelihood function for the model) and k (number of estimated parameters in the model). Great L will offer us a more accurate model but at the same time great k may lead to overfitting.

$$AIC=2k-2\log(L); \qquad (9)$$

Hence AIC encourages the advantage of fitting (by maximizing L) while trying to avoid overfitting (by minimizing k). The preferred model is the one with the minimum AIC value. In our study, we tried to find the preferred model among a group of common statistical models (Normal, Lognormal, Rayleigh, Weibull, Exponential, Gamma, Rician and Generalized Extreme Value) for our ICT usage data. The distribution results for urban, suburban and rural scenarios are shown in the following tables.

Input Parameter	Distribution	Param.1	Param.2	Param.3
Ht_{day}	GEV	3.562696e-1	4.532385e2	5.123877e2
Mt_{day}	GEV	-1.55576e-1	8.922579e1	1.566470e2
Lt_{day}	Weibull	4.120504e1	1.210874	
Ht_{night}	Weibull	9.040221e2	8.753780e-1	
Mt_{night}	Weibull	1.915478e2	1.548896	
Lt_{night}	Weibull	3.779658e1	1.159748	
$Hvol_{day}$	Weibull	3.789408e3	6.381982e-1	
$Mvol_{day}$	Weibull	5.900637e2	9.674856e-1	
$Lvol_{day}$	Lognormal	3.137842	1.304834e	
$Hvol_{night}$	Weibull	4.513852e3	6.264050e-1	
$Mvol_{night}$	Weibull	5.412720e2	9.230518e-1	
$Lvol_{night}$	Lognormal	3.134336e	1.306830	

Table 37 Distribution selection for usage data group of urban scenario

Input Parameter	Distribution	Param.1	Param.2	Param.3
Ht_{day}	Gamma	1.199636	9.934028e2	
Mt_{day}	GEV	-2.085134e-1	1.413730e2	2.283643e2
Lt_{day}	Weibull	6.628165e1	1.126797	
Ht_{night}	Weibull	8.617700e2	8.500429e-1	
Mt_{night}	Weibull	2.164593e2	1.176168	
Lt_{night}	Weibull	5.217715e1	1.032256	
$Hvol_{day}$	Weibull	4.215846e3	6.954090e-1	
$Mvol_{day}$	Gamma	1.125814	7.233229e2	
$Lvol_{day}$	Lognormal	3.793228	1.459122	
$Hvol_{night}$	Gamma	7.897441e-1	7.881916e2	
$Mvol_{night}$	Lognomal	5.680914	1.529319	
$Lvol_{night}$	Lognormal	3.567057	1.434982	

Table 38 Distribution selection for usage data group of suburban scenario

Input Parameter	Distribution	Param.1	Param.2	Param.3
Ht_{day}	GEV	3.992009e-1	4.499851e2	5.001061e2
Mt_{day}	GEV	5.338537e-2	9.253486e1	1.497340e2
Lt_{day}	Weibull	4.033680e1	1.105567	
Ht_{night}	Weibull	9.138381e2	8.435146e-1	
Mt_{night}	Weibull	1.967658e2	1.303428	
Lt_{night}	Gamma	1.10623	3.172726e1	
$Hvol_{day}$	Weibull	6.086792e3	6.560783e-1	
$Mvol_{day}$	Weibull	9.412760e+2	9.226993e-1	
$Lvol_{day}$	GEV	1.329584	1.645838e1	1.283718e1
$Hvol_{night}$	Weibull	7.731316e+3	6.842199e-1	
$Mvol_{night}$	Gamma	9.888754e-1	1.002908e3	
$Lvol_{night}$	Lognormal	3.434330	1.494722	

Table 39 Distribution selection for usage data group of rural scenario

For the 3G urban scenario, as shown in Table 40, highest Sobol' indices were found for the average time spent on voice call for heavy users during the day period and night period and average data traffic volumes for heavy users during the day period and the night period, which means that, for this specific scenario, most influent parameters are data concerning heavy users.

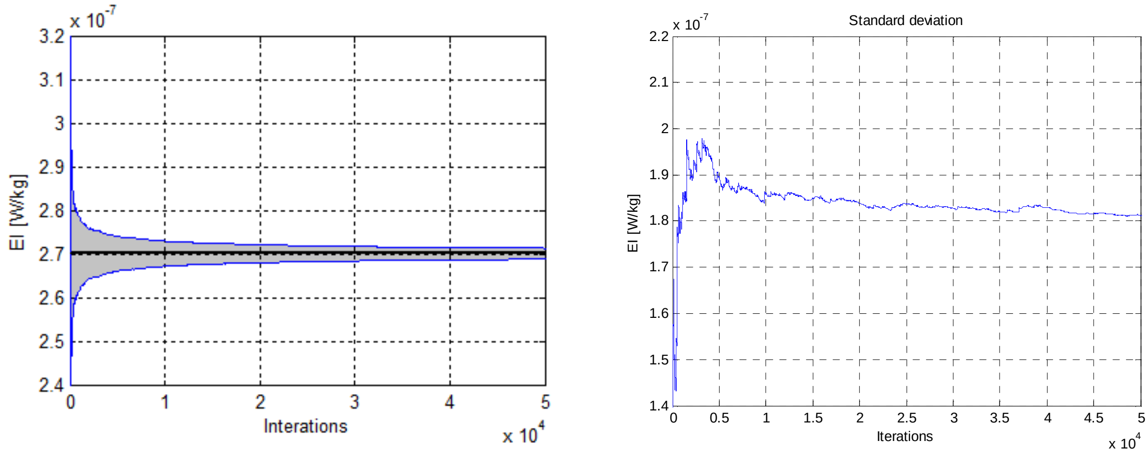
Parameter	Sobol' Indices
$\mathbf{Ht_{day}}$	0.5874
$\mathbf{Mt_{day}}$	0.0077
$\mathbf{Lt_{day}}$	0.0046
$\mathbf{Ht_{night}}$	0.1812
$\mathbf{Mt_{night}}$	0.0055
$\mathbf{Lt_{night}}$	0.0044
$\mathbf{Hvol_{day}}$	0.1625
$\mathbf{Mvol_{day}}$	0.0054
$\mathbf{Lvol_{day}}$	0.0043
$\mathbf{Hvol_{night}}$	0.1359
$\mathbf{Mvol_{night}}$	0.0043
$\mathbf{Lvol_{night}}$	0.0042

Table 40 Evaluated Sobol' indices for each ICT usage parameter for the urban scenario

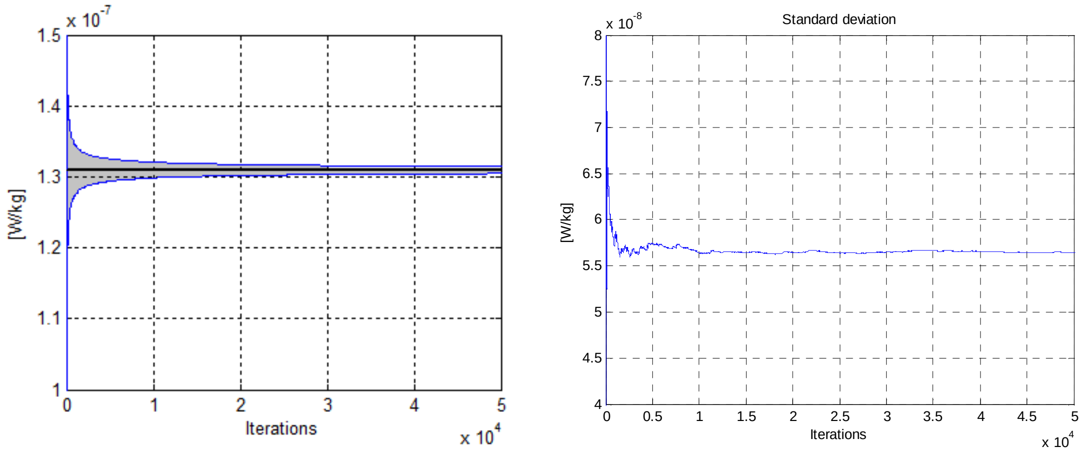
5.2.2 EI sensitivity analysis

Several input parameters are needed for EI calculation: life segmentation data, reference exposure data, received (Rx) / emitted (Tx) power data and personal wireless devices usage data. So in order to integrate the real exposure of the population in different considered scenarios, these main parameters should be considered one after another. In our study, we aim to characterize the variability of EI with respect to ICT usage data group (represented by the twelve parameters described in Table 36) by using Monte Carlo method. To this end, a random sampling from probability distributions of usage data was realized and all the factors in other three data groups (life segmentation, reference exposure and received (Rx) / emitted (Tx) power data group) were considered as constant values and derived from surveys and simulations in order to launch Monte Carlo simulations.

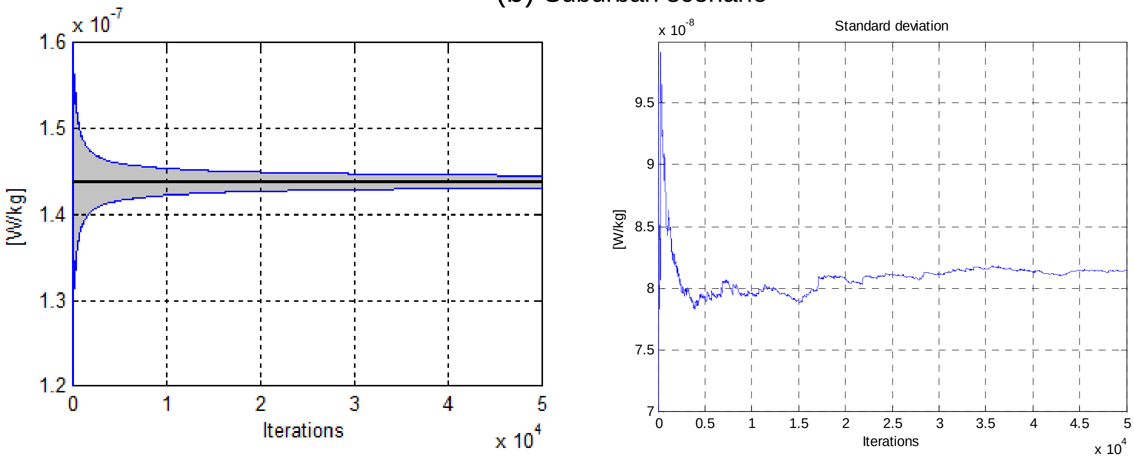
100000 sample sets data were considered to guaranty the large size simulations needed by Monte Carlo method. However, from our observation, the results were converging after 25000 simulations. The average global exposure (EI) was finally converging to 2.86e-7 W/kg for urban scenario, 1.31e-7 W/kg for suburban scenario and 1.43e-7 W/kg for rural scenario. The mean estimated central tendency (black line) and 95% confidence interval (grey zone) as functions of simulation iteration number for the three scenarios are shown in Figure 25. The standard deviation (σ) for the three scenarios is also given in the same figure. We obtain the average variation coefficients of 53% (urban), 43% (suburban) and 56% (rural) by dividing the mean by the corresponding σ. The important variation coefficients show that the global exposure is very sensitive due to the high complexity as well as high variability of ICT usage data.



(a) Urban scenario



(b) Suburban scenario



(c) Rural scenario

Figure 25 Mean estimated central tendency (black line) and 95% confidence interval / standard deviation as a function of simulation iterations for urban (a), suburban (b) and rural (c) scenario

6 CONCLUSION

In this final deliverable of WP2 concerning the global exposure metric, the built metric has been defined.
The proposed metric called Exposure Index (EI) has the advantage to overpass the limitations of the actual metrics that in fact are managing separately the exposure induced by personal devices and the one induced by the network equipment (base stations and access points). But devices, base station antennas and access points are definitely parts of the same wireless environment and the global wireless exposure is induced by all of them.

The EI is described with an analytical model with input variables describing the coverage area of interest, the accessible networks, the population and the habits in terms of location and of wireless devices usage. The output is the EI covering the day-to-day averaged exposure of population in a given area incurred by an entire wireless network from base stations and access points to individual devices.

The analytical model of the EI has been first detailed and the input variables defined. Then we presented the EI integration methodology on a concrete example: a macro dense urban 3G scenario. We have shown that, using all the input data collected, measured, and simulated during the LEXNET project we are able to integrate the metric we built on a comprehensive scenario.

First sensitivity analyses have shown that the EI is highly variable and, depending on the considered scenario, is driven by some more influent input parameters.

Finally, a new human exposure index to EMF is available, integrating people’s life segmentation and ICT usages and combining both exposure from mobile devices and exposure from base stations and access points.
The EI as it is at the end of the LEXNET project is usable but could make a good use of simplification, depending on the considered scenario.

This new metric might in the future benefit different user groups such as telecom operators as a Key Performance Indicator for network optimization, national regulators as such a metric reflects the real global exposure of a population to RF-EMF. We can expect also it would be used to feed health risk epidemiological studies.

7 REFERENCES

[BYUN13] Byun, Y-H et al., “Epidemiological Characteristics of Mobile Phone Ownership and Use in Korean Children and Adolescents,” *Env. Health and Toxicology*, vol. 28, published online 2013.

[Carte09] http://www.cartesfrance.fr/

[CISCO14] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013-2018, February 2014. Last update of the document can be found here: http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.html

[CHLWW08] Conil,E. Hadjem A., Lacroux F., Wong M. F. and Wiart J., “Variability analysis of SAR from 20 MHz to 2.4 GHz for different adult and child models using finite-difference time-domain,” *Phys. Med. Biol.*, vol. 53, pp. 1511-1525, 2008.

[CHRIST10] Christ, A.; Kainz, W.; Hahn, E. G.; Honegger, K.; Zefferer, M.; Neufeld, E.; Rascher, W.; Janka, R.; Bautz, W.; Chen, J.; Kiefer, B.; Schmitt, P.; Hollenbach, H.-P.; Shen, J.; Oberle, M.; Szczerba, D.; Kam, A.; Guag, J. W. & Kuster, N., “The Virtual Family--development of surface-based anatomical models of two adults and two children for dosimetric simulations,” *Phys. Med. Biol.*, vol. 55, pp 23-38, 2010.

[COOPER10] Cooper, A. R. et al., “Patterns of GPS measured time outdoors after school and objective physical activity in English children: the PEACH project,” *International Journal of Behavioral Nutrition and Physical Activity*, Vol. 7, N° 31, 2010.

[CREDOC13] R. Bigot, P. Croutte and E. Daudey, « La diffusion des technologies de l’information et de la communication dans la société française (2013), » Dec. 2013.

[CSTM15] CST. [Online]. Available: http://www.cst.com. [Accessed Sep. 2015].

[GCWW10] Gati, A, Conil, E., Wong MF, Wiart J., “Duality between uplink local and downlink whole body exposures in operating Networks," *IEEE Transactions on EMC*, Vol 52, n°4, Nov 2010.

[GLAS15] Google Glass. [Online]. Available: www.google.com/glass. [Accessed July 2015].

[GRAB15] "GrabCAD," [Online]. Available: www.grabcad.com. [Accessed July 2015].

[HETUS06] C. Aliaga, "How is the time of women and men distributed in Europe, Statistics in focus, population and social conditions," Apr. 2006.

[HOFFERTH01] S. L. Hofferth et al., "How american children spend their time," *Journal of Marriage and the Family*, vol. 63, N°2, May 2001.

[ICNI98] International Commission for Non Ionizing Radiation Protection (ICNIRP), "Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)," *Health Physics, Vol. 74, nº. 4*, Apr. 1998, pp. 494-522.

[IEEE02] TC95_SC1 - Techniques, Procedures, Instrumentation and Computation Working Group, C95.3-2002 - *IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields With Respect to Human Exposure to Such Fields, 100 kHz-300 GHz*, IEEE, 2002.

[INSEE11] L. Ricroch and B. Roumier, Enquête Emploi du temps 2009-2010, « Depuis 11 ans, moins de tâches ménagères, plus d'Internet,» Insee Premiere N° 1377, Nov. 2011.

[LARSON01] Larson,R. W., "How U.S. Children and Adolescents Spend Time: What It Does (and Doesn't) Tell Us About Their Development," Current Directions in Psychological Science, Vol. 10, N° 5, Oct. 2001.

[LARSON11] Larson, L. R. et al., "Children's Time Outdoors: Results and Implications of the National Kids Survey," *Journal of Park and Recreation Administration*, Vol. 29, N° 2, 2011.

[LEXNET D2.1 2013] Vermeeren, G., Thielens, A., Aerts, S., Joseph, W., Martens, L., Oliveira, C., Mackowiak, M., Correia, L.M., Pejanovic-Djurisic, M., Veljovic, Z., Nešković, A., Koprivica, M., Gati, A., Varsier, N., Hadjem, A., Wiart, J., Conil,E., “D2.1 Current metrics for EMF exposure evaluation” LEXNET project, April 2013.

[LEXNET D2.2 2013] Wiedemann P. M., Freudenstein, F., “D2.2 Risk and exposure perception” LEXNET project, July 2013.

[LEXNET D2.3 2013] Vermeeren, G., Plets D., Joseph, W., Martens, L., Conil E, Varsier N, Wiart J,, Corre Y, Oliveira, C., Sebastião D, Correia, L.M., Agüero R, Diez L, Rodríguez L, Koprivica M, Nešković A, Popović M, Milinković J, Nikšić S, “D2.3 Scenarios” LEXNET project, November 2013.

[LEXNET IR2.1 2013] “Numerical tools”, LEXNET project July 2013

[LEXNET D2.5 2014] Wiedemann P. M., Freudenstein, F., “D2.5 Risk and exposure perception” LEXNET project, November 2014.

[NAGAOKA08] Nagaoka, T. and Watanabe, S., “Postured voxel-based human models for electromagnetic dosimetry,” *Physics in medicine and biology*, vol. 53, pp. 7047-7061, 2008.

[PLETS15] Plets, D., Joseph, W., Aerts, S., Vanhecke, K., Vermeeren, G., Varsier, N., Wiart, J. and Martens, L., “Assessment of contribution of other users to own total whole-body RF absorption in train environment,” *Bioelectromagnetics* (accepted).

[SBOC12] Sebastiao, D., Branco, M., Oliveira, C. and Correia, L. M.,“Usage of mobile phones and concerns on electromagnetic radiations of Portuguese youngsters,” ICNIRP 7th International NIR Workshop 2012.

[TAFLOVE00] Taflove A and Hagness S C. 2000. Computational Electrodynamics: The Finite-Difference Time-Domain Method 2nd edn (Boston, MA: Artech House Publishers).

[TNS10] TNS Sofres survey, Observatoire Sociétal du téléphone mobile, Dec 2010

[TVPO15] T. V. Population. [Online]. Available: http://www.itis.ethz.ch. [Accessed Sep. 2015].

[WEIL77] Weiland,T., “A discretization model for the solution of Maxwell's equations for six-component fields”, *Electronics and Communication*, Vol. 31, Mar. 1977, pp. 116-120.

[WIART08] Wiart J., Hadjem A., Wong M. F. and Bloch. I., Analysis of RF exposure in the head tissues of children and adults.

Physics in medicine and biology, vol. 53, pp. 3681-3695, 2008.

8 MAIN PUBLICATIONS

Hadjem A., Varsier N., Conil E. et al., “Characterization of far-field and near-field exposure of the population for RF-EMF in realistic configurations of ICT usages,” BEMS 2014

Plets D., Joseph W., Aerts S., Vanhecke K., et al., “Prediction and comparison of downlink electric-field and uplink localised SAR values for realistic indoor wireless planning,” *Radiat Prot Dosimetry* (2014) 162 (4): 487-498. doi: 10.1093/rpd/ncu019

Huang Y., Krayni A., Hadjem A., Wiart J., Person C. and Varsier N., “Comparison of the average global exposure of a population induced by a macro 3G network in urban, suburban and rural areas,” URSI AT-RASC 2015

Krayni A., “Characterization of the exposure induced by a wireless network,” URSI AT-RASC 2015

Plets D., Joseph W., Vanhecke K., et al., “Joint Minimization of Uplink and Downlink Whole-Body Exposure Dose in Indoor Wireless Networks,” *BioMed Research International*, vol. 2015, Article ID 943415, 9 pages, 2015. doi:10.1155/2015/943415

Varsier N., Plets D., Corre Y., Vermeeren G., Joseph W., Aerts S., Martens L. and Wiart J., “A novel method to assess the human population exposure induced by a wireless cellular network,” *Bioelectromagnetics*, vol. 36, n°6, pp. 451-463, Sept. 2015

Plets, D., Joseph, W., Aerts, S., Vanhecke, K., Vermeeren, G., Varsier, N., Wiart, J. and Martens, L., “Assessment of contribution of other users to own total whole-body RF absorption in train environment,” *Bioelectromagnetics* (accepted).

APPENDIX 1: NUMERICAL DOSIMETRIC SIMULATIONS FOR GOOGLE GLASSES

This appendix describes the results of SAR simulations for Google glasses [GLAS15], using a numerical simulation tool (CST Microwave Studio [CSTM15]). The Glass is a pair of augmented reality glasses whose connectivity is assured by two wireless technologies, Wi-Fi and Bluetooth, in the 2.4 GHz band. No cellular module was implemented on the prototype.

These simulations have the aim of assessing the user exposure in the potential scenario of using cellular technologies in the Glass prototype. Accordingly, SAR values were evaluated for 900 MHz (GSM), 1940 MHz (UMTS) and 2600 MHz (LTE).

The Google glasses [GLAS15] were modelled using a CAD model [GRAB15], which was directly imported into CST Microwave Studio, Figure A.1.

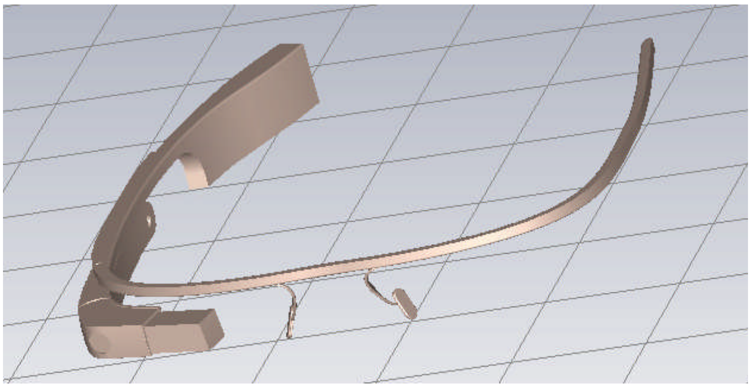


Figure A.1 Google glasses CAD model [GRAB15]

As it can be seen from Figure A.2, the Google glasses use a monopole whip antenna, which was modelled in CST as a wire and a ground plane both made of Perfect Electric Conductor (PEC), Figure A.3. A small vacuum gap was introduced between them to insert a discrete port as the feeding point.

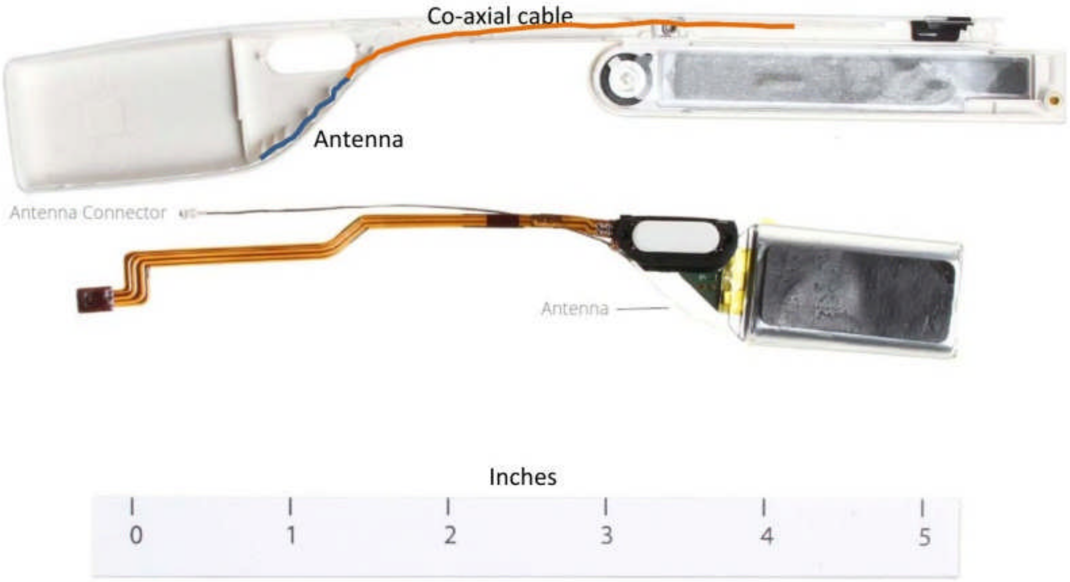


Figure A.2 Google Glass antenna [5]

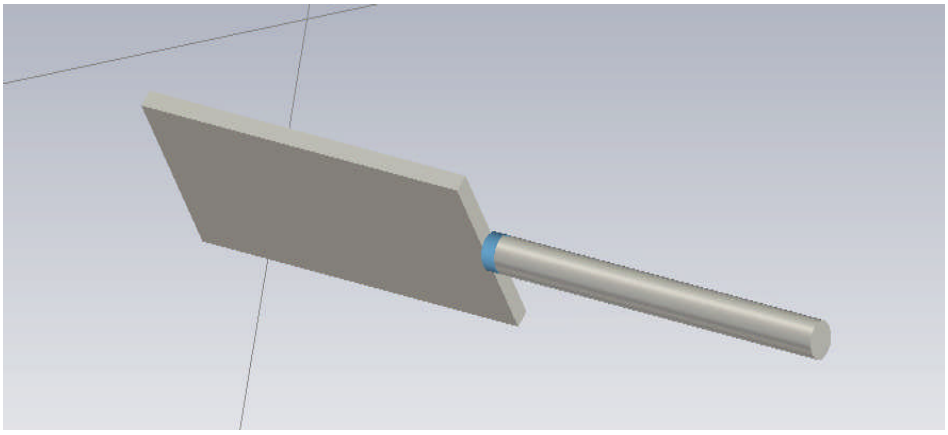


Figure A.3 – Google glasses modelled antenna

The antenna length was set using the Time Domain Solver Optimizer of CST tuned to minimise the S11 value at 2436 MHz. The antenna optimisation process used the Google glass CAD model, the modulated antenna and a head voxel model.

The value of the S11 parameter is presented in Figure A.4. Table A.1 shows the Google glasses and the antenna main characteristics after optimisation.

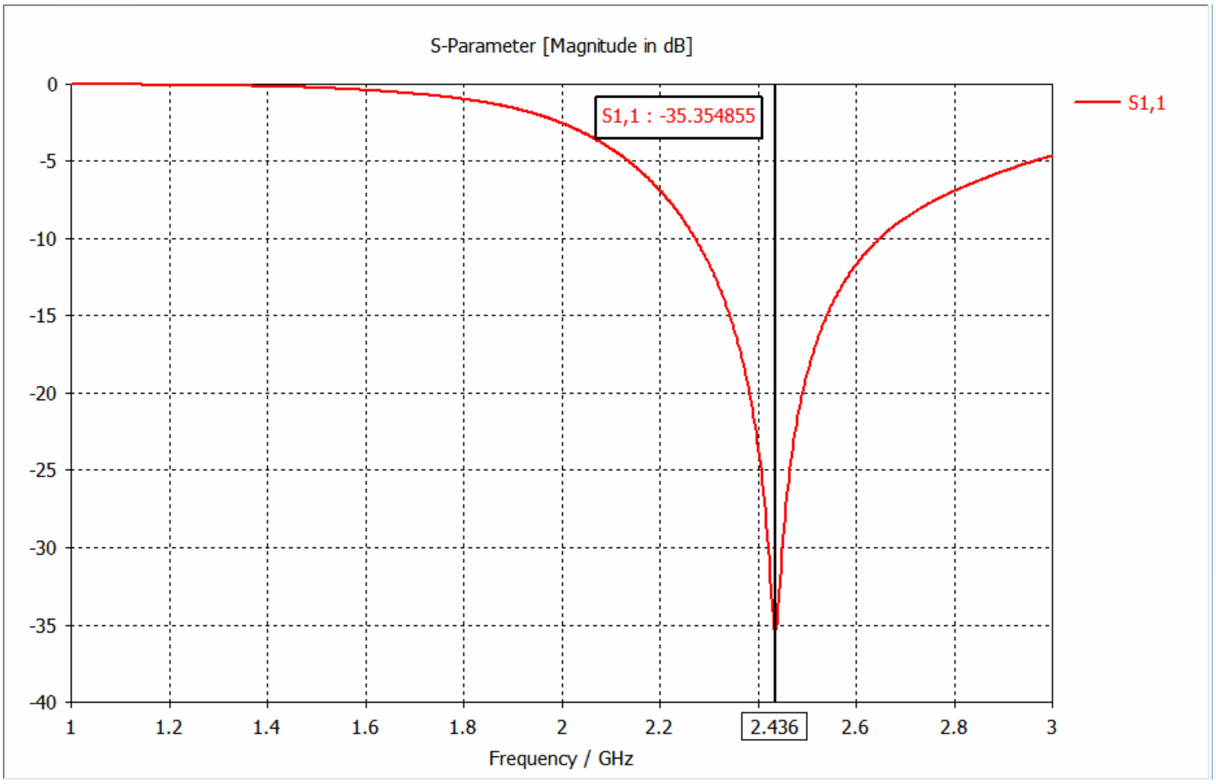


Figure A.4 S11 for Google glasses antenna

Table A.1 – Google glasses and antenna main characteristics at 2436 MHz

Antenna							**Google Glasses**
Ground plane		**Wire**		**Gap**		**S11 [dB]**	**Material**
Length [mm]	**Material**	**Length [mm]**	**Material**	**Length [mm]**	**Material**		
25.19	PEC	25.19	PEC	2.00	Vacuum	-35.4	Teflon (PTFE)

The computer used for the simulations contains a GPU NVIDIA TESLA C2050 that significantly reduces the simulation time for scenarios with a maximum of 50 million mesh cells. Nevertheless, the use of a full body voxel model would exceed this limit. Therefore, a voxel simulating only the head of a 26 years old woman [TVPO15] was used, Figure A.5. It should be noted that the SAR values are only relevant in the head regions near the antenna, therefore validating this approach.

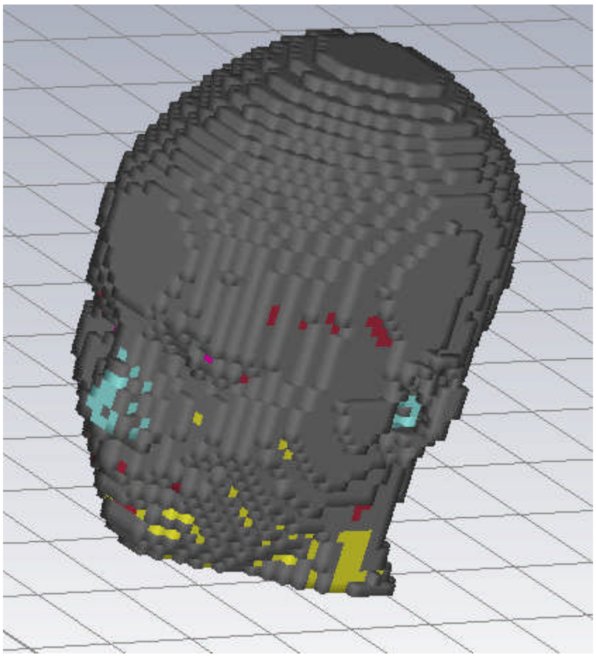
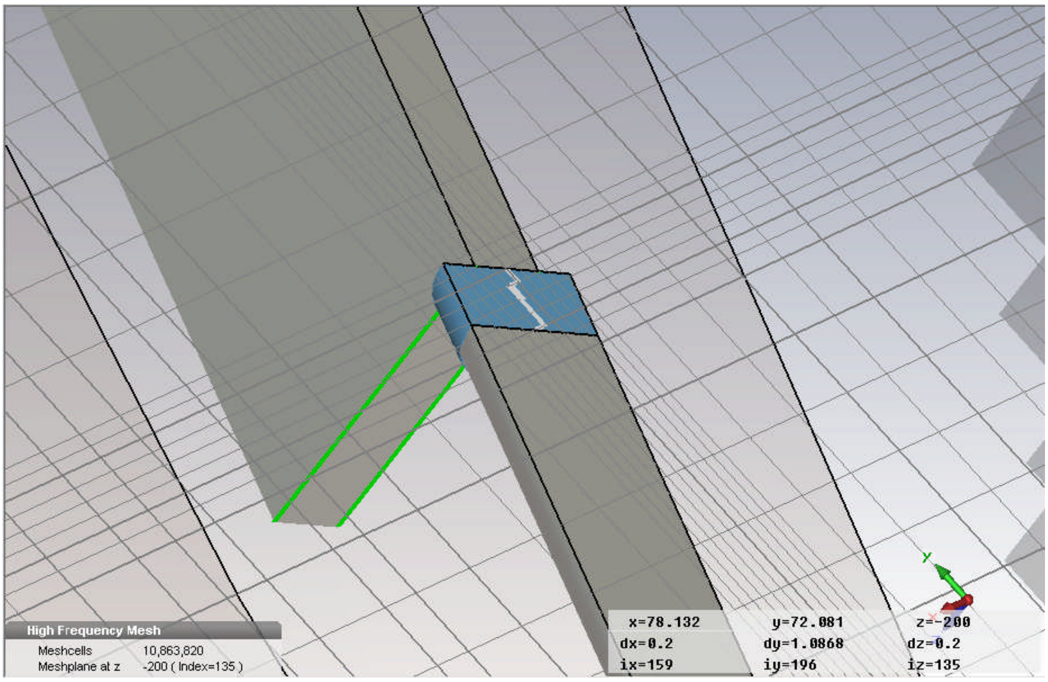


Figure A.5 – 26 years old woman voxel model (head) [TVPO15]

Simulations have been performed using the time domain solver, and the automatic mesh generation of CST. To achieve an accurate meshing, a maximum mesh step of 0.2 mm was defined for the antenna gap. This implies that the automatic mesh generator will not exceed this step width at the bounding box of the antenna gap. Figure A.6 shows the higher density mesh lines near the antenna gap (in blue).



```
High Frequency Mesh
Meshcells        10,863,820
Meshplane at z   -200 ( Index=135 )
```

```
 x=78.132      y=72.081      z=-200
dx=0.2        dy=1.0868     dz=0.2
ix=159        iy=196        iz=135
```

Figure A.6 – Mesh lines on the antenna gap

Figure A.7 shows the mesh lines for the upper frequency of 3000 MHz, which resulted in 10.86 million mesh cells.

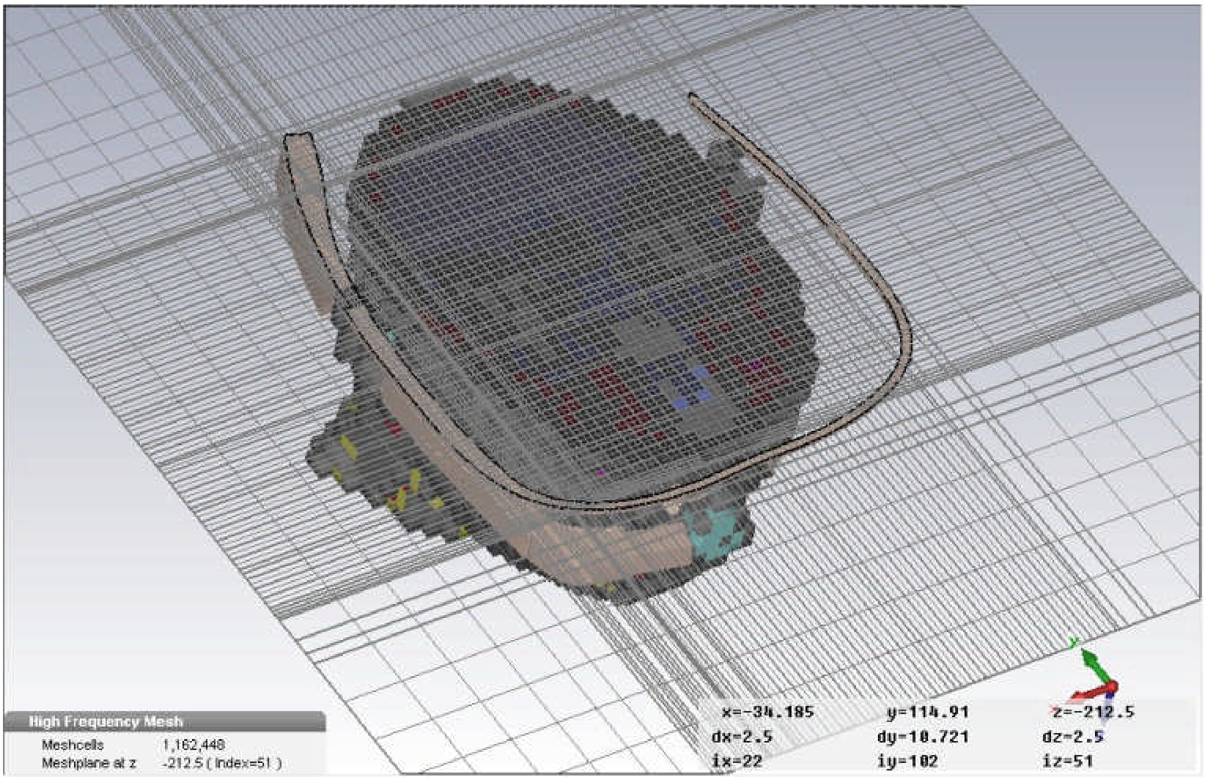


Figure A.7 – Model mesh lines for the upper frequency of 3000 MHz

SAR calculations were performed using the averaging method according to the IEEE C95.3 standard [IEEE02], and the reference (radiated) power was set to the normalised value of 1 W. The SAR calculation at the different frequencies assumes that there are no reflection losses.

Table A.2 presents the main parameters used in each simulation scenario. The simulation frequency range setting is important for the meshing process and the resulting number of mesh cells and simulation time. The use of a GPU results in a significant reduced simulation time, *e.g.*, for the 900 MHz scenario, the simulation time was reduced around 5 times compared to the case when no GPU is used.

The MLW (Maximum number of Lines per Wavelength) value, defines the upper limit of lines per wavelength of maximum frequency. Increasing this number leads to a higher accuracy, but also increases the total calculation time. The value was chosen to achieve a trade-off between simulation accuracy and simulation time.

Frequency [MHz]	**Frequency Range [MHz]**	**Mesh cells**				**Acceleration**	**Simulation Time**
		MLW	**Smallest [mm]**	**Largest [mm]**	**Number [106]**		
900	500 – 1000	10	0.20	28.90	1.16	2 Intel Xeon E620@2.40 GHz GPU Tesla C2050	3 m 53 s
1940	1000– 3000	10	0.20	9.80	10.86		1 h 0 m 58 s
2600							

Table A.2 Simulation setup

The cutting planes presenting SAR values for the 900 and 2600 MHz are shown in Figure A.8 and Figure A.9, respectively. One can observe the intuitive result that most of the energy is absorbed by the head region near to the antenna. Moreover, a higher absorption of energy at the lowest frequency (0.9 GHz) is noticeable.

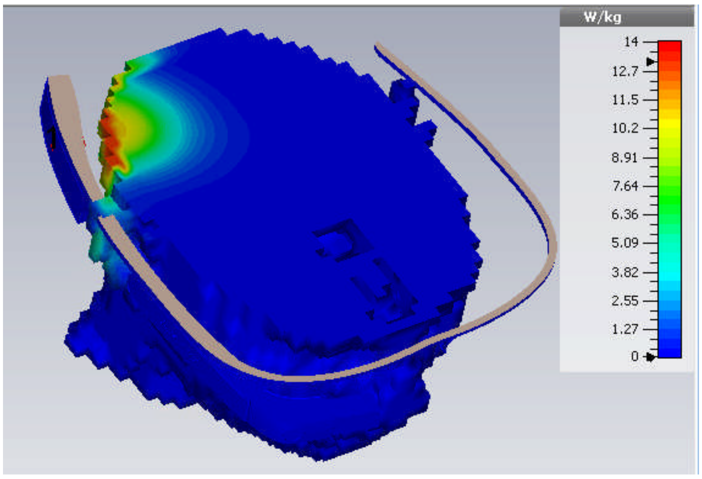


Figure A.8 Voxel cutting plane with SAR values for 900 MHz

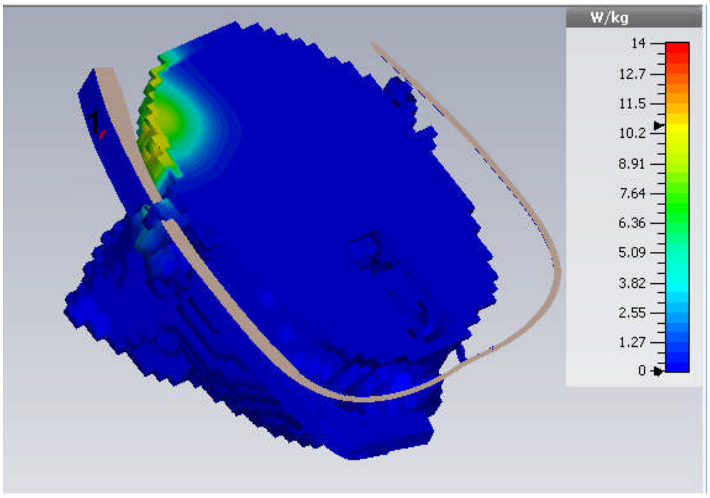


Figure A.9 Voxel cutting plane with SAR values for 2600 MHz

Table A.3 shows the peak-spatial averaged SAR (*psaSAR10g*) and the whole head SAR values for each band.

Frequency [MHz]	*psaSAR10g* [W/kg]	Whole head SAR [W/kg]	SAR Calculation Time
900	13.14	0.205	7 s
1940	13.72	0.128	10 m 51 s
2600	10.51	0.096	11 m 07 s

Table A.3 SAR values

The values on Table A.4 were evaluated for a radiated power of 1 W, which was used to normalise the results among the LEXNET partners, but overestimates the real typical exposure of 0.125 W for UMTS and 0.1 W for LTE.

The values of maximum radiated power (*Pmax*) to respect the maximum recommended SAR value for the head (*i.e.*, 2 W/kg [ICNI98]) are presented in Table A.4. So, one can see that, for UMTS and LTE, there are no problems of exposure, since the maximum radiated power that fulfils SAR requirements is above the maximum radiated by the devices; in GSM, the situation is different, and in order to respect the threshold, the device will have to radiate a maximum quite below the maximum allowed for a device in general, which can be implemented in the device without problems.

	Frequency [MHz]	***Pmax* [W]**	**Peak/Maximum EIRP Uplink [W]**
GSM	**900**	**0.152**	**2.000**
UMTS	**1940**	**0.146**	**0.125**
LTE	**2600**	**0.190**	**0.100**

Table A.4 Maximum radiated power for 2 W/kg SAR

APPENDIX 2: INTERNAL REVIEW

	Reviewer 1: Mick Wilson			Reviewer 2: Yoann Corre		
	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	Minor editorials only suggested	☐ M ☐ m ☐ a	☒ Yes ☐ No	Minor modifications suggested (mostly editorial corrections)	☐ 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