Exposure Assessment of Smartphones and Tablets

Carla Oliveira, Michał Maćkowiak, Luis M. Correia
Instituto Superior Técnico / INOV-INESC
University of Lisbon, Portugal
email: {carla.oliveira, luis.correia}@inov.pt

***Abstract*—This work assesses the uplink exposure of 3G/4G smartphones and tablets, as representative of current wireless usage trends. Numerical simulations are carried out to estimate SAR on whole body heterogeneous voxel models of an adult and a child, in standing and sitting postures, in a testbed comprising 16 scenarios, which is the main novelty of the work. The head and the hand absorb about 55% and 40% of the energy, respectively, during a voice call (on average), while using a tablet, on average, 96% of the energy is absorbed by the hands. The child model exhibits a higher sensitivity to frequency and to the body posture.**

***Index Terms*—SAR, 3G, 4G, uplink exposure, tablets, smartphones.**

I. Introduction

Recent studies report a massive usage of wireless technologies, *e.g.*, smartphones and tablets. Results from a Portuguese survey [1] reveal that almost each teenager has a mobile phone and sends an average number of 100 daily SMSs. In spite of this impressive usage, a part of the population is concerned about the exposure to ElectroMagnetic Fields (EMFs) from wireless technologies. The last Eurobarometer on EMFs [2] reveals that 70% of the respondents believe that mobile phone masts somehow affect their health.

The LEXNET projet [3] arises in this context of awareness about the possible adverse health effects from EMF exposure. The project has the strategic goal of improving the acceptability of existing and future wireless systems, through the development of low exposure systems without compromising the users perceived quality of experience. Moreover, a global exposure index was developed, measuring the average exposure of a population incurred by a wireless telecommunications network as a whole, over time and over space. It aggregates the downlink exposure induced all day long by base stations and access points, as well as the uplink one incurred by personal wireless communication devices.

The individual exposure induced by wireless devices is usually assessed through the Specific Absorption Rate (SAR) [4], averaged over the whole body of the user, or on a given organ, tissue or body volume [5]. SAR assessment via measurements is a complex and invasive procedure, thus, its estimation is commonly accomplished through numerical dosimetric simulations, *e.g.*, [6]. Numerical full-body phantoms (or body sections) are embedded in the electromagnetic codes.

The mobile phones boom and evolution boosted an outstanding number of studies related to the absorption of EMF on the head or the hand of a user. The authors in [7] reviewed the SAR values for the different generations of mobile phones aging from 1995 to 2011, showing that the internal microstrip antennas reduce SAR by 40-60%, compared to the old external helix ones. The importance of the geometric model of the device is highlighted in [8], being shown that the SAR distribution caused by generic source models cannot be extrapolated to the real device exposures.

Novel exposure scenarios have been arising, comprising new devices such as tablets or laptops, new postures (*e.g.*, standing with the device on the hands, or sitting with the laptop on the legs), and new users (*e.g.*, kids playing with the tablet). The World Health Organisation has identified the assessment of characteristic EMF emissions, exposure scenarios and corresponding exposure levels for new and emerging radiofrequency technologies, and also for changes in the use of established technologies, as one of its research agenda high-priorities. Some related studies are already found in the literature (*e.g.*, [10]), and for the particular case of tablets, the authors in [11] concluded that the localised SAR for these devices is lower than those for phones.

Exposure depends on many factors, such as 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. To characterise the realistic exposure of a population, LEXNET is conducting numerical dosimetric simulations for a comprehensive set of scenarios. This work deals with part of the LEXNET test-bed, addressing the individual exposure to the uplink by smartphones and tablets, in order to fill out a matrix of raw normalised SAR values.

Numerical dosimetric simulations were conducted to estimate the whole body, and the peak localised SAR, for a test-bed including 16 scenarios: 2 devices (a smartphone - voice usage and a tablet - data usage) $\times$ 2 radio access technologies (RATs) (3G and 4G) $\times$ 2 postures (standing and sitting) $\times$ 2 users (an adult and a child).

Apart from the contribution to the matrix of raw normalised SAR values to be used for the calculation of LEXNET global exposure index, the exhaustive number of analysed scenarios, and their relevance for the time being, constitute the main novelty of the work.

Five sections, including the present one, compose this paper.

In Section II, a description of the methodology of the work is presented. Section III provides an overview on the scenarios analysed, namely, the devices and the body models. Section IV is focused on the main outcomes from the exposure assessment. In Section V, the main conclusions are drawn.

II. Methodology

Numerical dosimetric simulations are carried out using *CST Microwave Studio* [12], a specialised tool for 3D simulation of high frequency devices, that implements the Finite Integration Technique (FIT). FIT is a numerical method that performs a spatial discretisation, in the time or frequency domains, of the integral form of Maxwells equations, instead of the usual differential one.

The simulations have been performed in the time domain (transient) solver of CST, using the automatic mesh generation feature, which is controlled by two important settings:

- M_{LW} - Lines per Wavelength (LW), which is the minimum number of mesh lines in each coordinate direction based on the highest frequency of evaluation.
- M_{RL} - Ratio Limit (RL), which is the ratio between the largest and the smallest distances between mesh lines. There is an increase on mesh quality when high aspect ratios exist, *e.g.*, edge coupled microstrip. As an alternative to the ratio limit, the smallest mesh step can be entered directly as an absolute value, rather than defining it relatively via the largest mesh step and ratio limit. The smallest mesh step determines the simulation time.

In order to better adapt the mesh for the given problem, the discretisation of the numerical phantoms used in this study was adjusted by using fixedpoints, Fig. 1. The fixedpoints force the mesh to be aligned within specific points indicated by the user. Due to the large dataset, a Matlab [13] script was developed to create a set of fixedpoints that force the mesh to be aligned to the edges of the numerical phantom model. Additionally, in order to increase the accuracy of the simulation, the meshing was even denser in the area of the excitation port of the antenna.

Fig. 1. Mesh tuning using fixedpoints.

A discrete edge port is used in CST as the feeding point source, having two pins connected to the source structure (*e.g.*, to the wireless communication device). This port enables the calculation of the corresponding *S*-parameters and impedance, based on the incoming and outgoing signals. In order to enable the EMF exposure assessment, a power loss density monitor is defined, and SAR calculation is carried out as a post-processing step after the simulation. SAR calculations were performed using the averaging method specified in the IEEE C95.3 standard [14], on the recommended practice for measurements and computations of radio frequency EMFs with respect to human exposure to such fields.

SAR measures the rate at which energy is absorbed in a tissue [4], being defined as the power absorbed by a mass of tissue, and it is related to the electric field *E* at a point by:

$$SAR = \rho |E|^2 / \sigma \text{ [W/kg]} \quad (1)$$

where:

- ρ is the conductivity of the tissue ([S/m])
- *E* is the root mean squared electric field strength in the tissue ([V/m])
- σ is the volume density ([kg/m^3])

The whole-body averaged SAR (*wbaSAR*) [4] is the basis for the exposure reference levels. The *wbaSAR* is averaged spatially over the mass of the body and, hence, is obtained by dividing the total power absorbed in the human body by the full body weight:

$$wbaSAR = 1/M \int_R SAR \, \mathrm{d}m \text{ [W/kg]} \quad (2)$$

where:

- *M* is the total mass of the human body model
- *R* is the region of the body

Hazardous exposures may occur above a whole-body averaged SAR value of 4 W/kg [15], as averaged over the entire mass of the body. For comparison with the guidelines, the *wbaSAR* is averaged over a 6 minute period.

The peak-spatial averaged SAR ($psaSAR_{10g}$), measured in [W/kg], is defined as the maximum local SAR, averaged over any 10 g of contiguous tissue [4].

A segmentation of the numerical models was carried out to enable the automatic estimation of SAR in different parts of the body, as illustrated in Fig. 2. For this purpose, a second algorithm was implemented in Matlab, which intersects the numerical model of the user with basic shapes (*e.g.*, cylinders), in order to segment the body model. A mirror model with four segments (*i.e.*, head, chest, arms, legs), is then created through a matrix containing the allocation to the body parts. The mirror model is used in the post-processing procedure of the numerical simulations.

III. Scenarios

This work addresses the individual exposure from the uplink by wireless communication devices, in a total of 16 scenarios: 2 devices: smartphone (voice), tablet (data); 2 frequencies: 1940 MHz (3G) and 2600 MHz (4G); 2 postures: standing, sitting; 2 users: adult, child.

Fig. 2. Body segmentation for post processing.

A smartphone [16] and a tablet [17] are used as examples of voice usage when making a phone call, and data usage when web browsing, respectively. The numerical models of these devices do not correspond to a specific model/brand, rather being fair representations of the commercial available ones, and were developed and validated within the LEXNET project for the numerical assessment of the exposure to EMFs. Both devices are working with a normalised input power of 1 W (peak value), which was used to normalise the results among the LEXNET test-be, but overestimates the real typical exposure of 0.125 W for 3G [18] and 0.1 W for 4G [19]. No power control transmission algorithms are considered, neither voice over IP communications.

The selected frequencies of 1940 and 2600 MHz typify the uplink bands for 3G, [1900, 1980] MHz and 4G, [2500, 2570] MHz, respectively. Simulations are not technology dependent, their only difference being on the frequency.

Numerical models of an adult and a child are used, taken from the Virtual Population Project [20]. The models are the heterogeneous whole body voxels of the male adult Duke and the female child Eartha. No differences between genres are expected, but, between different body mass indexes, exposure dissimilarities are expected. Besides the traditional standing posture, a sitting position obtained using deformation software is considered as well. Table I details the main characteristics of the voxel models used.

TABLE I
VOXEL MODELS.

	Duke	Eartha
Genre	Male	Female
Age [years]	34	8
Height [m]	1.77	1.35
Weigth [kg]	71.36	30.17
BMI	22.5	16.5
Resolution [mm^3]	2×2×2	

Table II provides an overview of the 16 scenarios considered for the simulations carried out in the work.

2 mm voxel models of the user and the device are used in the simulations, as represented in Fig. 3. It is worthwhile

TABLE II
OVERVIEW OF SCENARIOS.

	Model	Posture	Device (Usage)	Freq. [MHz] (RAT)
A.1	Duke	Standing	Smartphone (voice)	1940 (3G)
A.2		Sitting		
A.3	Duke	Standing	Tablet (data)	1940 (3G)
A.4		Sitting		
A.5	Duke	Standing	Smartphone (voice)	2600 (4G)
A.6		Sitting		
A.7	Duke	Standing	Tablet (data)	2600 (4G)
A.8		Sitting		
B.1	Eartha	Standing	Smartphone (voice)	1940 (3G)
B.2		Sitting		
B.3	Eartha	Standing	Tablet (data)	1940 (3G)
B.4		Sitting		
B.5	Eartha	Standing	Smartphone (voice)	2600 (4G)
B.6		Sitting		
B.7	Eartha	Standing	Tablet (data)	2600 (4G)
B.8		Sitting		

mentioning that the 2 mm resolution represents a fair trade-off between the required exposure accuracy and the available resources (*e.g.*, simulation time). For the selected frequencies, the impact of the voxel resolution on exposure calculation is small. A preliminary assessment shows that the error between $1{\times}1{\times}1$ mm^3 and $2{\times}2{\times}2$ mm^3 is always less than 5% for both *wbaSAR* and $psaSAR_{10g}$.

(a) Duke standing

(b) Eartha seated

Fig. 3. Examples of the voxel models.

Simulations were run in a dedicated workstation with 4 Intel Xeon Quadcore E5620 Processors, @2.4 GHz, 44 GB RAM, without GPU acceleration (due to hardware limitations).

IV. RESULTS

Tables III and IV indicate the performance of the simulations for the adult and the child models, respectively, in terms of the number of mesh cells and duration of simulation, together with the simulation parameters (simulated frequency band, meshing parameters).

A wideband analysis was chosen, as it performs faster due to the shorter excitation signal. However, the upper

TABLE III
SIMULATION PERFORMANCE FOR DUKE.

	Band [MHz]	M_{LW}	M_{RL}	Cells [10^6]	Sim. Time
A.1	[500, 2100]	5	40	58.59	2h52m54s
A.2				80.93	3h41m11s
A.3	[500, 2100]	5	40	89.25	8h05m32s
A.4				25.94	2h07m20s
A.5	[500, 3000]	5	40	58.59	3h45m40s
A.6				114.50	6h57m09s
A.7	[500, 3000]	5	40	116.25	18h24m47s
A.8				130.09	14h34m06s

TABLE IV
SIMULATION PERFORMANCE FOR EARTHA.

	Band [MHz]	M_{LW}	M_{RL}	Cells [10^6]	Sim. Time
B.1	[500, 2100]	5	40	33.97	0h54m59s
B.2				36.57	1h13m00s
B.3	[500, 2100]	5	40	45.24	4h11m07s
B.4				40.93	3h48m50s
B.5	[500, 3000]	5	40	95.88	3h14m39s
B.6				41.09	2h05m02s
B.7	[500, 3000]	5	40	63.75	12h34m55s
B.8				55.76	11h02m28s

frequency was chosen carefully, not being too large, as the number of mesh cells rapidly increases with it. The simulation time merely provides an indication value, as the conditions of computation were not the same over all the simulations (*e.g.*, number of threads, allocated memory, temporary files or internal temperature). Anyway, the child model leads to shorter simulations, due to its smaller dimensions.

Fig. 4 exemplifies the SAR distributions for Eartha using the smartphone, showing the intuitive results that most of the energy is absorbed by the body parts touching the device.

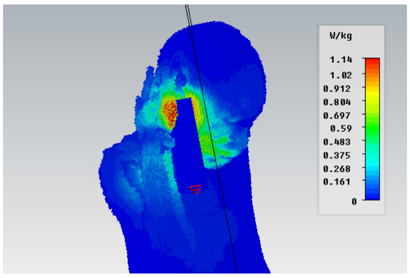

Fig. 4. SAR distribution (Eartha using the smartphone).

Table V and Table VI present an overview of the results for the *wbaSAR* and the $psaSAR_{10g}$, for Duke and Eartha, respectively. The whole body averaged SAR results are plotted in Fig. 5, while the peak SAR for the head (smartphone usage) and for the arms (tablet usage) are shown in Fig. 6.

During a voice call, the smartphone touches the hand and the head of user, thus, both Duke and Eartha present a higher $psaSAR_{10g}$ in these body parts. On average, the head absorbs

TABLE V
SAR OVERVIEW FOR DUKE.

		$psaSAR_{10g}$ [W/kg]			
	wbaSAR [W/kg]	Head	Chest	Legs	Arms
A.1	0.0052	1.1079	0.3629	0.0003	2.6304
A.2	0.0052	2.3929	0.176	0.0015	2.6224
A.3	0.0039	0.0480	0.0576	0.0101	3.5340
A.4	0.0081	0.0418	0.0524	0.0211	14.2519
A.5	0.0053	5.1638	0.4376	0.0003	1.4075
A.6	0.0047	7.5690	0.0612	0.0004	7.0115
A.7	0.0029	0.0713	0.0393	0.0226	2.2694
A.8	0.0370	0.0773	0.0192	0.0154	6.6761

TABLE VI
SAR OVERVIEW FOR EARTHA.

		$psaSAR_{10g}$ [W/kg]			
	wbaSAR [W/kg]	Head	Chest	Legs	Arms
B.1	0.0100	0.9435	0.3401	0.0008	1.1440
B.2	0.0116	3.5327	0.4655	0.0042	3.3447
B.3	0.0109	0.0859	0.0909	0.0052	4.2989
B.4	0.0135	0.0786	0.0877	0.0476	4.5143
B.5	0.0157	12.9505	0.2489	0.0003	12.4945
B.6	0.0147	6.5686	0.0023	0.0001	0.1813
B.7	0.0083	0.0935	0.0780	0.0144	3.0052
B.8	0.0094	0.0889	0.0700	0.0534	2.3139

about 55% of the radiation, and the hand about 40%. The less exposed body part are the legs, especially in standing position. While using the tablet, on average, the hands absorb about 96% of the energy, and exposure is generally higher in seated posture, as the device is closer to the user. No consistent differences between the adult and the child model were found concerning $psaSAR_{10g}$, both models experiencing the highest local absorption of energy in the head when exposed to the radiation of a 4G smartphone.

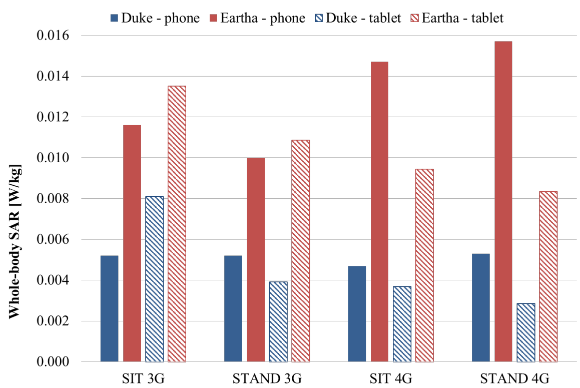

Fig. 5. Whole body averaged SAR.

Results suggest that the whole body exposure of the child is around twice the one from the adult, apart from the device used. As the *wbaSAR* is the ratio of the absorbed power over

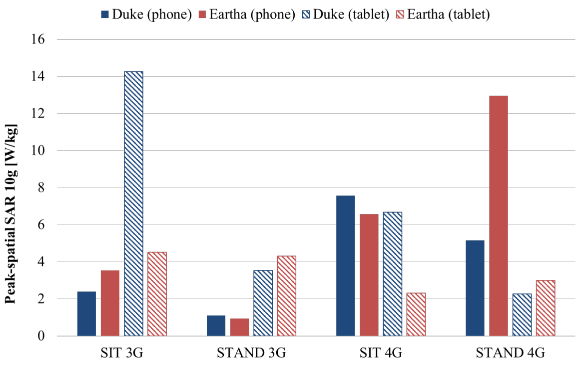

Fig. 6. Peak spatial averaged SAR.

the mass of the body, this result is a consequence of the smaller volume of the child model. Results suggest that whole body exposure is higher for tablets used in 3G band for both body models, but the child exhibits a higher sensitivity to the frequency, as well as to the body posture. The high values of SAR obtained in these simulations, in some cases above the recommended thresholds, are clearly above the real exposure, and are a consequence of the selected transmitted power of 1 W. As stated before, this value was selected to normalise the different results of the LEXNET testbed.

V. Conclusions

In spite of the massive usage of wireless technologies, many people believe that exposure to electromagnetic radiation somehow affect their health. The LEXNET project has the strategic goal of improving the acceptability of wireless systems through low exposure strategies without compromising the users perceived quality of experience.

This paper addresses part of the research conducted by LEXNET, aiming to assess - using numerical tools - the exposure induced by wireless systems in various usage scenarios, for representative segments of the population.

The work deals with the numerical assessment of the uplink exposure of a smartphone and a tablet, representing typical voice and data usages. Simulations were performed using a numerical simulation tool, with embedded whole body heterogeneous voxel models of an adult and a child. The post processing of the results includes the distribution of SAR over different body parts (head, chest, arms, legs).

A comprehensive test-bed was considered, including a total of 16 scenarios, which, together with their relevance for the current usage trends, constitute the main novelty of the work.

Results show the natural conclusion that the body parts near to the EMF source are the ones absorbing more energy. The whole body exposure to radiation emitted while using a tablet or a smartphone reveal no main differences. The child model exhibits a higher sensitivity to the frequency, as well as to the body posture.

The results from this work will be combined through an expert system to obtain quantitative values of the LEXNET global exposure index (including up- and downlinks exposure).

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References

[1] Oliveira,C., Sebastiao,D., Branco,M. and Correia,L.M, "Facts on the Usage and (Un)Awareness of Portuguese Teenagers with Mobile Phones", in *Proc. of 8th Congress of URSI Portuguese Committee*, Lisbon, Portugal, Nov. 2014.

[2] European Commission, *Electromagnetic Fields*, Special Eurobarometer 347, Wave 73.3 - TNS Opinion & Social, June 2010 (http://ec.europa.eu/public_opinion/archives/ebs/ebs_347_en.pdf).

[3] http://www.lexnet-project.eu/.

[4] *IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz*, IEEE Standards Coordinating Committee 28 on Non-Ionizing Radiation Hazards, IEEE C95.1-2005, USA, Apr. 2006.

[5] IEC, *Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices - Human models, instrumentation, and procedures - Part 1: Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (Frequency range of 300 MHz to 3 GHz)*, IEC 62209-1, 2006.

[6] 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.

[7] Rowel,C. and Lam,E., "Mobile Antenna Design", *IEEE Antennas and Propagation Magazine*, Vol. 54, No. 4, Aug. 2012, pp. 14-58.

[8] Keshvari,J. and Heikkil,T., "Volume-averaged SAR in adult and child head models when using mobile phones: A computational study with detailed CAD-based models of commercial mobile phones", *Progress in Biophysics and Molecular Biology*, Vol. 107, No. 3, Dec. 2011.

[9] *WHO Research Agenda for Radiofrequency Fields*, World Health Organization, 2010.

[10] Pelosi,M., Franek,O., Knudsen,M.B., Pedersen,G.F., "Antenna Proximity Effects for Talk and Data Modes in Mobile Phones", *IEEE Antennas and Propagation Magazine*, Vol. 52, No. 3, June 2010, pp. 15-27.

[11] Tateno,A., Tanaka,K., Nagaoka,T. and Watanabe,S., "Comparison of SAR in Human Body Radiated from Mobile Phone and Tablet Computer", in *Proc. of EMC14 - International Symposium on Electromagnetic Compatibility*, Tokyo, Japan, May 2014.

[12] CST, http://www.cst.com, May 2015.

[13] MATLAB, http://www.mathworks.com, May 2015.

[14] Techniques, Procedures, Instrumentation and Computation Working Group, *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 Std C95.3-2002 (Revision of IEEE Std C95.3-1991), 2002.

[15] ICNIRP, "Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz)", *Health Physics*, Vol. 74, No. 4, 1998, pp. 494-522.

[16] Pinto,Y.C., Varsier,N., Ghanmi,A., Hadjem,A., Conil,E., Person,C. and Wiart,J., "Numerical generic phone models validated by SAR spatial distribution resemblance criterion", submitted to *IEEE Transactions on Microwave Theory and Techniques*.

[17] Ghanmi,A., Varsier,N., Hadjem,A., Conil,E. and Wiart,J., "Design and validation of a generic LTE tablet for SAR assessment studies", in *Proc. of EuCAP 2014 - 8th European Conference on Antennas and Propagation*, La Haye, Netherlands, Apr. 2014.

[18] Benabdallah,N. (ed.), *RF System Scenarios*, 3GPP Technical Specification, No. 25.942, Ver. 2.1.1, Dec. 1999.

[19] Salo,J., Nur-Alam,M. and Chang,K., *Practical Introduction to LTE Radio Planning*, European Communications Engineering, Espoo, Finland, Nov. 2010.

[20] The Virtual Population, http://www.itis.ethz.ch/, May 2015.

[21] Faraj,N., Thiery,J.M. and Boubekeur,T., "VoxMorph: 3-Scale Freeform Deformation of Large Voxel Grids Shape Modelling", *Computer & Graphics Journal*, Vol. 36, No. 5, 2012, pp. 562-568.