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Hybrid approach of the measurement of actual head EMF exposure

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Abstract

With the widespread deployment of communication infrastructures, concerns about human exposure to electromagnetic fields (EMF) have grown significantly. One major component of this exposure is uplink emissions, which refer to the radiofrequency (RF) signals transmitted from a mobile phone to a base station. Here in this work, we adopt the indirect measurement method, by leveraging the information provided by the phone chipset. The measurement campaign is designed and conducted to cover different network technologies, services, by using the equipment called Nemo from Keysight. Afterwards, the transmit power, as well as the other relevant parameters, are extracted and analyzed. The head exposure is calculated by synthesizing the measured data and developed transfer function.

Résumé

Avec le déploiement généralisé des infrastructures de communication, les préoccupations concernant l'exposition humaine aux champs électromagnétiques (CEM) ont considérablement augmenté. Une composante majeure de cette exposition est constituée par les émissions montantes, qui correspondent aux signaux radiofréquences (RF) transmis d'un téléphone mobile à une station de base. Dans ce travail, nous adoptons la méthode de mesure indirecte, en exploitant les informations fournies par la puce du téléphone. La campagne de mesures est conçue et réalisée pour couvrir différentes technologies et services réseau, à l'aide de l'équipement Nemo de Keysight. La puissance d'émission, ainsi que les autres paramètres pertinents, sont ensuite extraits et analysés. L'exposition de la tête est calculée en synthétisant les données mesurées et en développant une fonction de transfert.

1 Introduction

Usually the assessments of radio frequency (RF) electromagnetic field (EMF) exposure is categorized into downlink and uplink. Unlike downlink exposure, which originates from base station antennas and affects a broader area, uplink exposure, which are the emissions from phones, can't be directly measured in situ, as body interactions (reflection, absorption) alter the fields. Their high spatial variability also makes localized measurements unreliable for estimating tissue absorption.

Furthermore, the complexity in modern mobile phones, diverse user scenarios and duration, make the assessment of uplink exposure more difficult. The uplink transmit power varies with factors like network architecture, wireless technology, and application type. To tackle it, a probe placed next to the phone can be used to evaluate the power emitted [1]. However distributed antennas in the mobile phone makes it more challenging to measure the phone's radiated power accurately. In this work, we use the network-based tool, Nemo from Keysight, to measure the transmit power from phone's chipset.

To address the challenges of direct EMF measurement, the EXPLORA project aims to characterize EMF exposure from mobile phones on French networks during voice calls and data use via an indirect method. Phones were tested in various positions to reflect typical usage, across 300 locations in the greater Paris area, ranging from rural to dense urban settings, to ensure diverse environmental representation. A balanced selection of the four main French operators was included for comprehensive and unbiased results. Measurements were taken in different scenarios: near the ear for calls and 30 cm from the body for data use.

Subsequently, the measured phone's transmitted (TX) power are used to evaluate organ-level exposure across various environments, networks, and postures with the help of SAR. SAR is calculated via numerical electromagnetic methods like the Finite-Difference Time-Domain (FDTD) technique. Here in this paper, digital models of the phone and human body were used for simulation. SAR estimation was performed using Sim4Life software and the Duke model from the Virtual Family, with phone placement mimicking real-world usage (at the ear for calls, in front of the user for data).

2 Measurement description

2.1 Measurement device

NEMO, a system by Keysight, enables indirect measurement of mobile phone TX power by accessing data from the telecom processor, including emitted power, frequencies, and data rates. Drive test equipment modifies the phone's OS to log these parameters, e.g., every 500 ms on Qualcomm chipsets. NEMO Handy, an Android app, captures wireless diagnostics per 3GPP standards. This method is adopted in this paper for independent assessments of real TX power across varied environments and mobility scenarios.

A phantom is utilized in the measurement as shown in Figure 1. The phantom consists of a head model and a right hand model, both filled with standardized equivalent liquid in compliance with IEC standards. The experimental protocol, similar as used in [2], includes two configurations: the first is designed for voice calls with the cell phone positioned adjacent to the phantom head, while the second, with the phone placed in front of the head, is intended for data transmission. During the measurement, 4G and 5G bands are locked respectively to compare the difference between two. Applications including VoCS, VoIP, Video call, FTP file uploading are used in the measurement protocol.

Figure 1: Phantom placement and measurement protocol

2.2 Measurement protocol

A dedicated measurement protocol was implemented (see Table 1). Voice call attempts lasted 15 seconds, with a maximum call duration of 150 seconds. The protocol involved band-locking GSM (900 MHz) for a 30-second VoCS call, then UMTS (900 or 2100 MHz) for 30-second VoCS and VoIP (WhatsApp) calls, followed by LTE (700–2600 MHz) for similar calls, with bands selected based on local base station services. To simulate speech transmission—important for technologies with discontinuous transmission—a standard text was read into a nearby microphone. For data, each attempt lasted up to 60 seconds, transmitting a 70 MB file via SFTP over UMTS and LTE, with frequency bands locked accordingly.

Nemo Commands	User Posture	Time	Attempt Timeout
Bandlock GSM	Ear-Holding		
Default Voice Call		30s	15s
Bandlock UMTS			
Default Voice Call		30s	15s
WhatsApp Voice Call		30s	15s
Bandlock LTE			
Default Voice Call		30s	15s
WhatsApp Voice Call		30s	15s
Change Posture			
Bandlock UMTS	Face-Viewing		

FTP Data Upload 70 MB		<150s	60s
Bandlock LTE			
FTP Data Upload 70 MB		<150s	60s

Table 1: Measurement protocol

3 Transfer Function

Using the numerical human model Duke and the numerical phone model, the SAR in organs and part of the body have been calculated. We first determine the power applied to the antenna that induces 1 W/kg, then estimate the SAR in any organ based on the SAR induced by the numerical phone operating at maximum output. Using Nemo, we record the maximum power emitted throughout the entire call and compare the actual emitted power to this maximum. The Table 2 provide the transfer function of a power emitted to the SAR in brain and whole body. As described previously the power emitted by the phone is considered as the maximum and is inducing a SARover10g equal to 1w/kg.

Voice Position				
	Brain Grey-matter	Brain white-matter	Head	Whole body
900 MHz	0.99	1.57	9.81	2.33
1.8 GHz	1.31	0.62	3.64	0.61
2.1 GHz	0.81	0.33	4.34	0.74
2.6 GHz	0.22	0.09	2.11	0.47
3.5 GHz	0.13	0.04	1.32	0.38
In Front of eyes				
	Brain Grey-matter	Brain white-matter	Head	Whole body
900 MHz	0.38	0.24	0.37	2.32
1.8 GHz	0.01	0.01	0.026	0.55
2.1 GHz	0.008	0.004	0.031	0.61
2.6 GHz	0.004	0.002	0.016	0.48
3.5 GHz	0.002	0.00093	0.017	0.26

Table 2: Transfer function for two positions

4 Results and Discussion

4.1 Tx power analysis

The total call durations for VoIP and VoLTE were 20.4 min at 700 MHz, 18.2 min at 800 MHz, 27.3 min at 1800 MHz, 13.1 min at 2100 MHz, and 25.7 min at 2600 MHz. In case of VoLTE the total call durations were 20.3 min at 700 MHz, 17.7 min at 800 MHz, 33.7 min at 1800 MHz, 13.6 min at 2100 MHz, and 22.7 min at 2600 MHz. These call durations were obtained from 40, 35, 61, 27, and 45 calls conducted over VoIP and VoLTE on 700 MHz, 800 MHz, 1800 MHz, 2100 MHz, and 2600 MHz bands, respectively. As a result, the calls on the 2100 MHz band are less representative compared to those on the 1800 MHz and 2600 MHz bands.

Figure 2 presents the average TX power of VoLTE and VoIP across the 700 MHz, 800 MHz, 1800 MHz, 2100 MHz, and 2600 MHz frequency bands. As shown in Figure 2, at 700 MHz, the average TX power for VoIP and VoLTE were 13.4 mW and 14.5 mW, respectively. At 800 MHz, the TX power for VoIP and VoLTE were 15.7 mW and 15.8 mW, respectively. In the 1800 MHz band, where large number of measurements were taken, the average TX power for VoIP and VoLTE were 4.9 mW and 9.3 mW, respectively. At 2100 MHz, the TX power for VoIP and VoLTE were 4.9 mW and 6.5 mW, respectively. Finally, at 2600 MHz, the TX power for VoIP and VoLTE were 18 mW and 20.6 mW, respectively. The average TX power values vary significantly across different frequency bands, with VoLTE generally exhibiting higher power levels than VoIP.

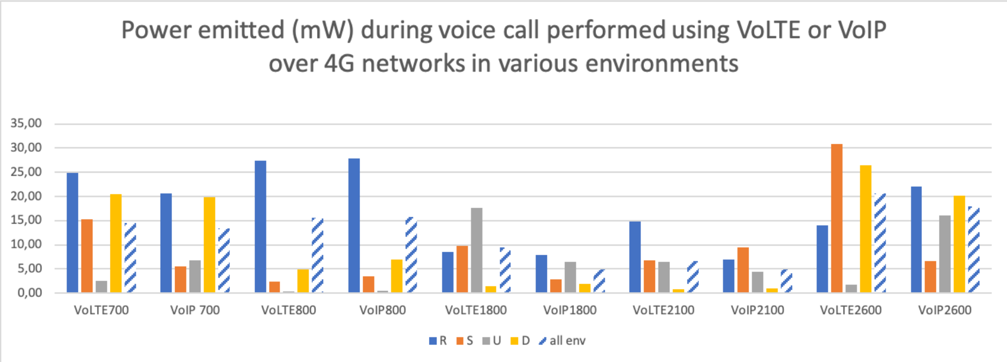

Figure 2. TX power (mW) of VoLTE and VoIP over LTE networks. R, S, U, D represent Rural, Suburban, Urban, and Dense Urban environments.

To assess the TX power during data transmission, we employed the SFTP protocol to transfer a 70 MB file. As illustrated in Figure 3, the average TX power measured on the 700 MHz, 800 MHz, 1800 MHz, 2100 MHz, and 2600 MHz bands was 89 mW, 171 mW, 107 mW, 114 mW, and 95 mW, respectively. The duration of the transmission varied depending on the throughput at the specific time and location of the measurements. For the conducted measurements, the average transmission durations corresponding to the aforementioned frequency bands were 1.63 minutes, 1.51 minutes, 1.18 minutes, 1.25 minutes, and 1.33 minutes, respectively.

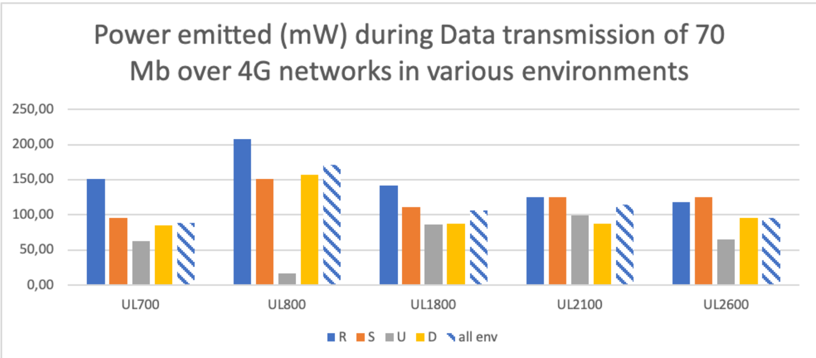

Figure 3. Emitted power(mW) during DATA transmission of 70 MB over 4G networks in various environments. R, S, U, D represent Rural, Suburban, Urban, and Dense Urban environments.

5 Conclusion

In conclusion, this paper provides a robust and realistic assessment of EMF exposure from mobile phones in France by combining extensive field measurements with advanced numerical simulations. By measure uplink TX power in different usage scenarios across diverse environments and network types, and estimating SAR using validated human and device models, the study offers valuable insights into real-world exposure levels. This indirect approach effectively overcomes the limitations of direct in-situ measurements, enabling a comprehensive evaluation of organ-level exposure and supporting informed risk assessment in mobile phone usage.

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