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SMART MANAGEMENT

24-Hour Temporal Variation of Indoor RF-EMF Downlink Exposure for Cellular Bands

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Abstract/Résumé

Wireless communication has been a part of human life and it is continuously evolving. Over the past decade, there has been a growth in cellular network traffic due to a significant increase in the usage of wireless communication devices. With the usage of these devices, the assessment of human exposure to radio-frequency electromagnetic field (RF-EMF) has now become very important due to public risk perception. The human exposure to RF-EMF at a given location exhibits variation in the time domain due to the dynamic nature of radio channels and traffic. With much spectrum having been re-farmed to new generation of technologies, it is necessary to investigate the time variability of each cellular band. This paper investigates the average 24-hour time variability of each cellular band by collecting one-week of measurement data using frequency selective measurement system at a stationary position in an indoor environment, which is located within a few hundred meters vicinity of two base station sites with several cellular antennas (2G, 3G, 4G and 5G) from four operators. We analyze the trend in the average 24-hour time variation of RF-EMF downlink (DL) exposure averaged per minute and per hour for each cellular band where the variation pattern depends on the cellular technologies being utilized. As a conclusion, the RF-EMF downlink (DL) exposure is higher during daytime than at night due to the increased cellular usage. Moreover, the 700 MHz, 2600 MHz and 1800 MHz bands dominate the variation pattern of the total RF-EMF DL exposure as they have higher contribution to the total RF-EMF DL exposure.

1 Introduction

Since the initial arrival in the late 1970s, cellular networks and technologies have evolved considerably with no signs of slowing down to meet ever-increasing demands and rising specification requirements [1]. This rapid evolution of radio technologies is always accompanied with public risk perception of radio frequency electromagnetic field (RF-EMF).

When a new generation (i.e., 4G/5G) network is introduced, the mobile traffic will gradually migrate from the older generation (i.e., 2G/3G) networks to the new one [2]. This opens up an opportunity to use the older generation spectrum for the new one using an innovative technique called spectrum refarming that supports different generations of cellular networks to operate in the same radio spectrum [3]. Some studies have investigated the short-term time variability of RF-EMF exposure [4-8]. These studies did not consider spectrum refarming as their studies were based on the technology (e.g., GSM in [7], GSM and UMTS in [4-6], GSM, UMTS and LTE in [8]).

In this study, we investigate the average 24-hour time variability trend and contribution percentage of each cellular band to the total indoor RF-EMF DL exposure. One-week measurements were conducted at a stationary position in a building. The building is located within a few hundred meters vicinity of two base station sites with several cellular antennas (2G, 3G, 4G and 5G) from four operators. First, we compute the average 24-hour temporal variation of E-field averaged per minute and per hour for each cellular band to compare the time variability trend of each band with the total RF-EMF DL exposure. Next, we compute the contribution percentage of each band to the total RF-EMF DL exposure. Afterwards, we analyze the variability of all bands and the total RF-EMF DL exposure. Finally, we analyze the results in order to consider spectrum refarming.

The remainder of this paper is organized as follows; we present the measurement equipment and the measurement description in Section 2. In Section 3, we analyze the results. Finally, we conclude with Section 4.

2 Measurement description

The frequency selective measurement system used in this study consists of a Tektronix RSA306B real-time spectrum analyzer, switch, Arduino-based hardware, tri-axis E-field probe and a PC that runs Tektronix SignalVu-

PC™ RF signal analysis software and a graphical user interface (GUI) to control the measurement parameters as shown in Figure 1. A Tri-axis E-field probe, commercialized by Microwave Vision Group (MVG) as TAS-1208-01, is connected to the 'one-port' spectrum analyzer through a switch, which is controlled by Arduino-based hardware. The electric field (E-field) is the root-mean square of the measurement on each axis. Our frequency selective measurement system allows measurement from 9 kHz to 6.2 GHz.

Figure 1: Frequency selective measurement system installed at a stationary position

We continuously measured the electric field strength at a stationary position in the indoor environment for one week with a probe fixed at the height of 1.5 m to assess the E-field level and then analyze the average 24-hour time variation of RF-EMF DL exposure for each frequency band.

3 Result and discussion

The base stations, which are located near the building, support several cellular antennas (2G, 3G, 4G and 5G) of four operators. Of the new generation networks, 5G operates on multiple bands (700 MHz, 2100 MHz and 3500 MHz) and LTE operates on all bands except 900 MHz and 3500 MHz bands [9]. Whereas, 2G and 3G operate on 900 MHz band. The electric field of each band ($E_i(t)$) is measured on each axis (Ex_i (t), Ey_i (t) and Ez_i (t)) and the total electric field is computed using Equation (1).

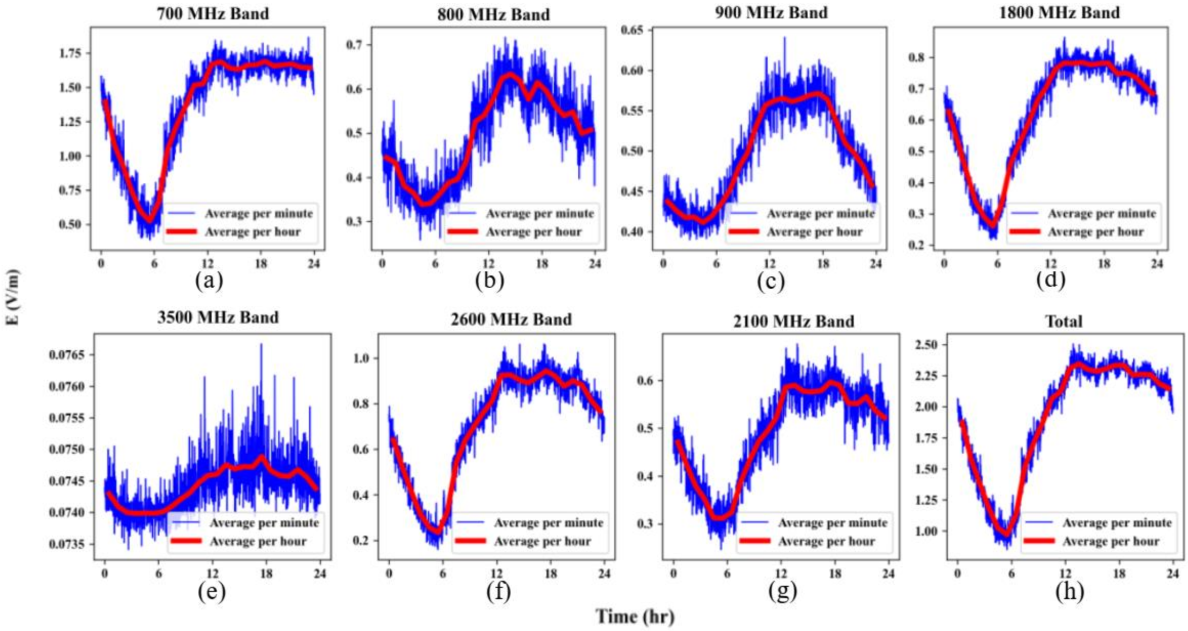

Figure 2: Time variation of E-Field for cellular bands in 24 hours

$$Total\ (t) = \sqrt{\sum_{i \in f} E_i^2(t)} \tag{1}$$

where f = {700 MHz, 800 MHz, 900 MHz, 1800 MHz, 2100 MHz, 2600 MHz, 3500 MHz} and

$$E_i(t) = \sqrt{Ex_i^2(t) + Ey_i^2(t) + Ez_i^2(t)}$$

Figure 2 shows the average 24-hour temporal variation of E-field averaged per minute and per hour for each cellular band. The trends of all bands' exposure levels look similar, which decrease at night and then increase during the daytime due to the significant increase of cellular usage. The trend of the temporal variation depends on the cellular technologies that are utilized on each frequency band as each mobile communication technology has its own technique to adapt and exploit the radio channel and traffic variations. Among all the technologies, LTE bands provide significant contributions to the total RF-EMF DL exposure, e.g., 700 MHz, 2600 MHz and 1800 MHz bands. They dominate the trend of the total RF-EMF DL exposure.

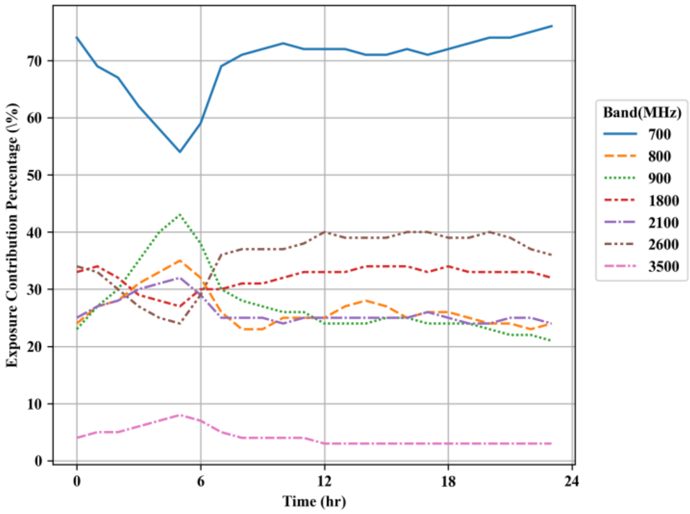

Figure 3: Time variation of contribution percentage of each band in 24 hours

Figure 3 shows that the contribution percentage of each band to the total RF-EMF DL exposure is almost constant from 7 am to midnight. We identified that the 700 MHz band has the highest the contribution percentage to the total exposure in 24 hours and most of the exposure comes from 4G network.

Table 1: The mean (μ), standard deviation (σ) and the coefficient of variation (σ/ μ) of each band during different hours of a day where the unit of both μ and σ is V/m

Band	Morning		Afternoon		Evening		Night	
	μ(σ)	σ/ μ	μ(σ)	σ/ μ	μ(σ)	σ/ μ	μ(σ)	σ/ μ
700 MHz	0.97(0.23)	0.24	1.59(0.1)	0.06	1.67(0.01)	0.01	1.07(0.42)	0.39
800 MHz	0.38(0.01)	0.03	0.57(0.06)	0.11	0.56(0.02)	0.04	0.41(0.06)	0.15
900 MHz	0.45(0.02)	0.04	0.55(0.02)	0.04	0.53(0.03)	0.06	0.43(0.02)	0.05
1800 MHz	0.44(0.08)	0.18	0.74(0.07)	0.09	0.75(0.02)	0.03	0.49(0.17)	0.35
2100 MHz	0.38(0.04)	0.11	0.56(0.04)	0.07	0.56(0.02)	0.04	0.41(0.08)	0.20
2600 MHz	0.50(0.13)	0.26	0.86(0.08)	0.09	0.89(0.02)	0.02	0.50(0.21)	0.42
3500 MHz	0.07(0.0002)	0.003	0.07(8×10^{-5})	0.001	0.07(5×10^{-5})	0.0006	0.07(0.0002)	0.003
Total	1.45(0.24)	0.17	2.22(0.15)	0.07	2.28(0.03)	0.01	1.54(0.45)	0.29

In Table 1, we provide the coefficient of variation (CV), which is the ratio of the standard deviation to the mean, to show the level of dispersion around the mean. The higher the CV, the greater the level of dispersion around the mean. The 3500 MHz band is almost constant throughout a day as insignificant traffic is present on this band. In the morning and at night, we have higher variability on other bands, except 900 MHz, due to low cellular usage in these periods of the day. The variability of all bands in the afternoon and in the evening is lower with relatively higher mean values as there are higher cellular usages during these periods of the day.

4 Conclusion

This paper analyzes the average 24-hour time variability of RF-EMF DL exposure inside a building with nearby cellular antennas located at few hundred meters away. One-week measurement has been conducted at a stationary position inside the building with the probe fixed at the height of 1.5 m to assess the average 24-hour time variation of DL exposure for each cellular band in order to consider spectrum refarming.

The RF-EMF DL exposure is higher during daytime than at night due to the increased cellular usage. Most of the exposure comes from the 4G network and 700 MHz band has the highest contribution to the total RF-EMF DL exposure. The variability of all bands in the afternoon and in the evening is lower with relatively higher mean values as there are higher cellular usages during these periods of the day.

As RF-EMF exposure exhibits variation in time domain due to the dynamic nature of radio channel and traffic, it is important to have a reference measurement during spatial measurements in order to take the scope of such variations of each band into account and normalize the spatial measurements.

References

[1] N. Bhandari, S. Devra, and K. Singh, "Evolution of cellular network: from 1g to 5g," International journal of engineering and techniques, vol. 3, no. 5, pp. 98–105, 2017.

[2] "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013–2018," White Paper, Cisco, San Jose, CA, USA, 2014.

[3] S. Han, Y.C. Liang, and B.H. Soong, "Spectrum Refarming: A New Paradigm of Spectrum Sharing for Cellular Networks," IEEE transactions on communications, vol. 63, no. 5, pp. 1895–1906, 2015.

[4] W. Joseph, L. Verloock, E. Tanghe, and L. Martens, "In-situ measurement procedures for temporal rf electromagnetic field exposure of the general public," Health physics, vol. 96, no. 5, pp. 529–542, 2009.

[5] Z. Mahfouz, A. Gati, D. Lautru, M.-F. Wong, J. Wiart, and V. F. Hanna, "Influence of traffic variations on exposure to wireless signals in realistic environments," Bioelectromagnetics, vol. 33, no. 4, pp. 288–297, 2012.

[6] Z. Mahfouz, L. Verloock, W. Joseph, E. Tanghe, A. Gati, J. Wiart, D. Lautru, V. F. Hanna, and L. Martens, "Comparison of temporal realistic telecommunication base station exposure with worst-case estimation in two countries," Radiation protection dosimetry, vol. 157, no. 3, pp. 331–338, 2013.

[7] G. Vermeeren, I. Markakis, F. Goeminne, T. Samaras, L. Martens, and W. Joseph, "Spatial and temporal rf electromagnetic field exposure of children and adults in indoor micro environments in belgium and greece," Progress in biophysics and molecular biology, vol. 113, no. 2, pp. 254–263, 2013.

[8] L. Verloock, W. Joseph, F. Goeminne, L. Martens, M. Verlaek, and K. Constandt, "Temporal 24-hour assessment of radio frequency exposure in schools and homes," Measurement, vol. 56, pp. 50–57, 2014.

[9] ANFR, "The map of radio sites and wave measurements." https://www.cartoradio.fr/.