Evaluation of electromagnetic field exposure in indoor spaces where there are located base stations with distributed antenna system

1st Marius Nedelcu[1,2], 2nd Victor Nițu[1], 3rd Teodor Petrescu[2]
[1] First Affiliation: Technology Department, Orange Romania, Bucharest, Romania
marius.nedelcu@orange.com , victor.nitu@orange.com
[2] Second Affiliation: Telecommunications Department, University Politehnica of Bucharest, Bucharest, Romania
teodor.petrescu@upb.ro

***Abstract*— In the context of the future development of the 5G (fifth generation) network, this paper focuses on assessing the level of exposure to electromagnetic field generated by mobile telephony stations installed inside buildings. A number of 60 broadband measurements of the power density of the ambient electromagnetic field were performed and the maximum exposure coefficient was calculated as a percentage value in shops belonging to Orange Romania. We also proceeded to the measurement of two office buildings in which the distributed antenna systems are larger than in the case of shops. In this case the measurements were made with a narrowband device with which it was possible to measure the contribution of each technology. For each site power density measurements were made based on the maximum exposure reference values for each technology and the total exposure coefficients were calculated under the hypothesis that the stations would emit at maximum power. The results showed that the exposure to the environmental field in shops is low, being 5 times lower than the reference value in over 90% of cases. In the office premises, where the maximum possible exposure coefficient was estimated, values of over 40% of the reference level were also highlighted, which in the context of 5G installation, if the emission powers are not reduced, could lead to values of the total exposure coefficient that would approach 100% of the reference level.**

I. INTRODUCTION

During the campaign for measuring the coefficient of exposure to environmental electromagnetic field in the vicinity of mobile telephony stations (with macro or micro coverage) located within inhabited areas, launched by Orange Romania in 2018, it was found that in 4 of the 1750 measurements, the maximum exposure coefficient had significantly higher values compared to the others, although still well below than the maximum allowed levels. Following the punctual analysis of these values, it was observed that the measurement points were a few meters from the access doors of some buildings where indoor mobile telephony sites operated. This aroused the interest of performing some measurements in buildings where indoor stations with a distributed antenna system operate, especially in the context in which Orange Romania wants to expand the 5G network.

Besides the mobile telephony stations installed on specifically design towers or on rooftops, which makes them the most visible mobile stations, there are also indoor stations with a distributed antenna system inside some buildings. They are installed inside buildings when the macro station serving outside cannot take over the large voice and data traffic generated by users inside the building or cannot ensure good signal coverage due to high penetration losses.

In 2019, the exposure to the ambient electromagnetic field was evaluated by measuring with a broadband measuring device the power density inside 60 Orange shops where indoor sites were installed. In March 2021, using a selective frequency measuring device, the case of two office buildings utilized by Orange Romania was analyzed. Starting from the measured values the maximum exposure coefficient was estimated under the purely hypothetical conditions in which all technologies would work at maximum load. In each office building there is a distributed antenna system consisting of antennas, splitters, tapers and cables.

The results obtained were compared with the reference levels. According to the Order of the Minister of Health and Family 1007/2002, completed by Order 1193/2006, the reference levels in Romania are those provided in the limitations imposed by the ICNIRP (International Committee on Non-Ionizing Radiation Protection) standard. ICNIRP is a non-governmental organization with the definite purpose of protecting the population against non-ionizing radiation, following the studies published in the literature and establishing, based on them, the maximum exposure limits. The ICNIRP standard divides the limits of exposure to non-ionized radiation into two categories: the general public and the people working with non-ionizing radiation sources. The first category, of the general public, includes individuals of all ages and with different health conditions, who are not necessarily informed about the ambient electromagnetic field and do not take any measures to protect against radiation. The second category, of the people working with radiation sources, is aware of the effects of the electromagnetic field and ensures that radiation protection measures are taken. [1]

II. METHODOLOGY FOR MEASURING

A. *Measuring instruments*

There are 2 major types of electromagnetic field measuring devices: broadband measuring devices and selective frequency and narrowband code measuring devices.

Those in the first category are used for general measurements, when it is desired to validate the observance of the standards, in which case the measured values must be related to the minimum limit defined for the frequency range measured by the device. The second category of devices are those that can select a narrow band, convenient for performing field measurements. They are in fact spectral analyzers that extract the values corresponding to each frequency from the analyzed band by processing the signal received from the electric or magnetic field probe. Narrowband instruments are used when greater sensitivity is required.

Although selective frequency measurement solves many of the problems of broadband measurements, it is still extremely difficult to clearly identify the share of exposure caused by different transmitters for the same frequency.

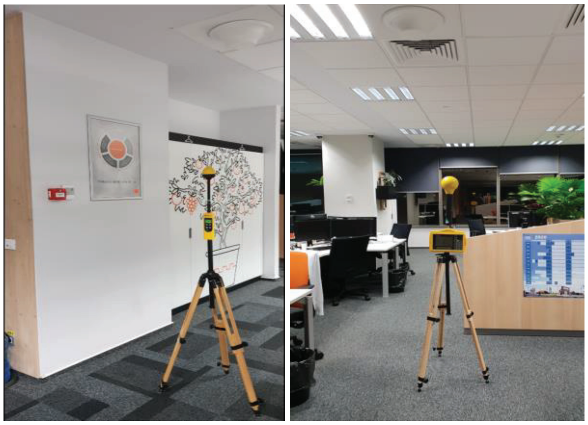
For systems where all base stations emit in the same frequency channel (like 3G or 4G), selective measurements in code are particularly useful because frequency-selective receivers cannot identify energy from different base stations. Selective receivers in the code are able to decode the signal emitted by each source and can separate the signal of interest from the rest of the sources.

Narrowband measurement provides more accurate results, which is why if two measurements performed in the same place, one in broadband and the other in narrowband, have different results, narrowband measurement is always considered. [2]

In the case of the 60 shops, the measurements were made according to the "rapid evaluation" method.

The broadband measuring installation used consists of an electric field probe and an electronic module for processing and displaying data received from the probe. A Narda NBM-520 electronic broadband module was used to which a Narda RF 1891 triaxial electric field probe with a band of 3 MHz – 18 GHz was connected. Using a triaxial probe, the measurement is made independently of the polarization of the transmitter. The mediation time was considered according to the ICNIRP requirements of 6 minutes and the physical quantity in which the field value was expressed is the power density. The measurement analyzer has been set to measure the maximum values recorded in the measurement time range. In order not to disturb the process, the probe was installed at a height of approximately 1.7 meters from the floor on a non-conductive tripod. In Fig. 1(a), the broadband measuring installation is presented. The measurements were centralized in a report containing the measured value for each point, temperature, humidity and calendar date.

For the two offices, the “Band Investigation” method was used. The measurements were performed based on the procedures presented previously and using the SRM-3000 spectral analyzer and a triaxial electric field probe, with the band 75 MHz – 3 GHz. The measuring analyzer was set to measure the maximum values, the measurement time for each point was about 6 minutes and the physical quantity in which the field value was expressed is the power density. The measuring installation was mounted on a non-conductive tripod with the probe positioned at a height of approximately 1.7 meters from the floor. Fig. 1(b) shows the narrowband measurement installation.



(a) **(b)**

Figure 1. Measuring system: **(a)** Broadband; **(b)** Narrowband

B. *Measurement methods*

Having magnetic and electrical properties, metals can interact with the electromagnetic field and can couple with the probe we use. It is thus necessary to keep a distance from metal objects. The measuring instruments must be placed on a non-conductive surface and the person performing the measurements must not stand next to the instruments. [2]

The ECC (02)04 Recommendation, prepared by the Electronic Communications Commission of the European Conference of Postal and Telecommunications (CEPT) presents the measurement of non-ionizing electromagnetic fields in the frequency range 9 kHz – 300 GHz in order to validate the observance of the available limits. The recommendation only describes how to measure human exposure to electromagnetic fields, without imposing any limits. [3]

In the case of mobile telephony systems, each station is equipped with one or more technologies, most stations being equipped with all 3 technologies licensed nationally (GSM (Global System for Mobile Communications), UMTS (Universal Mobile Telecommunications System) and LTE (Long-Term Evolution)).

The GSM system uses a transmit / receive unit (Transceiver - TRX) for each channel. Each cell is assigned a number of channels depending on the traffic. The channel on which the Broadcast Control Channel (BCCH) beacon signal is broadcast is the most important channel because it is used to transmit to all mobile subscribers the general system information about the cell in which the mobile terminal is located and the neighboring cells. The BCCH is always emitted at the maximum power set for the respective cell. The other logical channels used for traffic (TCH – Traffic Channel) are subjected to a power control algorithm, either on the same frequency as the BCCH or on the other frequencies of the cell. After a few iterations, the station performs an adaptation of the transmission power so that with the minimum power necessary to ensure the connection with the mobile terminal is reached. Using a spectral analyzer, the exposure measurement caused by the GSM mobile telephony stations is performed in the entire GSM transmission band on the downlink path in 900 MHz (925 – 960 MHz), and the resolution will be set corresponding to the width of a GSM channel, i.e. 200 kHz. To estimate the maximum exposure, the analyzer must be set to MAX HOLD mode and measure for 6 minutes in order to make a sufficient number of sweeps of the investigated band.

To estimate power density when a GSM cell emits at maximum power on all channels ($S_{\text{est\_G}}$), the power density measured on the BCCH frequency ($S_{\text{meas BCCH}}$) is multiplied by the number of transmitting/receiving units (n_{TRX}), using (1).

$$S_{\text{est\_G}}=S_{\text{meas BCCH}}*\ n_{\text{TRX}} \tag{1}$$

The UMTS system uses a single carrier for the transmission of all channels, the separation of channels being done by orthogonal codes. The station does not emit with a constant power, but a dynamic allocation takes place depending on the cell load and the needs of each user. Improvements to the analyzers have made it possible to decode and measure the pilot channel. In this way the measurement process was significantly simplified, the analyzer displaying the spreading code, the instantaneous level and the maximum level measured during a session. For accuracy, the measurement must be performed for each carrier, the center frequency of the measured signal must be as close as possible to the center frequency of the carrier.

Using an analyzer that can decode and measure the exclusive contribution of the pilot channel, estimating the power density ($S_{\text{est\_U}}$) in the conditions in which a cell emits with maximum power in the whole band is done using (2) and involves measuring the power density (S_{meas}) of the pilot and multiplying by 10, because the power assigned to the pilot is usually set to 10% of the total power of the measured cell.

$$S_{\text{est\_U}}=S_{\text{meas}}*10 \tag{2}$$

Similar to CDMA networks, all base stations in LTE networks work in the same frequency channel. The signals of the different cells cannot be separated by spectral measurement. The analysis of the maximum exposure can be done in two ways, depending on the measuring device with which the investigation is done. The first method involves the use of a modern analyzer with a decoder, which measures only the reference signals RS (Reference Signal) transmitted by the base station at a constant power and then extrapolates to estimate the maximum exposure. The second method, which was used for this analysis, involves the use of a spectral analyzer without decoder and takes into account the fact that the primary and secondary synchronization signals (P-SS - Primary Synchronization Signals and S-SS - Secondary Synchronization Signals) as well as the Physical Broadcast Channel (PBCH) are transmitted with the same characteristics regardless of the configuration or bandwidth of the service and extend over a 1080 kHz bandwidth (72 subcarriers of 15 kHz) set to the central frequency of the LTE channel. Only these subcarriers will be measured with the analyzer set to MAX HOLD and then, to determine the estimated power density ($S_{\text{est\_L}}$) according to (3), the measured value (S_{meas}) will be interpolated with a factor m which is calculated according to the bandwidth of the LTE carrier. The values of the factor m can be found in Table l.

$$S_{\text{est\_L}}=S_{\text{meas}}*m \tag{3}$$

TABLE I. THE THEORETICAL EXTRAPOLATION FACTOR, *m*

LTE channel bandwidth [MHz]	***m***
1.4	1
3	2.5
5	4.16
10	8.33
15	12.5
20	16.66

C. *Choice of measurement points*

In each of the 62 locations there is a distributed antenna system consisting of antennas, combiners, power dividers (splitters and/or tappers) and cables. Antennas usually have a horizontal omnidirectional directivity pattern and are mounted on the ceiling, but there have been a few cases where the antennas used were panel antennas, which are wall-mounted directional antennas with a maximum gain of 7dBi.

Antennas used in measured indoor systems operate in wide frequency bands, which is why the same antenna system is used for several bands and telephone systems. GSM, UMTS and LTE stations use the same distributed antenna system.

The measurement points should be chosen where, relative to the position of the antennas, the exposure for a person is maximum. To find the place, either the field is measured in different points or it is calculated based on the theoretical propagation model.

For each of the 60 Orange shops, the measurements were made at a single point at a horizontal distance of 1-1.5 meters from the antenna.

For the 2 offices, the chosen points were divided into two main categories:

- at 1 - 3 m from the antenna in horizontal plane, considered the area in the immediate vicinity of the antennas
- at 5 - 20 m from the antenna in horizontal plane, considered the remote area

The frequencies used by the transmission systems are higher than 800 MHz, which leads to a close reactive field that extends up to 37.5 cm of antennas, which is why we can consider that all measurements were made in the area where the plane wave model can be used.

III. RESULTS AND THEIR INTERPRETATION

The physical quantity in which the expression of the measured value of the field was chosen is the power density. In Romania, the basic restrictions governing exposure to electromagnetic field emissions for frequencies up to 300 GHz were established by the Order of the Minister of Public Health 1007/2002, then supplemented by the Order 1193/2006, which are based on the ICNIRP document [1] that sets for the first time the maximum allowable power density limit as a function of frequency, as can be seen in Table II.

TABLE II. POWER DENSITY REFERENCE LEVELS

Frequency	Power density [W/m^2]
10 – 400 MHz	2
400 – 2000 MHz	f/200
2 – 300 GHz	10

In the case of shop measurements the maximum estimated environmental exposure coefficient expressed as a percentage of the regulated limits was calculated using (4) below. The measured values were reported to the lowest reference value provided by national legislation for the general public in the case of systems mobile telephony. Based on the data in Table II, and the information related to the radio configurations of the installed systems, the 800 MHz LTE system operating on the downlink in the frequency band 806 – 816 MHz, determines 4.03 W/m^2 as the lowest value of power density reference.

$$C_{\text{exp\_max}}[\%]=S_{\text{meas}}/4.03*100 \tag{4}$$

Fig.2 illustrates the cumulative distribution function (CDF) of the 60 values of the maximum exposure coefficients measured. As can be seen, over 90% of the coefficients are below 17% of the limits provided by ICNIRP (where 100% is equivalent to reaching the power density value of 4.03 W/m^2), meaning over 5 times lower. The average of the values of the coefficients is of approximately 6.59% and 74% of the measurements are below 10% of the reference value. The maximum level recorded was of 23.28%, which is more than 4 times lower than the minimum reference level.

The system in the first headquarters, hereinafter referred to as "EH" (Europa House), is a medium-sized one, with 8 antennas distributed on 2 floors (4 antennas on each floor), connected by approximately 500 m of cable. The second headquarters, called "Skanska", contains 24 antennas and just over 1000 m of cable. In the system from "Skanska", as well as in the one from "EH" there are inserted a GSM station with 1 TRX operating in the 900 MHz band, a UMTS station that broadcasts on a single carrier in the 2100 MHz band and an LTE station that transmits on 2 carriers of 20 MHz in the 1800 MHz and 2600 MHz bands, respectively. In addition to the stations present in the buildings, there are also GSM, UMTS and LTE macro stations belonging to Orange, Vodafone and Telekom, but their contribution in the measured value is negligible. The measurements were not affected by interference from other radiant electromagnetic field sources present in the test buildings.

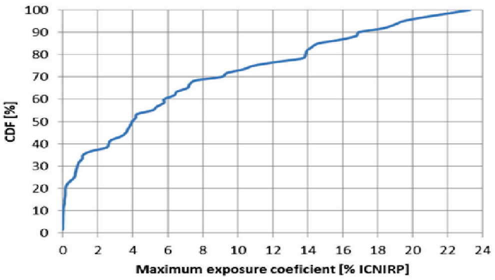


Figure 2. Cumulative distribution function of indoor shops measurements

Using the SRM-3000 spectral analyzer, in a first phase the BCCH channels of the GSM stations in each building were identified, the power densities measured on these channels being the same with the maximum estimated values of the power density generated by the GSM stations due to the fact that each GSM station has a single TRX. In the case of UMTS stations, they emit on a single carrier with the central frequency 2142.6 MHz, the pilot channels were decoded, the maximum power density measured on these channels was multiplied by 10 to obtain the maximum estimated power density if the station would emit at maximum power. For the LTE system, only the carriers on which the primary and secondary synchronization signals are transmitted as well as the physical broadcast channel were measured. They are transmitted with the same characteristics regardless of the configuration or bandwidth of the service and extend over a bandwidth of 1080 kHz (72 subcarriers of 15 kHz) mounted on the central frequency of the LTE carrier. To determine the maximum exposure, the measured power density was interpolated by a factor $m = 16.66$, corresponding to the 20 MHz bandwidth. The center frequencies of the LTE bands on which the analyzed stations broadcast are 1845.1 MHz and 2640.1 MHz, respectively.

For each measurement point, in each location, the maximum estimated exposure coefficient was calculated for each technology, using (5), (6) and (7). The maximum estimated coefficient was expressed as a percentage of the maximum allowed limit for the frequency. It was considered useful to present the maximum estimated total exposure coefficient at each measurement point. Its calculation involved summing up the estimated coefficients for each technology

$$C_{\text{exp\_max\_G}}[\%]=S_{\text{est\_G}}/\ S_{\text{ref\_G}}*100 \tag{5}$$

$$C_{\text{exp\_max\_U}}[\%]=S_{\text{est\_U}}/\ S_{\text{ref\_U}}*100 \tag{6}$$

$$C_{\text{exp\_max\_L}}[\%]=S_{\text{est\_L}}/\ S_{\text{ref\_L}}*100 \tag{7}$$

, where $S_{\text{est\_G}}$, $S_{\text{est\_U}}$, $S_{\text{est\_L}}$ are the maximum power densities calculated according to (1), (2), (3), and $S_{\text{ref\_G}}$, $S_{\text{ref\_U}}$, $S_{\text{ref\_L}}$ are the reference levels of power density for GSM, UMTS, LTE systems, calculated based on table II.

Fig. 3, Fig. 4, and Fig. 5 show the estimated exposure coefficients for the GSM system, the UMTS system and the LTE system for the area close to the antennas (4 antennas within "EH" and 5 antennas within "Skanska"), respectively.

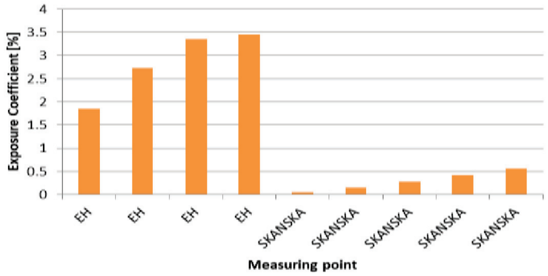


Figure 3. Estimated maximum exposure coefficient for GSM near the antenna

A first observation is the very low values of the exposure given by the GSM technology in the "Skanska" headquarters. From the analysis of the technical plan, it was found that the GSM sector served another part of the building, which is why, until the combination with the other technologies, a tapper with 7dB attenuation was inserted. The maximum values of the coefficients are up to 0.6% in the case of "Skanska", respectively up to 3.5% for "EH".

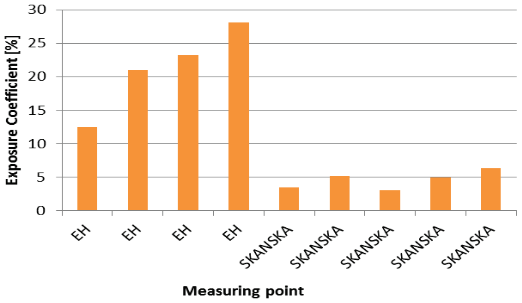


Figure 4. Estimated maximum exposure coefficient for UMTS near the antenna

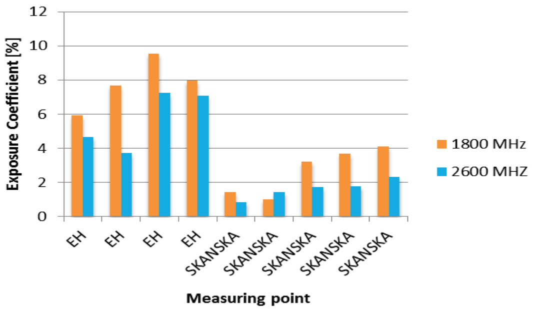


Figure 5. Estimated maximum exposure coefficient for LTE near the antenna

It is obvious that in the case of the "EH" headquarters, the UMTS system makes the largest contribution to the total exposure coefficient.

It is observed that there are no considerable differences between different measurement points in the same building, but, although all measurements were made near the antennas, there are significant differences between locations. The main reason why the exposure in the "EH" headquarters is higher is the small number of antennas in which the same power is inserted as in the case of the system in "Skanska", which has 3 times more antennas and, implicitly, more cable and power dividers. The second reason is the location of the ceiling. In the case of the "EH" building, the ceiling is 2.3 m above the floor, while in Skanska between the floor and the ceiling are 3.5 m, which made the measuring probe, located at a height of 1.7 m and a distance of 1-3 m in the horizontal plane from the antenna, to be approximately 2 times closer to the antenna in the case of the "EH" headquarters.

In Fig. 6 we have the representation of the maximum estimate of the total exposure coefficients for a person located near the antenna. For the "Skanska" headquarters, they vary between 5.85 and 13.28%, the latter being almost 8 times lower than the legal limit. The average calculated for the building "Skanska" is 9.18%. The lower values of the coefficients are due to the higher ceiling, the higher losses in the radiant system and implicitly of a seemingly lower radiated power. The average coefficient near antennas in the “EH” building is 37.48%, but the values of over 40% of the exposure coefficients make us think that the power inserted in the antenna system must be reduced. The uncertainty of the SRM-3000 device with which the measurements were made is -3.3/+2.4 dB [4], so insufficient to bring the exposure over 100%.

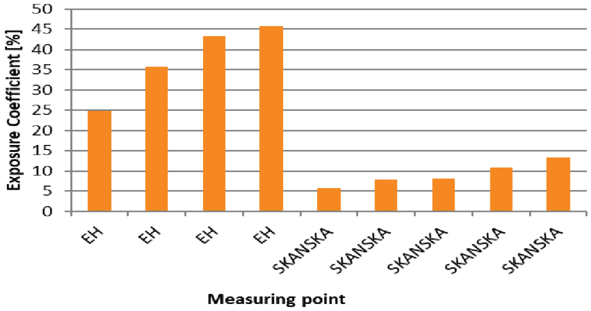


Figure 6. Estimated maximum total exposure coefficient near the antenna

Measurements in the area away from the antennas are also very useful, the field being small in that area, but it helps us to have an image of the average exposure coefficient at the building level. Fig. 7, Fig. 8 and Fig. 9, respectively, present the estimation results in the case of the GSM system, the UMTS system and the LTE system, respectively.

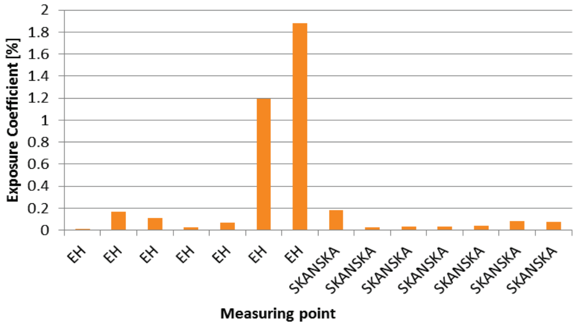


Figure 7. Estimated maximum exposure coefficient for GSM in distant area

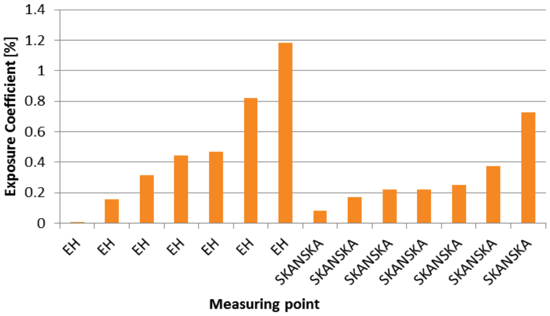


Figure 8. Estimated maximum exposure coefficient for UMTS in distant area

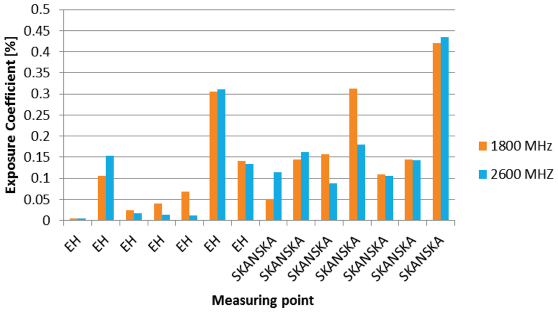


Figure 9. Estimated maximum exposure coefficient for LTE in distant area

The differences between the coefficients estimated in the 2 locations are no longer significant, because of the impact of the layout of the buildings. If in the measurements in the nearby area we had higher values in the case of "EH", now due to the compartmentalization of offices, the penetration attenuation is much higher in "EH" than in the case of "Skanska", where the building has significantly more open space.

For the ease of evaluating the maximum total exposure in the area far from the antennas, the maximum coefficients estimated at each point were summed and Fig. 10 represented the maximum estimated total exposure coefficients for a person at more than 5m from the antennas.

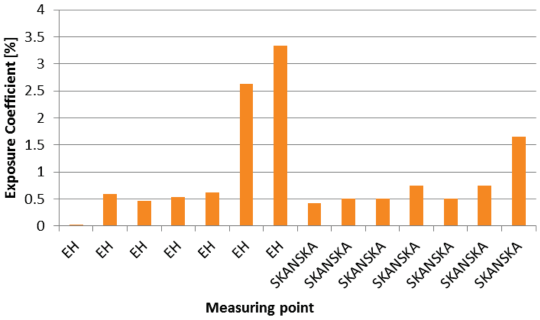


Figure 10. Estimated maximum total exposure coefficient in distant area

The total coefficients estimated in the remote area have close values in the two locations, they do not exceed 1.65%, except for two points in "EH" located at 10 and 15 m, respectively, but in visibility with the antenna. The average of the coefficients corresponding to the remote area from "EH" is 1.17%, meaning 20 times lower than the average near the antennas, and in the case of "Skanska" is 0.72%.

The lowest exposure values were obtained in "EH" in the kitchen area which is in the core of the building's concrete structure and where no antennas are installed.

If we were to calculate the average exposure coefficients for all measured points in each building, in "Skanska" we would get an average exposure coefficient of 4.24%, and in "EH" 14.37%, about 7 times lower than the limit.

IV. CONCLUSIONS

The measurements showed in the case of shops that the exposures to the ambient electromagnetic field generated by the indoor stations are reduced, the maximum estimated exposure coefficient being in over 90% of cases more than 5 times lower than the reference value. This is due to the location of the antennas at a height of about 3.5 – 4 m, the ceilings of the shops being higher than in the office buildings, and due to the lower transmit power setting, which in the case of shops are generally set to 2 W/TRX for GSM, 2 W/carrier for UMTS and 2x4 W for each LTE carrier.

In the case of office buildings, there is a rather large influence of the architecture of the buildings, in the "EH" headquarters there are considerable differences between the values of the exposure coefficients in the near area and the area far from the antennas.

Although in none of the buildings there were values of exposure coefficients to worry about, the prospect of introducing the 5G technology should be taken into account. From outdoor measurements we noticed that the exposure coefficient increases by about 17% due to 5G [5], to which we can add the uncertainty of the device with which the measurements were made (-3.3/+2.4 dB). Under this hypothesis, in the point where we obtained the highest maximum total estimated exposure coefficient of 45.88% we could reach a value of the maximum estimated total exposure coefficient of over 90% by considering the 5G and the measurement error. For this reason, in the case of the "EH" headquarters, it is recommended to reduce the emission power of the station on the existing technologies and to densify the distributed antenna system with additional antennas and power dividers.

The maximum estimates are theoretical, the possibility of such values being reached is extremely low. In order for this to happen, all terminals must be in poor radio conditions and the cell must be fully loaded. Given that the distributed antenna systems are specifically designed to offer good coverage in the entire building, the likelihood that the terminals will be located at the edge of coverage is almost zero.

This paper brings clarifications for the future 5G developments and evolution in radio access network part to support the challenging use cases and further 5G Network Applications.

ACKNOWLEDGMENT

The scientific, technical, and academic activities and the testing and validation of the results of the research disseminated in this article have been performed in the Orange 5G Lab, an advanced experimental facility in Bucharest, created with the CAMPUS Research Center of UPB – University POLITEHNICA of Bucharest. The Orange 5G Lab supports the prototyping, testing, and validation of 5G Use-Cases, new applications, and new equipment within a team of Industry-leading experts and academics.

This work was partly funded by the European Commission under the European Union’s Horizon 2020 program - grant agreement number 101016448 (5GASP project) and 101016567 (VITAL-5G). The paper solely reflects the views of the authors. The Commission is not responsible for the contents of this paper or any use made thereof.

REFERENCES

[1] ICNIRP GUIDELINES for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). 1998, HEALTH PHYSICS

[2] General Overview on methods for monitoring environmental electromagnetic fields (emf). G. d'Amore Environmental Protection Agency of Piedmont Region (ARPA Piemonte)

[3] Measuring Non-Ionizing Electromagnetic Radiation (9 kHz - 300 GHz). Administrations, Electronic Communication Committee (ECC) within the European Conference of Postal and Telecommunications. Vol. ECC RECOMMENDATION

[4] NARDA - Safety Test Solutions. SRM-3000 Selective Radiation Meter - Operating Manual. 2006. 3001/98.21

[5] M. Nedelcu, T. Petrescu, V. Nițu, “Evaluation of electromagnetic field exposure in the vicinity of mobile phone base stations,” IEEE International Black Sea Conference on Communications and Networking, Bucharest, Romania, 2021, in press.