Maximum electric field estimation in the vicinity of 5G base stations before their start-up

Aleksandar V. Lebl[a], *Djuradj* Budimir[b]

[a] IRITEL a.d., Department for Radiocommunications, Belgrade, Republic of Serbia,
e-mail: lebl@iritel.com, **corresponding author**,
ORCID iD: https://orcid.org/0000-0001-6544-6618

[b] University of Westminster, London, United Kingdom,
e-mail: d.budimir@westminster.ac.uk,
ORCID iD: https://orcid.org/0000-0002-7502-9129

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Abstract:

Introduction/purpose: This paper presents initial development of the procedure for electric field estimation in the vicinity of 5G base stations.

Methods: The procedure allows determination of future radiation levels before traffic is established over applied antenna systems on the basis of measured values of electric field levels caused by the signal forming Synchronization Signal Block. It is possible to perform necessary calculations for a very accurate estimation even if some important parameters of the radiation characteristics (such as the frequency span between the frequency carriers on the radio interface) are not a priori known. In this way, communication with mobile system operators before measurement is significantly simplified because operators do not need to know system technical details.

Results: The developed formula for electric field estimation is verified comparing the calculated values by its implementation to the practical results obtained by intensive measurements on a great number of 5G base stations in a highly developed country. The formula gives a pessimistic result, i.e. a higher electric field level than it is obtained by all such performed measurements.

Conclusion: This estimation allows mobile system operators to predict whether the electromagnetic field around base stations could be dangerous for human health when systems come to full operation while considering national and international recommendations dealing with radiation levels.

Key words: 5G electric field estimation, base station, Synchronization Signal Block, traffic beam, frequency subcarriers.

Introduction

Today mobile telephony becomes an unavoidable part of everyday life. It is hard to imagine everyday life and communication between people without mobile phones. People are exposed to electromagnetic radiation of mobile telephony base stations even when they do not use mobile phones. The number of mobile telephony base stations (BS) which are responsible for this radiation is constantly increasing. The final result of this increase is a growth of harmful effects of the electromagnetic radiation produced on all living beings (people). There is a consensus in science about some effects (first of all, when considering thermal effects) while the other, often much dangerous effects, are still in an investigation phase. This is a reason why electromagnetic field measurement according to international recommendations is often a research subject in the whole world. It is important to predict electromagnetic field levels before traffic is established, especially in the case of 5G systems implementation.

After this short introduction, Section II is a survey of the state of the art when considering already realized measurements for all system generations from 2G to 5G. This section also includes contributions and practical results in the same field which are the direct knowledge base for the presented investigation. Section III presents the procedure for determining the electric field in 5G systems. A formula for the electric field estimation which is developed in the Section III is then verified according to practical independent measurement results presented in the Section IV. Finally, the conclusions are in Section V.

State of the art

Measurements on different generations of mobile systems are numerous and the contributions presented in this paper are only a small part of them. It is important to notice that such measurements have been defined and realized in Serbia for a long time (Ilić et al, 2002). The main concept of frequency selective measurement based on the application of a spectrum analyzer which allows access to all existing frequency channels for measurements is presented in (Ilić et al, 2002). The same measurement principle is used also in (Hamid et al, 2003) where the results obtained by collecting data about GSM base stations radiation using directional and isotropic antennas are mutually compared. In other words, these two measurements are performed on the basis of an analysis based on a spectrum analyzer and a meter with a measuring probe. The results presented in (González & Infante Moreira, 2018) are based on a specific limited set of measurements on two traffic channels of the GSM system at 850MHz and 1900MHz which allowed estimation of total radiation levels for complete GSM systems using statistical analysis on the basis of the measured mean value and the standard deviation of the electromagnetic field deviation.

Broadband measurements of base station electromagnetic radiation are applied besides frequency selective measurements (Bieńkowski et al, 2015). Broadband measurements are more rarely applied than frequency selective measurements, but the obtained measurement results are less exposed to the risk of statistical uncertainty. The authors in (Kurmaz et al, 2018) have developed a calculation model to estimate the total electric field on the basis of six frequency bands with the highest level with the accuracy of at least 95% to avoid broadband measurements.

Statistical uncertainty of the obtained results by frequency selective measurements is manifested both in the sense of space where a measurement is performed and in the sense of measurement time. Such investigations are the subject of analysis in (Watanabe & Hamada, 2017). It has been proven that measurement results, when considering spatial uncertainty for W-CDMA and LTE systems, do not depend on the surroundings (urban or rural) or the analyzed frequency band. The spatial uncertainty depending on the height from the ground level where a measurement is performed is also analyzed in (Watanabe & Hamada, 2017). When considering time uncertainty, it is shown that a measurement in shorter time intervals of only 10s does not significantly degrade the accuracy of the results comparing to a measurement in time intervals of 6 minutes according to international requests and this is very important to speed up the measurement procedure. Estimation of measurement uncertainty is also the subject of analysis in (Koprivica, 2016).

The coexistence of different mobile system generations at one location is typical nowadays; nevertheless, their base stations are on the same pillar or are placed at a short distance from each other (not greater than 20m). The main directives to realise measurements in such a case are emphasized in (Telecommunication Engineering Centre, 2021) when considering the coexistence of 2G, 3G and 4G systems. Additionally, discussions about malicious effects of new 5G systems on human health are very frequent today. However, the results of the measurements in (Ofcom, 2020) prove that levels of electromagnetic fields in the vicinity of 5G base stations are significantly lower than when considering previous generation systems and, also, that these levels for 5G are lower than it is allowed according to the international recommendations. A comprehensive analysis in (Huang et al, 2022) further illustrates that there are sites which have even lower levels of electric fields, magnetic fields or power density after 5G system installation than before. The explanation may be that users of mobile systems of generations lower than 5G have switched to 5G systems where radiation is lower. The authors of (Huang et al, 2022) conclude that it is not sufficient to assume that 5G is a health hazard without epidemiological findings. When combining the results from (Huang et al, 2022) and the conclusion from (Şahín et al, 2013) that the safety distance from a base station is only 10m, we can conclude that radiation caused by base station operation is dangerous only in a high proximity to the base station which is further improved by the fact that radiation antennas are usually at the height greater than 10m thus decreasing the radius of health risk at the ground level.

Development of calculation methods to estimate electric field levels, especially in indoor conditions, is a major problem. The authors in (Lehmann et al, 2002) prove that a simple free space model gives very poor results when analyzing such indoor conditions. The free space model overestimates the real measured results. Besides, a disadvantage of the free space model is very low reproducibility and low standard deviation of the measured results comparing to a real situation.

The contributions (Matić & Paunović, 1995; Matić & Paunović, 1997; Matić et al, 2000; Lebl et al, 2017) dealing with the prediction of electromagnetic fields are the direct base which preceded the investigation presented in this paper. These fundamental considerations have included both a theoretical analysis to find an optimal selection procedure for prediction (Matić & Paunović, 1995; Matić & Paunović, 1997) and practical realization on the basis of digital signal processing algorithms (Matić et al, 2000). In the recent past, the contribution (Lebl et al, 2017) included the role of real telecommunication traffic processes in electric field level estimation in the vicinity of base stations. Practical realizations of measurement procedures are presented in (Tušup et al, 2022).

Electric field determination for 5G systems

Frequency selective measurement makes it possible to approximately determine the maximum electromagnetic radiation of base stations when all traffic channels are busy. One possible principle in the case that this method is applied is to measure the electromagnetic field only in channels where emission power is always constant and, for systems from 2G to 4G, maximal. After this field level is measured, the total radiation is further determined by calculation. Very similar formulas are used for calculation in the case of GSM (2G), UMTS (3G) and LTE (4G) systems (European Committee for Electrotechnical Standardization, 2014). For GSM systems, the following formula is used:

$$E = \sqrt{n_{TRX}} \cdot E_{BCCH} \quad (1)$$

where E_{BCCH} is the electric field level which originates from always active channels on the first carrier (Broadcast Control Channel – *BCCH*) and n_{TRX} is the number of available frequency carriers. Similar formulas for UMTS systems and LTE systems are presented in (European Committee for Electrotechnical Standardization, 2014; RATEL, 2018) where the power coefficient (n_P) is used instead of n_{TRX} for other types of mobile systems instead of GSM. Typical maximum values of coefficients under the square root in equations as (1) are presented in (W-Line, 2021). The formulas in these three emphasized cases imply that power control in traffic channels as a function of mutual distance between a base station and mobile stations is not applied and that all traffic channels are always busy. In such a way, it is achieved that the final result is directed to the safe side: the calculated field is higher than it will be in reality.

The expected forms of the electromagnetic field when 5G systems are applied are shown based on the analysis given in (Franci et al, 2020a; Franci et al, 2020b). Before showing the shape of the signal itself, the basic characteristics of the 5G signal that affect the shape of the signal will be mentioned.

In the time domain, the duration of the basic frame of the 5G signal is 10ms (as is also the case when 4G signals are implemented). This frame is divided to 10 subframes of 1ms duration. Each of these subframes is split to 2^{μ} slots where it is μ=0, 1, 2, 3 or 4. Each slot consists of 14 or, in some cases, 12 Orthogonal Frequency Division Multiplexing (OFDM) symbols. The applied modulation types correspond to those ones at 4G systems: Binary Phase Shift Keying - BPSK, Quadrature Phase Shift Keying – QPSK, Quadrature Amplitude of order 16, 64, 256 – 16QAM, 64QAM, 256QAM.

There are two ranges in the frequency domain dedicated to 5G signals. The first one (Frequency Range 1 – FR1) covers the frequency range 450MHz – 7125MHz and the second one (Frequency Range 2 – FR2) covers the frequency range 24GHz-50GHz. The further analysis will deal with FR1 as in Serbia the frequency range reserved for 5G systems is 3.4-3.8GHz.

The frequency bandwidth intended for one 5G system is 100MHz. This available frequency range is separated to a number of frequency subcarriers whose number depends on the frequency span between the defined subcarriers. This span is directly proportional to the symbol transmission rate in a subframe. That is why it may be expressed as $2^{\mu}\cdot 15$kHz. Considering the already emphasized values of μ in the range 0 to 4, the total number of subcarriers would be between n_{scmax}≈6660 (when it is μ=0) and n_{scmin}≈408 (when it is μ=4). The subcarriers are grouped into groups of 12 adjacent ones which form one Resource Block – RB.

It is very important to perform the first electromagnetic field measurements for 5G systems before their operation start-up. In such situations, only a signal in the Synchronization Signal/Physical Broadcast Channel (SS/PBCH) may be expected to exist. This signal is also called the Synchronization Signal Block (SSB). It consists of the Synchronization Signal (SS), the Physical Broadcast Channel (PBCH), and the Physical Broadcast Channel Demodulation Reference Signal (PBCH-DMRS) which is used as a reference signal for decoding the PBCH. This signal takes four symbols in the time domain and n_{scSSB}=240 mutually adjacent subcarriers (or 20 RB) in the frequency domain.

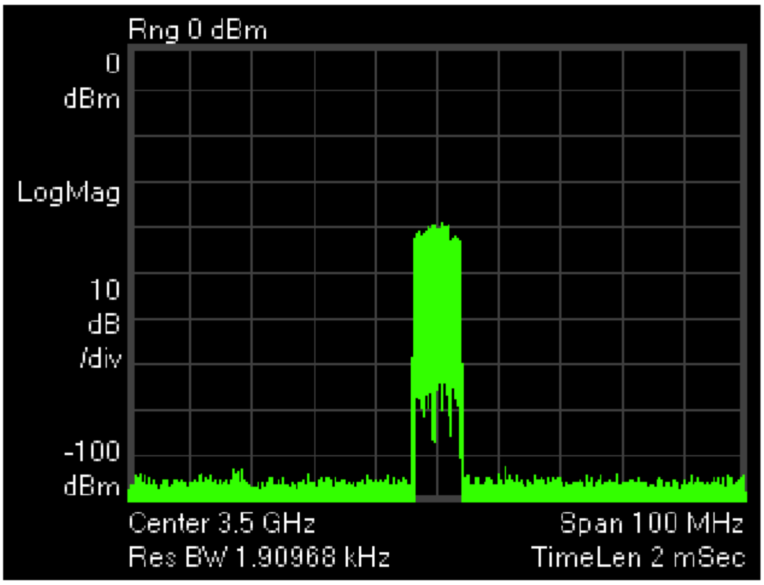

Figure 1 – SSB signal in the frequency domain, i.e. a 5G signal when there is no traffic
Рис. 1 – Сигнал SSB в частотной области, т.е. сигнал 5G при отсутствии трафика
Слика 1 – SSB сигнал у фреквенцијском домену, односно 5G сигнал пре успостављања саобраћаја

The specific shape of the SSB signal in the frequency domain is presented in Figure 1 (Franci et al, 2020b). This is also the shape when there is no traffic because the SSB signal is the only signal which then exists in the 5G subframe. Such a signal is also obtained when electric field intensity is recorded. The total frequency bandwidth where significant frequency components are registered is 7.2MHz (in relation to the whole bandwidth 100MHz for one 5G system). It, further, means that the total frequency span between two adjacent frequency subcarriers is 7.2MHz/240=30kHz or, in other words, it is μ=1. The frequency bandwidth of the SSB signal for other values of μ will be different.

If the value of μ is thus determined, this also determines the total number of frequency subcarriers which are used to calculate the value of the total electric field on the basis of the measured electric field with no traffic.This number is ≈3330, in accordance with the previous considerations. It is necessary first to measure the signal in the frequency band which corresponds to the SSB signal.

Starting from (1), the maximum value of the electric field for 5G systems only on the basis of the measured field caused by the SSB signal in a general case of any value of μ may be expressed as

$$E_{5G} = k_s \cdot \sqrt{\frac{n_{sc\max}}{n_{scSSB} \cdot 2^{\mu}}} \cdot E_{SSB} \tag{2}$$

or, in other words,

$$E_{5G} = k_s \cdot \sqrt{\frac{27.5}{2^{\mu}}} \cdot E_{SSB} \tag{3}$$

In these equations, E_{SSB} is the value of the electric field caused only by the SSB signal and k_s is the coefficient which has to be applied to multiply the obtained field value because traffic channels do not have the same power at the receiving point as the SSB channels. Among all available SSB channels, the one which causes the maximum electric field is selected. The concrete value under the square root in (3) follows from the previous consideration that 240 subcarriers form one SSB signal and the maximum electric field at the place of reception would appear in a very unreal traffic situation that all available 6660/2^{μ} subcarriers are transmitted to only one user. Equations (2) and (3) are based on the analyses and formulas from (Migliore, 2022). A more accurate (but very approximate) value of the number under the square root may be found according to (Malaysian Technical Standards Forum Bhd, 2021).

There is also another important characteristic which has to be emphasized when 5G signals are transmitted: implementation of antennas whose radiation pattern is variable (not fixed). The optimal beamforming for different signals in the 5G subframe is achieved in this way. When the SSB signal is considered, it is transmitted using several radiation beams in fixed, a priori defined directions to allow all users in the area around the base station to detect some of these signals in an adequate way. When traffic channels are the subject of analysis, a radiation beam is separately formed for each user (in a direction towards him) to allow optimal signal detection. The beams for SSB signals are considerably wide to allow for greater space to be covered by one beam. On the contrary, traffic beams are very narrow to decrease interference from other traffic channels at the receiving side as much as possible. This whole analysis is illustrated by Figure 2.

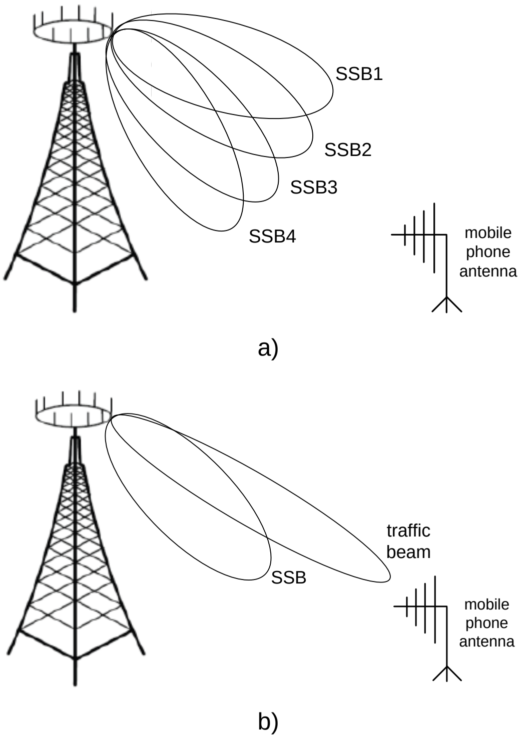

Figure 2 – Beamforming in the case of: a) SSB signals; b) traffic channel compared to SSB signals
Рис. 2 – Формирование пучка излучения в случаях: а) сигналов SSB; б) канала трафика по сравнению с сигналами SSB
Слика 2 – Формирање снопа зрачења у случају: а) SSB сигнала; б) саобраћајног канала у поређењу са SSB сигналом

Figure 2a) presents the radiation pattern for SSB signals which is formed, for example, when a 4-fold beam (SSB1 ... SSB4) is transmitted and when each of these 4 beams is transmitted in a different period of time. The maximum number of SSB beams is 8 for the frequency band 3-6GHz, which is used in Serbia for 5G systems (Migliore, 2022). After that, Figure 2b) presents the relation of two beams: the SSB signal beam and the traffic channel signal beam. As the beam corresponding to the traffic signal is directed directly towards a user, in the case without the applied power control, its level at the receiving side will be higher than the level of the SSB signal. The other important consequence of high directivity of traffic beams is that the electric field level is significantly lower when there is traffic to more than one user and thus distant users have very small influence on the electric field at the place of the considered user. This is the reason why the value of k_s in equations (2) and (3) calculated for some specific user depends primarily on (besides traffic) the antenna radiation pattern for SSB signals, i.e. on the angle between the direction of the maximum SSB signal from a BS and the direction of a BS towards a user. The value of k_s also depends on the ratio of the maximum radiation signals (at 0^o of the radiation pattern) for SSB signals and traffic signals. The data about the radiation pattern of active antennas applied for 5G systems are limited or often even not supplied (Migliore, 2022). In such conditions, the antenna characteristics from (Biscontini, 2021), presented in Figure 3, could be incorporated in the procedure of k_s calculation.

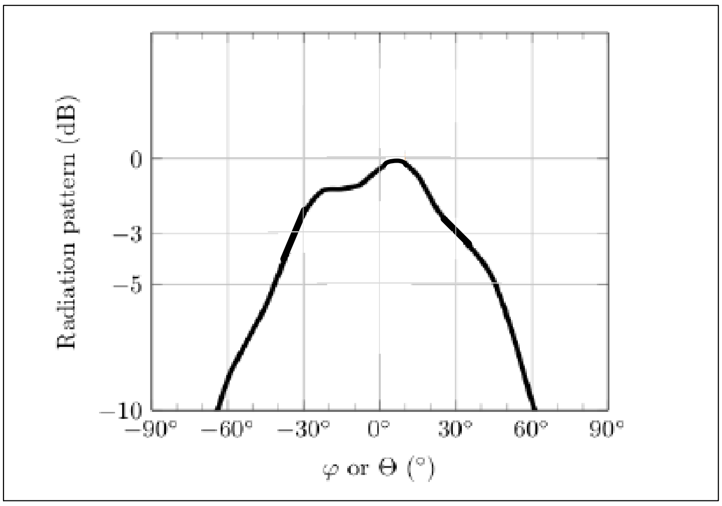

Figure 3 – Example of the radiation pattern of SSB signals (Biscontini, 2021)
Рис. 3 – Пример диаграммы направленности сигналов SSB (Biscontini, 2021)
Слика 3 – Пример дијаграма зрачења SSB сигнала (Biscontini, 2021)

The maximum value of k_s depends on the antenna radiation pattern attenuation at the α_{max} angle ($a_{\alpha max}$) where the SSB signal has the maximum attenuation and the ratio of the traffic signal beam amplitude and the SSB signal beam amplitude (r_{tSSBb}), i.e. their values at the angle 0^o of the radiation pattern. Or, in other words,

$$k_s = a_{\alpha \max} \cdot r_{tSSBb} \tag{4}$$

The implemented SSB beams must cover the whole area around a BS to allow all users to receive some of SSB signals. When considering the azimuth (φ), it is 360^o and when considering the elevation (θ), it is 180^o. This space is in this analysis covered by only four antennas. The beams of these four antennas are directed from the BS tower down at the angle of 45^o in relation to the horizontal plane. In such a case, the maximum angle between the highest radiation direction and the user position towards the BS for the nearest SSB signal is $\alpha_{max}≈60^o$ (OnlineMSchool, 2023). If the radiation pattern such as the one from Figure 3 is applied, the maximum BSS signal attenuation comparing to its peak would be about 10dB ($a_{\alpha max}$=3.16). With the maximum number of 8 beams, this angle would be even lower, but a further calculation will include the worst situation of four antennas.

When dealing with the r_{tSSBb} factor, its estimation is very complex (Adda et al, 2020). The factors which have influence on r_{tSSBb} are reflections, scattering objects around the measurement point, the fact that considered point may be in a Not Line of Sight (NLOS), implemented propagation model, etc. However, the analysis performed in (Adda et al, 2020)] (Figure 7) pointed out that it is r_{tSSBb}≤10dB, or again r_{tSSBb}≤3.16. This analysis presented by Figure 7 in (Adda et al, 2020) is limited to free space (Figure 7a) and to the case of free space with added one conducting plane at a significant distance (Figure 7b).

The influence of reflection as a very important factor which increases the electric field should be further modelled. One possibility is to increase the value of r_{tSSBb} by its multiplication with the factor 1+Γ:

$$r_{tSSBb\Gamma} = r_{tSSBb} \cdot (1+\Gamma) \tag{5}$$

where Γ is the coefficient of surface reflection (W-Line, 2021) and $r_{tSSBb\Gamma}$ is the ratio of the traffic signal beam amplitude to the SSB signal beam amplitude modified by the influence of the reflection coefficient.

The value of Γ is 0.3 in urban surroundings or 0.6 in rural surroundings. Practical importance of the influence of reflection is illustrated in (Conil & Agnani, 2020). Now, taking the value Γ=0.6, the estimated value of the factor ks is ks≤16. Formula (3) may be simplified to:

$$E_{5G} \leq \frac{84.29}{\sqrt{2^{\mu}}} \cdot E_{SSB} \tag{6}$$

Comment about the estimation results reliability on the basis of measurement results

The reliability of formula (6) may be verified on the basis of the results presented in (Agence nationale des fréquences, 2020). The value of the coefficient k_s used to multiply the measured electric field (E_{SSB}) before traffic is established in order to predict the maximum electric field after traffic is established is determined according to the measurement results presented in (Agence nationale des fréquences, 2020) and compared to the corresponding value in (6).

It is emphasized in (Agence nationale des fréquences, 2020) that the applied systems have μ=1, i.e. the frequency gap between carriers is 30 kHz. The value of k_s for such a case in (6) is 59.78. The corresponding values according to the table in the Executive summary of (Agence nationale des fréquences, 2020) are 45 maximum. This means that this paper's estimation is oriented towards the “safe side” i.e. it gives a higher electric field than it is in reality.

Conclusions

The main contribution of this paper is the development of a formula to calculate the maximum electric field for 5G mobile systems. The formula is implementable first of all to predict the field level in the phase before traffic is established. The prediction is based on the measured value of the electric field caused by the SSB signal which is the only signal that exists when there is no traffic. The formula development for 5G systems is based on similar known formulas for other generation systems and it is developed on similar principles. The obtained formula is verified on the basis of the measurement results performed in a highly developed country (Agence nationale des fréquences, 2020; Conil & Agnani, 2020) following a similar procedure as the one presented in this investigation. The analysis is performed in the theoretical sense but it is intended for future practical estimation of measurement results.

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Оценка максимального электрического поля вблизи базовых станций 5G до ввода в эксплуатацию

Александар В. Лебл[а], *Джурадж* Будимир[б]

[а] АО „ИРИТЕЛ», отделение радиосвязи, г. Белград, Республика Сербия, **корреспондент**

[б] Вестминстерский университет, г. Лондон, Великобритания

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Резюме:

Введение/цель: В данной статье представлена первоначальная разработка процедуры оценки электрического поля вблизи базовых станций 5G.

Методы: Процедура позволяет определять будущий уровень излучения до установления трафика по применяемым антенным системам, на основании измеренных значений уровней электрического поля, вызванных сигналами, образованными блоком сигналов синхронизации. Такой подход дает возможность выполнять необходимые вычисления для сверхточной оценки, даже когда важные параметры и характеристики излучения (такие как диапазон частот между несущими частотами на радиоинтерфейсе) неизвестны. Таким образом, связь с операторами мобильной системы перед измерением значительно упрощается, поскольку операторам необязательно знать технические детали системы.

Результаты: Верификация разработанной формулы для оценки электрического поля произведена путем сравнения вычисленных значений при ее внедрении с практическими результатами, полученными в результате интенсивных измерений на большом количестве базовых станций 5G в высокоразвитой стране. Формула дает пессимистичный результат, т.е. показывает *более высокий уровень электрического поля, чем при всех выполненных измерениях.*

Выводы: Благодаря данной оценке операторы мобильных систем могут прогнозировать, будет ли электромагнитное поле вокруг базовых станций при полном введении в эксплуатацию представлять угрозу здоровью человека, с учетом национальных и международных рекомендаций, касающихся уровня излучения.

Ключевые слова: оценка электрического поля 5G, базовая станция, блок сигналов синхронизации, пучок излучения, частотные поднесущие.

Процена максималне јачине електричног поља у близини базне станице 5G технологије пре њеног пуштања у рад

Александар В. Лебл[а], *Ђурађ* Будимир[б]

[а] ИРИТЕЛ а.д., Одељење за радио-комуникације,
Београд, Република Србија, **аутор за преписку**

[б] Универзитет Вестминстер, Лондон, Уједињено Краљевство

ОБЛАСТ: телекомуникације
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У раду је приказан почетни развој процедуре за процену јачине електричног поља у близини базне станице 5G технологије.

Методе: Процедура омогућава одређивање будућег нивоа зрачења на основу измереног нивоа електричног поља узрокованог сигналом који формира блок синхронизационих сигнала пре него што се успостави саобраћај преко примењеног антенског система. Могуће је извршити потребне прорачуне ради врло тачне процене, чак и ако неки важни параметри карактеристике зрачења (као што је размак фреквенција између фреквенцијских носилаца на радио-интерфејсу) нису унапред познати. На тај начин је, пре самог мерења, знатно поједностављен процес комуникације са оператором мобилног система јер он не мора познавати детаље техничких података о систему.

Резултати: Изведена формула за процену јачине електричног поља верификована је поређењем њених резултата са практичним резултатима добијеним интензивним мерењима на великом броју базних станица 5G технологије у једној високоразвијеној земљи. Формула даје песимистичан резултат, односно показује виши ниво електричног поља од онога који се добија у свим реализованим мерењима.

Закључак: Ова процена омогућава оператору мобилног система да предвиди да ли би електромагнетно поље у околини базне станице могло да буде опасно за људско здравље када систем ради пуним капацитетом, узимајући у обзир националне и интернационалне препоруке које се односе на ниво зрачења.

Кључне речи: процена електричног поља 5G технологије, базна станица, блок синхронизационих сигнала, саобраћајни сноп зрачења, фреквенцијски подносиоци.

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