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INFLUENCE OF TRAFFIC PROCESS CHARACTERISTICS ON THE ELECTRIC FIELD IN GSM BASE STATION CELL

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Abstract

In this paper we present a method for calculation of electric field intensity in the BS cell area as a function of traffic components: offered traffic, discontinuous transmission and power control implementation. It is proved that this calculated value of electric field intensity is significantly smaller than maximum value, determined on the base of widely used international recommendation. The obtained results of calculated power decrease comparing to the maximum power value calculated according to formula from recommendation are verified by the results, emphasized in one independent example from literature.

Keywords: electric field intensity, GSM, offered traffic, discontinuous transmission, power control.

INTRODUCTION

Today mobile telephone becomes more and more the part of our lives. It is hard to even imagine our everyday communications without a mobile phone. We are surrounded by continuously increasing number of different types of base stations (BS), which allow connection realization by mobile phones. As an inevitable consequence of the base stations operation, there is electromagnetic radiation, which we are constantly exposed to. The effects of this radiation on the human body are multiple and scientists do not agree about its harmfulness for our health. They may be divided into thermal effects and stimulatory effects, [1]-[3]. Thermal effects suppose considering heating of human tissue as a consequence of exposure to electromagnetic field. For this effect analysis specific absorption rate (SAR) is the measure of a rate at which energy is absorbed by human body. The stimulatory effect is the short-term effect which is manifested as irritation of the nerve and muscle cells, causing greater irritability and fatigue. There is no scientific consensus about other more serious effects of electromagnetic field from base stations on human health, as brain cancer, cognitive function, heart rate, or blood pressure, [4].

These numerous and frequently unproved effects are the reason why it is necessary to develop international standards dealing with intensity of BS radiation, [5]. In this paper we investigate the real electric field intensity (EFI) as the function of several elements important for traffic analysis in mobile (GSM) systems in relation to calculation method proposed in [5]. Before any analysis, formulas from [5] are emphasized in section II. Further, we present influence of offered traffic intensity in section III. One specific element for GSM systems is number of frequency carriers in GSM systems and this influence is, also, presented in section III. Influence of discontinuous transmission (DTX) is illustrated in section IV. In mobile system power control is usually implemented, which means that BS power is adjusted according to the mobile station (user) needs. Here we suppose that only distance between BS and user is the cause of power control. Influence of this element, together with supposed most often uniform users' surface density distribution, is analyzed in section V. The results (obtained on the base of formulas developed in sections III-V) and the analysis of these results are presented in section VI.

ELECTRIC FIELD CALCULATION FOR MOBILE SYSTEMS

The formula for EFI calculation around the electromagnetic radiation source (EMRS) is often presented in literature (for example, [6]):

$$E = \frac{\sqrt{30 \cdot P \cdot G \cdot K}}{r} = \frac{c}{r} \cdot \sqrt{P} \tag{1}$$

where P is BS emission power, G is antenna gain, K is correction factor for scattering objects, r is distance between EMRS and the considered point, and $c = \sqrt{30 \cdot G \cdot K}$.

If the EMRS consists of several channels (with equal power), the total power value of the source (P) is the sum of powers of all channels. From this consideration follows the formula from [5]. According to this standard, EFI as the function of traffic load for GSM system is determined by the expression

$$E_{traffic\_max} = \sqrt{n_{TRX}} \cdot E_{BCCH} \tag{2}$$

where n_{TRX} is the number of frequency carriers and E_{BCCH} is EFI caused by Broadcast Control Channel (BCCH), [15].

In this formula it is supposed that power in each traffic channel is always the same and that it has its maximum value. But, in real situation for mobile (GSM) systems this suppose is at the great extent an overestimation. Overestimation, as already may be concluded form introductory section, is the consequence of real traffic channel occupancy as the traffic process consequence, implementation of DTX function in voice signal transmission (signal is transmitted only in the time of voice activity) and power adjustment according to BS-user distance.

INFLUENCE OF OFFERED TRAFFIC ON THE ELECTRIC FIELD INTENSITY

GSM systems are based on implementation of time division multiplex (TDMA) on each frequency carrier of frequency division multiplex (FDMA). Each TDMA on a carrier frequency consists of 8 time channels. Some of these channels are intended for signalling information transmission, as two channels on the first frequency carrier and, eventually, one or more channels on other frequency carriers, if two channels on the first carrier are not enough to transmit all signalling information. The remaining channels are traffic channels, [7]. Signal on the first carrier (two signalling channels and 6 (remaining) traffic channels) are always sent with maximum power, regardless of the implementation of DTX function, power control or the fact that, possibly, traffic channel is not busy.

Signal level in traffic channels on other carriers may be adjusted as the function of BS-user distance. In these channels there is no signal sending if channel is not busy in that moment, or if there is no activity BS→MS (user is not speaking) in the considered time interval.

If the considered GSM mobile system consists of only one frequency carrier, total emission power of 6 available traffic channels and 2 signalling channels is always the same, [8]:

$$P = P_{BCCH} \tag{3}$$

where P_{BCCH} is the BS emission power for one BCCH channel. The EFI is then, according to (1) and (3):

$$E = \frac{c}{r} \cdot \sqrt{P_{BCCH}} = E_{BCCH} \tag{4}$$

In this case obtained formula (4) completely corresponds to formula (2) from [5].

When the system has more than one frequency carrier, the mean value of total emission power may be expressed as

$$P = P_{BCCH} \cdot \left(1 + \frac{1}{8} \cdot \sum_{i=7}^{6+(f_c-1)\cdot 8} (i-6) \cdot p(i) \right) \quad (5)$$

where f_c is the number of available frequency carriers (it may be f_c=2,3,4,…) and *p(i)* is the probability that *i* traffic channels are busy.

Similar as in the case of only one frequency carrier, EFI is now

$$E = \frac{c}{r} \cdot \sqrt{P_{BCCH} \cdot \left(1 + \frac{1}{8} \cdot \sum_{i=7}^{6+(f_c-1)\cdot 8} (i-6) \cdot p(i) \right)} = E_{BCCH} \cdot \sqrt{1 + \frac{1}{8} \cdot \sum_{i=7}^{6+(f_c-1)\cdot 8} (i-6) \cdot p(i)} \quad (6)$$

Probabilities *p(i)* are determined using Erlang distribution from queueing theory, [9], [10]:

$$p(i) = \frac{\frac{A^i}{i!}}{\sum_{l=0}^{N} \frac{A^l}{l!}}, \; i = 0,1,...,N \quad (7)$$

where *A* is the offered traffic and *N* is the number of available traffic channels. This formula was first implemented in the analysis of switching systems and after that it is implemented in many other cases.

Probability that call request may not be realized (call blocking probability - BP) is equal to the probability that all *N* traffic channels are busy:

$$BP = p(N) = \frac{\frac{A^N}{N!}}{\sum_{l=0}^{N} \frac{A^l}{l!}} \quad (8)$$

Call blocking probability is usually criteria for channel number calculation. Typical maximum value of blocking probability in busy hour (when offered traffic is the greatest) for a mobile system is 2%, as it is in the examples from [11]. In the rest of a day offered traffic and (as a consequence) EFI are smaller. The exceptions are rare, special situations, when call blocking probability may be greater than 2%, thus increasing EFI.

INFLUENCE OF DISCONTINUOUS TRANSMISSION

During one conversation, there are periods when users are active (they are speaking) and when they are inactive (not speaking). It is usually supposed in literature that period of voice activity is 40-45% of the conversation duration. The value 43% is obtained as the solution of the Brady model, [12], [13], [7]. This value is the probability that user is speaking alone or in a doubletalk phase with the second conversation participant.

The aim of DTX function in mobile systems is to stop mobile signal sending in case when there is no voice activity. Signal switching off or on is based on the function of voice activity detection (VAD). Signal switching off may not be realized exactly in the moment when conversation stops. That’s why slightly longer period p_{DTX}=0.45=45% is adopted for the probability of voice activity in this paper. In [1] this value is estimated as p_{DTX}=55-60%.

Formulas (5) and (6) are modified as the consequence of DTX function implementation:

$$P = P_{BCCH} \cdot \left(1 + \frac{p_{DTX}}{8} \cdot \sum_{i=7}^{6+(f_c-1)\cdot 8} (i-6) \cdot p(i) \right) \quad (9)$$

and

$$E = E_{BCCH} \cdot \sqrt{1 + \frac{p_{DTX}}{8} \cdot \sum_{i=7}^{6+(f_c-1)\cdot 8} (i-6) \cdot p(i)} \quad (10)$$

INFLUENCE OF POWER CONTROL

Emission power for one traffic channel (which is not on the first frequency carrier) may be expressed as, [14]

$$P_1 \approx a \cdot r^{\gamma} \quad (11)$$

where *r* is the distance between BS and the considered user, *a* is constant for adjustment and *γ* is environmental propagation coefficient, [13]. In practice it is 2≤*γ*≤5, [15].

Maximum BS power is intended for the user at the BS cell rim (i.e. at the maximum BS-user distance). Emission power in this case is

$$P_{1\max} \approx a \cdot R^{\gamma} \quad (12)$$

where *R* is the BS cell radius.

According to (11), BS power control (PC) is performed continually as the function of distance. This is a valuable approximation of the real situation that BS power is adjusted in 15 steps of 2dB, [16].

The ratio of one channel mean output power to the one channel maximum output power is calculated in [14]. Mean output power corresponds to the emission power with power control (P_{PC}) and maximum power corresponds to the power without power control ($P_{wo/PC}$). That's why the same formula from [14] may be implemented for the calculation of coefficient of BS emission power decrease (η_{PC}) when PC is implemented to the power without PC:

$$\eta_{PC} = \frac{P_{PC}}{P_{wo/PC}} = \frac{2}{\gamma + 2} \qquad (13)$$

This coefficient from (13) is used to further correct the equations (9) and (10):

$$P = P_{BCCH} \cdot \left(1 + \frac{p_{DTX}}{8} \cdot \eta_{PC} \cdot \sum_{i=7}^{6+(f_C-1)\cdot 8} (i-6) \cdot p(i) \right) \qquad (14)$$

and

$$E = E_{BCCH} \cdot \sqrt{1 + \frac{p_{DTX}}{8} \cdot \eta_{PC} \cdot \sum_{i=7}^{6+(f_C-1)\cdot 8} (i-6) \cdot p(i)} \qquad (15)$$

In this section, when considering influence of power control on BS power and EFI we supposed that users are uniformly distributed in area of BS cell. Variations in user distribution [17] in the area of BS cell have influence on BS power and EFI, because users located nearer to BS need less power. But, this element is not analyzed in this paper.

THE VALUES OF ELECTRIC FIELD INTENSITY

The results of EFI calculation as a function of offered traffic *A*, comparing to the EFI caused by one BCCH channel (maximum power of one traffic or signalling channel), are presented in Figs. 1-4. Fig. 1 corresponds to the system with one frequency carrier (6 traffic channels), Fig. 2 is for the system with two frequency carriers (14 traffic channels), Fig. 3 is intended for the system with three frequency carriers (22 traffic channels) and Fig. 4 for system with four frequency carriers (30 traffic channels). Five characteristics are presented in each figure. The first one is for the case when only influence of offered traffic is considered (characteristic BS w/o DTX). The values for this characteristic are obtained implementing (4) for the system with one frequency carrier (Fig. 1) and (6) for systems with more than one carrier (Figs. 2-4).

The second characteristic is for systems where influences of traffic and DTX are considered, but it is supposed that there is no PC (characteristic BS w/ DTX). The values for Figs. 2-4 are obtained using (10). As there is no DTX function implementation for systems with one carrier (Fig. 1), the values are in this case equal to the characteristic BS w/o DTX.

The third and fourth characteristics are presented for system, where all three analyzed influences are considered: this is a system where offered traffic, DTX and PC are taken into account. The characteristics are presented for systems in Figs. 2-4 for γ=2 (characteristic BS w/ DTX gamma=2) and for γ=5 (characteristic BS w/ DTX gamma=5). These calculations are performed on the base of (15). The difference is again for system with one carrier (Fig. 1), where PC is not implemented and where these two characteristics do not differ from previous characteristics.

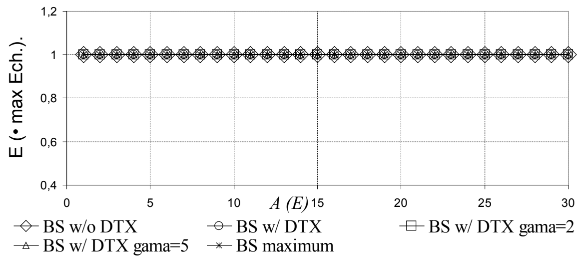

Fig. 1. *BS EFI for the system with one frequency carrier (6 traffic channels): without DTX, with DTX, with PC when γ=2 and γ=5 and maximum EFI*

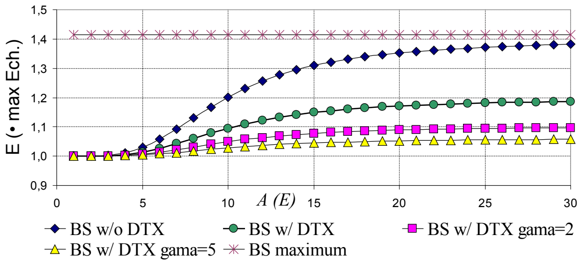

Fig. 2. *BS EFI for the system with two frequency carriers (14 traffic channels): without DTX, with DTX, with PC when γ=2 and γ=5 and maximum EFI*

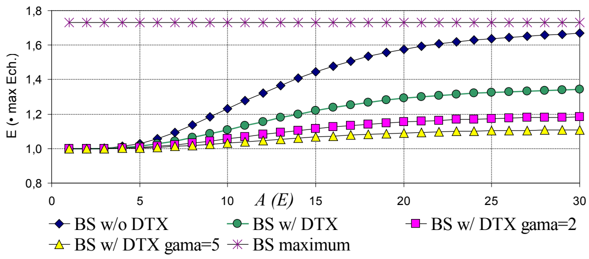

Fig. 3. *BS EFI for the system with three frequency carriers (22 traffic channels): without DTX, with DTX, with PC when γ=2 and γ=5 and maximum EFI*

The last presented characteristic in Figs. 1-4 is the maximum EFI, calculated using (2) according to [5]. It is obvious that there is EFI overestimation comparing to all four other characteristics, presented in Figs. 2-4.

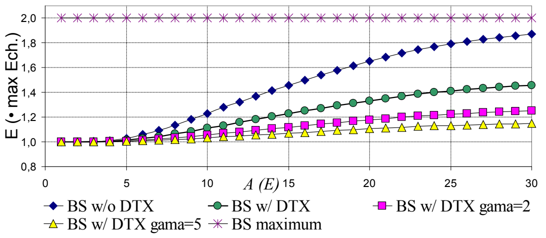

Fig. 4. *BS EFI for the system with four frequency carriers (30 traffic channels): without DTX, with DTX, with PC when γ=2 and γ=5 and maximum EFI*

As it is already emphasized, mobile systems are usually projected to satisfy BP, which is not greater than 2%. The corresponding values of offered traffic are 8.2E for systems with two carriers, 14.9E for systems with three carriers and 21.9E for systems with four carriers, [18].

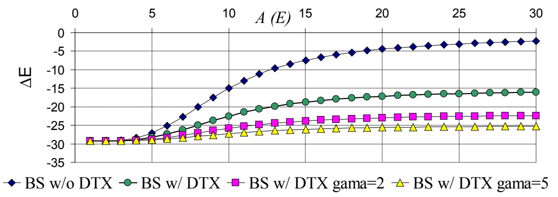

Fig. 5. *BS EFI comparing to maximum EFI according to [5] for the system with two frequency carriers (14 traffic channels): without DTX, with DTX and with PC when γ=2 and γ=5*

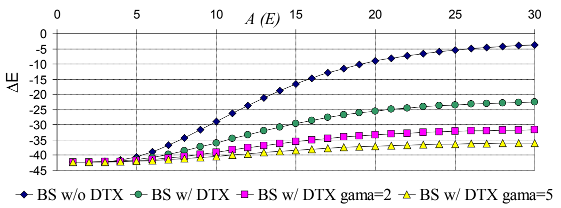

Fig. 6. *BS EFI comparing to maximum EFI according to [5] for the system with three frequency carriers (22 traffic channels): without DTX, with DTX and with PC when γ=2 and γ=5*

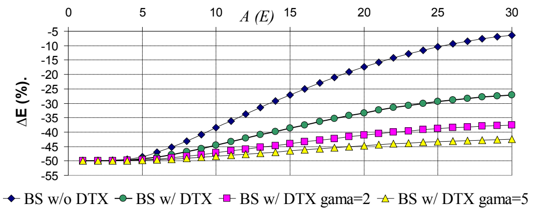

Fig. 7. *BS EFI comparing to maximum EFI according to [5] for the system with four frequency carriers (30 traffic channels): without DTX, with DTX and with PC when γ=2 and γ=5*

Figs. 5-7 present the expected percent of EFI decrease as a function of offered traffic when formulas from this paper are implemented, comparing to the calculation method from [5]. Characteristics are presented for two frequency carriers (Fig. 5), three carriers (Fig. 6) and four carriers (Fig. 7). As in Figs. 1-4, characteristics correspond for systems where only influence of offered traffic is considered (BS w/o DTX), then with influence of offered traffic and DTX (BS w/ DTX) and, finally, two characteristics with the influence of traffic, DTX and PC (BS w/ DTX gamma=2 and BS w/ DTX gamma=5).

Example 1: Let us observe the obtained values of EFI decrease for the system in which maximum blocking probability 2% is allowed and where all three analyzed elements are considered. For systems with two carriers from Fig. 5 follows that EFI decrease is more than 28% (A=8.2E). In the case that system has three carriers, this value of decrease is 35% or more (A=14.9E in Fig. 6). If there are four carriers (A=21.9E in Fig. 7), decrease is 40% or more. In [19] it is emphasized that average output power during high traffic hours in 2G (i.e. GSM systems) is 65% or below of the maximum available power for systems with two or more carriers. This value approximately corresponds to the estimation of EFI decrease calculated in this example.

CONCLUSION

In this paper it is presented that EFI in the area of GSM BS cell depends on mobile traffic characteristics. The considered elements are A and implementation of DTX. Besides these factors, EFI depends on implementation of PC to adjust separately emission power for each active user. Additional factor in this adjustment is the value of γ. It is proved that real expected EFI, as a function of A, DTX and PC implementation is significantly smaller than the value, which is obtained on the basis of recommended formula, [5]. This level of EFI decrease may be greater than 40% for systems with more than three frequency carriers for a traffic value, which causes blocking probability 2%. Exceptions are systems with only one frequency carrier. In such systems formula from [5] is completely satisfied, because DTX function, PC and switching off inactive traffic channels are not implemented on the first carrier.

Presented method for EFI estimation is useful, because it may be a guide how to estimate EFI in the BS cell area when it is not possible to perform measurements.

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