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Influence of power control in the mobile network on the radiation level

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The paper evaluates how the control of transmitted power affects the intensity of radiation in a mobile network cell. Cell models without power control, with standard power control and a model with power control and channel reallocation are considered. The relative reduction of radiation is evaluated and several examples of calculations are presented. Remarks are given on the dependence of radiation reduction on the number of traffic channels, traffic intensity and signal attenuation coefficient. The assessment procedure and results are based on previously verified traffic process simulation models.

Keywords: non-ionizing radiation, traffic process, power control, channel reallocation

1 Introduction

It is well known how power control in both directions affects battery saving, energy saving in the base station and reduction of interference for other connections. Procedures were developed for calculating the impact of power control on other factors. This paper shows how power control in the network of mobile users affects the amount of non-ionizing radiation.

2 State of the art

In recent years, much attention has been paid to radiation. On the technical side, sources of radiation are studied, calculations [1, 2] and measurements [3] are performed. From the medical side, the impact of radiation on human health is being studied [4] and regulations on the permissible level of radiation are being adopted [5]. The traditional approach to the calculation of the radiation level implies that the maximum level of radiation is emitted in all directions around the base station and that all traffic channels are occupied. In recent time more and more attention has been paid to the calculation of real radiation values, which usually do not exceed a value of 25% of maximum calculated radiation [1, 6].

3 Model, assumptions and designations

We are interested in the impact on radiation sources and therefore want to study how the source of radiation can be affected. A base station that emits communication signals at n frequencies will be observed. At each frequency there are t time channels to which the signals are sent in time multiplex. Signals in the first frequency channels are transmitted at maximum power due to identification by mobile users. It should be emphasized that signals on this frequency are broadcast even when the channels are not used for traffic.

The usual designation W_{max} for maximum power and W_m for mean power will be used.

Signal transmission without power control is performed by transmitting the maximum power in each busy channel, starting from the second frequency, and the signal is attenuated on reception if necessary. Starting from the second frequency, there is no signal emission in idle channels. Power control is the procedure to transmit sufficient signal power in the busy channel from the second frequency onwards. Sufficient signal power in different channels is that which will have the same level when received by the mobile station. It is well known that signal attenuation in transmission depends on the distance of the mobile station and the attenuation coefficient of the environment α. Clearly, this simple power control saves power and reduces the interference that this connection causes to other connections.

The number of traffic sources M, i.e. of mobile stations, is significantly higher than the total number of traffic channels, N. The total intensity of calls is denoted by λ and the average length of time the channel is busy is $1/\mu$. The number of occupied channels depends on the traffic whose offered value is $A=\lambda/\mu$. The probability that i channels are busy is calculated using the Erlang state formula

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$$P(i,N,A) = \frac{\frac{A^i}{i!}}{\sum_{j=0}^{N} \frac{A^j}{j!}} \qquad i = 0,1,2,\ldots,N-1,N$$

The part of the connections that cannot be realized due to the limited number of channels is called the loss probability and is denoted by $B = P(N, N, A)$.

Radiation is expressed as the electric field intensity, which will be denoted by E. The symbols for the maximum and mean value of radiation are E_{max} and E_m.

4 System without power control

We assume that idle channels are engaged starting from the first traffic channels of the first frequency (ordered hunting with homing). In this system, the maximum radiation value is equal to the level when all channels are busy. This conclusion is not entirely correct, since the maximum radiation value remains even when some of the traffic channels (channels 1 to 6) are idle in the first frequency. The probability of this event is low if ordered hunting with homing is used, so this event will be considered as non-existent. The error made by this assumption is smaller if the frequency number is higher [7].

Numerical proof is the following example: there are two frequencies, i.e. 14 traffic channels. The offered traffic is 10 Erl. For the assumed seizure procedure, the served traffic of each channel can be calculated [8]. From this data, the probability that the channel is idle may be calculated. Probability that all channels are busy, i.e. that the transmitted power is the maximum one is

$$B = P(14,14,10) = 0.0568$$

If we now calculate the probability that all channels are busy except the channel 6, which again gives the maximum transmitted power, it is obtained that this probability is 0.00046, which is negligible compared to the probability B. The maximum value of the emitted power is $P_{max} = n \cdot P_{1f}$, where P_{1f} is the value of the transmitted power on the carrier that always emits the maximum power and n is the number of carriers.

The maximum radiation level is obviously

$$E_{max} = E_{1f}\sqrt{n}, \qquad (1)$$

where E_{1f} is the radiation value of the first frequency that is always transmitted at the maximum power, regardless of the busy state of its traffic channels. The probability of this event is very nearly equal to the probability that all channels are busy, B. To assess the impact of radiation on the environment, it is important to know how long the maximum radiation lasts. The number of required traffic channels is determined according to the offered traffic A. The number of required channels N is such that the part of lost calls B does not exceed a few percent, for example 5%, during the main traffic hour, BHCA (Busy Hour Call Attempts). Under normal operating conditions, this result is achieved when $A<N$.

This means that the maximum radiation will not last longer than a part of the time that is equal to the part of time B, when all the traffic channels are busy. This is a consequence of the equality of call congestion and time congestion in Erlang's formula. For the study of the impact of radiation, it is sometimes important whether the radiation is continuous or is carried out in separate intervals, so the impact is observed cumulatively. Determining the time interval of the maximum radiation comes down to determining the average sojourn time in the state i, $t_m(i)$, where the states may be i=0, 1, … N–1, N:

$$t_m(i) = \frac{1}{\lambda + i \cdot \mu} \qquad i < N \qquad (2.1)$$

$$t_m(N) = \frac{1}{N \cdot \mu} \qquad i = N \qquad (2.2)$$

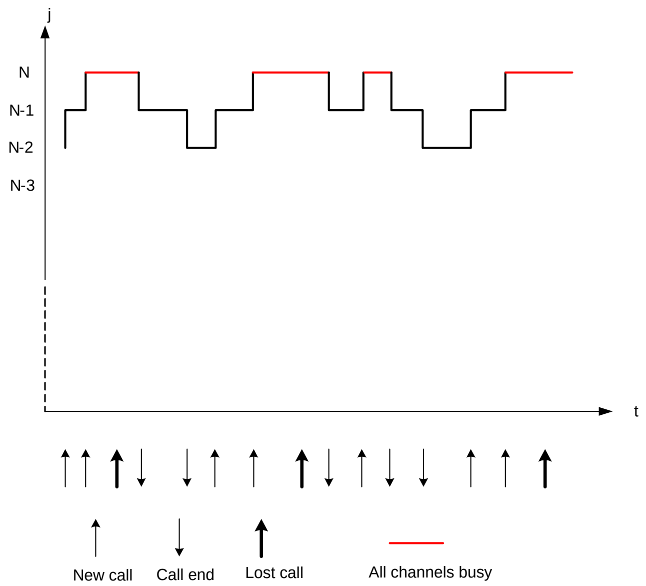

Fig. 1. Symbolic representation of the traffic process when the radiation is largest

It is obvious that the average time that the system stays continuously in the state of the maximum channel occupancy, thus of the maximum radiation intensity

$t_m(N)$, is numerically significantly less than the total time of the maximum radiation B. This means that the maximum radiation in this model occurs impulsively as, in principle, presented in Fig. 1.

In the previous numerical example when $n=2$, $N=14$, $A=10$, $\mu=0.01$/s it is obtained $t_m(N)$ = 7.1 s which is significantly less than the total time in BHCA during which the system stays in the state of maximum load 1 hour·× B = 3600 s·× 0.0568 = 204.5 s. In calculating this case the maximum radiation state appears about 30 times on average during a busy hour.

If all channels are not busy, the radiation value could be calculated using the radiation value of one channel and then making the sum of all busy channels. It should be emphasized that states in which the radiation is less than the maximum one change faster according to equations (2) and (2a). If l channels are idle in the second and the following frequencies, then the transmitted power and radiation power in the system without power control is

$$P_3 = P_{1f} \cdot \frac{8 \cdot n - l}{8}$$

$$E_3 = E_{1f} \cdot \sqrt{\frac{8 \cdot n - l}{8}} \tag{3}$$

5 Power control

Power control is the process of determining sufficient power in all connections realized over traffic channels from the second frequency to the last. It is considered that the distance of the mobile station from the base station has the greatest influence on the power of a channel with power control. A cell is viewed as consisting of circular rings containing users who require approximately the same (+ or –1 dB) power. There are 15 such rings, so power control can be carried out in the range of 30 dB [9]. The probability that the user belongs to ring i (i=1, 2, 3, … 14, 15) is p_i, $\sum p_i=1$. In principle, in this system as well, the highest value of radiation appears when all channels are busy but by users from the ring that is farthest from the BTS. It is clear that, due to the randomness of the traffic process, such an event is unlikely, since its probability has a value of $(p_{16})^N$, which would be approximately $(1/15)^N$. This value in the simple case when n=2 is less than 10^{-8}.

Therefore, in this case it is more correct to calculate with mean values, since the distance of the user randomly changes from call to call. The mean value of transmitted power and total radiation when all channels are busy in this case is

$$P_4 = P_{1f} + P_{fm} \cdot (n-1)$$

where P_{fm} is the mean transmitted power of a single carrier with power control when all channels are busy. It further holds

$$E_4 = \sqrt{P_{1f} + P_{fm} \cdot (n-1)} = E_{1f} \cdot \sqrt{1 + k \cdot (n-1)} \tag{4}$$

where E_{fm} is the mean value of radiation of one frequency when all channels are busy. This mean value is

$$E_{fm} = \sqrt{k} \cdot E_{1f}$$

where k depends on the surface density distribution of users in the cell. The value of the quantity k for the three characteristic users' surface densities is as follows [10]:

$$k_1 = \frac{2}{\alpha + 2} \tag{4.1}$$

for the uniform users' surface density,

$$k_2 = 6 \cdot \left(\frac{1}{\alpha + 2} - \frac{1}{\alpha + 3}\right) \tag{4.2}$$

for the decreasing users' surface density from the cell centre to its rim, and

$$k_3 = \frac{3}{\alpha + 3} \tag{4.3}$$

for the increasing users' surface density from the cell centre to its rim, where α = 2 to 5 is the environmental attenuation coefficient.

6 Control with channel reallocation

As proved in [11], the transmitted power may be reduced by reallocating traffic channels if the power control procedure is improved. Namely, in the process of connections establishment, channels that always emit the highest power should be assigned to users who are farthest from the base station. In this reference, the power saving (G) given by equation (3) is calculated which can be applied in ideal and realistic cases. It is shown that the power saving decreases with the increase in the number of channels and the increase in traffic and increases with the increase of the environmental attenuation coefficient (α). It is obvious that the radiated power will depend on factor G,

$$P_5 = \frac{P_4}{G}$$

and the radiation power in this case will decrease proportionally to the root of the power saving coefficient

$$E_5 = \frac{E_4}{\sqrt{G}} . \quad (5)$$

It is clear that we may compare the radiation level at different models by taking the maximum value for the model without power control (which is also the mean value), and for the model with power control and the model with channel reallocation the mean value will be considered. In these two models, there is a maximum value, but the probability of its occurrence is so small that the mean value is a more realistic indicator of radiation that has a greater impact.

To compare the radiation in individual models, the intensity of the radiation at the highest traffic will be used, i.e. the maximum value in the model without power control and the mean radiation value when the channels are busy in the two models with power control.

In the case of models without emission power control, the highest radiation value is given by Eqn. (1), thus $E_{\max} = E_{lf} \cdot \sqrt{n}$. In the model with power control, the mean power at peak traffic is

$$E_4 = E_{1f} \cdot \sqrt{1 + k \cdot (n-1)}$$

according to Eqn. (4). The comparison of radiation level gives

$$\frac{E_4}{E_{\max}} = \frac{E_{lf} \cdot \sqrt{1+k \cdot (n-1)}}{E_{lf} \cdot \sqrt{n}} = \sqrt{\frac{1+k \cdot (n-1)}{n}} \quad (6)$$

Comparison of the radiation level for the model with channel reallocation and the model without power control gives

$$\frac{E_5}{E_{\max}} = \frac{E_4}{E_{\max} \cdot \sqrt{G}} = \sqrt{\frac{1+k \cdot (n-1)}{G \cdot n}} \quad (7)$$

7 Examples

7.1 A cell model with two carriers (n=2) is considered, and the environmental attenuation coefficient is α=2. It is necessary to determine the maximum radiation level in the model with power control for different cases of users' surface density in the cell, i.e. its ratio to the maximum radiation in the system without power control.

From [10, Figure 1], it can be seen that W_{fm} has values of $0.3 \cdot W_{max}$, $0.5 \cdot W_{max}$, and $0.6 \cdot W_{max}$ for decreasing, uniform, and increasing users' surface density, respectively. It follows that the radiation level, according to equation (6): $E_4/E_{\max}$= 0.80, 0.86, 0.89 for decreasing, uniform, increasing users' surface density distribution in the cell, respectively.

7.2 The same cell is considered, but the environmental attenuation coefficient is α=4. Using Eqns. (6), (4.1), (4.2) and (4.3), it is obtained that the results are $E_4/E_{\max}$= 0.27, 0.46, 0.81.

7.3 A cell with two carriers is considered, the users' surface distribution is uniform and α=2. From the example 1 it can be seen that the power control reduces the radiation level to $E_4/E_{\max}$ compared to the radiation in the cell without power control. Determine the radiation reduction of this cell in relation to the radiation of the model without power control if channel reallocation is applied and the offered traffic A is in the range from 6 Erl to 12 Erl.

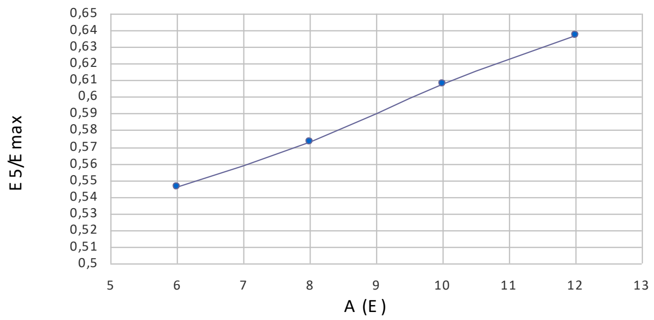

Fig. 2. The ratio of the radiation level of the system with channel reallocation and the system without power control in the case of 2 carriers when it is α=2.

Using Eqn. (7) and the diagram from Fig. 6 in [11], the graph in Fig. 2 is obtained.

7.4 Determine the change in radiation level in cells with 2, 3 and 4 carriers if the traffic channels of each cell are offered with traffic A that causes loss of about 5%. The environmental signal attenuation coefficient is α=2. The number of traffic channels is 14, 22 and 30 and the offered traffic is 10, 17 and 25 Erl. Using Eqn. (7) and the values of G from Table 1 from [11], the graph in Fig. 3 is obtained.

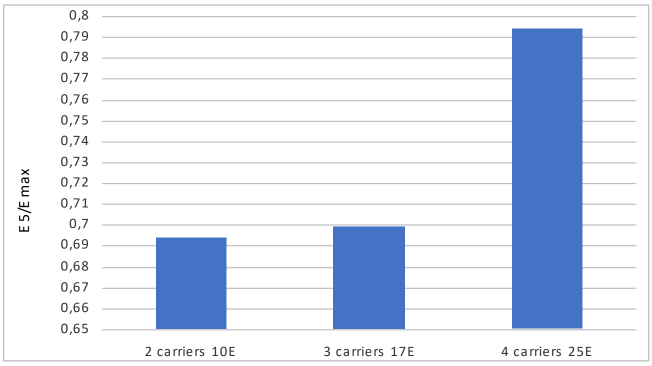

Fig. 3. The ratio of the radiation level E_5/E_{max} of the system with channel reallocation and the system without power control in the case of 2, 3 and 4 frequency carriers when it is α=2 and the value of the offered traffic produces a loss of about 5%.

8 Simulation verification

The simulation verification that was realized in [10] and [11] is applied as a basis in this paper as well. It is a classic Roulette or Monte Carlo simulation that has been known for a long time [12], to which we have added the generation of a random number that corresponds to the distance of the mobile user from the base station, which is the basis for determining the emission power of the base station for the considered user. This second random number is generated only if the first generated random number matches the initialization of a new connection. The procedure for converting the second generated number into distance and then random power is described in detail in [13].

9 Conclusion

The paper shows that control of emitted power, in addition to saving energy and reducing interference, also contributes to the radiation reduction.

Control of the emission power by matching the power with the user's distance affects the reduction of radiation in proportion to the increase in the number of frequency carriers. The radiation level depends on the distribution of the users' surface density in the cell and on the environmental signal attenuation coefficient.

Additional control of the emission power by channel reallocation can further reduce the radiation level. This reduction is greater when there is a smaller number of frequency carriers (but greater than 1), with less offered traffic and with a higher attenuation coefficient.

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