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CALCULATION OF THE MEAN EMISSION POWER IN A MOBILE NETWORK CELL AS A FUNCTION OF USERS' DENSITY DISTRIBUTION

Aleksandar LEBL[1], Dragan MITIĆ[2], Žarko MARKOV[1]

[1] IRITEL a.d., Department of Radiocommunications, Batajnički put 23., Belgrade, Serbia
[2] IRITEL a.d., Department of Optical Communications, Batajnički put 23., Belgrade, Serbia
Corresponding author: Aleksandar LEBL, E-mail: lebl@iritel.com

Abstract. In this paper we consider two random variables in a cell in the network of mobile users. The first random variable (RV) is the distance of active mobile user from a base station. The second RV is emission power for the random active user if the control of emission power exists. RV emission power is dependent RV of the first RV. That's why the calculations of mean values for these RVs differ one from the other. The first RV depends only on the users' density area distribution. The second RV depends on the signal attenuation value in the considered environment. It is proved that, in real conditions, emission power to a user at the mean value of distance from a base station is always lower than mean value of emission power to a user. The difference between these two power values increases as the signal attenuation coefficient increases. These two values are calculated for three characteristic user density distributions in a cell. The results are verified by original computer simulation programs.

Key words: base station emission power, users' density distribution, user at a mean distance, mean emission power.

1. INTRODUCTION

In a telephone network of mobile users (mobile stations – MS) it is necessary to provide sufficient, but not too high emission power. As it is well known, too high emission power has unfavourable influence on the environment and causes unnecessary interference. Emission power decrease is performed by power control [1] i.e. by emission power adjusting in both directions to the sufficient level. This procedure has several positive consequences: energy consumption decrease, disturbances decrease, fading overcoming, prolonged user batteries life, radiofrequency radiation decrease.

In order to predict the network part characteristics, it is necessary to provide as precise as possible power and other cell characteristics calculations in the main mobile network part, a mobile network cell. Traffic process in a cell is performed as a random process and this is the reason why calculations are performed using mean values. In the calculations related to random processes mean values are always used except for radiofrequency radiation estimation where maximum values are mainly analyzed.

Therefore, the correct determination of mean values of cell performances is the basis of accurate cell dimensioning. The most important variables in one cell are the distance between MS and base transceiver station BTS, and the emission power sent to the user. Knowing the properties of a RV distance between MS and BTS allows calculation of users' moving characteristics in a network, handover [2] and BTS emission power. Knowledge of BTS emission power towards an active MS allows total necessary power calculation at the highest traffic load (busy hour) and the calculation of mutual interference in different channels.

In this paper it is presented how to calculate the mean value of distance between MS and base station (BTS) and the mean value of power for MS in a cell if there is power control. The basis for the calculation of the mean distance between BTS and MS is the knowledge of users' surface density distribution in a mobile network cell. The basis for the calculation of the mean emission power in a cell with power control are the knowledge of users' surface density distribution and knowledge of power dependence on loss in signal transmission.

Wireless telecommunications are the subject of intensive studies, among others, for two reasons: 1. an attempt to save energy due to the energy crisis and interference and 2. possible influence to human health [3].

The investigation of the 5G devices is especially numerous and interesting [4]. In recent years, we have been most interested in our investigations in as precise as possible determination of the dependence of transmitted power on different factors: the percentage of internal connections, the influence of users' moving, the influence of handover and so on. This paper presents the results of determining the mean values of certain parameters of a mobile network cell with power control, which are important for the precise determination of emission power.

Mean values of emission power are more important for mobile systems function than maximum power levels. Maximum power is considered only when effect of radiation is estimated (according to international recommendations) although this effect is also manifested over mean power values. According to our knowledge, such analysis of the mean power in the available literature is related to the value of the whole system mean power obtained by extensive measurements on a significant number of different dimension systems which operate in different operational conditions. The results are available for 2G to 4G systems [5–8] and in a number of other investigations. The ratio mean to maximum emission power is in the range from 1 for GSM systems with only one frequency carrier [5] (because there is no power control on the first carrier) and 65% or less when there are two or more frequency carriers also in GSM systems [6] over 20-26% for 3G [7] to only 2.2% or even less than 1% for 4G systems [8]. The results for 3G and 4G systems follow after a great number of measurements in various propagation conditions and with different traffic levels. The reasons for such improvement are traffic variations, fast and advanced power control, discontinuous transmission (DTX) and soft handover [8]. Our original contribution is that we analyze this ratio separately for each established connection while considering only the effect of power control due to variable distance MS-BTS which, further, allows us to estimate the mentioned power ratio instead of performing massive measurements. The paper is a valuable clarification and addition to our investigations presented in [9], [10] as it resolves a dilemma on which basis to calculate mean emission power i.e. whether we may apply mean distance MS-BTS for this purpose.

Computer simulations are very suitable method for analytical results verification. Such simulations may be applied for much more demanding variable distributions than it is in our case [11]. All the more, the results of our mathematical analysis can be reliably supported by the results obtained by simulation. We have no practical (measurement) results in this paper; the results of simulation are the verification of our calculations. However, the obtained theoretical results are a support to extensive measurements (presented in [5–8] and other literature) which are related to a very important problem of non-ionizing radiation influence on human health.

It is especially interesting to determine ratio of mean emission power to one user and emission power to a user on the mean distance from BTS. The model, assumptions and designations used in this paper are adopted in the Section 2. The mean value of distance between MS and BTS for different distributions of users' density is determined in the Section 3. The mean value of emission power to one user is calculated in the Section 4 and after that in the Section 5 this power is compared to the emission power to a user on the mean distance from BTS. The method of simulation is briefly presented in the Section 6. The paper conclusion follows in the Section 7.

2. THE MODEL, ASSUMPTIONS AND DESIGNATIONS

Let us consider a circular mobile network cell of the radius R. The number of the users in the cell is significantly higher than the number of available channels used for connections realization. Users' surface density (g) may be different, but usually three MSs surface densities are considered: uniform in the whole cell, linearly decreasing as a function of distance from BTS (where the density is g_0) to the cell rim (where the density is g_R , $g_R < g_0$) and linearly increasing as a function of distance from BTS ($g_R > g_0$) to the cell rim ($g_R = 1$). The general expression for any distance x between MS and BTS for all these three users' surface distributions is expressed by:

$$g_x = g_0 - (g_0 - g_R) \cdot \frac{x}{R} \tag{1}$$

where $0 \le x \le R$.

The instantaneous distance of the considered user from BTS is designated by d. The probability of randomly distributed variable x is designated by $P(x)$. The probability cumulative distribution function, CDF, of the variable y is designated by $F_y(x)$, $F_y(x)=P(y\le x)$. The probability density function, PDF, of the RV x is $f_x(x)$. The mean values are designated by the subscript m, the mean distance between the user and BTS is d_m. The emission power is designated by W. It is supposed that there is emission power control to the users and that power level depends only on the distance of user from BTS, $W = a \cdot d^\gamma$, $\gamma = 2$–5 [12], where γ is the coefficient of signal attenuation in some environment and a is the coefficient which adjusts dimensional and numerical properties of two expression sides. It is obvious that it is $P_{max} = a \cdot R^\gamma$. The value of emission power to an active user is not independent RV but random function of user distance from BTS. It is supposed that traffic process is random, i.e. the moment of call origin and release are random as also the distance of active user from BTS.

3. THE MEAN VALUE OF DISTANCE BETWEEN A USER AND BTS

It is presented in the paper [9] how CDF of distance between MS and BTS, $F_d(x)$ may be determined. This variable is expressed by (7) in [9] for the case of uniform ($g_0 = g_R$), decreasing ($g_0 > g_R$) and increasing ($g_0 < g_R$) users' density. CDF may be determined comparing the surface of cell parts or volumes which present MSs' density in the case of three mentioned density distributions. As it is known, PDF is determined from CDF as its derivative

$$f_d(x) = F_d'(x), \tag{2}$$

and the mean value of distance MS-BTS is

$$d_m = \int_0^R x \cdot f_d(x) \cdot \mathrm{d}x \tag{3}$$

According to the equation (7) in [9] the calculated values of mean distance MS-BTS for three analyzed surface users' density distributions (uniform, decreasing and increasing) are $d_{mun} = 2R/3$ ($g_0 = g_R$), $d_{mdec} = 0.5R$ ($g_0 = 1$, $g_R = 0$), and $d_{minc} = 3R/4$ ($g_0 = 0$, $g_R = 1$), respectively. It may be emphasized here that the mean value of distance between MS and BTS depends only on the surface users' density distribution in a cell. The concrete values are d_{mun}, d_{mdec} and d_{minc} which are here emphasized.

4. THE MEAN VALUE OF EMISSION POWER TO A USER

As it is already emphasized, emission power to some user is not independent RV but random function and it depends on RV d. It is well known [13, Section 5.2.], that PDF of dependent RV (emission power to the user) may be obtained using PDF of independent RV. The mean value of dependent RV may be also obtained using theorem (equation) (5.29) from [13] which uses only probability density function of independent RV (d) and function of dependent RV (W):

$$W_m = \int_0^R a \cdot x^\gamma \cdot f_d(x) \cdot \mathrm{d}x \tag{4}$$

Here $f_d(x)$ is given by the expression (2) whereas it is on the basis of (7) from [9]:

$$F_d(x) = \frac{3 \cdot x^2 \cdot g_0 + \dfrac{2 \cdot x^3 \cdot (g_R - g_0)}{R}}{K} \tag{5}$$

where $K = 2 \cdot R^2 \cdot g_R + R^2 \cdot g_0$.

If the random function $W = a \cdot d^{\gamma}$ is applied in the case of uniform distribution of surface users' density, $(g_0 = g_R)$, the mean emission power to a user is

$$W_m = \frac{2 \cdot W_{\max}}{\gamma + 2}, \tag{6}$$

where $W_{max} = a \cdot R^{\gamma}$.

It is clear from this consideration that mean value of emission power to a user (besides surface users' density distribution in a cell) depends on coefficient γ i.e. on the signal level attenuation in the space.

It is obtained in the same way for the linearly decreasing users' density distribution from BTS to the cell rim, $g_0 = 1$, $g_R = 0$:

$$W_m = 6 \cdot W_{\max} \left(\frac{1}{\gamma + 2} - \frac{1}{\gamma + 3} \right). \tag{7}$$

If surface users' density in a cell increases linearly from BTS to the cell rim ($g_0 = 0$, $g_R = 1$), the mean value of emission power to MS is calculated from:

$$W_m = \frac{3 \cdot W_{\max}}{\gamma + 3}. \tag{8}$$

The mean emission power to one user as a function of propagation coefficient (γ) for uniform, decreasing and increasing users' density distribution in BTS cell is presented in Fig. 1. The precise values are calculated using expressions (6), (7) and (8). These calculation results in Fig. 1 agree with the measurement results that this value is 0.65 for GSM systems with two or more frequency carriers, which is emphasized in an Introduction.

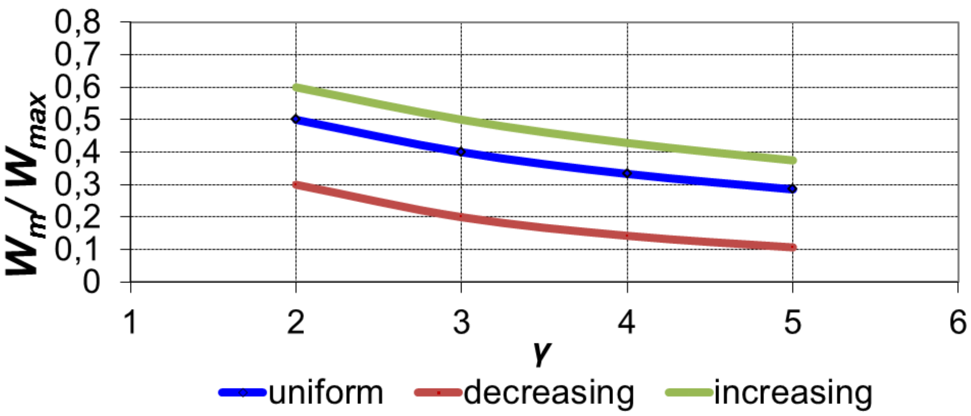

Fig. 1 – The mean emission power (W_m) to a user as a function of propagation coefficient (γ) for different user density distributions.

5. COMPARISON OF THE MEAN USERS' POWER AND THE POWER OF A USER AT THE MEAN DISTANCE FROM BTS

The main goal of this paper is to compare the mean emission power to one user, W_m, and the emission power to a user at mean distance, i.e. $W_{dm} = a \cdot d_m^{\gamma}$. This comparison is illustrated using graphics in Fig. 2 for uniform, in Fig. 3 for decreasing and in Fig. 4 for increasing users' density. In more detail, the values in the Figs. 2–4 are determined in the following way:

1. the expression (6) is used to obtain W_m and after that W_{dm} to the user at the mean distance d_{mun} is calculated in the case of uniform users density distribution – Fig. 2;
2. the expression (7) is used for W_m and after that W_{dm} to the user at the mean distance d_{mdec} is calculated in the case of decreasing users density distribution – Fig. 3;
3. the expression (8) is used for W_m and after that W_{dm} to the user at the mean distance d_{minc} is calculated in the case of increasing uniform distribution – Fig. 4.

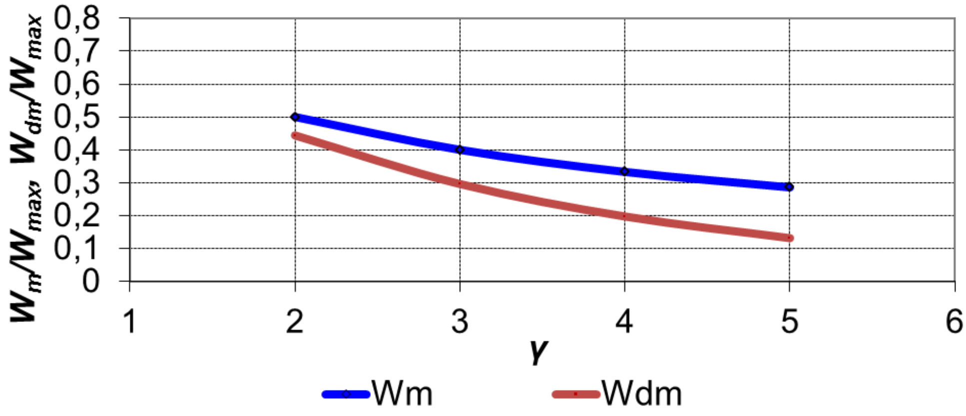

Fig. 2 – The mean emission power to one user (W_m) and the emission power to a user on the mean distance from a base station (W_{dm}) as a function of the propagation coefficient (γ) for uniform users' surface distribution.

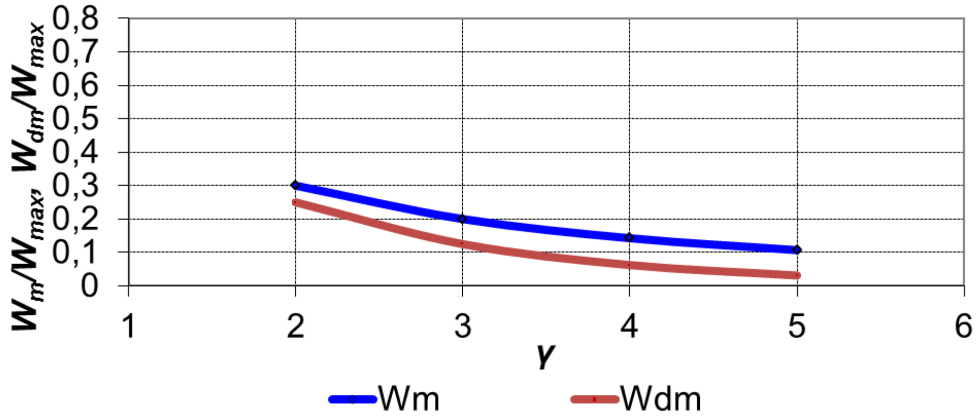

Fig. 3 – The mean emission power to one user (W_m) and the emission power to a user on the mean distance from a base station (W_{dm}) as a function of the propagation coefficient (γ) for decreasing users' density distribution as a function of users' distance from BTS.

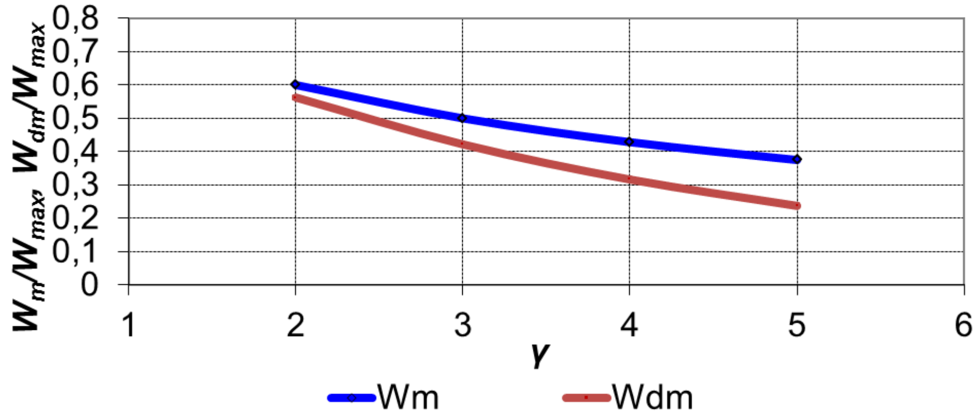

Fig. 4 – The mean emission power to one user (W_m) and the emission power to a user on the mean distance from a base station (W_{dm}) as a function of the propagation coefficient (γ) for increasing users' density distribution as a function of users' distance from BTS.

It is obvious that mean emission power to a user (W_m) is always greater than the power which is transmitted to a user whose distance from BTS has the mean value (W_{dm}) for all real conditions when it is $\gamma > 1$, i.e.:

$$W_m > W_{dm} = a \cdot d_m{}^{\gamma} \quad \gamma > 1. \tag{9}$$

This difference exists when absolute values of emission power is considered and even more when relative ratio is analyzed, as presented in the Fig. 5. The power ratio may reach nearly 3.5 for decreasing users' density distribution and attenuation coefficient $\gamma = 5$.

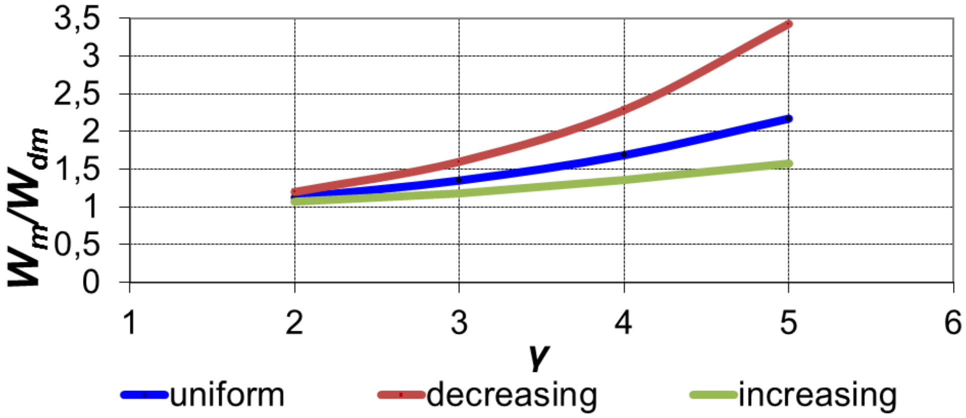

Fig. 5 – The ratio of mean emission power to one user (W_m) and the emission power to a user on the mean distance (W_{dm}) from a base station as a function of the propagation coefficient (γ) for uniform, increasing and decreasing users' density distribution as a function of users' distance from BTS.

The analysis in this paper is based on the alpha-beta-gamma (ABG) propagation model implementation [14]. The coefficients in this model are calculated in such a way to obtain the best fit curve to the measured or more accurately calculated path-loss characteristic. A survey of real characteristics applicable to mobile systems from 2G (GSM) to 5G may be found in [14]. It is possible to model all these characteristics by ABG model. The highest influence among the three emphasized coefficients has the third one (γ) and we have limited our analysis in this paper on its implementation. The propagation conditions for sub-6GHz radio waves are approximately modelled by ABG model. So, the results from our analysis are easily applicable for 2G, 3G, 4G and sub-6GHz 5G systems. According to [15], there is a difference in propagation conditions between sub-6GHz signals and higher frequency signals which may be also applied for 5G systems. As a consequence, ABG model is not optimal one in the case of frequencies higher than 6GHz. Nevertheless, the example values of parameters α, β and γ at higher frequencies than 10GHz in some indoor circumstances are emphasized in [16]. Among these examples there are situations when γ may be significantly less than 2. Thus, we have to expand our analysis at the values $\gamma < 2$ to obtain widely applicable results.

6. SIMULATION RESULTS

Simulation performed in our analysis is based on the simulation process already presented in [9]. The paper [9] is just a part of our total volume of contributions dealing with simulations first of all in mobile telephony, which are summarized in [17]. All our simulation programs are based on Monte Carlo method which is presented in [18] for the first time.

The development presented here includes also traffic simulation to increase confidence in the obtained results meaning that the value of traffic intensity and number of available traffic channels are defined before the simulation.

When considering simulation for the case of mean emission power, the program flow corresponds to the one applied in [9]. It is important to emphasize that in this case each generated random number is modified according to the coefficient dependent both on users' density distribution and propagation coefficient γ. Modification is realized by the calculation of inverse function. At the end of simulation the mean emission power is calculated as the mean value of power in all traffic channels when they are in active state.

When simulation is performed for the case of power to the user at the mean distance from BTS, the applied simulation program is slightly changed. The generated random number is modified according to the coefficient which is dependent only on the users' density distribution in the cell. The mean value determined in such a way during simulation process is finally raised to the degree equal to γ.

The selected value of offered traffic in the simulation process has been A=12E (erlangs) and the number of available traffic channels has been N=16. The results determined by simulation correspond to those obtained by calculation with difference less than 1% for only 25000 generated random numbers and for between 5000 and 6000 initiated traffic connections during simulation process.

Interested readers may obtain the simulation program by contacting the authors.

7. CONCLUSION

Determination of mean values of distance between MS and BTS, d_m, and emission power to a user, W_m, are performed in different ways because the distance between MS and BTS is independent RV and its mean value depends only on the distribution of MSs' density in a cell. The mean value of emission power to a user depends on a distance MS ↔ BTS and on the attenuation coefficient γ. The mean value of distance between MS and BTS is important when power is calculated for mobile users [19].

The mean value of emission power determination is based on the method of mean value of random function calculation and is important in all cases of energy efficiency estimation [9, 10]. Emission power determined using the power to the user at the mean distance is lower according to the expression (9). In some cases of users' density distribution and attenuation coefficient γ values this power is even not more than 30% of mean emission power. Such high difference is clear proof that calculation of mean emission power may not be replaced by the calculation of power to the user on the mean distance from BTS.

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