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INFLUENCE OF MOBILE USERS' DENSITY DISTRIBUTION ON THE CDMA BASE STATION POWER

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In this paper we analyze the influence of users' density distribution in one cell of CDMA mobile network (*ie* adjusted power control on the forward link) on base station emission power. This influence is analyzed for different circles radii around base station within which same emission power is generated for all mobile users, and for different values of propagation loss coefficient. It is proved that emission power in this cell must be increased comparing to the similar cell, which uses complete power control. The power increase is greater when greater number of users are situated near base station, and for greater values of propagation loss coefficient. The results are presented, illustrated by numerical examples and verified by simulation for three users' density distributions: uniform, decreasing and increasing density from the base station to the cell rim. The simulation process, which is based on random traffic process, is presented briefly.

Keywords: mobile cell, user density, forward and reverse power control, CDMA, GSM, adjusted power control

1 INTRODUCTION

Power control in the networks of mobile users is applied more and more in the base station (BS) and in the mobile user's station (MS) [1–5]. The results of measurement of emission power, without power control and with power control, are presented in [6]. In the networks based on TDMA (time division multiple access) and FDMA (frequency division multiple access), which are used in GSM (global system for mobile communications) this control is not mandatory for the BS emission power, but, nevertheless, it is implemented to save power and to reduce interference. In the cell, which uses CDMA (code division multiple access), power control is essential for the CDMA systems functioning. In principle, BS emission power for one connection depends on distance between BS and MS. It means that BS emission power depends on distribution of users' density in the cell: the greater the MSs concentration in the vicinity of BS, the smaller the BS emission power, and vice versa. In the majority of papers taking into account power control uniform users' density in the cell is considered. In this paper we investigate influence of surface distribution of users' (MSs') density on the total BS emission power for two cases. The first one is implementation of frequency and time multiplex in the GSM network with power control. The second one is the cell which uses CDMA and adjusted power control on forward links. (Adjusted power control means that in the forward direction emission power for the users, who are near base stations, does not decrease as the function of the users' distance from the base station, but it is constant). As almost in all analysis is supposed that users' distribution around base station is uniform, the main contribution of this paper is to model the influence of distribution of users' density in the cell on the variation of base station emission power in the CDMA cell. The aim of the paper is also to determine this variation of power when radius of the circle where constant emission power is generated towards all users is changed, while considering different values of propagation loss coefficient. Section 2 presents existing contributions from this area, and Section 3 presents the cell models, designations and assumptions. The cell characteristics in relation to transmitted power for the first and the second model are described in Sections 4 and 5. In Section 6 we compare the powers in the first and in the second case. Numerical examples of power increase calculation in the second model for different distributions of users' density in the cell are presented in Section 7. Several remarks about verification of calculated results by simulation are given in Section 8.

2 RELATED WORK

The need to implement power control in BSs and MSs in the older generation networks is analyzed in many papers [1–5]. In order to carry out power control efficiently, it is necessary to know precise methods for emission power calculation. Calculation of one channel emission power and the whole BS emission power as dependent random variable in GSM network is presented in [7]. Calculation of BS power as the function of the traffic type and value

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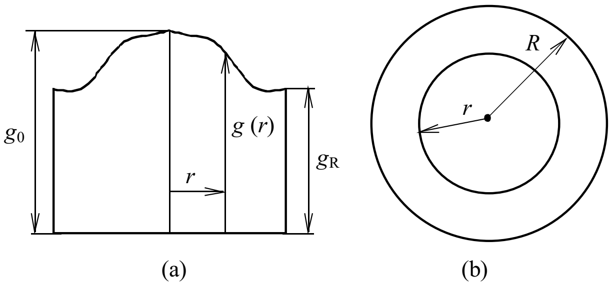

Fig. 1. Distribution of surface users' density around BS

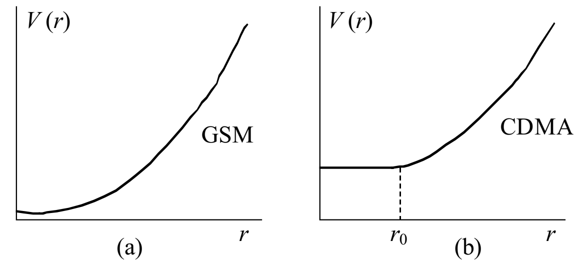

Fig. 2. Models of BS power control: (a) — monotonically increasing power as the function of distance, (b) — monotonically nondecreasing function (users at the distance $r \leq r_0$ receive power as if they are on the distance r_0)

is given in [8–10]. Dependence of power in GSM cell on the distribution of users' density is analyzed in [11]. The verification of results, presented in [7, 8, 10, 11], by simulation of random telephone traffic process in the cell, is described in [12]. Emission power per each active channel can be reduced applying various technics, which reduce necessary channel bandwidth, as, for example, half-rate coding. In [13] it is explained how implementation of half-rate coding increases system traffic capacity, but it is also emphasized that, as a parallel positive effect, emission power is decreased. The results of measurement of emission power, without power control and with power control, are presented in [6]. The results from this contribution show that power control in one GSM (2G) network decreases emission power for 4 dB in 80 % of cases.

In the networks, based on CDMA principles, power control is of crucial importance, because it has influence on cell capacity. One of good presentations of CDMA network principles can be found in [14]. There are two directions of power control in CDMA network: direction BS → MS (downlink, forward link) and direction MS → BS (uplink, reverse link). One sophisticated method of power control on reverse link is presented in [15], and the method of power control on forward link is presented in [16–18]. In these papers uniform distribution of users' density in CDMA cell is considered.

3 MODEL, DESIGNATIONS AND ASSUMPTIONS

Let us consider the cell model in the network of mobile users in two cases. The first one is the cell with power control in the whole cell dependent on distance between BS and MS (the first model). The second one is the cell with power control implemented only for the users at the greater distance, while emission power for the users nearer to the BS has small value, which does not depend on distance. This small power guarantees satisfactory signal to interference ratio for connection realization (the second model or CDMA model). The collection of one connection characteristics (frequency, timeslot, code) is called channel in the following part of the paper. It is supposed that the cell is circular with radius R. Only channels with power control are considered. Instantaneous, mean and maximum power of one channel are designated as w_1, w_{1m} and $w_{1\max}$. Probability distribution function (PDF) and cumulative distribution function (CDF) will be designated as $f(\cdot)$ and $F(\cdot)$, respectively, for example: PDF of power (w) is $f_w(x)$ and CDF of the same variable is $F_w(x) = \text{Prob}(w \leq x)$.

The output BS power is w_B. The part of connections realized between the users in the same cell (intra-cell connections [8]) is neglected, *ie* it is supposed that one channel is used for each connection. The mean number of users, who leave the cell in the unit of time, is equal to the mean number of users, who arrive to the cell. The number of users in the cell is N_{MS}, the number of channels (active users) in the cell is N and the offered traffic is A. As in [7], the real assumption that the request from MS is generated in a random time instant is adopted, and r (distance between MS and BS) satisfies the condition $r \leq R$. Distance between MS and BS is independent random variable, (r). That's why instantaneous power of one channel in the system with complete power control in the whole cell is dependent random variable w_1,

$$w_1 = v(r) = b + ar^{\gamma} \tag{1}$$

where a is coefficient of proportionality, $\gamma\,(2 \leq \gamma \leq 5)$ is propagation loss exponent, while b can be neglected.

The mean power of one channel, $w_{1m,}$ however, depends also on the fact how often some user distances from BS appear in the traffic process. It means that surface density of (active) users in the cell becomes the factor, which has the influence on the mean power of one channel and, also, on the total BS power, w_B. Figure 1 presents one arbitrary dependence of surface density $G(r)$ on the distance between BS and MS, r. It is important to mention that the density of active users, $g(r)$, and the density of all users, $G(r)$, have the same distribution. The density of active users in the centre of the cell is designated as g_0, and the density at the cell boundary is designated as g_R.

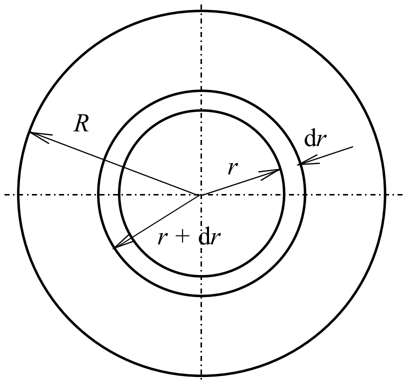

Fig. 3. Illustration for the calculation of BS power

4 THE FIRST MODEL

In the cell of the first model with power control emission power of one channel is changed from very small, *ie* negligible value b, (40 mW, for example) to maximum value $w_{\max}$, (40 W, for example). It is proved in [7, 10–12] that emission power can be calculated as dependent random variable from (independent random variable) distance between MS and BS, $v(r)$, and distribution of users' density, $f_r(r)$, is also considered in the calculation. PDF of power for one channel is based on the equation

$$f_W(w) = \frac{1}{|v'(r)|} f_r(r) \,. \tag{2}$$

The important characteristic of power in the channel of first model with power control is monotonically increasing dependence of $v(r)$, Fig. 2a.

Power control is realized on the basis of distance between BS and MS. The BS emission power to one MS at the distance $r\,(0 \le r \le R)$ from BS is

$$w_1 = \left(\frac{r}{R}\right)^c w_{\max} \tag{3}$$

where c is the number, which depends on different factors. References [14] and [16] consider the cases when $c \le \gamma$, and in [17] it is pointed out that it can be also $c > \gamma$. In this paper we suppose that it is $c = \gamma$ when we compare value of power for two presented models.

Calculation of mean power for one connection is based on PDF from equation (2):

$$w_{1m} = \int_{w_{\min}}^{w_{\max}} x f_w(w) \mathrm{d}x \tag{4}$$

where $w_{\min}$ is minimum (≈ 0), and $w_{\max}$ is maximum power of one connection, $w_{1\max}$.

5 THE SECOND MODEL

The main difference of CDMA technology (the second model), comparing to GSM technology (the first model), is that power control is mandatory, when system is implemented in the network. Functioning and the capacity of this system depend a lot on signal to interference ratio, and power control is one of the methods to increase this ratio. Power control is implemented in the direction BS → MS (downlink, forward link) and in the direction MS → BS (uplink, reverse link). Power control on downlink direction is especially interesting. In [14, 16, 18] it is proved as the good solution that small, constant power, necessary to guarantee satisfactory signal to interference ratio, is generated towards the nearer users, and the power, which is increased when distance between BS and MS is increased, is implemented for distant users, according to the rule

$$w_1 = \begin{cases} \left(\frac{r_0}{R}\right)^\gamma w_{\max} & \text{for } 0 < r \le r_0 \,, \\ \left(\frac{r}{R}\right)^\gamma w_{\max} & \text{for } r_0 < r \le R \,. \end{cases} \tag{5}$$

The value r_0 is called threshold value in [17]. This method of power control (adjusted power control [14]) improves the signal to interference ratio for the users, who are nearer to BS, thus increasing system capacity, *ie* the number of channels. The dependence of power on a distance between BS and MS for this method of power control is presented in Fig. 2b. It is monotonically nondecreasing function. The model of the cell with uniform distribution of surface users' density, value $c = \gamma = 2$ in (3) and the value $r_0 = 0.55R$ in (5) is considered in [16]. It is proved that the increase of total emission power when power control according to the characteristic from Fig. 2b is implemented in relation to power control according to Fig. 2a is about 9 %. It is pointed out in [16] that the optimum power control is for $r_0 = 0.657R$ and $r_0 = 0.75R$ if $\gamma > 2$.

In this paper we shall analyze the influence of distribution of surface users' density in the cell and influence of parameters γ and r_0 on the emission power. In the following calculations it will be supposed that the value of γ from equation (5) is equal to the coefficient of signal attenuation, although it is said in [18] that this may not be always true to achieve optimal power control.

6 THE VALUE OF POWER FOR TWO MODELS AS THE FUNCTION OF DISTRIBUTION OF USERS' DENSITY IN THE CELL

Let us consider the annulus with the inner radius r and outer radius $r + \mathrm{d}r$, Fig. 3.

The number of active users in the annulus is equal to the product of annulus area ($2\pi r \mathrm{d}r$) and surface density of active users $g(r)$.

$$\mathrm{d}N = 2\pi r g(r) \mathrm{d}r \,. \tag{6}$$

The maximum BS emission power to active users in the annulus in the first model is

$$\mathrm{d}w = a r^\gamma \mathrm{d}N = g(r) c r^{\gamma+1} \mathrm{d}r, \quad c = 2a\pi \,. \tag{7}$$

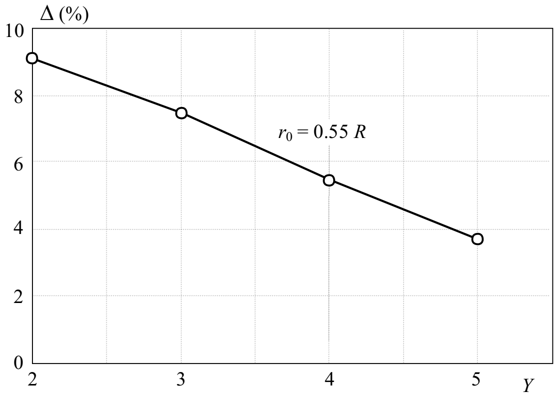

Fig. 4. The variation of BS power (Δ) as the function of γ in the case of uniform users' density for $r_0 = 0.55R$

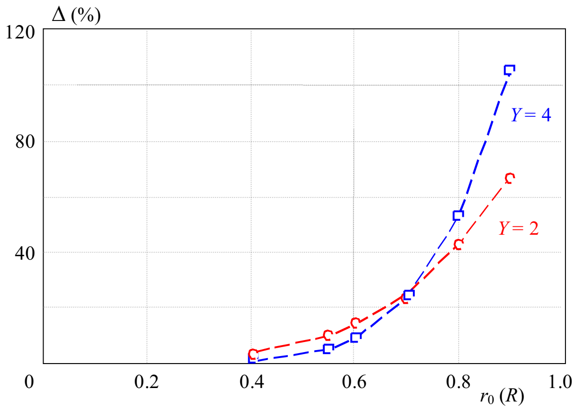

Fig. 5. The variation of BS power (Δ) as the function of r_0 in the case of uniform users' density for $\gamma = 2$ and $\gamma = 4$

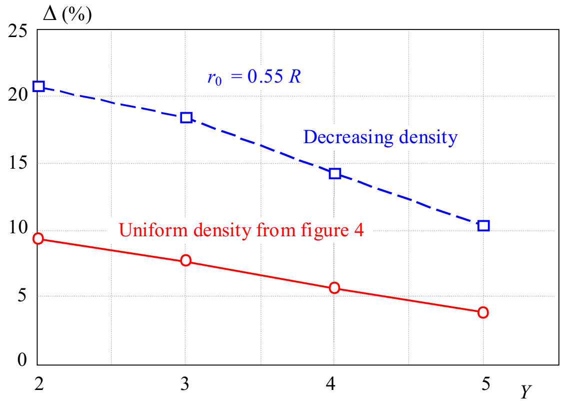

Fig. 6. The variation of BS power (Δ) as the function of γ in the case of decreasing users' density ($g_0 = 6$, $g_R = 1$) for $r_0 = 0.55R$

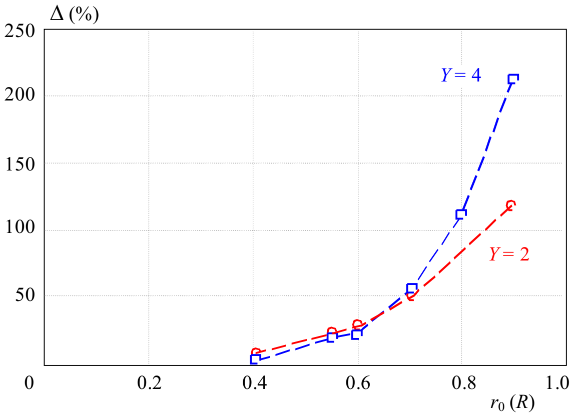

Fig. 7. The variation of BS power (Δ) as the function of r_0 in the case of decreasing users' density ($g_0 = 6$, $g_R = 1$) for $\gamma = 2$ and $\gamma = 4$

The maximum total emission power in the cell in the first model is, obviously

$$w_{BS1} = c \int_0^R g(r) r^{\gamma+1} \mathrm{d}r\,. \tag{8}$$

The total power in the second model of cell consists of two components. The first one is related to the circle with the radius r_0 and its value is

$$w_c = 2\pi a r_0^{\gamma} \int_0^{r_0} r \mathrm{d}r = \frac{c r_0^{\gamma+2}}{2}\,. \tag{9}$$

The second one is related to the annulus with the inner radius r_0 and outer radius R and its value is

$$w_r = 2\pi a \int_{r_0}^{R} g(r) r \mathrm{d}r\,. \tag{10}$$

The total emission power of the second cell model is the sum

$$w_{BS2} = w_c + w_r\,. \tag{11}$$

Relative increase of total emission power of the second model in relation to the power of the first model is

$$\Delta = \frac{w_{BS2} - w_{BS1}}{w_{BS1}}\,. \tag{12}$$

Equation (12) may be used to calculate the increase of power as the function of distribution of users' density, coefficient γ and radius of circle in which emission power is constant, r_0.

7 NUMERICAL EXAMPLES

Let us consider the three most common distributions of surface (active) users' density: uniform, linearly decreasing density from BS to cell rim (decreasing density in the rest of the text) and linearly increasing density from BS to cell rim (increasing density in the rest of the text). These three densities can be expressed by

$$g(r) = g_0 - (g_0 - g_R)\frac{r}{R}\,. \tag{13}$$

The density, expressed by (13), is uniform if $g_0 = g_R$, decreasing if $g_0 > g_R$, and increasing if $g_0 < g_R$. Using the substitutions in equations (5) to (13), we can obtain the expression for the relative difference of total emission

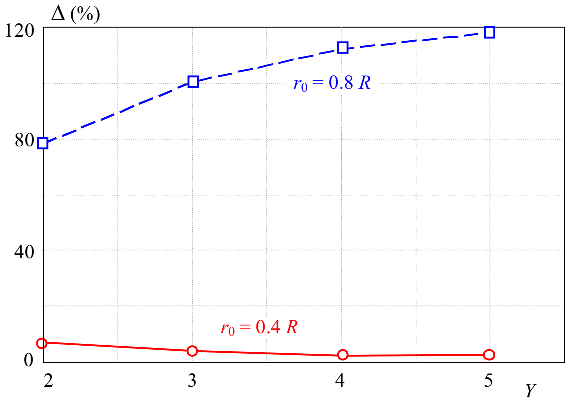

Fig. 8. The variation of BS power (Δ) as the function of γ in the case of decreasing users' density $(g_0 = 6,\ g_R = 1)$ for $r_0 = 0.4R$ and $r_0 = 0.8R$ as the value of parameter

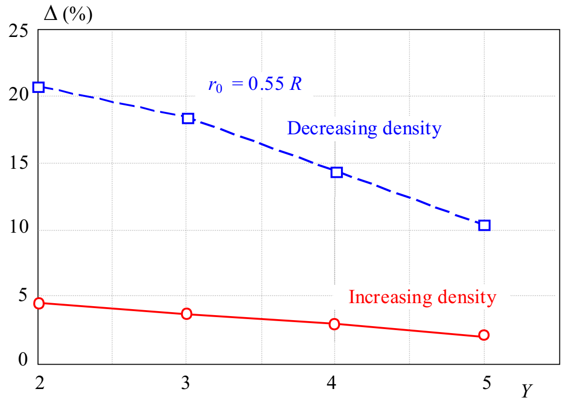

Fig. 9. The variation of BS power (Δ) as the function of γ in the case of increasing $(g_0 = 1,\ g_R = 6)$ and decreasing $(g_0 = 6,\ g_R = 1)$ surface users' density for $r_0 = 0.55R$

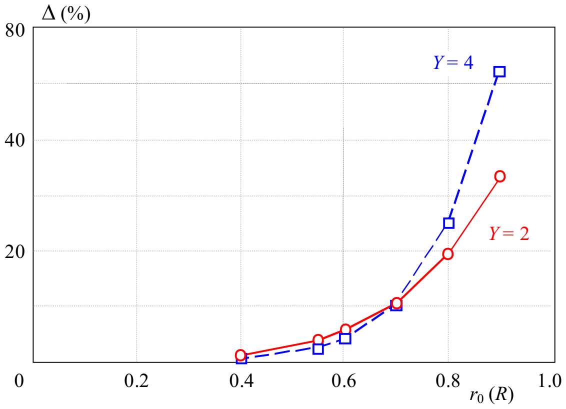

Fig. 10. The variation of BS power (Δ) as the function of r_0 in the case of increasing users' density $(g_0 = 1,\ g_R = 6)$ for $\gamma = 2$ and $\gamma = 4$

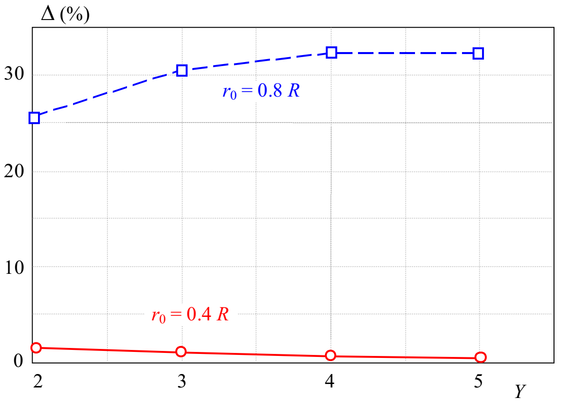

Fig. 11. The variation of BS power (Δ) as the function of γ in the case of increasing users' density $(g_0 = 1,\ g_R = 6)$ for $r_0 = 0.4R$ and $r_0 = 0.8R$ as the parameter

power between two analyzed models:

$$\Delta = \frac{\dfrac{g_0 r_0^{\gamma+2}\gamma}{2(\gamma+2)} - \dfrac{(g_0-g_R)r_0^{\gamma+3}\gamma}{3R(\gamma+3)}}{\dfrac{g_0 R^{\gamma+2}}{(\gamma+2)} - \dfrac{(g_0-g_R)R^{\gamma+2}}{(\gamma+3)}}\,. \tag{14}$$

7.1 Power in the model with uniform users' density distribution

Figure 4 presents dependence of power increase (Δ) in the second model on the propagation loss exponent γ for $r_0 = 0.55R$.

Figure 5 presents dependence of power increase (Δ) in the second model on r_0, *ie* on the radius of circular area, where emission power is constant, when $\gamma = 2$ and $\gamma = 4$.

7.2 Power in the model with decreasing users' density

Let us consider the cell with decreasing density of (active) users. The density decrease is expressed by the equation (13), where it is $g_0 = 6$ and $g_R = 1$. This model is the same as the one presented in [11].

Figure 6 presents increase of power (Δ) if, instead of complete power control, the circle of radius $r_0 = 0.55R$ is introduced, where power for all users is constant (dashed line). The variation of power increase is presented as the function of propagation loss exponent γ $(2 \le \gamma \le 5)$. The power increase for the previous case of uniform distribution (Fig. 4) is also presented by the full line.

The power increase (Δ) as the function of the radius of the circle with constant power (r_0) is presented in Fig. 7 for the propagation loss exponent values $\gamma = 2$ (full line) and $\gamma = 4$ (dashed line). It can be concluded that increase of total emission power for radii $r_0 < 0.5R$ is negligible. The other characteristic of this increase is that the growth of emission power increase is steeper for the greater values of propagation loss exponent, γ.

It is presented in Fig. 8 that the nature of the variation of emission power (Δ) is different: for small r_0 values $(0.4R$, full line) power increase is small and it decays when propagation loss exponent increases; for greater r_0 values $(0.8R$, dashed line) power increase in the second model is greater and it grows when γ increases.

7.3 Power in the model with increasing users' density

Let us consider now the cell with increasing (active) users' density. The density increase is expressed by (13), where $g_0 = 1$ and $g_R = 6$. This model is also analyzed in [11], when calculation of mean power in GSM network is performed. Fig. 9 presents power increase (Δ) in the second model in relation to the first model as the function of γ for $r_0 = 0.55R$ (full line).

As the comparison, the same dependence is presented in Fig. 9 for decreasing users' density (dashed line).

Figure 10 presents power increase (Δ) in the second model as the function of the radius of circle with constant power, r_0, for two values of propagation loss exponent: $\gamma = 2$ (full line) and $\gamma = 4$ (dashed line).

Figure 11 presents power increase (Δ) in the second model if users' density increases, for two values of radius $r_0 = 0.4R$, full line, and $r_0 = 0.8R$, dashed line. The main conclusion from Figs. 9, 10 and 11 is that power increase, caused by the implementation of the second model with increasing users' density, is very small comparing to power increase when users' density is decreasing.

8 SIMULATION AND ITS RESULTS

All results of calculation, presented in Figs. 4–11, are confirmed by the simulation. The method of simulation is intended for CDMA systems. It takes into account characteristics of traffic process in BS, the conditions of signal propagation (propagation loss exponent) and users' distribution in the mobile cell area. But, it includes also specific characteristics of CDMA systems, first of all the implemented mode of power control. The method of simulation is based on the simulation presented in [12] and [11] (which is developed for GSM systems), where decreasing and increasing users' density towards the cell rim is considered. It is upgraded to confirm the results for the cell of the second model, *ie* for the part of the cell where emission power is constant.

The flow-chart of the simulation process is presented in Fig. 12. Similarly as in [11], traffic process is simulated at first (requests are generated). After that, distance between BS and MS is determined for each generated request. On the basis of this distance, necessary BS power is calculated for this connection.

The change in simulation process in relation to the process presented in [11] and [12] is performed in steps 9–13 and 17 in Fig. 12. These parts of simulation program, which are new comparing to the simulation process presented in [11], are specially emphasized in Fig. 12 (bold lines). Besides determining BS power immediately, on the basis of randomly generated distance between BS and MS (RD) — system with complete power control (P_t, blocks 7 and 8), the aim is also to determine necessary power for the CDMA system. This is performed in new blocks 9–13. It is first checked whether the distance between BS and MS is less than the threshold value r_0 (block 9). If the distance is less or equal to the value r_0, BS power (RP) is determined as the distance between BS and MS is equal to r_0 (*ie* without power control) (block 10). If, on the contrary, distance is greater than r_0, BS power is determined as the function of the distance between BS and MS (block 11). There are two values of generated power on the basis of random distance: power for MSs on distance $d \leq r_0$ (P_c, block 12) and power for MSs on distance $d > r_0$ (P_a, block 13).

Random distance between BS and MS is determined using randomly generated numbers with uniform distribution on the basis of inverse function of their density distribution in the area of BS cell, as the function of distance between BS and MS. If the MS density is uniform, it means that the density will be in quadratic dependence of distance, *ie* distance will be determined by the calculation of the square root of randomly generated number. If users' density is non-uniform, the inverse function cannot be easily calculated in general case, or it can be calculated approximately. In that case inverse function is found using some specialized program, as MATHEMATICA or MATLAB. This stands also for the case of users' distribution, which is defined for the models in sections 6.2 and 6.3 in this paper.

At the end of simulation it is necessary to perform analysis (comparison) on the basis of values P_t, P_c and P_a, which are obtained in the simulation. This is realized in block 17. The results presented in Figs. 4–11 are the output of block 17.

Each result calculated in this paper is confirmed by at least three simulation trials. The total number of realized connections for each combination of input data was more than 15000 in each trial. The greatest mutual difference between power increase, obtained by calculation and by simulation, is 4 %, when we compare the case of partial power control (no power control in the circle of radius r_0) to the case of complete power control. This is illustrated in Fig. 13 for one of calculated and simulated characteristics (the case of increasing users' density towards the BS cell rim, where there is no BS power control in the circle of radius $r_0 = 0.55R$).

There is another element of confirmation: to determine if the calculated value is in 95 % confidence interval about the mean value obtained by simulation. The results are treated as confirmed, because the calculated value was in this interval in all cases.

9 CONCLUSION

The functioning of CDMA cell with constant power for the users nearer to BS (the second model or the model with adjusted power control) always increases emission power in relation to the cell with complete emission power control. This is the expected result. There are three characteristic cases, which demonstrate influence of users' density on the BS emission power.

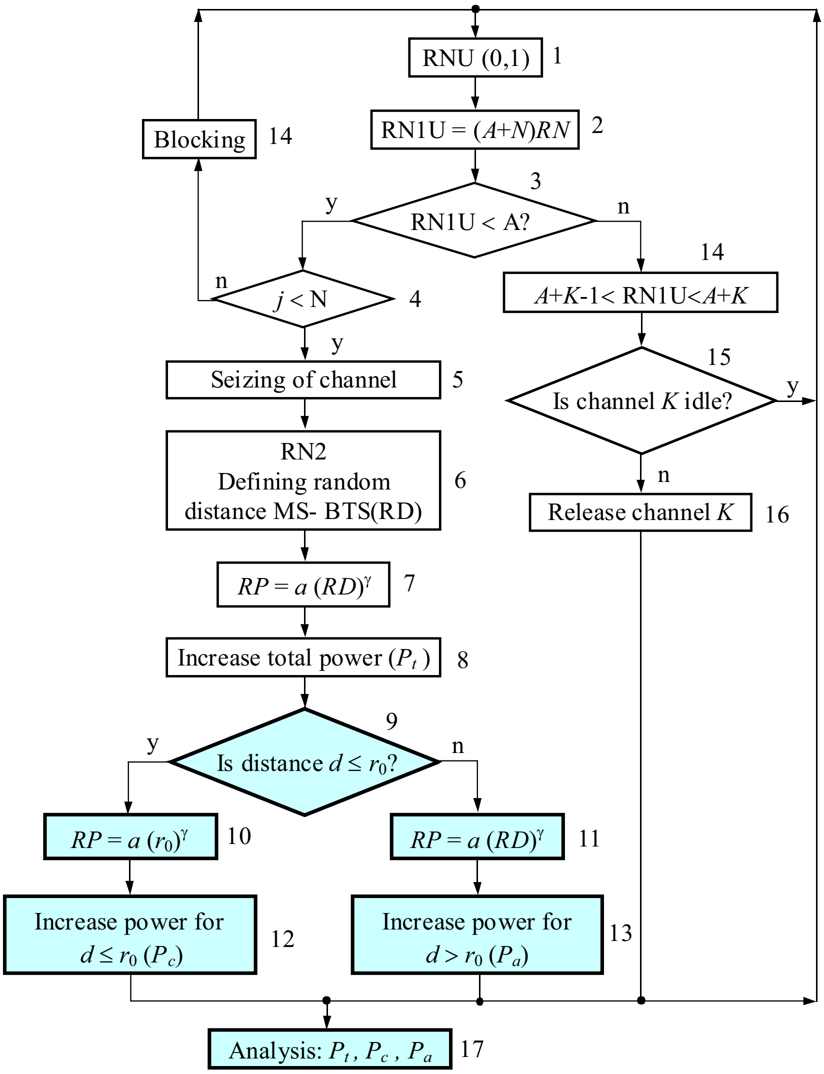

Fig. 12. Flow-chart of the simulation process

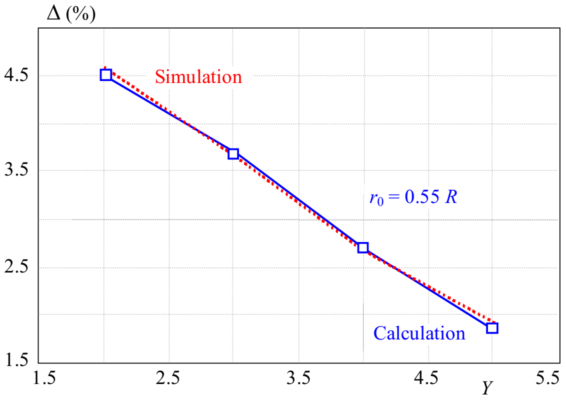

Fig. 13. Comparative presentation of the results of calculation and simulation for $r_0 = 0.55R$ in the case of increasing users' density ($g_0 = 1$, $g_R = 6$)

Case 1. If the distribution of users' density is uniform, and the radius of the circle with constant power is not greater than half of cell radius, power increase is till 10 %. This case is analyzed in many papers.

Case 2. If users' density decreases from the cell centre towards cell periphery, the power increase of the second model in relation to the first model is considerably greater (two or three times for some values of propagation loss exponent and radius of the circle with constant power). This result is very important, because decreasing users' density appears frequently in real cells.

Case 3. Contrary to the case 2, if users' density increases towards the cell periphery, power increase is significantly smaller. Unfortunately, the cells with increasing users' density are rarer than the cells with decreasing density.

Decreasing users' density (case 2) in GSM cell with complete power control requires the smallest power, [11], while in the case of the CDMA cell this type of users' density requires biggest increase of power. This is unexpected result, which can't be intuitively predicted.

Increasing the radius of the circle for the users with constant power leads in all cases to the increase of total emission power. On the contrary, simple dependence cannot be determined for the power variation when propagation loss exponent γ is increased.

In this paper only the difference of emission power is calculated for two considered models. It is clear that the value of emission power depends on the served traffic in all cases. Traffic process had to be simulated in the simulation program to confirm calculation results. The results of simulation are confirmed for different traffic values.

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