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Power Control of Base Station in GSM: Influence of Users' Density in the Cell

In this paper is presented that base station output power can be decreased by the power control in each channel. In this case very important is the distribution function of users' density in the cell. We present the examples of the cells without power control and the examples of the cells with power control, where the distribution of users' density in the cell is of various types. Some results are compared to the results of measurements, and some to the results obtained by simulation.

Key words: Base station output power, GSM, Non-uniform users' density

Kontrola snage bazne stanice u GSM: utjecaj gustoće korisnika u stanici. U radu se pokazuje da se izlazna snaga bazne stanice može smanjiti upravljanjem snage pojedinih kanala. U tom slučaju značajnu ulogu ima funkcija raspodjele gustoće korisnika u stanici. Dati su primjeri stanica bez upravljanja snagom i primjeri stanica s upravljanjem snagom gdje je raspodjela gustoće korisnika u stanici različitog tipa. Neki rezultati uporeðeni su s rezultatima mjerenja, a neki sa simulacijskim rezultatima.

Ključne riječi: Izlazna snaga bazne stanice, GSM, neuniformna gustoća korisnika

1   INTRODUCTION

Power saving in all networks of mobile users, including GSM, has more and more importance [1]-[5]. One of the ways of saving is the reduction of emission (output, downlink) power of base transceiver station (BTS). Output power reduction, besides power saving, allows decreasing the disturbances (interference) in the signal and human exposure to electromagnetic radiation. The reduction of BTS output power is enabled by recognizing all the factors, which have influence on the output power. Traffic in GSM cell is the factor, which has great influence on the output power. Output power control is the method to determine the emission power level for each connection in the cell. The power, which is necessary for one connection, depends on signal attenuation, i.e. on distance between mobile terminal (mobile station, MS) and BTS. In this paper we consider two types of cells: the first one without power control and the second one with power control. We determine power consumption of the second cell and how this consumption depends on distribution of users' density in the cell. The model of GSM cell without power control is presented in Section 2, and the model of the same cell with power control is analyzed in Section 3. Only the output power of BTS for the model with uniform distribution of users in the cell is calculated in Section 3. The calculation

of output power of the channel in the cell with non-uniform users' density is presented in Section 4. The estimation of mean BTS output power for two different distributions of users' density in the cell is given in Section 5. Conclusion of the analysis is given in Section 6.

2   MODEL 1 (WITHOUT EMISSION POWER CONTROL)

Let us consider one circular GSM cell with radius R where FDM and TDM technics are used. GSM cell has n carriers (f_1, f_2, $f_3, \ldots, f_n$). Each frequency (carrier) has 8 time slots, TS0–TS7, as presented in [6]-[8]. The number of traffic channels, N, is slightly less than $8n$, because several time slots (here TS0 and TS1) in the first carrier are used as control channels (CCH). The remaining time slots in the first carrier (TS2–TS7) are used as traffic channels (TCH). Time slots at other carriers are all used as traffic channels. It is necessary to have one channel for each connection. The offered traffic to the group of channels is designated by A, and the served traffic by Y, $Y = (1 - B)A$, where B is call loss probability caused by the lack of idle channels. The MS number, N_{ms}, is much greater than the number of channels, N, so the traffic process in the group of traffic channels can be described by the Erlang model with call loss, [7]. In this model the probability that j chan-

nels are busy, if the total number of channels is N and the offered traffic is A, $P(j, A, N)$ (truncated Poisson distribution, [9]):

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

(1)

where:

$$B = P(N, A, N) = ERL(N, A, N).$$ (2)

Cumulative distribution function (CDF) of the number of busy channels in Erlang model is $F_E(x)$. It is the probability that the number of busy channels, k, is less or equal to x:

$$F_E(x) = P(k \leq x) = \sum_{i=0}^{i=x} ERL(i, A, N).$$ (3)

Emission power of one channel is w, and its greatest value $w_{\max}$. As it is known, [6]-[8], in the model without emission power control all channels of the first carrier f_1 always have maximal power. If there is no traffic, dummy bursts are sent with maximal power in traffic channels of the first carrier. In traffic channels of the remaining carriers f_n ($n = 2, 3, \dots$) maximal power is sent only when the channel is busy. If the channel is idle, no power is sent, Fig. 1.a).

Emission power of the base station, w_B, is random variable, which depends on the number of busy traffic channels. The number of busy channels in carriers $f_n(n = 2, 3, \dots)$ can be $0 \leq i \leq 8(n - 1)$. The probability that i channels are busy in these carriers is $ERL(i, A_1, N)$, where A_1 is the traffic offered to the channels in carriers $f_n(n = 2, 3, \dots)$. In the same time, emission power of the base station can be calculated as the mean value of the emission power in all channels, i.e. by dividing the power of each channel by 8:

$$w_B = \frac{1}{8} w_{\max} \left[8 + \sum_{i=1}^{i=8(n-1)} i \cdot ERL(i, A_1, N) \right].$$ (4)

The second term in equation (4) represents the served traffic in the channels corresponding to the carriers $f_2, f_3, \dots, f_n$. From this equation following conclusions about the emission power of the base station without power control can be made:

- in principle, emission power of the base station depends on the traffic except in the case that only one carrier exists, when the power is constant and equal to the greatest value

- this power dependence on traffic increases with the number of frequencies/carriers

- mean emission power of one busy traffic channel is equal to the greatest power $w_m = w_{\max}$

- emission power does not depend on the users' density, nor on their position in the cell

- emission power represents discrete variable, because its value is changed in steps, which are equal to the integer multiple of $w_{\max}$.

The cumulative distribution function of the ratio of base station emission power to the greatest value of this power, $w_B / w_{B\,\max}$ (normalized downlink output power), $F_{w_{B2}}(x) = P(w_B / w_{B\,\max} \leq x)$, $0 \leq x \leq 1$, for the cell with two carriers is presented in Fig. 2. We presented the curves for the results obtained by measurements ([8], Fig. 1). The results calculated by developed analytical model and obtained by traffic simulations are also shown in Fig. 2. In this case, simulation process is very simple and well-known process of telephone traffic simulation, called *Monte Carlo* or *roulette*, [10]-[12].

The curves $w_B / w_{B\,\max}$ start to rise from the value 0 at $x = 0.5$, because the power in the first carrier always has its maximum value, independent of the traffic and there is only one carrier more. The power of the second carrier is dependent on the traffic and on the distance between MS and BTS. So, the maximum power of the second carrier can be the same as that of the first carrier when all 8 channels in the second carrier are busy and if the distance between 8 active MSs and BTS has its maximum.

The method used for energy saving in this model may be discontinuous transmission, DTX, and it is specified in [8] that output power of traffic channels for carriers f_2, $f_3, \dots, f_n$ can thus be reduced on $0.6 w_{\max}$. The relationship of power levels when implementing this method is presented in Fig. 1.b).

Fig. 3 presents cumulative distribution function of the ratio of base station output power to the greatest value of this power, $w_B / w_{B\,\max}$ (normalized downlink output power), $F_{w_{B5}}(x) = P(w_B / w_{B\,\max} \leq x)$, $0 \leq x \leq 1$, for the cell with five carriers. We presented the curves for the results obtained by measurements ([8], Fig. 1), our calculation and our simulation, similar as in Fig. 2.

Comparing the results presented in figures 2 and 3, it can be concluded that the influence of constant power of the first carrier becomes smaller as the number of carriers becomes greater. The power is changed only between $0.5 w_{B\,\max}$ and $w_{B\,\max}$ for the model presented in Fig. 2, while the power is changed between $0.2 w_{B\,\max}$ and $w_{B\,\max}$ for the model presented in Fig. 3, i.e. in general between $w_{B\,\max}/n$ and $w_{B\,\max}$ if there are n carriers.
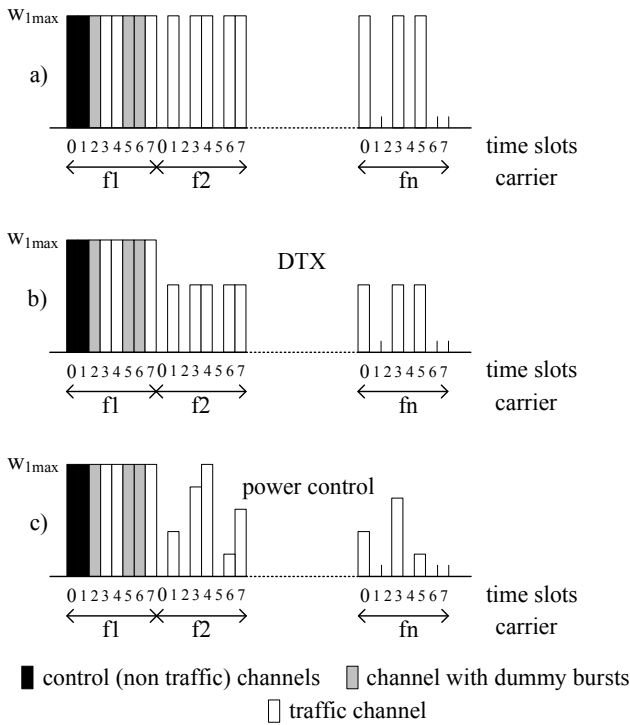
Fig. 1. Symbolic presentation of the power in channels on air-interface of base station a) without power control; b) without power control, but with DTX signal processing; c) with power control
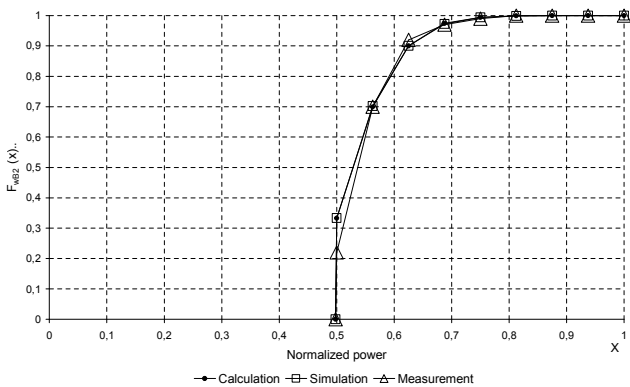

Fig. 2. Cumulative distribution function of the ratio of base station output power and the greatest value of this power, $w_B/w_{B\,\text{max}}$, (normalized downlink output power) for the cell with two carriers, f_1 and f_2 (results of measurements ([8], Fig. 1), calculation and simulation)

3 MODEL 2 (EMISSION POWER CONTROL, UNI-FORM USERS' DENSITY IN THE CELL)

Let us consider now the cell, similar to the one presented in model 1, but with the output power control for the carriers f_2, f_3, ..., f_n. Power control is performed for
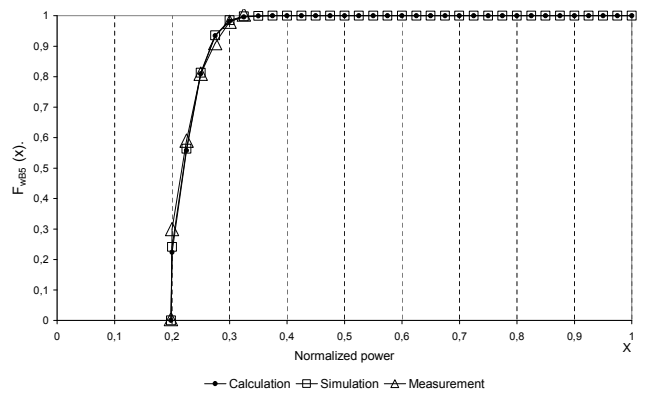

Fig. 3. Cumulative distribution function of the ratio of base station output power and the greatest value of this power, $w_B/w_{B\,\text{max}}$, (normalized downlink output power) for the cell with five carriers, f_1, f_2, f_3, f_4 and f_5 (results of measurements ([8], Fig. 1), calculation and simulation)

each user in steps of 2dB. Fig. 1.c) presents power levels in each channel. For this model we suppose that output power is changed continually.

It is supposed in this model that users are uniformly distributed in the cell, i.e. their area density is constant. Output power control is performed for each channel according to signal attenuation, which depends on the distance between MS and BTS. This distance is designated by d. The output power of each channel, w, depends on distance d according to some function $w = v(d)$, which can be supposed to be exponential:

$$w = v(d) = a \cdot d^\gamma, \qquad (5)$$

where a represents the constant (factor) of proportionality, and the value γ is between 2 and 5, [7]. We suppose that the power of the signal is negligible in the immediate proximity of the base station, which is not quite true, but does not affect correctness of calculation. We suppose that maximum power of one channel, w_{max}, is constant, and that the radius of the cell is determined in such a way that it is $w_{\text{max}} = aR^\gamma$. Traffic in the cell is random process and the distance between the user and the base station is independent random variable. On the basis of these assumptions it is proved in [13] that the mean value of the power of one channel is:

$$w_m = \frac{2w_{\text{max}}}{2 + \gamma}. \qquad (6)$$

It is well-known that in real conditions is always $\gamma > 2$. That's why mean power of one channel with power control is always at least two times smaller (3dB) than the mean power in model 1, where there is no power control. The total base station output power still depends on the traffic value, but it is important to notice that the decrease of mean

power in one busy channel does not depend on traffic. In reference [8], which is devoted to the measurement of base station power, on Fig. 9 can be found an example of one network, where implementation of power control leads to power decrease of at least 4dB in about 80% situations. We suppose that in 20% remaining situations, where BTS output power decrease is less than 4dB, the considered base stations have one or two carriers, and so constant value of power of the first carrier is dominant.

If base station emission power control is implemented, it can be changed in small steps. Thus the base station emission power becomes close to the continually changeable variable, on the contrary to model 1.

4 MODEL 3 (POWER CONTROL, NON-UNIFORM DISTRIBUTION OF USERS' DENSITY IN THE CELL)

Let us consider the model with emission power control, as the model 2, but with non-uniform distribution of users' density in the cell.

The users' density, g, in the cell is considered in two cases. The first one is when the density of MS is greatest in the centre of the cell, and it is linearly decreased to its smallest value at the cell rim, $g_0 > g_R$, figures 4.d), 4.e) and 4.f).
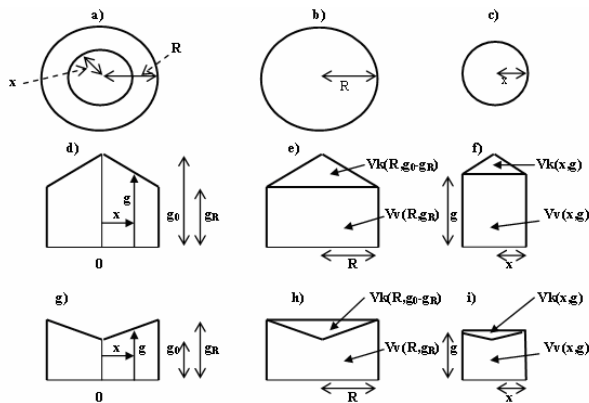

Fig. 4. Circular cell and the two cases of users' density distribution in it

The second one is when the MS density is smallest in the centre of the cell, but it is linearly increased towards the rim, $g_0 < g_R$, figures 4.g), 4.h) and 4.i).

The important remark, dealing with the calculation of base station output power in this model, is the following one: we consider only the channels where power control is carried out, i.e. the channels belonging to the carriers f_2, f_3, ..., f_n. In this way we shall compare variation and saving of emission power without the influence of constant

term, which is related to the channels belonging to the carrier f_1. The calculation of total power is enabled by adding the term, which presents the power of carrier f_1.

The emission power of one channel, w, is random variable, which depends on independent random value of distance between MS and BTS, d.

The PDF of output power (as dependent random variable) is, according to [14], Section 5:

$$f_w(w) = \left[\frac{1}{|\nu'(d)|} \right] f_d(d). \tag{7}$$

Now it is necessary to determine PDF $f_d(x)$ of random variable distance between MS and BTS, d. It can be calculated from the distribution of telephone density in the cell. Let us suppose that telephone density in the cell is linearly dependent on the distance of the telephone from the centre of the cell, Fig. 4:

$$g = g_0 - (g_0 - g_R)\frac{x}{R}, \tag{8}$$

in the case of decreasing density from BTS to the periphery, ($g_0 > g_R$), Fig. 4.d), or

$$g = g_0 + (g_R - g_0)\frac{x}{R}, \tag{9}$$

in the case of increasing density from BTS to periphery, ($g_0 < g_R$), Fig. 4.g).

The CDF of variable d is $F_d(x) = P(d \leq x)$ and it is proportional to the number of MSs in the circle with radius x. Let us consider the case when $g_0 > g_R$. The number of MSs in the circle of radius x can be determined in this case as the sum of volumes of the cylinder $V_v(x, g)$ (radius x, height g) and the cone $V_k(x, g_0 - g)$ (radius x, height $g_0 - g$), Fig. 4.f). Probability that the distance between MS and BTS is less or equal to x is equal to relationship between the number of MSs in the circle with radius x and the total number of MSs. The total number of MSs can be presented by the total volume of "great" cylinder and the cone, $V_v(R, g_R) + V_k(R, g_0 - g_R)$, Fig. 4.e):

$$F_d(x) = P(d \leq x) = \frac{Vv(x, g) + Vk(x, g_0 - g)}{Vv(R, g_R) + Vk(R, g_0 - g_R)}. \tag{10}$$

In the case of increasing density, ($g_0 < g_R$), it is necessary to calculate the difference of volumes of cylinder and cone instead to calculate their sum, figures 4.h) and 4.i).

Using the well-known expressions for calculating the volumes of cylinder and cone, it can be obtained from (8), (9) and (10):

$$F_d(x) = \frac{3x^2 g_0 + \frac{2x^3(g_R - g_0)}{R}}{K}, \tag{11}$$

where $K = 2R^2 g_R + R^2 g_0$,

$$f_d(x) = F_d'(x) = \frac{6(x g_0 + \frac{x^2(g_R - g_0)}{R})}{K}. \tag{12}$$

Using (5) and (12), the PDF of output power of one channel can be calculated from (7):

$$f_w(w) = \frac{6g_0}{\gamma K a^{\frac{2}{\gamma}}} w^{\frac{2-\gamma}{\gamma}} + \frac{6(g_R - g_0)}{\gamma R K a^{\frac{3}{\gamma}}} w^{\frac{3-\gamma}{\gamma}}. \qquad (13)$$

If we introduce designations:

$$A_1 = \frac{6g_0}{\gamma K a^{\frac{2}{\gamma}}} \quad \text{and} \quad A_2 = \frac{6(g_R - g_0)}{\gamma R K a^{\frac{3}{\gamma}}}, \qquad (14)$$

then the mean power of one channel is:

$$w_m = \int_{w_{\min}}^{w_{\max}} w f_w(w) dw =$$
$$= \frac{A_1 \gamma w_{\max}^{\frac{2+\gamma}{\gamma}}}{2+\gamma} + \frac{A_2 \gamma w_{\max}^{\frac{3+\gamma}{\gamma}}}{3+\gamma}, \qquad (15)$$

and the CDF of one channel is:

$$F_w(x) = \int_0^x f_w(w) dw = \frac{A_1 \gamma x^{\frac{2}{\gamma}}}{2} + \frac{A_2 \gamma x^{\frac{3}{\gamma}}}{3}. \qquad (16)$$

Verification of calculated results for model 3 by simulation is performed for the numerical example $\gamma = 3$, $R = 20km$, $w_{\max} = 40W$, in two cases. The first one is for decreasing MS density: $g_0 = 6$, $g_R = 1$, and the second one is for increasing MS density: $g_R = 6$, $g_0 = 1$. The simulation is performed by the method presented in [13].

The results of calculation ($\square$ and $\diamond$) and the results of simulation (x) of CDF, $F_w(x)$, for one channel are presented in Fig. 5.
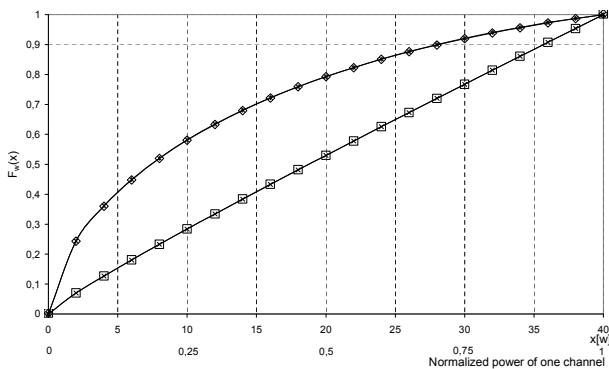

Fig. 5. CDF of output power of one GSM channel for $\gamma = 3$, $R = 20km$, $w_{\max} = 40W$, $g_0 = 6$, $g_R = 1$ (upper curve) and $\gamma = 3$, $R = 20km$, $w_{\max} = 40W$, $g_R = 6$, $g_0 = 1$ (lower curve)

The difference between the results of calculation and of simulation is negligible. The mean power in the first case is 11W and in the second case is 19.2W.

It can be seen that in the case of decreasing users' density towards the cell rim, the power decreased by 5.6dB (from 40W to 11W). If signal processing by DTX is implemented in this case, mean power of one channel would be 0.6 times the previous power, i.e. it would be less for 2.2dB more, or 7.8dB altogether. It is clear that in the case of greater decrease of users' density towards the cell rim, the decrease of mean power would be even greater. It can be concluded from equation (6) that average power can be even smaller if γ is greater.

5 ESTIMATION OF BASE STATION EMISSION POWER

The mean emission power of all channels, w_{Bm}, can be calculated as the product of served traffic, Y, and the mean power that one channel contributes to the total power, ω_m, [13]:

$$w_{Bm} = \omega_m Y = \omega_m A(1 - B), \qquad (17)$$

where it is $\omega_m = w_m/8$ (each frequency carries 8 time slots), and B is call loss calculated from (2).

The dependence of mean total output power of BTS on offered traffic is presented in Fig. 6. The lower curve refers to the case $\gamma = 3$, $R = 20km$, $w_{\max} = 40W$, $N = 16$ and decreasing users' density from the centre of the cell to the periphery ($g_0 = 6$, $g_R = 1$). The upper curve refers to the same case, but for increasing users' density ($g_R = 6$, $g_0 = 1$). The difference between calculated results and the results of simulation in Fig. 6 is negligible.
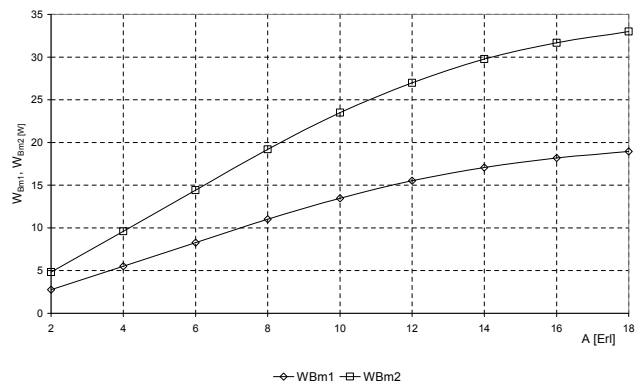

Fig. 6. Mean output power of BTS for $\gamma = 3$, $R = 20km$, $w_{\max} = 40W$, $N = 16$, $g_0 = 6$, $g_R = 1$ (lower curve W_{Bm1}) and $g_R = 6$, $g_0 = 1$ (upper curve W_{Bm2}) as the function of the offered traffic

Calculation of BTS output power can be very complex, because it is the sum of great number of random variables. That's why only the results of simulation are presented for CDF of total BTS output power. CDF of output power of one BTS, $F_{w_B}(x)$, is the probability that

BTS output power, w_B, is less or equal to the power x, $F_{w_B}(x) = P(w_B \leq x)$, $0 \leq x \leq w_{B\max}$, and is presented in Fig. 7. Figure 7 can be also treated as CDF of output power as the probability that output power is less or equal to the normalized value of output power, i.e., $F_{w_B}(x) = P(w_B/w_{B\max} \leq x)$, $0 \leq x \leq 1$. If the mean values of the power in one channel (Section 4) are known, the probability that certain number of channels, i.e. users, is busy can be determined from Fig. 7. The number of channels is $N = 16$, the offered traffic is $A = 8.88$Erl (causing about 1% of loss), and the other conditions are the same as in Fig. 6. The upper curve presents CDF for the case of decreasing users' density from the centre of the cell to the periphery ($g_0 = 6$, $g_R = 1$), while the lower curve presents the same characteristic, but for increasing users' density ($g_R = 6$, $g_0 = 1$).
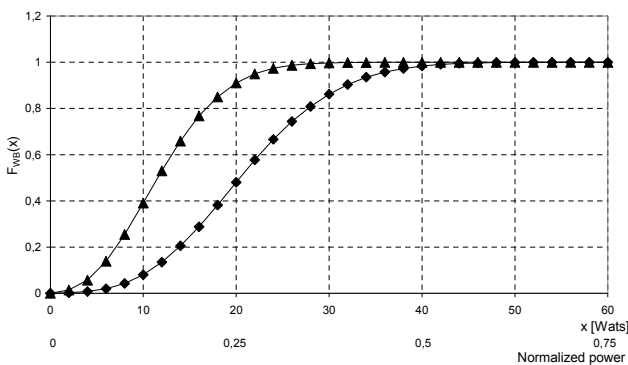

Fig. 7. CDF of BTS output power for $\gamma = 3$, $R = 20km$, $w_{\max} = 40W$, $N = 16$ (f_2 and f_3), $A = 8.88Erl$, $g_0 = 6$, $g_R = 1$ (upper curve) and $g_R = 6$, $g_0 = 1$ (lower curve)

As can be seen on figures 5, 6 and 7, distribution of users' density in the cell has influence on the output power of base station, where power control is used. It is presented in [8], Fig. 9, that implemented power control in some cases can decrease output power of base station up to 26dB. In most cases this decrease is 10–12dB. It can be supposed that great decrease of base station output power can be achieved in the cells where great number of users are concentrated near the base station, so that the distribution of users' density is steeper than the one considered in the numerical example ($g_0 = 6$, $g_R = 1$).

6 CONCLUSION

Calculation of base station output power in GSM network without power control is simple, because output power depends on traffic. The output power in this case can be decreased by speech signal processing and DTX transmission.

Output power in GSM cell with power control, besides traffic, depends also on signal attenuation, i.e. on the dis-

tance between the user and base station. The mean value of distance between user and base station depends on the distribution of users' density in the considered cell.

In this paper we present that BTS output power in GSM network depends on (besides attenuation and traffic) position of mobile users in GSM cell. In the paper only linear change of area users' density is considered. This change is decreasing from BTS to periphery, or vice versa. If the users' density is decreasing, the emission power is smaller than in opposite case, which is rarer in practice. Numerical example illustrates that power difference in these two cases can be very significant.

The obtained results are compared to the results of simulation and to some published results of measurements.

ACKNOWLEDGMENT

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