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Calculating Limits of Base Station Emission Power in GSM

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Original scientific paper

This paper compares the influence of various factors on the output power of each GSM channel and connection, and on the output power of whole base transceiver station in GSM network. The considered factors are the influence of sending signal only when speech exists (DTX), implementation of power control in signal sending, influence of users' distribution in the range of coverage of base station, the power of one intra-cell connection and the power of one half-rate connection. It is analyzed how emission power of base station can be reduced by implementing various methods in signal sending.

Key words: base transceiver station, GSM channel, influence of various factors on output power

Izračunavanje granica emisije snage bazne stanice u GSM-u. U ovom radu uspoređuje se utjecaj različitih čimbenika na izlaznu snagu svakog GSM kanala i veze te utjecaj na izlaznu snagu cijele bazne stanice u GSM mreži. Promatrani čimbenici su utjecaj predajnog signala samo kada govorni signal postoji (DTX), implementacija kontrole snage pri slanju signala, utjecaj raspodjele korisnika ovisno i području koje pokriva bazna stanica, snaga jedne unutar-ćelijske veze i snaga veze koja koristi pola protoka. Analizirano je kako se emitirana snaga bazne stanice može smanjiti koristeći različite metode za slanje signala.

Ključne riječi: bazna stanica, GSM kanal, utjecaj različitih čimbenika na izlaznu snagu

1 INTRODUCTION

The usage of radio communication is greatly increasing. That's why it is concluded that energy saving is important at least because of two main reasons. The first one is price of energy, and the second one is environmental protection, [1], [2]. Energy saving is important at all elements, included in wireless communication. At remote units, it is important, because they are powered by batteries, which have limited capacity [3]. The scenario of energy saving is called *GREEN* (*Globally Resource-optimized and Energy-Efficient Networks*) *Radio*. In order to implement this program, it is very important to know the dependence of BTS (*Base Transceiver Station*) output power on various factors. Energy consumption, i.e. instantaneous electrical power consumption of BTS in the network of mobile telephones (GSM) depends on various factors, as traffic value, signal attenuation in GSM cell, users' density distribution in the cell, implementation of half rate channels, part (percent) of intra-cell connections. When the transmitting power decreases, self-interference also decreases, and so the necessary quality of service is achieved (*Quality of Service*, QoS) in the conditions of optimal BTS output power. Considering all these reasons, it is necessary to know the dependence of BTS output power on all factors considered in the analyzed cell. In this paper we shall indicate the limits for the values of output power in one cell. In the section 2 the model, abbreviations and some assumptions used in the paper are presented. In the section 3 it is described how power comparison is made. In sections 4-7 the influence of each characteristic on output power of channel and BTS is analyzed. In the last sections comparison of output power of different models is performed.

2 MODEL, DESIGNATIONS AND ASSUMPTIONS

Let us consider one BTS and one cell in GSM network, [1], [2]. The cell is circular and its radius is *R*. The network functions using FDMA (*Frequency Division Multiple Access*) and TDMA (*Time Division Multiple Access*) is used on each carrier (frequency). The number of carriers, that are used in one BTS, is n and the number of time slots on each frequency is N_s(=8). Number of mobile stations (MS) is N_{ms} and it is much greater than the number of traffic channels N. The mean number of active channels is designated as N_{ac}. In this paper we consider the cases when the output power of one connection from BTS is not changed (cell without power control), or it is changed according to the needs of the concrete connection (cell with power control). Half rate (HR) connections can be used in the cell. The model with power control is considered. It is supposed that even in this model on some channels power control is not implemented (e.g. channels on the first carrier). The part of connections between the users belonging to the same cell (intra-cell (internal) connections, Fig. 1) can be very great, especially when one BTS covers one place (town) or great company [4], [5]. The distribution of users in the cell can be very different: starting from uniform distribution to variable distribution, which can increase from the centre of the cell towards the rim, or vice versa. The offered traffic to the BTS is A. The call loss, caused by the lack of free traffic channels, is designated by B. The served traffic, i.e. mean number of realized connections, is designated by Y, $Y = A \cdot (1 - B)$ and it is, generally, different from the mean number of busy channels, N_{ac}, because two channels are necessary for intra-cell connection, or two HR connections can be realized on one channel.

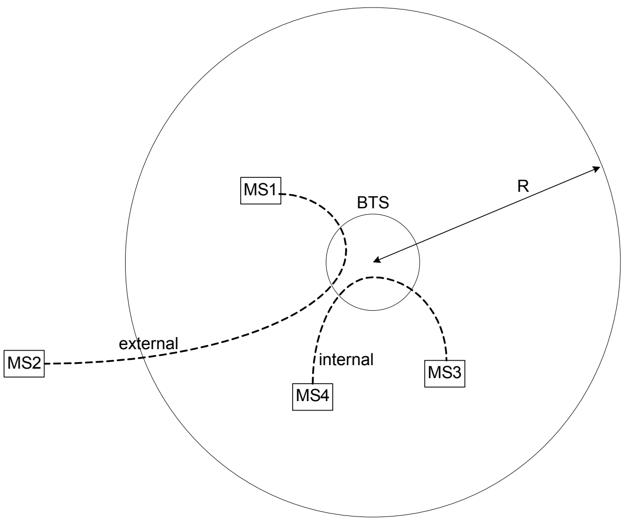

Fig. 1. Schematic presentation of internal and external connections

Instantaneous, mean and maximum power of one channel are designated by w_1, w_{1m} and w_{1max}. Mean power, which is necessary for one connection, is designated by w_{1cm}. Maximum power corresponds to one of classes [1], and it is supposed that this power is constant. Output power of BTS is w_B. The BTS output power is equal to one eighth of the sum of output power of each active channel, $\omega_1 = (1/8) \cdot w_1$. The traffic channel, which uses the full rate, is designated by FR and the channel, which uses half rate, is designated by HR. Internal connections are established between the users, who are situated in the area of the coverage of the same BTS. On the schematic presentation in the Fig. 1, internal connection is realized between users MS3 and MS4. On the other side, external connection is realized between the users from the areas of two different users (MS1 and MS2 in Fig. 1). Throughout the paper, internal connections are designated by an index i and external connections (outgoing and incoming connections) are designated by index e. It is supposed that attenuation is the same in the whole cell and that the cell dimensions depend on the attenuation value (when attenuation is increased, the cell radius is decreased and vice versa).

3 HOW POWERS ARE COMPARED

In this paper we shall estimate the influence of different factors on BTS output power. These factors can be divided in two groups: the group, which has influence on the output power of each GSM channel and the group, which has influence on total BTS output power.

In the first group are: transmission of only parts with speech signal (i.e. pauses in speech are not transmitted (DTX), propagation attenuation, distance MS–BTS (the influence is realized by the distribution of users in the cell) and in the second group: bit flow used for the transmission of one telephone connection (HR, FR) and the kind of connection (internal, external).

Comparative value of power, w_{1max}, which is the maximum value of one channel output power necessary for the transmission of speech using full rate (FR), is defined for the comparison of output power in one channel.

4 POWER CONTROL AND DTX

As presented in Fig. 2, which is taken from [6], all BTSs can be divided in two groups: the ones which have no output power control (Fig. 2.a)) and the ones, which have power control (Fig. 2.c)). BTSs, which have output power control, have no such control for the channels on the first carrier $f1$ (Fig. 2.c)). Besides this, traffic channels on the first carrier always have maximum power, no matter they are busy or not (channels 5 and 6, Fig. 2.).

If there is no power control, total BTS output power is:

$$w_B = \frac{1}{8} \cdot (8 + N_{ac}) \cdot w_{1\max} \tag{1}$$

where N_{ac} is here the number of all active channels in the carriers $f2, ..., fn$.

One of the methods to decrease BTS output power is to use discontinuous transmission, DTX, Fig. 2.b). In this case speech signal is not transmitted during the pauses in the speech. It can be supposed that BTS output power is, then, 60% of the power when DTX is not used, [7]:

$$w_{BDTX} = \frac{1}{8} \cdot \left(N_{no} + 0.6 \cdot \frac{1}{8} \cdot N_{ac} \right) \cdot w_{1\max} \tag{2}$$

where N_{no} is the number of all active channels where no power control is implemented.

If power control exists, then mean power of one channel and mean number of necessary channels for one connection must be calculated to determine BTS output power. Mean value of output power of one channel when power control is implemented depends on propagation attenuation and on mean value of distance between MS and BTS.

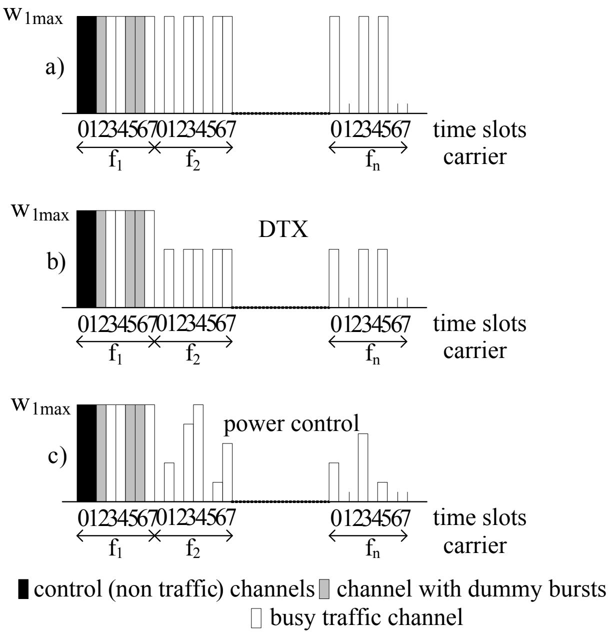

Fig. 2. Output power of BTSs without power control (Fig. 2a)), with the implementation of DTX (Fig. 2b)) and with power control (Fig. 2c))

5 PROPAGATION ATTENUATION

Propagation attenuation affects the output power of one channel with power control according to the law:

$$w = a \cdot d^{\gamma} + b \quad (3)$$

where a is coefficient of proportionality, $\gamma = 2 - 5$, [1], [2], and b is output power for the connections of users who are in the immediate vicinity of BTS. This power b can be neglected in the following considerations, so $w = a \cdot d^{\gamma}$. As the greatest power of channel is constant, the radius of cell can be determined from the equation $w_{max} = a \cdot R^{\gamma}$.

It is proven in [8] that mean output power of one channel, w_{1m}, if power control exists, and signal is transmitted in the environment where coefficient of propagation attenuation is γ and users' distribution in the cell is uniform, equals:

$$w_{1m} = \frac{2 \cdot w_{1\max}}{\gamma + 2} \quad (4)$$

It can be concluded from (4) that the cell and the mean power of one channel are smaller for the greater values of propagation attenuation. Although (4) is valid for the cell with uniform distribution of users, the conclusion about the influence of coefficient γ can be spread for all distributions of MSs density in the cell.

6 DENSITY

It is obvious from equation (3) that output power of one channel in the cell with power control depends on distance MS-BTS. Traffic process is random, so the distance MS–BTS, *d*, can be considered as independent random variable. The mean value of this variable depends on users' position in the cell, i.e. on distribution of users' area density in the cell. It is clear that mean distance MS–BTS will be smaller if greater number of users is concentrated near BTS, than in the case of uniform users' distribution in the cell. It is also clear that smaller mean distance MS–BTS will cause smaller mean value of output power of one channel and smaller total power of BTS.

7 INTRA-CELL

Besides the considered factors, which have influence on the mean value of output power of each channel, two more factors have influence on the mean BTS output power: part of intra-cell connections, [4] and [9], and the use of one channel for two connections (half rate), [10] - [12].

Intra-cell (or internal) connections in the cell always exist, but in different percent. This percent is negligible in the town, but in one place, which is covered by only one BTS can be significant [4], [5]. The part of intra-cell connections can be very great in the cells covering rural area or a great company. The part of intra-cell connections will be designated by *p*. Intra-cell connection occupies two channels, while external connection occupies only one channel [13].

The mean output power for one intra-cell connection is

$$w_{1cmi} = 2 \cdot w_{1cme} \quad (5)$$

The mean BTS output power for external connections can be calculated as the product of mean output power of one channel and mean number of active channels for external connections. The mean number of active channels for external connections is equal to the value of served external traffic

$$\begin{aligned} w_{Bem} &= \omega_{1m} \cdot N_{ace} = \\ &= \omega_{1m} \cdot Y_e = \omega_{1m} \cdot (1 - B_e) \cdot A_e \end{aligned} \tag{6}$$

The losses are often negligible, $B_e \approx 0$, so it is $w_{Bem} = \omega_{1m} A_e$.

The mean value of BTS output power for intra-cell connections can be calculated as the product of mean output power of one channel and the mean number of active channels. The mean number of active channels is equal to the double value of served internal traffic

$$\begin{aligned} w_{Bim} &= \omega_{1m} \cdot N_{aci} = \\ &= 2 \cdot \omega_{1m} \cdot Y_i = 2 \cdot \omega_{1m} \cdot (1 - B_i) \cdot A_i \end{aligned} \tag{7}$$

or, often $w_{Bim} = 2\omega_{1m} A_i$.

It can be concluded that mean power of one channel, i.e. the relation of mean output power $w_{Bm} = w_{Bem} + w_{Bim}$ and total offered traffic $A = A_e + A_i$ equals $(A_e + 2 \cdot A_i)/(A_e + A_i)$ and that it is as greater as the component of intra-cell traffic is greater.

8 HALF RATE

In order to reduce losses caused by the lack of channels on Air-interface, dynamic channel allocation with half rate (HR) is often used, [1], [10], [11], [12]. Usage of HR connections by the implementation of repacking channel assignment is considered in this paper. (Repacking scheme of HR channel assignment means that one time slot is used for two HR connections, [11], [12]). It is clear that mean output power of one channel w_{1m} is divided on two connections. That's why the mean output power of one HR connection is equal to half the power of one FR connection:

$$w_{1cmHR} = 0.5 \cdot w_{1cmFR} \tag{8}$$

The mean BTS output power for certain number of connections is as smaller as the part of HR connections is greater. The probability that the connection is realized using half rate is designated by q.

For GSM traffic realization, besides reduction of call loss probability and reduction of BTS emission power, it is very important to improve voice quality. Several approaches are applicable to achieve this goal. Enhanced full-rate codec (EFR) (also designated as GSM 06.60) is one method to obtain connection quality not much worse than the quality obtained by G.711 codec, but with much less throughput. The other method is implementation of adaptive multirate voice codec (AMR), which can be realized as narrow-band (AMR-NB) or wide-band (AMR-WB) codec. The first one (AMR-NB) supports the bandwidth of traditional telephony, while the other one (AMR-WB) supports two-fold bandwidth (till 7 kHz). Some of AMR-NB codecs can be implemented in HR channels, thus reducing BTS output power.

9 COMPARISON OF MODELS

The following statements can be expressed for the BTS output power in GSM network:

9.a. The greatest mean power, independently of power control implementation, is the power in time slots, belonging to the first carrier. The output power of time slots in first carrier is constant and, according to (1), its value is always:

$$w_B = w_{1\max} \tag{9}$$

This power does not depend on the number of connections, which are realized using time slots of first carrier. If more than one carrier exists, output power depends also on the traffic.

9.b. The output power of other carriers ($f2, ..., fn$) depends on the number of active channels. This output power can be treated as the value of total output power and as the value of power of one connection.

9.b.1. The greatest value of output power is in the model of BTS without power control, and it is equal to the product of the number of active channels and the value of greatest channel power, as in (1)

$$w_B = N_{ac} \cdot w_{1\max} \tag{10}$$

9.b.2. The output power is little less than in case 9.b.1., if DTX is implemented, the power is 2.2dB smaller than without DTX.

9.b.3. The output power, which is used for one connection, is obtained as the quotient of mean BTS power, w_{Bm}, and the traffic (it is supposed that the loss is small and that the served traffic is equal to the offered traffic), A. The mean power is obtained if the connections, which use one channel, two channels and half of the channel, are considered. This value depends on the part of intra-cell traffic (*p*) and on the part of HR connections (*q*). One channel is used by:

- external connections with full rate, their probability is *(1-p)·(1-q)* and

- internal connections with HR, their probability is *p·q*.

Intra-cell connections with full rate use two channels, and their probability is *p·(1-q)*.

Half channel is used by external connections with half rate, the probability of these connections is *q·(1-p)*.

The mean BTS power without power control is

$$w_{Bm} = \left\{ \begin{array}{l} (1-p) \cdot (1-q) + p \cdot q + \\ +2 \cdot p \cdot (1-q) + \\ +0.5 \cdot q \cdot (1-p) \end{array} \right\} \cdot A \cdot w_{1\max} \tag{11}$$

and mean power of one connection is

$$w_{1cm} = \left\{ \begin{array}{l} (1-p)\cdot(1-q)+p\cdot q+ \\ +2\cdot p\cdot(1-q)+ \\ +0.5\cdot q\cdot(1-p) \end{array} \right\} \cdot w_{1\max} \quad (12)$$

It is obvious that mean BTS output power increases when p increases and decreases when q increases.

9.b.4. Further power reduction is possible if implementing power control. In that case the mean BTS output power is equal to the product of mean number of active channels and mean value of power of one channel.

The greatest mean power is now obtained when signal is transmitted with the smallest loss, γ=*2*. For uniform users' distribution in the cell, this mean power has half the value of power without power control (3dB less than the power in case 9.b.1.), [8]. In real case, when γ=*3-4*, the power is decreased between 4dB and 4.8dB.

It is obvious that the power for one connection in this case also increases when increasing the part of intra-cell connections, and that it decreases when increasing the number of HR connections. The equation (12) for BTS with power control becomes:

$$w_{1cm} = \left\{ \begin{array}{l} (1-p)\cdot(1-q)+p\cdot q+ \\ +2\cdot p\cdot(1-q)+ \\ +0.5\cdot q\cdot(1-p) \end{array} \right\} \cdot w_{1m} \quad (13)$$

9.b.5. The smallest power is obtained when the coefficient of loss is great, (γ=*5*, reduction of 5.4dB) and when the great number of users are concentrated in the near vicinity of BTS. It is presented by the results of measurements in [7], Figure 9, that implemented power control in some cases can decrease output power in the range 10–12dB. In some cases, where we suppose that users' concentration around BTS is great, BTS output power reduction can reach 26dB.

Figure 3 presents graphically the reduction of mean power of one channel in the GSM cell, depending on: DTX implementation, power control usage, coefficient of environment attenuation and distribution of users in the cell. Points 1–6 in Fig. 3 represent the following cases:

- point 1 represents the power of one channel when there is no power control and no DTX implementation;

- point 2 represents the case of channel power without power control, but with DTX implementation;

- point 3 represents mean output power of one channel in the cell with uniform distribution of users and ideal (minimum) value of γ=*2*;

- point 4 corresponds to the mean output power of one channel in the cell with uniform users' distribution and medium value γ=*3-4*;

- point 5 represents the mean output power of one channel in the cell with uniform users' distribution and with great value γ=*5*;

- point 6 corresponds to the mean output power of one channel in the cell where the users' density decreases linearly from BTS to the rim of the cell [6] (it is six times smaller on the rim than in the centre), and where it is, γ=*5*.

It is necessary to remark that mean output power of one channel can be decreased even more, if the users' density near BTS is greater than it is presented for point 6.

Figure 4 represent the range of mean output power per one connection. The greatest value of output power from Fig. 3 can be doubled for one connection in the case of intra-cell connection, point 1 in Fig. 4. The mean power of one connection can be also halved if the connection is external and if it is realized using HR, point 5 in Fig. 4.

10 PROCESS OF SIMULATION

The values presented in Figures 3 and 4 and the other conclusions from this paper are proved by simulation process, which is explained in more detail in [13], [14]. The main goal of the simulation was to verify values of mean power of one connection for various users' density distributions and for various coefficients of attenuation. The process of simulation is performed in such a way that, for each simulation run, users' distribution and coefficient of attenuation are chosen at first. In order to simulate real situation, 8, 16 or even more channels exist in the simulation and at least one thousand of calls are generated per each channel. Real traffic process is also simulated, which means that we simulated calls generation and termination. The mean output power of one channel is than determined as the mean power for all connections realized in each channel, considering also call duration.

The simulation is based on *Monte Carlo*, or *roulette* model. The generated random numbers are uniformly distributed in the range (0, *A*+*N*), where *A* is traffic load, offered to the simulated group of channels and *N* is the number of channels. In the case that generated random number falls in the range (0, *A*), the new call is generated (if less than *N* channels are busy in that moment). The range of numbers (*A*, *A*+*N*) is divided in *N* parts (subranges), each subrange corresponding to one traffic channel. In the case that generated random number falls in the subrange (*A+i*, *A+i+1*), the call is terminated if HR channel *i+1* is busy in that moment. In such way traffic part of simulation is performed.

Determination of user's distance from BTS is, generally, more complicate. It is because we want to simulate some areal distribution of users, and we need to calculate linear distance between MS and BTS. Thus the problem

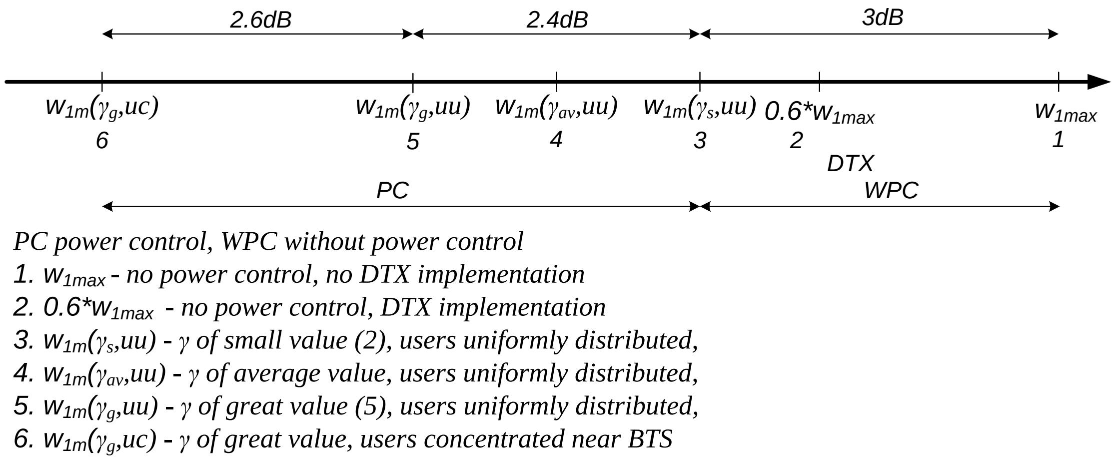

Fig. 3. Symbolic presentation of the relation of mean one channel power in the cell of GSM network depending on the power control, coefficient of attenuation and distribution of users in the cell

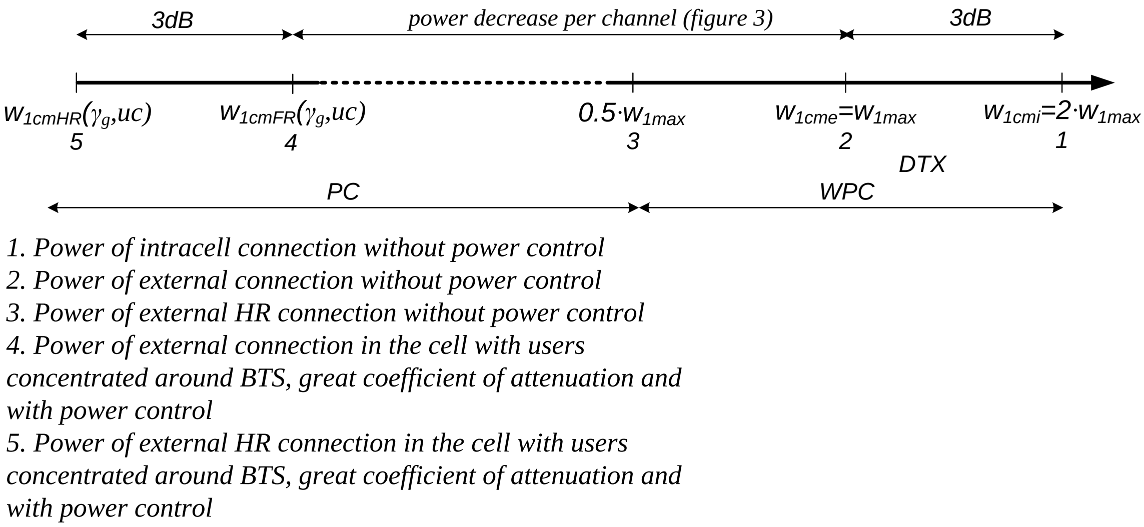

Fig. 4. Symbolic presentation of the relation of mean power of in the cell of GSM network depending on the type of connection, power control, coefficient of attenuation and distribution of users in the cell

of finding distance between MS and BTS leads to finding inverse function of the function, which models users' density. If the users are uniformly distributed, the calculation of distance between MS and BTS is based on calculating square root of generated, uniformly distributed, random number. But, in general case, it is not ease to determine inverse function in closed form, and we use programs MATHEMATICA or MATLAB to calculate it. In even more complicate case, there is no closed form expression for inverse function. Then we determine approximate expression for inverse function, again using MATHEMATICA or MATLAB. In such a way we can determine power of the connection, when users are concentrated around BTS, Fig. 4.

Calculation of BTS power, depending on signal attenuation, is performed by using distance between MS and BTS, which is calculated according to one of methods explained in the previous paragraph. The calculated value of this distance is introduced to the formula, corresponding to the simulated attenuation law.

The program, which we developed, can, also, simulate influence of intra-cell connections. The part of intra-cell connections in total number of connections can be changeable. But, in the simulation relevant for this paper we used

0% of intra-cell connections (complete traffic is external) and 100% of intra-cell connections (there is no external traffic, i.e. complete traffic is intra-cell).

11 CONCLUSION

In this paper we indicated some factors, which have influence on the increase or decrease of the power of one BTS. In this paper we have tried to determine the possible saving of transmitted power in one typical BTS. The output power of traffic channels in one GSM BTS can be decreased using DTX technique, but maximum reduction is achieved by implementing power control, except for the channels on the first carrier. It can be seen from the example that the reduction can be till 10dB. In some cases, [7], it can be even greater. The degree of saving depends on the number of carriers: if there are more carriers, power saving is greater. If users are concentrated near BTS, power reduction is significant if power control is implemented.

The power, needed for one connection, has even greater range if the part of intra-cell connections is great. If the part of intra-cell connections is great, BTS must be supplied by greater power then if the number of external connections is dominant. Mean power per one connection can be reduced using the decreased flow for one connection (HR).

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