# Influence of Intra-cell Traffic on the Output Power of Base Station in GSM

*Mladen MILEUSNIĆ*[1], *Predrag JOVANOVIĆ*[1], *Miroslav POPOVIĆ*[2], *Aleksandar LEBL*[1], *Dragan MITIĆ*[1], *Žarko MARKOV*[1]

[1] IRITEL A.D. Beograd, Batajnički put 23, 11080 Beograd, Serbia
[2] Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia

mladenmi@iritel.com, pesccia@iritel.com, miroslav.popovic@rt-rk.com, lebl@iritel.com, mita@iritel.com, zarko.markov@iritel.com

**Abstract.** *In this paper we analyze the influence of intra-cell traffic in a GSM cell on the base station output power. It is proved that intra-cell traffic increases this power. If offered traffic is small, the increase of output power is equal to the part of intra-cell traffic. When the offered traffic and, as the result, call loss increase, the increase of output power becomes less. The results of calculation are verified by the computer simulation of traffic process in the GSM cell. The calculation and the simulation consider the uniform distribution of mobile users in the cell, but the conclusions are of a general nature.*

## Keywords

GSM, intra-cell traffic, output power, power distribution.

## 1. Introduction

Power saving is very important demand today. This fact is also obvious in telecommunication services, i.e. in mobile telecommunications [1]-[6]. In this area efforts are directed to adjust power consumption to the telecommunication requirements, i.e. to the traffic [6]. The program of power saving in mobile networks is called *GREEN Radio* (*Globally Resource-optimized and Energy-Efficient Networks*). This program has several directions, but for this paper the most important is the one, often called TANGO (*Traffic-Aware Network planning and Green Operation*) [7] which concerns the characteristics of telecommunication traffic to save power. This direction is based in the fact that power consumption is proportional to traffic. In this paper we shall prove that this proportionality is not always strictly fulfilled.

GSM networks can be divided on the networks with power control (PC) and on the networks without power control (WPC). In the networks with PC power saving is achieved, because the energy of active channels is adjusted according to the needs of the connection. It is important to mention that in both types of networks, the power of all channels on the first carrier (frequency, or BCCH carrier) is not adjusted. All channels always have maximum power on this first carrier.

Besides external (outgoing and incoming) traffic, considerable component of traffic between the users from the same cell, i.e. intra-cell traffic, can also exist in one cell of mobile network. The general characteristic of intra-cell traffic is that it uses more traffic resources than outgoing and incoming traffic. The influence of intra-cell traffic on the output power of one base station is calculated in this paper. Intra-cell traffic is briefly described in Section 2. In this section, other references concerning intra-cell traffic in mobile networks are also presented. The method for calculating the mean output power of one GSM traffic channel is presented in Section 3. The base station mean output power, when mixed intra-cell, outgoing and incoming traffic exists in the cell, is calculated in Section 4. How calculated results are verified by simulation is presented in Section 5. Numerical examples are presented in Section 6.

## 2. Intra-cell Traffic

Let us consider one cell in GSM network of mobile users with $N_t$ traffic channels with PC. It is supposed that output power on these channels is adjusted according to the distance between the mobile station (MS) and the base station (BTS). The changes of this distance caused by MS moving are neglected. For outgoing and incoming connections one traffic channel is used. The offered traffic, which requests one radio channel in the cell, is the sum of outgoing and incoming offered traffic, and it will be called external traffic and designated as $A_e$. The offered traffic, which requests two channels for connection realization between the users, who belong to the same cell, is called intra-cell or internal traffic and is designated as $A_i$, as in [8]. Intra-cell traffic is especially present in the cells situated in rural areas and in the cells which cover greater companies. (Intra-cell traffic is also called intrasite, [9], intraBTS, [10], or internal [11] in literature).

The effect of intra-cell traffic is not often analyzed in the literature. Especially the literature that considers the influence of intra-cell traffic on the output BTS power in public mobile networks is missing. The calculation of one private network of mobile users with intra-cell traffic is presented in [9]. The characteristic of this private network is that it is the network with call waiting, if no free traffic channel is found, while the public mobile network, analyzed in this paper, is with call loss. But, [9] analyzes only traffic characteristics in the mentioned private network, not the necessary BTS output power, which is analyzed in this paper. One specific rural network, where intra-cell traffic is dominant, is analyzed in [10]. This paper demonstrates the importance of intra-cell traffic in rural areas. But, it tells nothing about the loss from the aspect of telephone traffic, and the data about the maximum power on the radio front end of the system presented in [10] is not analyzed considering the part of intra-cell traffic. Approximate calculation of resources in the network of mobile users, where the intra-cell part of connections cannot be neglected, is presented in [11]. But, as it is proved in [8], the calculation method presented in [11] gives worse results (i.e. smaller loss) than it is in reality. The results of traffic analysis and BTS output power calculation in this paper are based on the results presented in [8].

The results of output power measurements for similar base stations WPC in rural and urban areas of public mobile network are presented in [12]. The results presented in [12] seem to be the nearest to the subject of this paper. It is the dependence of BTS output power on intra-cell traffic in public mobile network. Unfortunately, intra-cell traffic is not mentioned in [12]. We suppose that difference of BTS power in rural and urban areas is caused by intra-cell traffic. Indirect proof of this assumption is the authors' indication in [12] that BTS power is obtained indirectly by measuring the traffic, i.e. the number of busy channels. Detailed analysis of the system with mixed external and intra-cell traffic is presented in [8].

The probability that in one group of $N_t$ traffic channels there exist $i$ intra-cell and $e$ external connections is $p(i,e,A_i,A_e,N_t)$. It is pointed out in [8] that one model from classic telephone technics, [13], can be used for the calculation of this probability:

$$p(i,e,A_i,A_e,N_t)=\frac{\dfrac{A_i^i\cdot A_e^e}{i!\cdot e!}}{\displaystyle\sum_{j=0}^{2\cdot j+k\le N_t}\sum_{k=0}\frac{A_i^j\cdot A_e^k}{j!\cdot k!}}=\frac{\dfrac{A_i^i\cdot A_e^e}{i!\cdot e!}}{\displaystyle\sum_{j=0}^{T[N_t/2]}\sum_{k=0}^{N_t-2\cdot j}\frac{A_i^j\cdot A_e^k}{j!\cdot k!}}\;. \quad (1)$$

All traffic parameters can be calculated on the base of this probability: the probability that $k$ external connections exist, $p_e(k,A_i,A_e,N_t)$, the probability that $k$ intra-cell connections exist, $p_i(k,A_i,A_e,N_t)$, the probability of external call loss, $B_e$, the probability of intra-cell call loss, $B_i$, the mean probability of call loss in the group with mixed (intra-cell and external) traffic, $B_{ie}$. It is proved in [8] that call loss is increased under the influence of intra-cell traffic component comparing to the pure external traffic. That's why Erlang model or model proposed in [11] gives underestimated results for loss calculation when mixed traffic is applied.

## 3. Output Power

Let us consider one cell in the GSM mobile network, with PC, where it can be supposed that one traffic channel is necessary for each connection. In order to save energy, the output power of each of $N_t$ traffic channels in BTS is adjusted according to the distance between MS and BTS, and according to the signal attenuation in the cell. The output power of BTS depends on the distribution of users' density in the cell, and on the number of simultaneous connections, i.e. on the total served traffic. Let us suppose that the cell forms a circle of radius $R$ and that output power of one channel, $w$, depends on the distance between MS and BTS, $d$:

$$w=g(d)=a\cdot d^{\gamma} \quad (2)$$

where the value of $\gamma$ is from 2 to 5, [14], $a$ is the coefficient of proportionality (in W/km$^{\gamma}$), and where $w_{max}=a\cdot R^{\gamma}$. In fact, equation (2) is the approximation of the equation $w=b+a\cdot R^{\gamma}$ where $b$ is the channel power, which is sent to mobile users in the vicinity of base station. As the power $b$ is very small, we neglect it in relation to the total power.

Let us consider the simplest case of uniform MS distribution in the cell. For this case the probability density function (PDF) and the cumulative distribution function (CDF) of one channel output power is calculated in [15]. It is proved that mean output power of one channel is

$$w_m=\left[\frac{2\cdot a}{(2+\gamma)\cdot R^2}\right]\cdot R^{2+\gamma}=\frac{2}{2+\gamma}\cdot w_{\max}\,. \quad (3)$$

It is, further, proved in [15] that mean output power of BTS, $w_{Bm}$, if there is no intra-cell traffic, equals

$$w_{Bm}=\omega_m\cdot A\cdot(1-B)=\omega_m\cdot Y \quad (4)$$

where $\omega_m = w_m/8$ is the mean one channel output power, which contributes to the total output BTS power, $B$ is the loss probability due to the lack of free channels, $Y$ is the served traffic, i.e. the mean number of busy channels.

## 4. Influence of Intra-cell Traffic on the Output Power

In the model, where equation (4) is valid, each connection uses one channel, i.e. mean number of connections (served traffic) is equal to the mean number of busy channels.

In the model, where intra-cell traffic is not negligible, equation (4) is not valid. In this case, the mean number of busy channels is equal to the mean number of external connections increased by twice the mean number of intra-cell connections.

The mean number of internal connections in the model with intra-cell component of traffic, i.e. the served intra-cell traffic, $Y_i$, is in this case

$$Y_i = \sum_{k=1}^{T[N_t/2]} k \cdot p_i(k, A_i, A_e, N_t) \quad (5)$$

where $T[N_t/2] = N_t/2$ if $N_t$ is even number, and $T[N_t/2] = (N_t - 1)/2$ if $N_t$ is odd number. The probability that there are $k$ intra-cell connections, $p_i(k,A_i,A_e,N_t)$, is:

$$p_i(k, A_i, A_e, N_t) = \sum_{e=0}^{N_t - 2\cdot k} p(k, e, A_i, A_e, N_t) \ . \quad (6)$$

The mean number of external connections in the model with intra-cell traffic, i.e. the served external traffic, $Y_e$, is

$$Y_e = \sum_{k=1}^{N_t} k \cdot p_e(k, A_i, A_e, N_t) \quad (7)$$

where $p_e(k,A_i,A_e,N_t)$ is the probability that there are $k$ external connections

$$p_e(k, A_i, A_e, N_t) = \sum_{i=0}^{T[(N_t - k)/2]} p(i, k, A_i, A_e, N_t) \ . \quad (8)$$

It is obvious that the mean number of busy channels, $n_m$, is:

$$n_m = Y_e + 2 \cdot Y_i \ . \quad (9)$$

Now, when intra-cell traffic exists, the mean output power of BTS, $w_{Bmi}$, is:

$$w_{Bmi} = \omega_m \cdot n_m = \omega_m \cdot (Y_e + 2 \cdot Y_i) \ . \quad (10)$$

It can be concluded that, when intra-cell traffic exists, $A_i > 0$, output power is greater than the output power, calculated by (4):

$$w_{Bmi} > w_{Bm} = \omega_m \cdot Y \ . \quad (11)$$

The relation between the mean BTS output power when intra-cell traffic exists and when it does not exist is:

$$\frac{w_{Bmi}}{w_{Bm}} = \frac{Y_e + 2 \cdot Y_i}{Y} \ . \quad (12)$$

The percent of the increase of BTS output power, caused by the intra-cell traffic, can be defined as:

$$\Delta = 100 \cdot \frac{w_{Bmi} - w_{Bm}}{w_{Bm}} \ . \quad (13)$$

It is important to give the remark on the estimation of output power of channel group in one base station, where intra-cell traffic cannot be neglected, if the approximate method presented in [11] is used for calculating the necessary number of channels. As it is presented in [8], the loss calculation gives the smaller values of loss, giving the greater values of served traffic than the real one. Therefore the estimated output power is greater than it is real.

# 5. The Verification of Calculated Results by Simulation

The calculated results are verified by computer simulation. In the simulation we considered GSM cell with $N_t$ traffic channels, where output power is adjusted according to the distance MS-BTS (cell with PC). The offered external traffic, which includes both outgoing and incoming traffic, is $A_e$. The offered intra-cell traffic is $A_i$. The total offered traffic is $A=A_e+A_i$.

The simulation program is based on the well-known program for simulation of telephone traffic and serving, called *roulette* or *Monte Carlo*, [16] - [18]. *Monte Carlo* method of simulation is performed in discrete time in order to simulate the process in continuous time. When simulation is performed, random events (new call, connection end, empty event) are generated according to the value of (pseudo)random number, RN1. Generated random numbers (RN1) have uniform distribution in the range (0,1). That's why distribution of time intervals between events has geometric distribution. Geometric distribution in discrete time has the characteristic that it is memoryless, as the negative exponential distribution of time, which is valid for the real process. It is the main reason why *Monte Carlo* simulation is credible. The first step in the simulation is to generate random number RN1 from the interval $(0,\ A_e+A_i+N_t)$. Depending on the value of random number RN1, this program simulates four event types:

- generation of new external call, if random number is $0 \le$ RN1 $< A_e$ and the number of busy channels, $j$, in that moment is $j < N_t$,

- generation of new intra-cell call, if random number is in the range $A_e \le$ RN1 $< A_e + A_i$ and the number of busy channels is $j < N_t - 1$,

- termination of the existing connection on channel $K$, if random number is $A_e + A_i + K - 1 \le$ RN1 $< A_e + A_i + K$ and channel $K$ is busy,

- empty event, if random number is $0 \le$ RN1 $< A_e + A_i$, and the number of busy channels is $j = N_t$ for external call and $j \ge N_t - 1$ for intra-cell call, or if random number is $A_e + A_i + K - 1 \le$ RN1 $< A_e + A_i + K$ and channel $K$ is idle.

We upgraded this known method by introducing generation of randomness of distance between mobile users and base stations. It is done by introducing two new random number generators, RN2 and RN3. The random distance between MS and BTS (and the power of channel) in external connection is determined on the basis of random number RN2, and the random distance (and the power of channel) for both users in intra-cell connection is determined on the basis of random numbers RN2 and RN3. The generated random numbers (RN2 and RN3) have uniform distribution in the range (0,1). Let us suppose that the CDF of distance MS – BTS is designated by $F_d$. In order to obtain the values of distance, which satisfy $F_d$, it is neces-

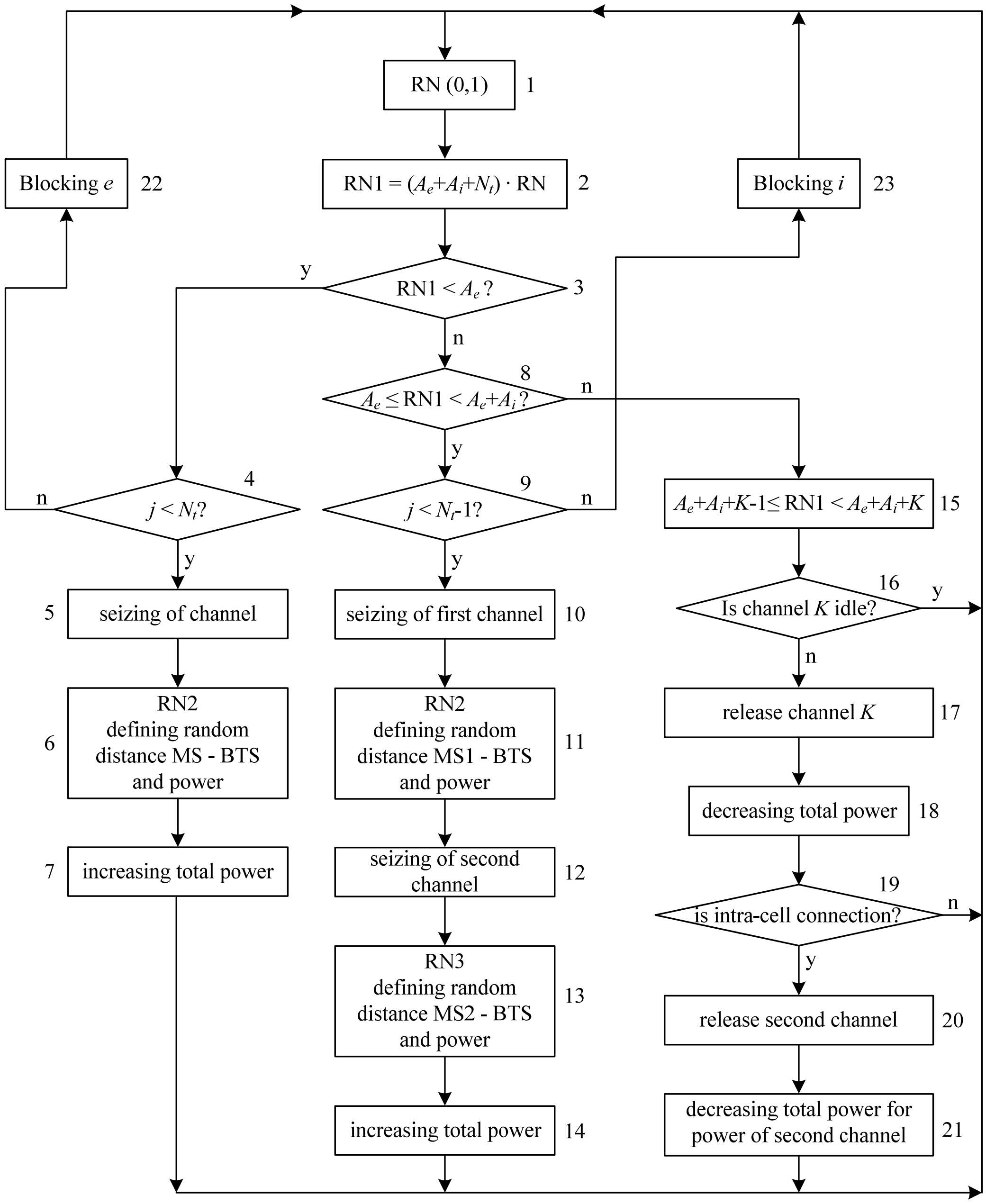


**Fig. 1.** Flow chart of simulation program.

sary to implement the inverse function $F_d^{-1}$ on the random numbers RN2 and RN3, as presented in [19], section 7.2.2. and in [20], section 7.3.3. We consider the examples where users are uniformly distributed in the cell area. In our case of uniform distribution of MSs in the cell, $F_d$ depends on the square of distance. Therefore, in simulation the random distance is obtained from random numbers as $d1 = R \cdot \sqrt{RN2}$ and $d2 = R \cdot \sqrt{RN3}$ .

The flow chart of the program for simulation is presented in Fig. 1. In the random instant we suppose that number of busy channels is $j$.

Blocks 1 and 2 determine the generation of random numbers. Block 3 determines whether new external call is generated. Blocks 4, 5, 6 and 7 define whether new external call can be realized and, if it can be realized, what is the (random) distance MS-BTS. According to the distance, it is determined what output power is used for this connection. Block 8 determines whether random number RN1 is in the range of generating the new internal call or in the range of call termination. Blocks 9-14 define whether internal call can be realized and, if it can be realized, what are distances MS1–BTS and MS2–BTS and, also, what is the output power in both channels. Block 15 is used to find the number of channel, which is the candidate for call termination. In block 16 it is determined whether the chosen channel is busy. If it is busy, blocks 17 and 18 present channel release in the case of external connection and decrease of BTS emission power, as one channel is released. Block 19 determines whether intra-cell connection was terminated.

Blocks 20 and 21 present the second channel release in intra-cell connection and decrease of total BTS emission power, as the second channel used for intra-cell connection is released. Blocks 22 and 23 are used for the evidence of lost calls when external and intra-cell call, respectively, cannot be realized.

The final results of the simulation (output power or difference of power) are considered as the results of measurements and are compared to the calculated results. In our examples at least three simulations are performed for the points, where great groups of channels are tested (e. g. $N_t = 16$, or two TRX without first carrier), and five simulations are performed for small groups of channels, (e. g. $N_t = 8$, or one TRX without first carrier). The number of realized connections in simulation was always greater than 1000 per one traffic channel (or more than 8000 per one TRX), i.e. 1000 external connections for the model without intra-cell traffic per one traffic channel, or cca. 700 external connections and cca. 300 intra-cell connections, if intra-cell traffic exists. The simulation is performed for the cell with intra-cell traffic and for the cell without intra-cell traffic. Power control is implemented for both cell types. The results of these simulations are mean values of output power in both types of cells, $w_{Bm}$, and $w_{Bmi}$. Based on the differences in these values of power, the calculation value of the difference $\Delta$ is checked (line 1 in Figs. 5 and 6). The final results of several simulation trials (three or five in our examples) are treated as the results of measurements and analyzed by statistical test. These tests are often presented in the literature. For the measurements in telephony they are presented in [21], section 12. Fig. 7 presents the values of power differences ($\Delta$) and the 95% confidence interval (Student's distribution) for the simulation results when the part of intra-cell traffic in total traffic is $p = 0.1$, 0.3, 0.5, 0.7 and 0.9.

The results of simulation are suitable to prove the mean values. Proving CDF of BTS output power is difficult. Calculating CDF of output power is very complex because it is based on calculation of convolution, so in general case CDF can be determined only by simulation.

## 6. Numerical Examples

Before presenting numerical examples of calculation of base station output power with PC, we shall compare the results of measured power from [12] with the simulated results. The results of measuring (normalized) output power of similar base stations (with the same number of carriers, i.e. channels) in rural and urban areas are presented in [12]. The results are presented as cumulative distribution function (CDF) of normalized BTS output power. As already stated, the BTS output power is calculated indirectly based on the traffic ("traffic to power translation"). Unfortunately, these base stations have no PC, so maximum channel power is used for each connection, Fig. 2. The base station with three carriers (3 TRX) is considered. As it is known, the power of all time slots of the first carrier (BCCH carrier) is always maximum ($w_{max}$), no matter they are busy or not (dummy bursts). For the remaining carriers maximum power is sent in the busy traffic channel, but if the channel is idle, no power is sent. The total power is easily obtained by summing the fixed power of the first carrier and the power of remaining channels that are seized up according to Erlang model.

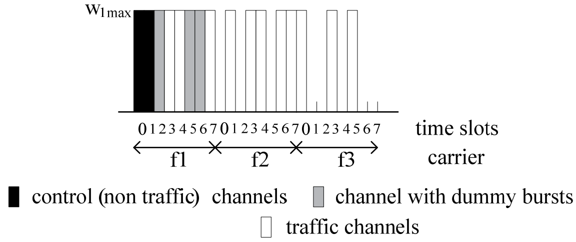


**Fig. 2.** Symbolic presentation of time slots (channels) in the base station with three carriers, WPC, as in [12].

Offered traffic is $A$. Let us suppose that in the urban cells there is no intra-cell traffic, i.e. the traffic is pure external. The second cells are rural and the part of the offered intra-cell traffic is $p$, $A_i = p \cdot A$, and the part of the offered external traffic is $(1 - p)$, $A_e = (1 - p) \cdot A$, $A_i + A_e = A$.

The measurement results from [12] (CDFs of normalized power) are presented in Fig. 3 for urban and rural base stations with three carriers (3 TRX). It is stated in [12] that compared distributions depend only on the fact whether urban or rural area is considered, not on the traffic value (the influence of high and low traffic is considered separately in [12]).

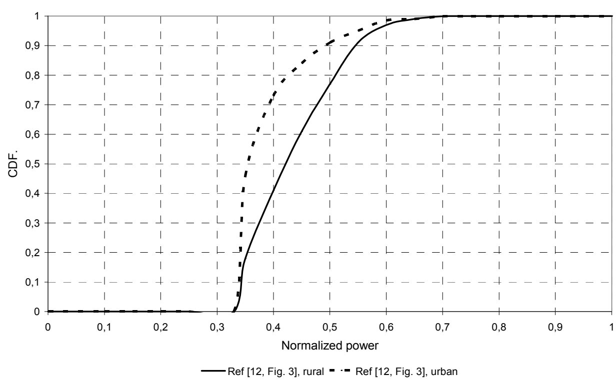


**Fig. 3.** Results of measurements (CDFs of normalized power) from [12] for urban and rural base stations with three carriers (3 TRX).

The results of simulation and calculation (CDFs of normalized power) for the model of base station with three carriers when $\gamma = 3$, $p = 0$ and $p = 0.5$ are presented in Fig. 4. It is important to note that the graphs from Fig. 4 are smoothed, because the real CDF in this case is the stepped function, as the base station power takes discrete values, i.e. an integer multiples of $w_{max}$.

The intention of presenting the results of measurements from [12] is to try to prove the assumption that the power in rural BTS is greater than the power in urban BTS

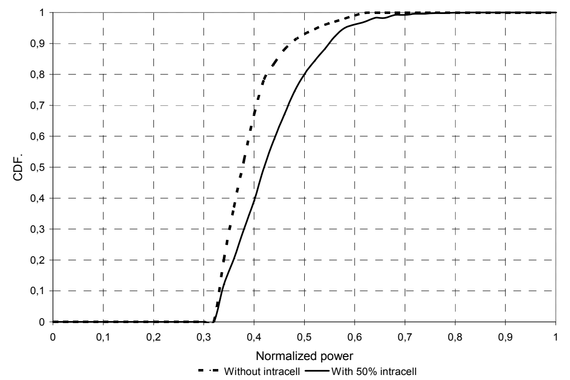


**Fig.4.** Simulation results (CDFs of normalized power) of the model with 3 TRX for which the results of measurements are presented in Fig. 3.

due to the increased part of intra-cell traffic in total traffic. Comparison of Figs. 3 and 4 shows the agreement of the measurement results and our results of simulation for $p = 0.5$. For example, probability that instantaneous normalized power in rural area is less than 0.4 of maximum power is 0.4 in both cases. In the case of urban area, these values are 0.72 for the measured results and 0.65 for the results of simulation. Probability that instantaneous normalized power in rural area is less than 0.5 of maximum power is 0.77 for measured results and 0.8 for simulation results. In the case of urban area, these values are 0.91 for measured results and 0.93 for the results of simulation.

Let us consider two cells with PC in GSM network. Both cells have the same number of traffic channels, $N_t$. PC is implemented on all $N_t$ channels. Therefore, we consider all channels except the channels on the BCCH carrier. Intra-cell traffic, whose part is $p$ in the total traffic, exists in one cell, and in the other one does not exist. Figs. 5 and 6 present the percent of output BTS power increase $\Delta = 100\cdot(w_{Bmi} - w_{Bm})/w_{Bm}$ when intra-cell traffic exists ($p = 0.3$) compared to the case when intra-cell traffic does not exist ($p = 0$), as the function of the offered traffic, line 1. Number of channels $N_t$ is 8 (Fig. 5) and 16 (Fig. 6). These figures also present intra-cell traffic loss ($B_i$, line 2) and total traffic loss ($B_{ie}$, line 3) as the function of offered traffic. Line 4 presents the loss in the same group of channels, but without intra-cell traffic ($p = 0$) to illustrate the influence of intra-cell traffic.

The main characteristics of intra-cell traffic influence on the mean BTS output power can be noticed in Figs. 5. and 6.

Intra-cell traffic increases the output power of BTS compared to the output power of BTS with pure external traffic. The influence of intra-cell traffic part ($p$) is presented in Fig. 7. Fig. 7 gives the increase of BTS output power ($\Delta$) as the function of the part of intra-cell traffic $p$.

When traffic values are small, the increase of output power is equal to the part of intra-cell traffic. In this situation $B_e \approx 0$ and $B_i \approx 0$. That's why $Y_i \approx A_i$, $Y_e \approx A_e$ and $Y \approx A$. From (4), (10), (12) and (13), it follows:

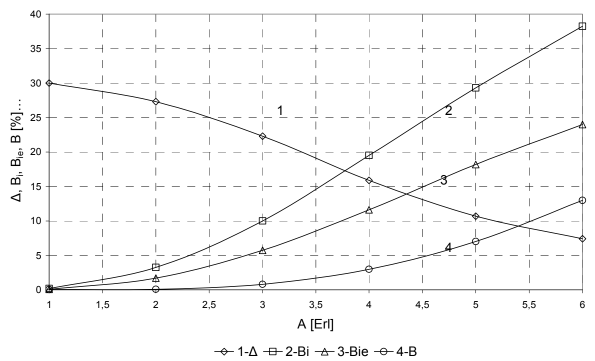


**Fig. 5.** Percentage of output power increase ($\Delta$, line 1), intra-cell traffic loss ($B_i$, line 2), mean intra-cell and external traffic loss ($B_{ie}$, line 3) for the model of $N_t = 8$, $p = 0.3$, and the traffic loss in Erlang model, i.e. model without intra-cell traffic ($B$, line 4) for the model of $N_t = 8$, $p = 0$, as the function of offered traffic.

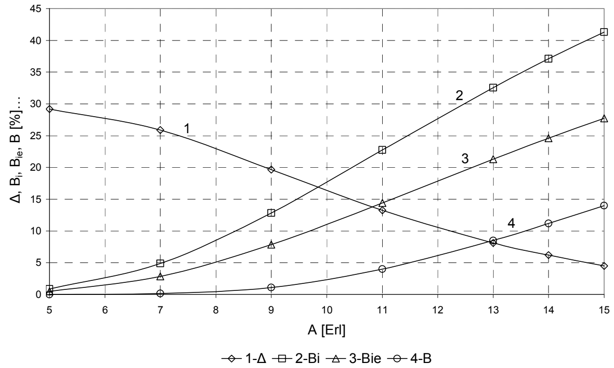


**Fig. 6.** Percentage of output power increase ($\Delta$, line 1), intra-cell traffic loss ($B_i$, line 2), mean intra-cell and external traffic loss ($B_{ie}$, line 3) for the model of $N_t = 16$, $p= 0.3$, and the traffic loss in Erlang model, i.e. model without intra-cell traffic ($B$, line 4) for the model of $N_t = 16$, $p= 0$, as the function of offered traffic.

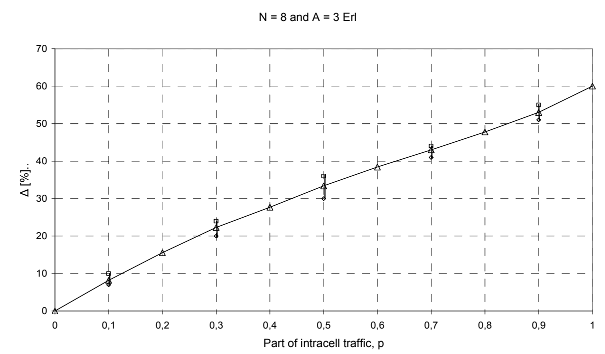


**Fig.7.** Dependence of output power increase ($\Delta$) on the part of intra-cell traffic for the group of $N_t = 8$ channels with offered traffic $A = 3Erl$, $A = p\cdot A_i + (1 - p)\cdot A_e$, calculated results (line) and 95% confidence intervals of simulated values for $p = 0.1, 0.3, 0.5, 0.7$ and 0.9.

$$\begin{aligned}\Delta &= 100\cdot\frac{w_{Bmi} - w_{Bm}}{w_{Bm}} = 100\cdot\frac{\omega_m\cdot(Y_e + 2\cdot Y_i) - \omega_m\cdot Y}{\omega_m\cdot Y} = \\ &= 100\cdot\frac{(Y + Y_i) - Y}{Y} = 100\cdot\frac{Y_i}{Y} \approx 100\cdot\frac{A_i}{A} = 100\cdot p\end{aligned} \qquad (14)$$

When offered traffic is increased, the increase of output power due to intra-cell traffic decays. This fact can be explained in the following way. When the offered traffic increases, the loss of intra-cell traffic increases more than the loss of external traffic. That's why the served external traffic increases more than the served intra-cell traffic, and, so, the increase of output power is smaller.

Let us mention that output power increase because of the intra-cell traffic does not depend on the kind of the service (speech, data). The reason is that this is the full availability group, for which insensitivity to holding time distribution is valid [22].

## 7. Conclusion

When considering the cell with non-negligible part of intra-cell traffic, the main conclusion of this paper is that it is more correct to consider that base station output power in GSM network is proportional to the mean number of busy channels than that it is proportional to the traffic.

In this paper it is presented that intra-cell traffic increases the BTS output power. This increase is equal to the part of intra-cell connections for small traffic values, when there is no traffic loss. When traffic is increased, the intra-cell traffic loss increases faster than external traffic loss, and, so, relative increase of BTS output power is less. Unfortunately, the great number of calls is lost in this case. It can be said that BTS output power increase is equal to the part of intra-cell traffic while traffic loss is negligible. The analysis is performed for uniform distribution of users in GSM cell, but the principles of calculation are also valid for other distributions. The mean output power depends on the signal attenuation because of propagation, but relative power increase because of intra-cell traffic does not depend on this attenuation. The similar influence of intra-cell traffic on the power increase can be also noticed for the BTS without power adjustment, but the power values would be greater in that case. The calculated results are verified by originally upgraded simulation program, where random distances MS-BTS are simulated besides traffic event simulation.

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# About Authors ...

**Mladen MILEUSNIĆ** was born in Bjelovar, Croatia, in 1958. He received his B.Sc. and M.Sc. from the Faculty of Electrical Engineering in Belgrade, Republic of Serbia, in 1982 and 1999, respectively. He received his Ph.D. from the Faculty of Technical Sciences in Novi Sad in 2014. From 1983 until 1985 he was employed at TANJUG News Agency technical department. From 1986 he is employed in Radio Communications Department of Institute for Electronics and Telecommunications IRITEL in Belgrade, where he now holds the position of principal technical associate. He worked on many research and development projects in area of communication systems. Currently, he is a head of radio communications engineering department, responsible for services in public mobile communications networks and wireless access networks.

**Predrag JOVANOVIĆ** was born in Belgrade, Serbia in 1985. He is an R&D engineer in the Institute for Telecommunications and Electronics (IRITEL) in Belgrade, Serbia. From 2008 to 2009, he worked in the Institute for Microwave Technique and Electronics in Belgrade, Serbia. He joined IRITEL in 2010. His main area of research is active electronically scanned arrays, embedded system design, digital signal processing, software defined radio and cellular radio systems (GMS, UMTS). He has a B.S. and M.S. degree from the University of Belgrade, School of Electrical Engineering, in 2008 and 2009, respectively. At the moment, he is pursuing Ph.D. thesis from the School of Electrical Engineering, University of Belgrade, Serbia.

**Miroslav POPOVIĆ** is a full professor on the Faculty of Technical Sciences, Department of Computer Science and Interprocessor Communication. He received his B.Sc., M.Sc. and Ph.D. from the Faculty of Technical Sciences in Novi Sad, Republic of Serbia, in 1984, 1988 and 1990, respectively. Within the educational activities, he was the lecturer on the courses: System software support, Operating systems, Interprocessor communication and computer networks, Computer networks and Designing systems with integrated services. Author of three books and more than hundred professional and scientific papers. Until now he participated on more than twenty international, federal and provincial research projects. Areas of professional and research activities are system software support, interprocessor communication and computer network technology, as well as designing of systems based on computers. Professor Popović is the member of the following societies: IEEE, IEEE-CS, IEEE-TC-ECBS and ACM.

**Aleksandar LEBL** was born in Zemun, Serbia, in 1957. He received his B.Sc. and M.Sc. from the Faculty of Electrical Engineering in Belgrade, Republic of Serbia, in 1981 and 1986, respectively, and his Ph.D. from the Faculty of Technical Science in Novi Sad, in 2009. He is employed in the Switching Department of Institute for Electronics and Telecommunications IRITEL in Belgrade since 1981. During years he worked on the project of Digital Switching System for Serbian Telecommunication Industry.

**Dragan MITIĆ** was born in Belgrade, Serbia, in 1953. He received his B.Sc. and M.Sc. from the Faculty of Electrical Engineering in Belgrade, Republic of Serbia, in 1977 and 1984, respectively, and his Ph.D. from the Faculty of Technical Science in Novi Sad, in 2002. Dr Mitić is a scientific associate in IRITEL, Institute for Electronics and Telecommunications, Belgrade, Serbia. From 1977 until 1989 he was employed at the Land Forces Military Technical Institute in Belgrade, and since 1989 in IRITEL. Dr Mitić is author or co-author of more than 70 international and national scientific and professional papers. He works on several research projects for equipment of specific applications.

**Žarko MARKOV** was born in Žitište, Serbia, in 1946. He received his B.Sc., M.Sc. and Ph.D. from the Faculty of Electrical Engineering in Belgrade, Republic of Serbia, in 1969, 1975 and 1976, respectively. Dr Markov is a scientific counselor in IRITEL, Institute for Electronics and Telecommunications, Belgrade, Serbia. Area of work: Switching technics, teletraffic theory, network signaling. He is the author or co-author of more than hundred papers and six books. At the University of Belgrade, School of Electrical Engineering, Dr. Markov was a professor at the course of switching techniques and network signaling.