

## ABOUT ESTIMATION OF BASE STATION OUTPUT POWER IN GSM LIKE SYSTEMS UNDER REAL CONDITIONS

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**Abstract:** The output power of traffic channels in one cell of GSM like systems is estimated in this paper. We consider the real case: the number of users is much higher than the number of channels, the output power of one channel depends on the cube of the distance between a mobile user and the base station, and the distribution of users in the cell is uniform. We derive the expressions for cumulative distribution of output power of one channel and for the mean output power of the whole base station. Results of the calculation are confirmed by computer simulation.

**Keywords:** Base Station, Communication System Traffic, GSM, Mobile Network, Output Power.

**MSC:** 68U35, 68U20, 90B22, 90B18.

## 1. INTRODUCTION

The use of radio links and mobile communication is increasing fast and it is necessary to strictly save energy in this field. Energy should be saved because it is expensive and to preserve the environment. Otherwise, increased energy production has detrimental effect, [26],[3]. Energy saving is important in modern mobile communications, too, [30],[2],[27],[19]. The program of energy saving is called *GREEN (Globally Resource-optimized and Energy-Efficient Networks) Radio*. One part of this program deals with saving energy using the telephone traffic characteristics. This part is often called *TANGO (Traffic-Aware Network planning and Green Operation)*. Energy consumption, that is, instantaneous consumption of electrical power of one base station (*Base Transceiver Station*, BTS) in the GSM network depends on different factors. One of the important factors is instantaneous number of mobile telephone calls, i.e., instantaneous value of telephone traffic. Minimizing the transmitter power leads to minimizing of self-interference in the system, to maintenance of requested quality of service (*Quality of Service*, QoS) in the conditions of optimal output power emission in BTS. Another part of the problem is correct dimensioning of battery backup in BTS, which is used if primary power source from electric power network is interrupted, or if alternative energy source is used. If all these reasons are considered, it is necessary to know characteristics of the output power of BTS. These characteristics are mean output power of one channel, cumulative distribution function (CDF) of output power determined for one channel and mean output power determined for the whole base station.

BTS emission power depends on many factors. Some of them are users' distance from BTS, their surface distribution over the BTS cell, implemented codec type (full-rate or half-rate codec), the characteristics of users' moving (direction, speed, changing BTS cells by handover), traffic type (intra-cell or external) and its value, implemented technology (GSM, CDMA, LTE), and so on. We investigated the influence of these factors and for each analyzed influence, we developed the simulation program ([13],[14],[22],[23],[24],[25],[17],[18]), thus simplifying the analysis. Simulations based on the same or similar principles may be found in many areas of human activities and scientific fields, as, for example, in operations researches [16]. Besides, the goal in mobile system dimensioning is to achieve the optimum Quality of Service while reducing the applied base station emission power. Energy planning and, in this way, environmental protection is also one of the aims of investigations in operations researches [31]. In mobile telephony, the BTS emission power is decreased by proper BTS positioning. This problem may be solved by integrated linear programming approach, characteristic for operations research [21]. In our paper we calculate the value of this decreased emission power, adjusting it according to the mutual distance between BTS and the user.

The rest of the paper is split in four parts. Section 2. deals with the model presentation. This section also gives some important assumptions and the list of designations, which are used in the paper. In section 3., we calculate CDF of output power of one traffic channel and the mean output power for the group of

channels. Some numerical examples are presented in section 4., and the conclusion of the paper is given in section 5.

## 2. MODEL, ASSUMPTIONS, DESIGNATIONS AND PROBLEMS

It is supposed that dynamic power control is implemented in one BTS of GSM network, [29],[5],[7]. The fundamental characteristic of this network is implementation of FDMA (*Frequency Division Multiple Access*) and TDMA (*Time Division Multiple Access*) on each dedicated frequency, [13]. It is supposed that the number of frequencies is  $N_f$ , and the number of time slots is  $N_s$  (8, by default). All available channels are not intended to be traffic channels, i.e., some of the channels are used for signalling. The number of traffic channels,  $N_t$ , used for telephone connection establishment, is  $N_t < N_c = N_f \cdot N_s$ . The total offered traffic in BTS is  $A$  and the served (handled) traffic is  $Y$ . The number of users, that is, mobile stations (MS)  $N_{ms}$  in a cell, covered by the analyzed base station, is much greater than the number of traffic channels, that is,  $N_{ms} \gg N_t$ . So, we can use Erlang model, which is usually used for traffic calculations, [7],[33],[1],[11]. Each user generates small traffic [9]. That is why the total offered traffic does not depend on the number of established connections. The call loss (or blocking), caused by lack of idle traffic channels, is designated by  $B$ .

We suppose that one traffic channel is used in the considered cell for each connection, i.e. that intra-cell traffic is negligible, [34]. If this traffic is not negligible, as is in private and professional networks [6],[4], the calculation is performed by the implementation of multidimensional traffic models, [11],[4],[10],[14],[24],[25].

The output power of one traffic channel ( $W$ ) is defined as the mean power during the useful part of GSM burst.

The output power of one traffic channel, as part of total BTS power, is  $\omega = W/8$ .

The mean output BTS power is mean value of power as the sum of all traffic channel powers,  $W_{Bm} = \sum(\omega_i)$ ,  $i = 1, 2, \dots, N_t$ , Fig. 1.

We suppose that output power of BTS is adjusted for all active traffic channels on all frequencies only according to the user's distance. It means that output power of one channel ( $W$ ) is the random variable dependent on the random distance, ( $D$ ), between MS and BTS. Let us suppose that in this case output power in one channel depends on the third power (cube) of the distance between MS and BTS:

$$W = g(D) = a \cdot D^3, \quad (1)$$

where  $w_{max} = g(R) = a \cdot R^3$  is the largest emission power of one channel. The maximal output power of one channel, which is the part of the output power of BTS, is  $\omega_{max} = w_{max}/8$ . It can be supposed that this dependence is the best approximation of real propagation conditions.

The distance between BTS and MS,  $D$ , is independent random variable and its distribution function:

$$F_D(x) = P(D \leq x), \quad (2)$$

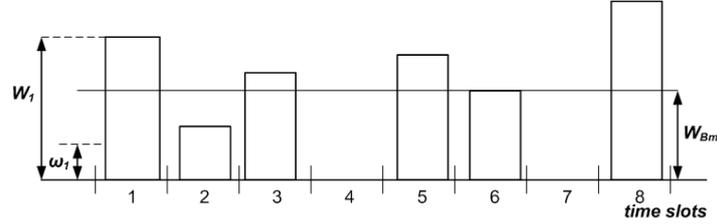


Figure 1: Symbolic presentation of output power for one BTS with 8 traffic channels:  $W_1$  - output power of first traffic channel,  $\omega_1$  - output power of first channel as part of mean BTS output power,  $\omega_1 = W_1/8$ ,  $W_{Bm}$  - mean output power of BTS,  $W_{Bm} = \sum(\omega_i) = 1, 2, \dots, 8$ .

represents probability that the distance is less or equal to some value  $x$ . This assumption means that output power of one traffic channel is continuous random variable (as also  $D$ ), which is in practice not completely true because the output power changes in steps of 2 dB. The distribution density of random variable  $D$  is  $f_D(D)$ . We also suppose that mobile stations are uniformly distributed in the cell area. The cell area is the circle with radius  $R$ . In that case, for the CDF of the distance MS - BTS, it is valid

$$F_D(x) = P(D \leq x) = \frac{\pi \cdot x^2}{\pi \cdot R^2} = \frac{x^2}{R^2}, \quad 0 \leq x \leq R, \quad (3)$$

and for the density (PDF) of this distance

$$f_D(x) = \frac{2 \cdot x}{R^2}. \quad (4)$$

The output power of a base station depends on the power of each traffic channel, on the mean number of active channels (traffic).

Estimation of the base station output power is the problem, which takes into account users' distance from BTS, dependence of output power in one radio channel on the distance MS-BTS, and the instantaneous number of active channels, that is instantaneous traffic. Estimation of the output power of one BTS is successful if we get dependence of mean power on traffic or, better, CDF of output power as the function of traffic.

### 3. OUTPUT POWER OF ONE CHANNEL AND OUTPUT POWER OF THE GROUP OF CHANNELS

Output power of one traffic GSM channel ( $W$ ) depends on the distance between MS and BTS in one cell,  $D$ , which is the random variable. It can be said that output power is the function of the random variable  $D$ . Probability density function of the output power is, according to [28], section V and equation (1):

$$f_W(w) = \frac{1}{|g'(D)|} \cdot f_D(D) = \frac{1}{3 \cdot a \cdot \left(\frac{w}{a}\right)^{\frac{2}{3}}} \cdot f_D\left(\left(\frac{w}{a}\right)^{\frac{1}{3}}\right), \quad (5)$$

and CDF of the probability of one channel output power

$$F_W(x) = \int_0^x f_W(w) \cdot dw = \frac{2}{R^2 \cdot a^{\frac{2}{3}}} \cdot x^{\frac{2}{3}}. \quad (6)$$

The mean output power of one channel is:

$$w_m(x) = \int_0^{w_{max}} w \cdot f_W(w) \cdot dw = \frac{2}{5 \cdot R^2 \cdot a^{\frac{2}{3}}} \cdot w_{max}^{\frac{2}{3}}. \quad (7)$$

(Note: this method, equations (5)-(7), derived for the cubic dependence of power on the distance between MS and BTS, equation (1), can be also carried out in the same way for other dependences.)

Mean output power of one channel, which is the part of BTS output power, is  $\omega_m = w_m/8$ .

The mean output power of all channels is:

$$W_{Bm} = \sum W(k) \cdot P(k, A), \quad (8)$$

where  $P(k, A)$  is the probability that  $k$  channels are busy (if the offered traffic is  $A$ ), and  $W(k)$  is the mean output power provided by  $k$  channels,  $W(k) = k \cdot \omega_m$ . Our assumption is that the number of users (that is the number of MS) is great,  $N_{ms} \gg N_t$ . In this case, truncated Poisson distribution, [11], section 4.3, can be adopted to express the probability  $P(k, A)$ . This distribution determines the probability that  $k$  of  $N_t$  channels are busy if the offered traffic is  $A$  in the Erlang model. This can be assigned as  $ERL(k, A, N_t)$ . The mean output power of BTS is:

$$W_{Bm} = \sum_{k=1}^{N_t} k \cdot \omega_m \cdot ERL(k, A, N_t) = \omega_m \cdot A \cdot (1 - B), \quad (9)$$

as is

$$\sum_{k=1}^{N_t} k \cdot ERL(k, A, N_t) = Y = A \cdot (1 - B), \quad (10)$$

the carried traffic in Erlang model, [11].

It is clear that the value of mean output power of the base station depends on traffic and can be in the range  $0 \leq W_{Bm} \leq N_t \cdot w_{max}/8$ .

#### 4. NUMERICAL EXAMPLES

Let us suppose that we have a BTS in class 4, that is  $w_{max} = 40W$ ,  $R = 20$  km. CDF of output power determined for one channel,  $W$ , according to (6), is presented in Fig. 2. This distribution also presents the CDF of one channel power, that is the part of total base station power,  $\omega = W/8$ .

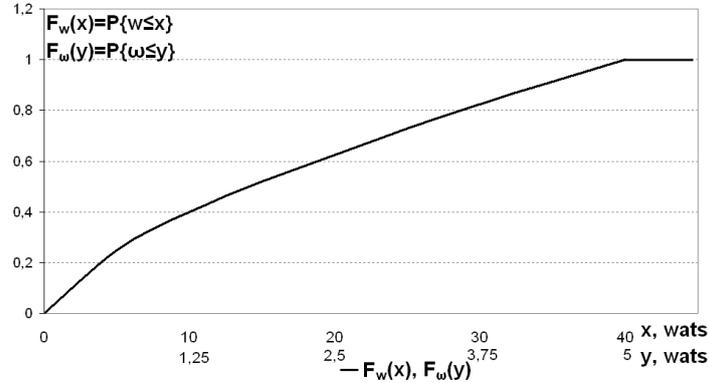


Figure 2: Cumulative distribution of the probability  $F_w(x)$  of one channel output power  $W$  and cumulative distribution of the probability  $F_w(y)$  of one channel output power  $\omega$ , which is the part of total power [13]

The mean output power of BTS,  $W_{Bm}$ , as the function of traffic, is presented, in Fig. 3. Line 1 presents dependence of mean output power of BTS when traffic load is small, that is when offered traffic causes negligible loss ( $B = 0.1\%$ ). Line 2 presents dependence of mean output power of BTS when offered traffic produces loss  $B = 1\%$ . Lines 3 and 4 present the increase of mean output power of BTS in the case of traffic overload, which causes loss  $B = 5\%$  (line 3) and  $B = 20\%$  (line 4).

Results from Fig. 2 and Fig. 3 are verified by computer simulation. The simulation program is based on *roulette* or Monte Carlo modeling, [8],[15],[20],[12],[32]. In the simulation, the distance between MS and BTS is selected randomly. The random selection of distance is made according to *a priori* determined density of mobile users in the cell [22]. In this case it is uniform density of mobile users across the cell. The results of simulation are considered valuable after at least 1000 connections over each traffic channel. The simulation results confirm calculation results because the difference between them is negligible.

As the calculation of CDF of total BTS output power may be very complex, this CDF is determined only by simulation [23].

Two CDFs of BTS output power in class 4 ( $w_{max} = 40$  W) for the cell with diameter  $R = 20$  km are presented in Fig. 4 and Fig. 5. The number of traffic channels is  $N_t = 14$ . The first line corresponds to small traffic load  $A = 5$  Erl. This traffic load causes negligible traffic loss ( $B = 0.05\%$ ). The second line presents distribution function of the output power of the same BTS in the condition of great traffic load ( $A = 13$  Erl). This traffic load causes great is enough traffic loss ( $B = 15\%$ ).

Fig. 5 presents details from Fig. 4. It is obvious that power of 20.2 W is necessary to provide 95% of all connections at small traffic load (5 Erl). It is necessary to provide 33.5 W or 65.8% more for 95% of all connections at great

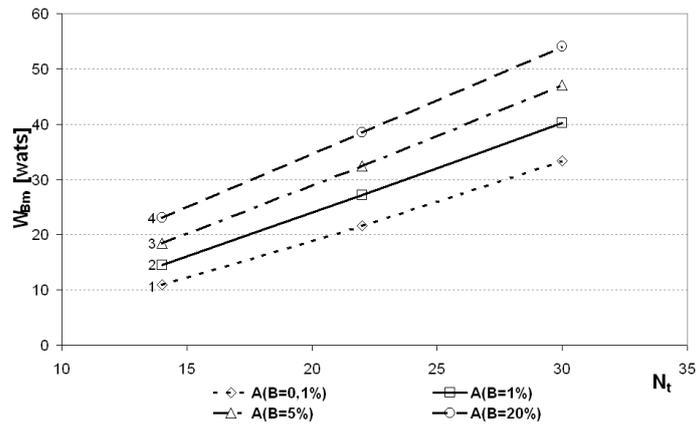


Figure 3: Dependence of mean output power of BTS on traffic.

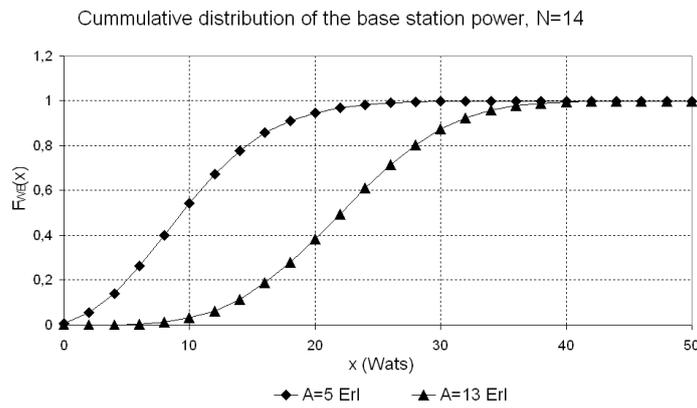


Figure 4: CDF of output power for one BTS with  $N_t = 14$  channels,  $A = 5$  Erl and  $A=13$  Erl.

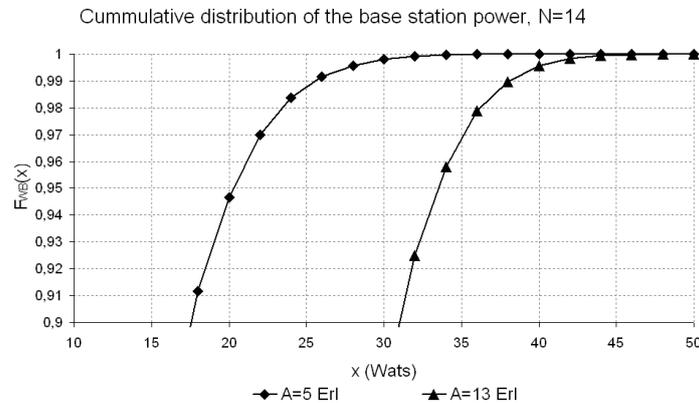


Figure 5: CDF of output power for one BTS with  $N_t = 14$  channels,  $A = 5$  Erl and  $A=13$  Erl (detailed).

traffic (13 Erl).

The same analysis, as in Fig. 4 and Fig. 5, is performed for  $N_t = 30$  traffic channels. The results are presented in Fig. 6 and Fig. 7. The values of offered traffic are, again, chosen to have traffic loss of  $B = 0.05\%$  ( $A = 15.8$  Erl) and  $B = 15\%$  ( $A = 31$  Erl). In the case of small traffic load (15.8 Erl) it is necessary to provide 48.5 W, while in the case of great traffic load, it is necessary to provide 68.5 W or 41.2% more to satisfy 95% of all connections.

## 5. CONCLUSION

The output power of a base station in GSM like systems depends on the cell traffic over the base station. In this paper, we derived the expression for cumulative distribution function calculation of output power of one traffic channel. The base of this calculation is the fact that the power of one channel is a random variable, which depends on the distance between the mobile and base station. The principle of power calculating for one channel is the same for all models, but we adopt real dependence of the power of channel on the distance and the distribution of users' density in the cell. In this paper we used cubic dependence of channel power on the distance and uniform users' distribution in the cell. Based on the distribution of one channel output power, we derived very simple expressions for calculating mean output power of base station. The values of cumulative distribution function of one channel output power and the mean values of output power of the whole base station are confirmed by computer simulation because the simulation results match calculated results noticeably very much. Cumulative distribution of total output power of a base station in the function of offered traffic is estimated only according to the simulation.

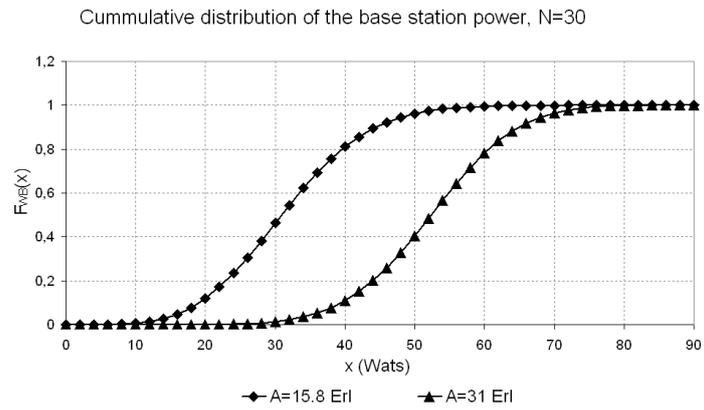


Figure 6: CDF of output power for one BTS with  $N_t = 30$  channels,  $A = 15.8$  Erl and  $A = 31$  Erl.

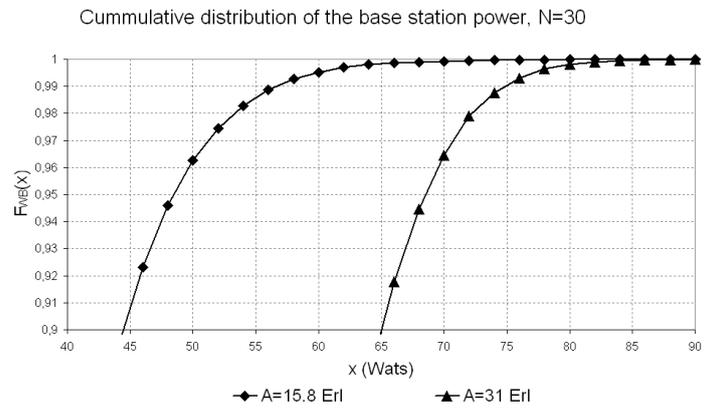


Figure 7: CDF of output power for one BTS with  $N_t = 30$  channels,  $A = 15.8$  Erl and  $A = 31$  Erl (detailed).

The important contribution of this paper is the development of a simulation model, which is the part of our simulation program collection intended for dimensioning in mobile telephony. The main goals in such a dimensioning are to determine the number of necessary traffic channels and the base station emission power. Our simulation programs are relatively simple, based on universal principles of Monte Carlo simulations. Their special value is in the analysis of relatively complicated systems, where it is difficult to define mathematical model because the base station emission power and traffic capacity depend on many factors. It is very difficult to obtain satisfactory analytical solutions even when a few of contributing factors are considered.

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