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TRAFFIC SIMULATION OF GSM CELLS WITH HALF–RATE CONNECTION REALIZATION POSSIBILITY

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This paper presents simulation model for the analysis of characteristics of base station, which may establish half-rate connections. Accuracy of realized simulation model is analyzed comparing its results to a number of corresponding results, which are obtained by calculation or presented in referenced literature. These corresponding results are obtained, in the first case, analytically, solving the system of equations, which are modelling the system and, in the second case, from the literature, which deals with the similar systems. At the end, simulation model is implemented to analyze in detail several systems with different total number of traffic channels. The results of simulation pointed out how much probability of connection loss decreases in the case of great traffic load, when half-rate connections realization is implemented.

K e y w o r d s: GSM, tele-traffic simulation, base station, half-rate connection

1 INTRODUCTION

Energy and traffic resources saving become more and more important in modern telecommunications. The goal is to transmit as great traffic volume as possible using as small energy consumption as possible. This intention is obvious, also, in modern mobile networks.

Energy saving in one mobile connection is realized by direct and indirect methods. Direct methods are based on the control of base station (BTS) emission power and the control of mobile users' power. BTS emission power is adjusted depending on the instantaneous distance between mobile user and base station and depending on the attenuation. In the indirect sense, the type of realized connections (relation number of internal (intra-cell) connections to the number of external connections) and instantaneous BTS traffic load (*ie* number of busy users in the area of base station availability) have influence at the BTS emission power. Traffic load is important, because radio signal is not transmitted on the air interface in traffic channels, where there is no established connection. The influence of mentioned factors on the BTS power is presented in [1–6].

Besides the BTS emission power, the other important element in its dimensioning is determination of number of traffic resources. It depends on total offered traffic, but also on type of traffic in the BTS cell and also on the number of users in the area of BTS radio-coverage in relation to the total number of BTS channels [7]. Saving of traffic resources is achieved by implementation of small bandwidth coders/compressors and by implementation of half-rate coders. Half-rate coding decreases bandwidth per user to one half in the relation to the standard implemented coding/compression method [8, 9]. As the parallel positive effect of half-rate coding implementation, the BTS total emission power is also decreased.

The disadvantage of half-rate codec implementation is worse quality of established connection. That's why full-rate coding is implemented till some defined threshold (of the number of busy channels in BTS), and half-rate coding is implemented when the number of busy channels is over this threshold. Some user mobile stations (telephones) (MS) may use half-rate signal coding and for their connections half-rate coding will be used when the number of busy channels exceeds the threshold, which is previously defined. MSs without the possibility to establish half-rate connection will further establish full-rate connections. Implementation of half-rate connections contributes to the decrease of blockage probability (connection loss), besides other previously cited positive effects.

Analytic model, which would be used to calculate traffic characteristics of real system when half-rate coding is implemented, is too complex to define. For example, authors in [8] limit their analysis on the simpler case, where it is supposed that users with MSs which are able to setup half-rate calls establish this connection type in each case, independently of the network state. In such a situation analytic expressions are obtained by complex mathematic operation. The solution for the system which always dedicates half a channel to the user, who is able to establish half-rate connection [9], may be expressed analytically.

In this paper we shall present simulation model, which estimates traffic characteristics of the BTS when it establishes both (full-rate and half-rate) connections, in real conditions. The implementation of simulation models to determine BTS power in some traffic conditions is already presented in [10].

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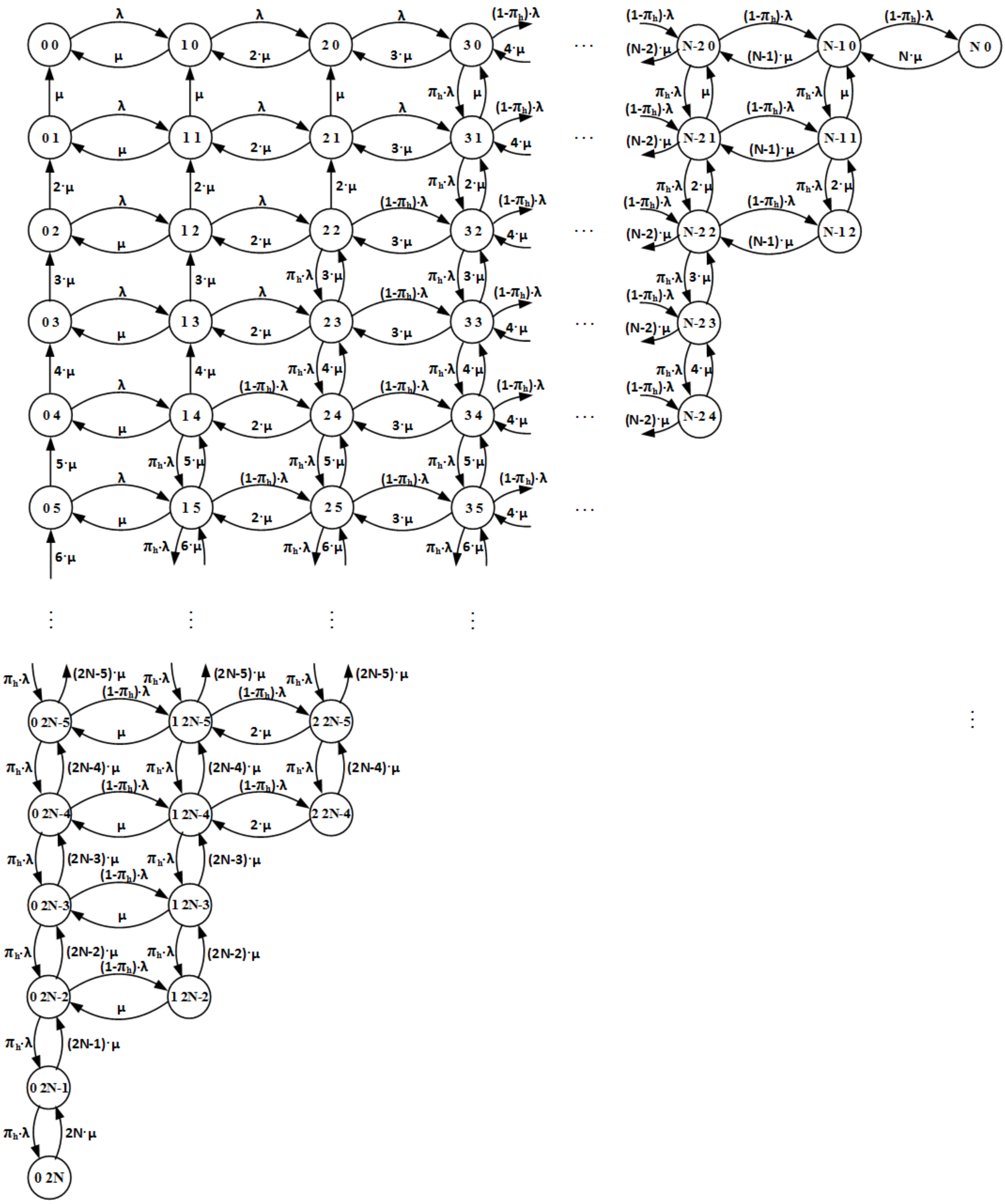

Fig. 1. Markov traffic model of GSM BTS, where half-rate connections may be established

2 MODEL, DESIGNATIONS AND ASSUMPTIONS

Let us suppose that total number of channels in one GSM cell of mobile network is N. Each channel may be used for full-rate or half-rate connections. GSM cell with the possibility to establish full-rate and half-rate connections may be modelled by two-dimensional Markov process, where two-dimensional variable $\{n_\mathrm{f}, n_\mathrm{h}\}$ presents instantaneous number of established full-rate and half-rate connections and the number of busy channels is $n_\mathrm{f} + 0.5 n_\mathrm{h} \leq N$. Let us, further, suppose that if the number of busy channels is less than $K(= pN)$, only full-rate connections are established. The intensity of new requests

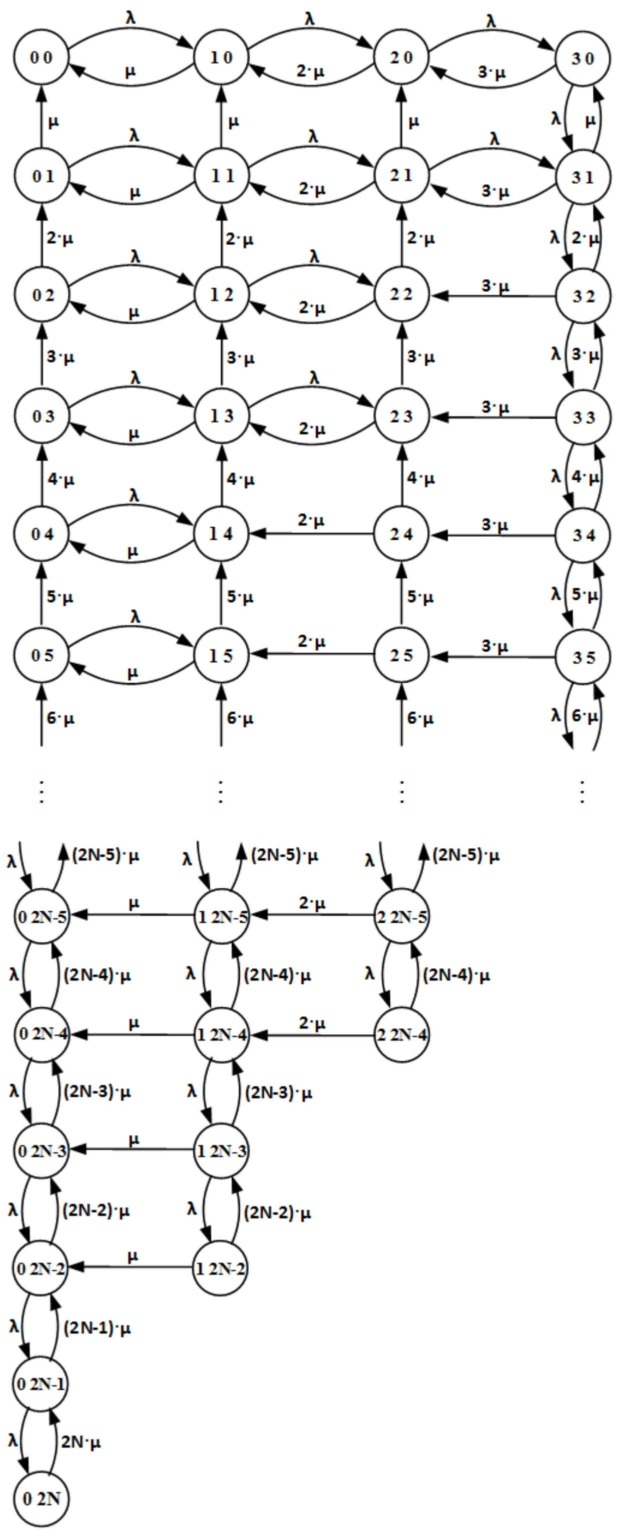

Fig. 2. Markov traffic model of GSM BTS, where half-rate connections are always established when number of busy channels is greater than the threshold

generation is λ and the probability that the user, who generates the request, may establish half-rate connection, is $\pi_{\rm h}$. Call duration of both connection types is random variable with exponential distribution and with mean duration $t_p = 1/\mu$. In the period when both kinds of requests are generated, the intensity of full-rate requests generation is $\lambda(1-\pi_{\rm h})$, while the intensity of half-rate requests generation is $\lambda\pi_{\rm h}$. In the state, when $n_{\rm f}$ full-rate and $n_{\rm h}$ half-rate connections are established, full-rate connection is finished with the intensity $n_{\rm f}\mu$ and half-rate connection with the intensity $n_{\rm h}\mu$. If during traffic process realization happens that two one-half time slots appear (*ie* two channels with only one half-rate call per channel), these two calls are gathered in one completely busy channel, while the other channel becomes completely idle (complete re-packing, [9]).

Traffic model of the system with the characteristics, cited in the previous paragraph, is presented in Fig. 1. In the system on Fig. 1, the threshold when BTS starts to establish half-rate connections is $K = 3$ busy channels and the number of channels in the system is $N > 6$. The system states in Fig. 1 are expressed by two numbers, the first one being the number of established full-rate connections, and the second one the number of established half-rate connections. The intensities of transitions between system states are emphasized in the figure (by setup of new request or by release of some previously established connection).

Figure 2 presents special case of the model in Fig. 1 when all mobile users can establish half-rate connections ($\pi_{\rm h} = 1$). In this case half-rate connections are always realized when number of busy channels is greater than the defined threshold. As in Fig. 1, the model is presented for $K = 3$ and $N > 6$. Comparing to the general model in Fig. 1, it is obvious that there is significantly smaller number of system states and also the smaller number of transitions between system states.

In the stationary state of Markov system, the probabilities of system states tend to unchangeable values. It means that for each system state $\{n_{\rm f}, n_{\rm h}\}$ the equation of the form

$$\begin{aligned}P(n_{\rm f},n_{\rm h})\big(\lambda(n_{\rm f},n_{\rm h})+\mu(n_{\rm f},n_{\rm h})\big)=&\\ P(n_{\rm f-1},n_{\rm h})\lambda(n_{\rm f-1},n_{\rm h})+P(n_{\rm f},n_{\rm h-1})\lambda(n_{\rm f},n_{\rm h-1})+&\\ P(n_{\rm f+1},n_{\rm h})\mu(n_{\rm f+1},n_{\rm h})+P(n_{\rm f},n_{\rm h+1})\mu(n_{\rm f},n_{\rm h+1})&\quad (1)\end{aligned}$$

may be defined. In this equation $P(n_{\rm f}, n_{\rm h})$ presents the probability of system state, where $n_{\rm f}$ full-rate and $n_{\rm h}$ half-rate connections exist (each half-rate connection occupies one-half channel). Then, $\lambda(n_{\rm f}, n_{\rm h})$ is the intensity of new calls generation, and $\mu(n_{\rm f}, n_{\rm h})$ is the intensity of existing calls termination in the state $\{n_{\rm f}, n_{\rm h}\}$. It is also necessary to satisfy the condition

$$\sum_{n_{\rm f}=0,n_{\rm h}=0}^{n_{\rm f}+2n_{\rm h}=N} P_{n_{\rm f},n_{\rm h}} = 1 \qquad (2)$$

The probabilities of system states are calculated by solving the system of equations, which is expressed using equations (1) for each system state, together with the condition (2).

Table 1. Probabilities of system states on the base of simulation (mean value after 3 simulation trials) and the calculation for the model with $N = 4$ channels, offered traffic is 3E, half-rate connections realization starts at $K = 3$ busy channels, probability of half-rate call is $\pi_h = 0.8$

Number of full-rate channels	Number of half-rate channels	Simulated state probability (mean value)	Calculated state probability
0	0	0.054893825	0.054998
1	0	0.146801455	0.146905
2	0	0.180993165	0.181054
3	0	0.121143620	0.121175
4	0	0.018205505	0.018176
0	1	0.018099135	0.018088
1	1	0.060504990	0.06052
2	1	0.101064565	0.101029
3	1	0.111235590	0.111183
0	2	0.005915255	0.005916
1	2	0.023170930	0.023138
2	2	0.045568275	0.045534
3	2	0.058910090	0.058832
0	3	0.002142655	0.002147
1	3	0.010012320	0.010005
2	3	0.024291845	0.024276
0	4	0.000718870	0.000719
1	4	0.003762510	0.00376
2	4	0.010101960	0.010086
0	5	0.000254900	0.000255
1	5	0.001550755	0.00155
0	6	0.000081580	8.16×10^{-5}
1	6	0.000537680	0.000538
0	7	0.000028535	2.8×10^{-5}
0	8	0.000009990	8.39×10^{-6}

All equations with the form corresponding to (1), together with (2) can be presented in the matrix form as:

$$\mathbf{0} = \mathbf{PA} \tag{3}$$

where $\mathbf{P}$ is vector of probabilities of all system states, $\mathbf{A}$ is the matrix of all possible transitions between system states, and $\mathbf{0}$ is the vector, whose all elements (originating from equations (1)) are 0, while the last element (originating from equation (2)) is 1. The solution of this system is

$$\mathbf{P} = \mathbf{A}^{-1}\mathbf{0} \tag{4}$$

where $\mathbf{A}^{-1}$ is the inverse matrix of matrix $\mathbf{A}$.

3 PROGRAM FOR SIMULATION

Markov model for the system with half-rate traffic is complex. In the general case, when there is the threshold for starting implementation of half-rate connections, the product of coefficients in clockwise direction is not equal to the product of coefficients in counter clockwise direction, when considering the model in Fig. 1 or Fig. 2. It means that Kolmogorov criterion for reversible process [11, Section 7.2] is not satisfied. That's why the system does not have the characteristic of reversibility, *ie* local balance does not exist, and the solution can not be expressed in closed (product) form [9]. This fact makes analytic (calculation) approach to modelling even more complex. Besides, when increasing the number of channels, the number of possible system states is increased in the square proportion, and this is the additional limiting element in this case. That's why the development of simulation model for analysis of traffic characteristics of GSM BTS is very important when they may establish half-rate calls.

The significance of other factors on the BTS traffic load is already emphasized in references [4, 7]. The significance of factors, as intra-cell traffic or limited number of users (Engset model) in the area of BTS coverage often cannot be neglected, nor presented by some simpler mathematical model. When these factors are combined with half-rate calls, simulation models are even more important for modelling. In this paper, the analysis is restricted to simpler cases, which imply only external connections, where only one channel is seized per connection (one full channel for full-rate connections, or half a channel for half-rate connections) and the great number of users in relation to the total number of channels (Erlang model).

Simulation is based on *roulette* or *Monte Carlo* method. Stability and reliability of simulation results is achieved after several simulation trials and generation of great number of calls (several tens of million) in each simulation trial. Flow-chart of the simulation program is presented in Fig. 3. Figure 3 presents only generation of events in the simulation (call generation, termination and loss). Each passage of simulation program starts from the generation of random number with uniform distribution in the range $(0, 1)$ (step 1). This number is shifted into the range $(0, A + N(1 + \pi_h))$ (step 2), where A is the value of offered traffic, which is simulated, N is the total number of channels, and π_h is the probability of half-rate calls. After that the simulation starts. If the generated random number is in the range $(0, A)$, (step 3), the new call will be generated, if other conditions allow this. Thus, if the total number of busy channels is smaller than the threshold (K), which is defined in advance (step 4), full-rate call is generated (step 7). In the case that total number of busy channels is not less than threshold K, step 8 is used to choose whether it is necessary to generate the full-rate or the half-rate call. The value of previously generated random number is tested again, and if it is smaller than $A\pi_h$ (where π_h is the probability of half-rate call), the following call is half-rate (in opposite, the following call is full-rate). If full rate call has to be generated, it is checked whether the total number of busy channels is smaller or equal to $N - 1$ (step 5). In the case that this condition is satisfied, full-rate call is generated (step 7). If there are no free channels, the call is lost (step 6). The steps 9, 11 and 10 for half-rate calls correspond to the steps 5, 7 and

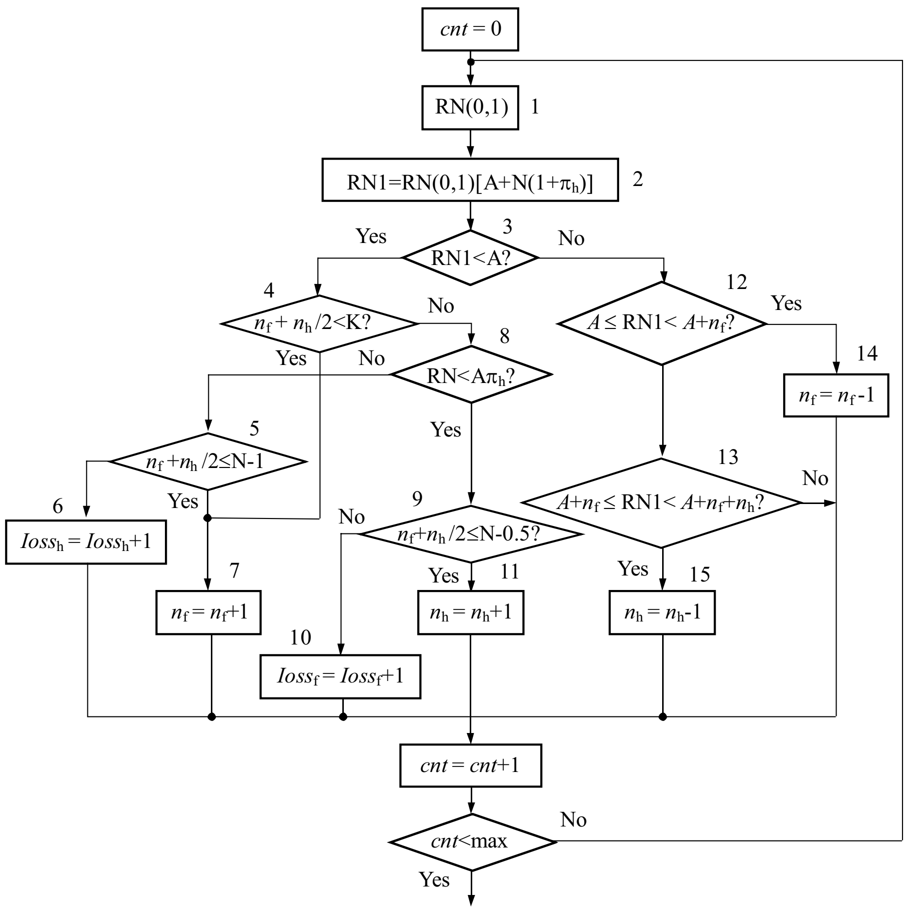

Fig. 3. Flow-chart of the simulation program

6 for full-rate calls, with the difference that half-rate call is generated if there is at least half an idle channel.

If the generated random number is greater than A, according to test in step 3, it is necessary to check whether the call has to be ended. Thus, if the generated number is in the range $(A, A + n_{\rm f})$, according to step 12 (where $n_{\rm f}$ is the number of channels, which are engaged by full-rate connections), the full rate call is ended (step 14). In step 13 it is tested whether it is necessary to end half-rate connection. Half-rate connection is ended if the generated random number is in the range $(A + n_{\rm f}, A + n_{\rm f} + n_{\rm h})$ (step 15). If the last two conditions are not satisfied, the situation in the system remains unchanged.

The number of simulation program passages is regulated by the value of counter (*cnt*). The simulation is finished when it reaches its maximum value. The value of *cnt* in each simulation trial is 100 millions and the corresponding number of generated calls during one simulation trial is several millions. The results of several simulation trials are processed statistically by calculating mean values and confidence interval.

4 TESTING SIMULATION RESULTS

The main contribution of this paper is development of simulation model of system, which may establish half-rate calls. In order to investigate accuracy of realized simulation program, three types of tests are performed. The first test is realized in such a way that, (using matrix calculation) according to (3), all state probabilities of traffic process are calculated. Then the same traffic process is simulated and state probabilities are determined by simulation. These, in two ways determined probabilities of system states, are compared to perceive the level of their matching. Testing on the basis of comparing the probabilities of system states are suitable, because all other characteristics of the system can be determined if system states are considered.

The second and the third test are performed by comparing the results of simulation to the results presented in [9]. In the second test, the probabilities of call loss, which are presented in Table 3 in [9], are compared to the results of simulation of the corresponding system. The simulation is performed for all combinations of values of initial parameters, presented in Table 3 in [9]. The maximum values of served traffic for the simulated system and for the system with the characteristics as those in Fig. 3 in [9] are compared in the third test.

The first test is realized on the system with four channels. The threshold, when establishment of half-rate calls starts, is $K = 3$ busy channels. The offered traffic is 3E, and the probability of half-rate calls is $\pi_{\rm h} = 0.8$ of total number of calls. The probabilities of system states for

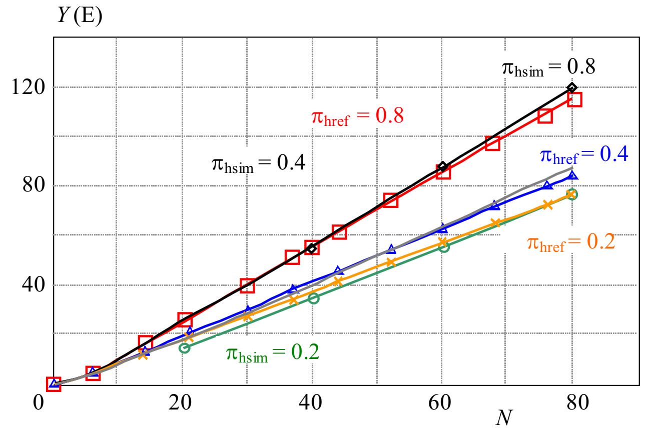

Fig. 4. The total served traffic (Y) as the function of the number of traffic channels (N) for different percent of half-rate traffic (π_{h}): the results of simulation (mean value after 3 simulation trials — lines designated by the parameter π_{hsim}) compared to the results from [9] (lines designated by π_{href})

such a system, according to simulation and calculation, are presented in Table 1. It can be concluded after comparing these results that there is a great level of matching between the results of simulation and calculation.

The second test is realized on the system with $N = 6$ channels, and the threshold value (K) when generation of half-rate calls starts is variable. The offered traffic is 3E. The probability of half-rate calls is $\pi_{\text{h}} = 0.2$, 0.4 and 0.8 of the total number of calls. The exact value of call loss, the call loss according to approximation in [9] and the call loss, obtained in the simulation (mean value after 3 simulation trials) according to the simulation program flow-chart from Fig. 3, are presented in Table 2. The deviation of probability of call loss is "on the safe side", *ie* the probabilities of call loss according to simulation are slightly greater than the exact values.

The third test is realized to compare the results of simulation to the results presented on the graphic in Fig. 3 in [9]. The designation in Fig. 3 in [9] is that maximal traffic is presented, but in this paper, instead of maximal traffic, we use the term served traffic (Y) with the same meaning. The total number of traffic channels is changed in the simulation (20, 40, 60 and 80 channels) and for each simulated number of channels the traffic is adjusted until the value of loss was approximately 2 %, as it is also supposed for the graphic in Fig. 3 in [9].

The number of busy channels when implementation of half-rate traffic starts (threshold K) was, also in accordance to the value from [9], $K = 0.15\,N$ of total number of channels. The graph, which compares the results from literature and the results of simulation (mean value after 3 simulation trials) are presented in Fig. 4. The significant level of matching between the results of simulation and the results from [9] can be also noticed in this case.

5 TRAFFIC CHARACTERISTICS OF THE SYSTEM WITH HALF–RATE CONNECTIONS

Figure 5 presents connections loss probability (P_{loss}) as the function of number of channels when implementation of half-rate connections starts (threshold K). The system is analyzed using our originally developed simulation model. The parameter in Fig. 5 is the probability P_{loss} that mobile user may establish half-rate connection (number of half-rate capable MSs in relation to the total number of MSs). Connection loss is presented for $N = 6$, 14, 22 and 30 channels, and the offered traffic is $A = 6$E, 14E, 22E and 30E, respectively, *ie* the numerical value of traffic in Erlang units (E) is equal to the total number of channels ($A = N$). As it is already explained in [4], there are eight channels on each carrier frequency of one base station. From this total number, two channels on the first carrier frequency are control channels, while the remaining six channels on this first carrier are traffic channels. It is supposed that on other carrier frequencies, all eight channels are traffic channels. Therefore, numbers 6, 14, 22 and 30 channels correspond to the number of traffic channels in one GSM BTS, which has one, two, three or four carriers, respectively.

Connection loss probability (P_{loss}) can be significantly decreased if half-rate connections are implemented. Modern MSs mainly have possibility to establish half-rate connections (of good quality), so implementation of such a possibility contributes to increasing probability of successful connection realization and, besides, to decreasing BTS emission power.

Example. Let us consider the system with $N = 29$ channels where only full-rate connections are established. In this system the offered traffic value (A) has such a value that the call loss probability is 20 %. This level of call loss is too great, so half-rate coding is introduced. Which threshold value for the number of busy channels should be used to start half-rate coding in order to decrease the call loss probability on 1 %?

Solution. This type of problem can be solved easier using simulation, than analytically. In this paper it is mentioned that there is no mathematical formula in the closed form to analytically express the solution in the general case. Solving the system of equations, which presents the model, is very complex, because the traffic model according to Fig. 1 looks differently for each threshold value (K) when half-rate connections realization starts (intensities of transitions between system states change for each K). That's why it is, practically, necessary to constitute different model for each K, and the number of states and intensities of transitions in the case of each K is great (it is explained in section 3 that the number of system states is proportional to the square of number of channels). When simulation is implemented, the result is determined after few attempts, where only values K and π_{h} are variable.

It is easy to find by the implementation of simulation program or Erlang tables that traffic of $A = 32.6$E,

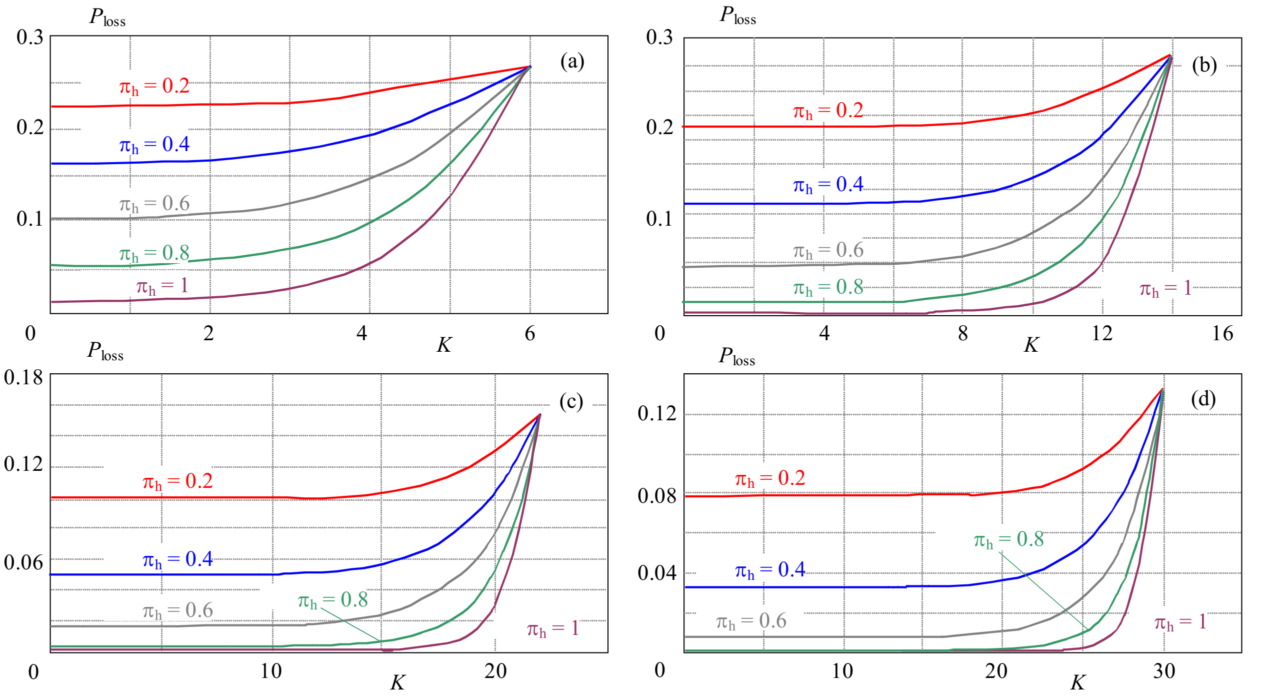

Fig. 5. The call loss probability ($P_{\rm loss}$) for different threshold values (K) when half-rate connections realization starts

Table 2. The call loss probabilities ($P_{\rm loss}$): the exact value, the approximate value according to [9] and the value obtained by simulation (mean value after 3 simulation trials), (all values in %) for the system with 6 channels, offered traffic 3E and variable threshold (K) when half-rate connections realization starts

	$\pi_{\rm h} = 0.2$			$\pi_{\rm h} = 0.4$			$\pi_{\rm h} = 0.8$		
K	$P_{\rm loss}$ exact	$P_{\rm loss}$ reference	$P_{\rm loss}$ simulated	$P_{\rm loss}$ exact	$P_{\rm loss}$ reference	$P_{\rm loss}$ simulated	$P_{\rm loss}$ exact	$P_{\rm loss}$ reference	$P_{\rm loss}$ simulated
0	5.22	5.22	5.214	5.22	5.22	5.216	5.22	5.22	5.220
1	4.87	4.73	4.950	4.10	3.95	4.342	2.12	2.04	2.626
2	4.49	4.36	4.575	3.20	3.10	3.411	0.94	0.88	1.222
3	4.17	4.09	4.2421	2.59	2.55	2.743	0.46	0.44	0.601
4	3.96	3.93	4.000	2.23	2.23	2.317	0.26	0.26	0.328
5	3.86	3.85	3.887	2.07	2.08	2.109	0.20	0.20	0.215
6	3.84	3.84	3.841	2.04	2.04	2.046	0.18	0.18	0.183

which is offered to the group of 29 channels, is served with loss probability $P_{\rm loss} = 20\,\%$. If we now implement half-rate connections in the system, we conclude that the requests of the presented example for $\pi_{\rm h} = 20\,\%$, $40\,\%$ and $60\,\%$ can't be fulfilled for any K. Further, we find by simulation that probability of call loss is $P_{\rm loss} \approx 1\,\%$ for $\pi_{\rm h} = 80\,\%$ when the threshold is $K = 22$, and for $\pi_{\rm h} = 100\,\%$ when the threshold is $K = 25$.

6 CONCLUSION

This paper presents simulation program for the analysis of traffic load of GSM BTS, which may establish half-rate connections. In the general case, there is no mathematical formula, which (in closed form) expresses probabilities of system states or probabilities of call loss for the system with half-rate connections. Besides, when the total number of channels increases, the number of possible system states increases at the square degree and that's why definition and solving of one analytically defined system become significantly more difficult. In such conditions simulation model becomes more important. In this paper simulation model is limited to the analysis of traffic characteristics of GSM BTS, and model supplement is planned in the future to determine the necessary BTS power when it establishes half-rate connections.

The accuracy of simulation model is multiple tested, using three different accesses in the comparison to different reference systems. In the first case analytically defined system from this paper was used as the reference, while in the following two cases the results of simulation are compared to the results presented in [9]. All these methods of testing demonstrated significant level of matching between the results of simulation and the results obtained for the reference system.

The significant saving of necessary traffic resources is achieved by the implementation of half-rate connections. In the duet of system parameters — traffic load and probability of call loss, it is necessary to keep one of them fixed, while the other is determined by simulation. We decided to keep the traffic fixed, and determine the probability of call loss. Our analysis proves that, in the case of great traffic load in the system, even only small implementation of half-rate connections significantly decreases call loss probability. For example, if there are 30 traffic channels and the traffic is 30E, defining the threshold to start implementation of half-rate connections at 18 traffic channels decreases blockage probability from 13 % to less than 1 % if only 60 % of mobile users may establish half-rate connections.

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