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ANALYSIS OF REAL MOBILE TELEPHONY TRAFFIC SCENARIOS USING A UNIVERSAL SIMULATION PROGRAM

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The paper considers a group of channels in a cell of mobile users. Estimating serving properties in a group is not simply because a high complexity of the traffic process does not allow the implementation of Erlang and other known calculation procedures. The cell characteristics are a limited number of traffic sources, external and intra-cell traffic, and prioritized serving of handover traffic (with channel reservation). Universal simulation program which allows properties estimation (for example, traffic loss) of such a model with several input parameters has been developed. The main paper contributions are summarized as 1. simplifying and, in some cases, even enabling analysis of complex traffic scenarios in mobile telephony systems; 2. it is allowed to follow these systems' behaviour when input parameters (number of reserved traffic channels only for handover calls, part of intra-cell traffic in total traffic, number of mobile users in the cell) one by one or at the same time gradually approach their limiting values. The simulation model verification is performed using the model where one or two factors are missing among the total number of factors for which calculation procedures exist. The description of the simulation program and numerical examples are presented in the paper.

1. INTRODUCTION

Usable frequency spectrum limitation and energy saving, among other reasons, have caused the development of a mobile network with small dimension cells. Such cells and movable users inevitably become the reason for numerous existing connection handovers [1]. Call loss due to the lack of idle resources is supposed to be very undesirable. That's why various techniques have been developed to decrease the probability of handover call loss [2–7]. One of the most often applied techniques is channel reservation for handover calls, which decreases handover calls loss at the expense of primary calls loss. One solution of the model with the mixed primary and handover traffic is presented in [7]. The systems which may not be precisely described by the model from [7] may be found in some cells. Those models have a limited number of users and significant intra-cell traffic [8]. This paper aims to estimate the influence of these two effects on the primary and handover call loss when a simple model with channel reservation is applied. This objective is achieved by the development of a universal simulation model of telephone traffic in the mobile telephony system cell, which includes the following variable factors that influence the traffic process: number of users in the cell, percent of intra-cell traffic in total traffic, handover probability and the number of traffic channels reserved only for handover traffic.

A traffic model which considers more traffic types, each with its components of primary and handover traffic and the limited possible number of traffic sources, is presented in [9]. Mathematical expressions correspond to the general case of *k*-dimensional traffic and simulation results for the 4-dimensional model (2 primary and 2 handover traffic types). This seems very close to the model analyzed in this paper. However, contribution [9] does not consider the possibility that one realized connection takes 2 traffic channels, as is the case when intra-cell traffic exists. Intra-cell traffic often may be important or even dominant traffic component, especially if the implementation of mobile telephony systems in rural areas [10] or private networks [11] is considered. According to our knowledge, intra-cell traffic has not been analyzed until now, together with its handover component. Instead of intra-cell traffic, the influence of intra-cell (and inter-cell) interference on the performances of W-CDMA networks is analyzed in [12]. The interference level is one of the criteria for determining W-CDMA systems' traffic properties.

The number of traffic sources for the analysis is significantly related to the dimensions of the analyzed cells. Therefore, traffic analysis in the case of micro-cells is necessarily based on Engset model implementation [13].

Just to summarize, the purpose of this paper is to determine the traffic properties of channels in a fully available group when it is analyzed in a cell of a mobile telephony network. In a traffic sense, this cell contains all important special cases: 1. A limited number of traffic sources; 2. external and intra-cell traffic; 3. handover calls and 4. channel reservation. It would be hard to perform calculations for such a complicated, universal model. That's why system performances are evaluated based on simulation program results. The correctness of the simulation process is verified for special situations when one or two of the total four emphasized parameters tend to zero or their limiting values. In such special cases, analytical models exist, and mutual comparison of the calculation and simulation results is possible.

Designations and assumptions in the considered model are emphasized in section 2, and the previous results are presented in section 3. Analyzed cases which correspond to the systems with mixed traffic whose one component is intra-cell traffic with reserved channels exclusively for handover calls are defined in section 4. These cases, after excluding one or more input components, tend to be familiar cases from the former literature. Section 5 presents the results obtained by the originally developed simulation program whereby the elements of the traffic process are

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successively changed towards cases described in section 4. The simulation program is described in Section 6.

2. THE CONSIDERED CELL, DESIGNATIONS, AND ASSUMPTIONS

Let us consider the cell in the network of mobile users. This cell has M users and N ($N < M$) channels to establish communication connections. Two connection types are realized in a cell from the priority point of view [1]. The first ones are the connections of users who started the connection in some other network part but arrived at the considered cell due to their movement. Such resource requests are called handover calls, and they have priority. The number of such requests in the unit of time is called the intensity (or rate) of handover calls (λ_h). Generally speaking, the intensity of calls is the number of calls (λ) in a unity of time. When we multiply this value by the average request duration, we obtain traffic intensity (A) which is a measure of the average occupancy of a channel or a group of channels during a specified period.

The second connection type originates from the requests initiated in the considered cell, which are designated primary calls. The intensity of such calls is λ_p. It is supposed that both request types (primary and handover) from all users are generated randomly.

The impossibility of realizing a handover call due to the lack of idle resources is especially undesirable. Such an event is called handover call loss, and its probability is designated by B_h. The primary call loss is the less serious event, and its probability is designated by B_p. One of the most often applied methods to achieve negligible low handover call loss probability is the method of reservation [7]. When this method is applied, last r resources remain reserved for handover calls and, consequently, primary call loss is increased.

The so-called intra-cell connections may be also realized in the considered cell. These are connections between two users from the same cell [8]. These connections seize two resources in the considered cell. It means that primary call intensity has two components: the first one related to external connections and the second one related to intra-cell connections, *i.e.*, $\lambda_p = \lambda_{pe} + \lambda_{pi}$. Handover calls may also finish in the considered cell or again two resources are necessary. Handover call intensity is $\lambda_h = \lambda_{he} + \lambda_{hi}$.

The considered cell which has a limited number of traffic sources, two traffic types according to their priority, and two traffic types that take a different number of resources is obviously very complicated when considering traffic serving. That's why we are going to consider the models with only one of the mentioned properties in the following section and pay attention to its influence on the calls serving.

The meaning of some variables used in this paper is as follows:

– N – number of available traffic channels;
– M – number of mobile users in the cell;
– r – number of traffic channels reserved only for handover calls;
– A – total traffic;
– A_e, A_i – offered external and intra-cell traffic;
– A_p, A_h – offered total primary and handover traffic;
– A_{pe}, A_{he} – offered external primary and handover traffic;
– A_{pi}, A_{hi} – offered intra-cell primary and handover traffic.

There is no telecommunication standard that would define what traffic types should be analyzed when mobile telephone traffic is considered. But, external and intra-cell traffic, primary and handover calls together with the number of traffic channels reserved only for handover calls and a limited or unlimited number of mobile users in the cell are nearly all-important variable input parameters in the model. The remaining parameter is the implementation of half-rate connections, which take only half of a traffic channel. In modern mobile telecommunication systems, such connections are rarely applied because their connection quality is worse than in other cases, and resource sparing is not important due to the higher number of available traffic channels.

3. PREVIOUS MODELS

3.1. MODEL WITH A LIMITED NUMBER OF TRAFFIC RESOURCES

This model where the number of traffic sources is greater than the number of serving channels but not too much ($M > N$) is known as Engset model. The main features of this model are that the call arrival rate depends on the number of idle traffic sources. It is more efficient than Erlang model for some value of offered traffic and time congestion is greater than call congestion [14]. This model is highly dependent on the ratio between the number of channels and the number of traffic sources. It approaches Erlang model when the number of traffic sources increases. The traffic loss in Erlang and Engset models will be designated by $B(A,N)$ and $B(A,N,M)$, respectively. Besides many references, the results of calculation and simulation for Engset model are presented in [8].

3.2. MODEL WITH INTRA-CELL TRAFFIC

Intra-cell connections are established between two users from the same cell. External connections are those which are used by one user from the cell. Intra-cell connections require two resources/channels and external connections. The four possible connection types are presented in Fig. 1: 1. intra-cell by the solid line between mobile users 1 and 2; 2. external by the dashed line from user 3 towards the rest of the network; 3. intra-cell between the user who has come to the cell after handover and the user from the cell by the dotted line between the users 4 and 5; 4. external of the user who has come to the cell after handover by the dot-dash line from the user 6.

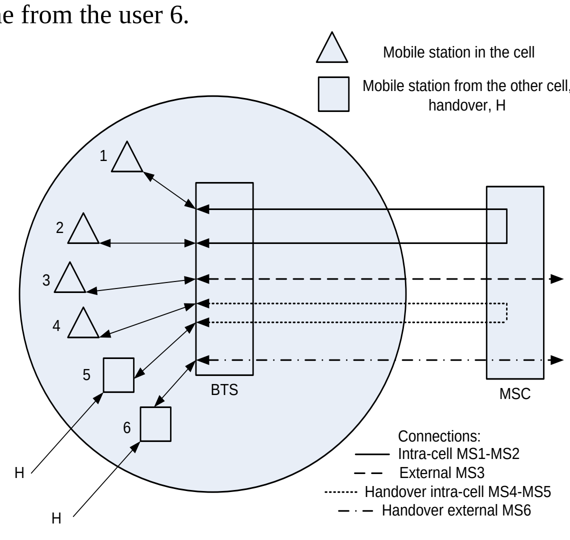

Fig. 1 – Symbolic presentation of intra-cell and external connections in one cell with primary and handover calls.

Table 1

The results obtained using the originally developed simulation program which is presented in this papr and the results on the base of the same initial conditions from the available literature

case	Conditions							result		test
	A_{pe} (E)	A_{pi} (E)	A_{he} (E)	A_{hi} (E)	N	r	M	B_p (%)	B_h (%)	
c1	9.797	0	0	0	14	0	200	5	0	this paper
	9.84									[18]
c2	8.395	0	0	0	14	0	30	1	0	this paper
	8.39									[18]
c3	0.7·7.35	0.3·7.35	0	0	14	0	200	6.92	0	this paper
							$\to\infty$	7		[8] Fig. 5
c4	0.7·7.35	0.3·7.35	0	0	14	0	28	4.77	0	this paper
								4.5		[8] Fig. 5
c5	9.998	0	1.596	0	14	3	160	25.42	$36\cdot10^{-5}$	this paper
	10		1.53				$\to\infty$	25.31	$38\cdot10^{-5}$	simulation in [7]
c6	0.9·1.91	0.1·1.91	0	0	6	0	18	0.01553	0	this paper
	0.9·1.91	0.1·1.91						0.0155		[8] Fig. 6
c7	0	10.024	0	1.554	28	6	320	25.28	$36\cdot10^{-5}$	this paper
	9.998	0	1.596	0	14	3	160	25.42	$36\cdot10^{-5}$	c5, this paper
c8	7.41	0	1.187	0	14	0	28	1.1	1.1	this paper

Influence of two properties (limited number of traffic sources and intra-cell connections) on the calculation of necessary resources number is presented in [8]. As these two properties have opposite influences on the number of necessary resources, their quantitative effect is determined in this paper. It is also proved in [8] that this model of mixed traffic is well-known from the classic telephone techniques [15]. Traffic loss in the model with intra-cell connections will be designated by $B(A_e,A_i,N)$. The method and the results of calculation and simulation for the model with external and intra-cell calls are presented in [16].

3.3. A MODEL WITH CHANNEL RESERVATION

Primary and handover calls should be adjusted to high-quality handover call service. This aim is achieved in praxis by r of total N resources/channels reservation only for handover calls [1–7]. This method provides that handover call loss is negligible while primary call loss increases. Primary call loss is designated by $B_p(A_p,A_h,N,r)$. Handover call loss will be designated as $B_h(A_p,A_h,N,r)$. The results of the calculation (the small model) and process and results of the simulation are presented in [7].

4. **THE PURPOSE OF THIS PAPER**

The main purpose of this paper is to determine the characteristics of the resource group in one cell of mobile users' networks. The group of resources has all characteristics mentioned in section 3. The model of a such cell will be called a combined or considered model. This is the group with limited traffic sources number M which is not much higher than the number of channels N. It may be concluded that the group has the Engset model properties.

The part of intra-cell calls in the cell is not negligible. The consequence is that intra-cell and handover call groups exist depending on the necessary number of resources.

The same resources are used in the cell to serve both primary and handover calls, but with different requested Quality of Service, *i.e.*, loss. All traffic channels (N) are used for handover calls, while N-r channels are used for primary calls serving. The primary calls loss in such complicate model will be designated by $B_p(A_{pe},A_{pi},A_{he},A_{hi},N,r,M)$ and the handover call loss by $B_h(A_{pe},A_{pi},A_{he},A_{hi},N,r,M)$.

The analytical model of this complicated system would also be very complicated. The following procedure is suggested to estimate the characteristics of this model. First, a universal simulation model which includes all initial parameters for the model will be developed. These parameters are all components of offered traffic (external, intra-cell, primary, handover), number of channels, number of reserved channels, and number of traffic sources. The main problem in the simulation results estimation is the obtained results verification, as calculation results do not exist due to the model complexity. This verification is the second step in the procedure realization. The following analysis is suggested for the results verification.

Suppose $B_p(A_{pe},A_{pi},A_{he},A_{hi},N,r,M)$ is the primary call loss probability obtained by simulation. This value will be considered close to the real value if the following cases c1-c8 are satisfied.

Case c1:

$$\lim_{\substack{A_{pe}+A_{pi}+A_{he}+A_{hi}\to A,\ M\to\infty,\ r\to 0}} B_p(A_{pe},A_{pi},A_{he},A_{hi},N,r,M)\to B(A,N) \quad (1)$$

Such a case tends to the classic Erlang model in the simulation. It may be supposed that the number of users who generate the traffic (M) tends to infinity if it is at least 10 times greater than the number of available traffic channels. That's why in such situations, we specify in this paper that it is $M > 10\cdot N$. The condition related to the traffic $A_{pe}+A_{pi}+A_{he}+A_{hi}\to A$ means that the situation tends to have only one traffic component, *i.e.*, there is no internal and handover traffic. When the simulation is practically realized, handover probability is successively decreased ($P_h\to 0$), as also the intra-cell traffic probability ($P_{int}\to 0$). As we approach the situation without handover calls, we also approach the system where there is no need for channels reservation only for handover calls, *i.e.*, we assign $r\to 0$.

The loss probability for the classical Erlang model may be frequently found in the available literature, and we have used tables from [17] in this paper.

Case c2:

$$\lim_{\substack{A_{pe}+A_{pi}+A_{he}+A_{hi}\to A,\ r\to 0}} B_p(A_{pe},A_{pi},A_{he},A_{hi},N,r,M)\to B(A,N,M) \quad (2)$$

This is the case which tends to the classical Engset model with a limited number of users. In our simulation, we supposed that number of users is approximately two times greater than the number of channels ($M \approx 2 \cdot N$). All other conditions in the simulation are the same as in case c1.

Case c3:

$$\lim_{\substack{A_{pe}+A_{he} \to A_e,\ A_{pi}+A_{hi} \to A_i,\ M \to \infty,\ r \to 0}} B_p(A_{pe}, A_{pi}, A_{he}, A_{hi}, N, r, M) \to B(A_e, A_i, N) . \quad (3)$$

The component of intra-cell traffic exists in this case while the condition $P_h \to 0$ from c1 and c2 remains. Compared to case c1, it is specified that P_{int} = 0.3 (the value of intra-cell traffic probability 30 %). Such P_{int} may be expected in rarely populated rural areas where one cell covers the whole village [16]. If professional or private mobile networks are considered, the part of intra-cell connections may be even greater [11]. (The analysis in [11] goes even to 100 % of intra-cell connections).

Case c4:

$$\lim_{\substack{A_{pe}+A_{he} \to A_e,\ A_{pi}+A_{hi} \to A_i,\ r \to 0}} B_p(A_{pe}, A_{pi}, A_{he}, A_{hi}, N, r, M) \to B(A_e, A_i, N, M) . \quad (4)$$

This case of comparison corresponds to case c3 with the addition that the available number of users is limited. This number of users is selected to satisfy $M = 2 \cdot N$.

Case c5:

$$\lim_{\substack{A_{pe}+A_{pi} \to A_p,\ A_{he}+A_{hi} \to A_h,\ M \to \infty}} B_p(A_{pe}, A_{pi}, A_{he}, A_{hi}, N, r, M) \to B_p(A_p, A_h, N, r) . \quad (5)$$

This is the case when intra-cell traffic exists. We selected that 3 of 14 available traffic channels are assigned exclusively to handover traffic (r = 3). The part of handover traffic is fixed at the value P_h = 0.17 concerning the offered primary traffic ($A_h = 0.17 \cdot A_p$), as it is mainly specified in the realized simulations [7]. Intra-cell traffic is successively decreased, thus causing the condition of the simulation $P_{int} \to 0$ is satisfied, and the number of users is significantly greater than the number of available traffic channels ($M > 10 \cdot N$).

Case c6:

This case of comparison corresponds to the one presented by case c4. That's why condition (4) is satisfied. The number of available traffic channels is changed, and the number of users is selected such that it is satisfied $M = 3 \cdot N$. The probability of intra-cell traffic is P_{int} = 0.1.

Case c7:

This case is intended to test the simulation program's correctness when the traffic process contains intra-cell handover traffic. The available literature does not contain the contribution which could be applied as the reference for the comparison. That's why we started from case c5 to verify the correctness of the simulation program in the traffic case when we have only external primary and handover traffic (P_{int} = 0). Verification is now realized so that the results obtained in c5 are compared to the hypothetical case when we have only intra-cell primary and handover traffic without an external one (P_{int} = 1).

As intra-cell traffic always takes two traffic channels, simulation is performed for the system with 28 traffic channels in relation to 14 channels in case c5. The number of users is doubled (320 in relation to 160), and r is also doubled (r = 6). It is further P_h- = 0.17 as in c5.

Case c8:

This case allows us to test whether the same value of B_p and B_h is obtained when r = 0 [18]. Based on the expression (9.7a) from [18], it is clear that an approximately constant ratio P_h exists in calculations/simulations between the primary and handover traffic intensity independently of the offered traffic properties. In the case that offered traffic has Erlang properties, its intensities λ_h and λ_p on the left and right side of the eq. (9.7a) from [18] may be simply replaced by the values of offered traffic A_h and A_p. If the number of users in the cell is finite compared to the number of channels, *i.e.*, that offered traffic has Engset properties, the intensity of offered traffic is not constant in time, but it depends on the number of busy channels in the considered moment. Both the numbers of primary and handover calls are considered. The offered traffic intensity may be expressed as $(M\text{-}K_p\text{-}K_h) \cdot \alpha$, where K_p is the number of instantaneously busy channels by primary traffic, K_h is the number of instantaneously busy channels by handover traffic, and α is traffic intensity per user. The same values of the factors $(M\text{-}K_p\text{-}K_h) \cdot \alpha$ must exist on both sides of the eq. (9.7a), *i.e.*, the values M, K_p, and K_h are the same on both sides of the equation to keep their main sense. This is important when the simulation model is defined in this paper.

This last test comparison is only performed between the values of B_p and B_h from the simulation trial (these values have to be equal), not between the results obtained in the simulation and some other already known cases.

The obtained results for cases c1 - c8 are recapitulated in Table 1. For each case (except c8), two results are presented: the first one based on the simulation from this paper and the second one from the available previous literature. This comparison shows a high degree of agreement with the results, thus proving the simulation program's accuracy.

5. **EXAMPLE**

The dependence of primary calls loss (B_p) and handover calls loss (B_h) on the total four factors are analyzed in this paper. The four factors are the number of users (M) in the base station cell, the probability of intra-cell traffic (P_{int}), the probability of handover calls (P_h), and the number of reserved channels (r) only for handover calls. Due to such a great number of variables, the problem is to present the dependence of B_p and B_h on all mentioned factors. Therefore, we have decided to present graphics where two independent variables have a constant value, the third one is a parameter for the curves in the graphs, and the fourth one tends to its ultimate envisaged value. The graphs are presented in Fig. 2 – Fig. 5. In all cases, the total offered traffic is A_o = 7.35E and N=14 is the number of available traffic channels.

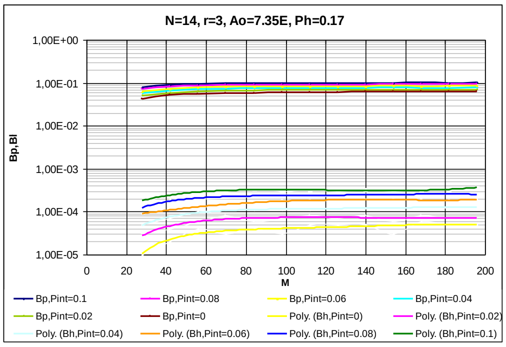

Fig. 2 – Primary (B_p) and handover (B_h) calls loss as a function of the number of users (M), intra-cell traffic probability (P_{int}) as a parameter in the system with N = 14 traffic channels, r = 3 reserved channels, totally offered traffic A_o = 7.35E and handover probability P_h = 0.17 (case 5).

Figure 2 presents the dependence of B_p and B_h on the number of users in the cell. It is interesting to consider the number of users increase, *i.e.*, a successive transition of the model with Engset characteristics to the Erlang model. The values of r and P_h are fixed at $r = 3$ and $P_h = 0.17$. The probability of intra-cell traffic is expressed as the parameter on the graph whereby low values of intra-cell traffic ($P_{int} \leq 0.1$) are considered. The loss of both traffic components reaches its maximum value when the number of users is about four times greater than the number of available traffic channels ($N = 14$), therefore $M \approx 56$. Such behavior is well known in classical telephony, where calls may be considered primary (external or internal). Our analysis proves that the same conclusion is valid also for handover traffic. The curves in Fig. 2 are presented starting from the number of users equal to the double number of traffic channels ($M = 28$).

It is necessary to perform very long simulation trials to obtain low values of B_h with high accuracy, as in the example presented in Fig. 2. Instead of such a long simulation, we have performed each of our trials by the generation of relatively not many random numbers and the obtained curves of B_h are approximated by the trend line as the polynomial of the fourth degree.

The graph in Fig. 3 is also presented for the fixed values $r = 3$ and $P_h = 0.17$ as in Fig. 2. M is the curve parameter, while the values of B_p and B_h are presented as a function of P_{int}. It is interesting to notice the behavior of B_p and B_h when $P_{int} \rightarrow 0$. Both values of loss decrease in that case. Such behavior is logical as intra-cell connections utilize two traffic channels. It may be said that all traffic channels become busy at lower values of offered traffic when the part of intra-cell traffic is more significant. The relative decrease of B_p is lower than B_h: for example, for $M = 28$ B_p decreases from $B_p = 0.07$ to $B_p = 0.04$ when the probability of internal traffic decreases from $P_{int} = 0.1$ to $P_{int} = 0$, or less than two times. At the same time, B_h drops more than 10 times (from $B_h = 0.000105$ to $B_h = 0.00001$).

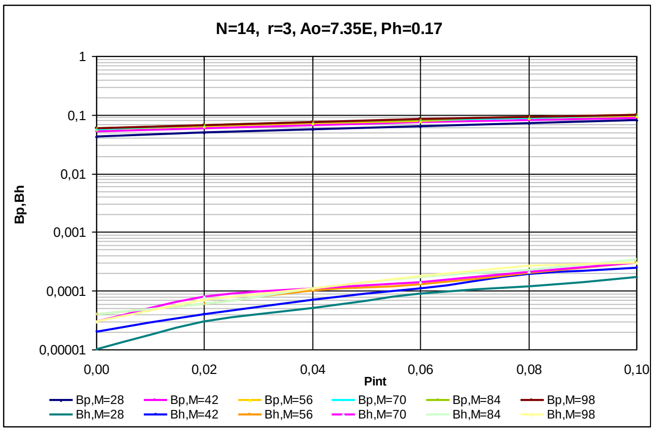

Fig. 3 – Primary (B_p) and handover (B_h) calls loss as a function of intra-cell traffic probability (P_{int}), the number of users (M) as a parameter in the system with $N = 14$ traffic channels, $r = 3$ reserved channels, totally offered traffic $A_o = 7.35$E and handover probability $P_h = 0.17$ (case 5).

The graphs in Figs. 4 and 5 are presented for the fixed number of users in the base station cell ($M = 28$) and fixed $P_{int} = 0.3$. The parameter for the graph in Fig. 4 is r and the loss probability is presented when $P_h \rightarrow 0$. The graphs are presented starting from the value $P_h = 0.001$, *i.e.*, not for $P_h = 0$, because the calculation of B_h has no sense for $P_h = 0$. A very small change of all loss values is obvious from this figure when P_h is decreased from 0.1 to 0 except when B_h is considered for $r = 2$. This traffic loss decreases from $B_h = 0.001$ at $P_h = 0.1$ to $B_h = 0.00007$ at $P_h = 0.001$ or more than 15 times. One more fact is obvious from Fig. 4: when r is decreased, B_p is decreased and B_h is increased while they do not become nearly equal at $r = 0$.

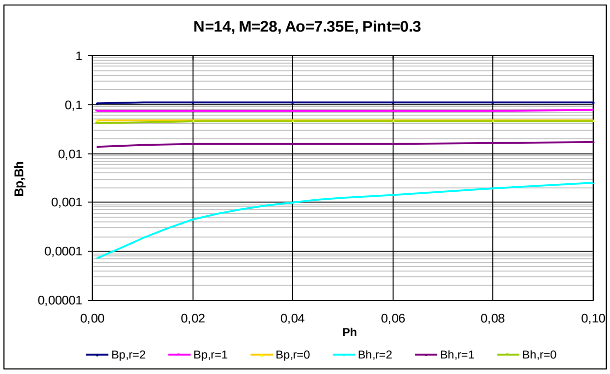

Fig. 4 – Primary (B_p) and handover (B_h) calls loss as a function of handover traffic probability (P_h), the number of reserved channels (r) as a parameter in the system with N=14 channels, $M = 28$ users, totally offered traffic A_o= 7.35E and intra-cell traffic probability $P_{int} = 0.3$ (case 4).

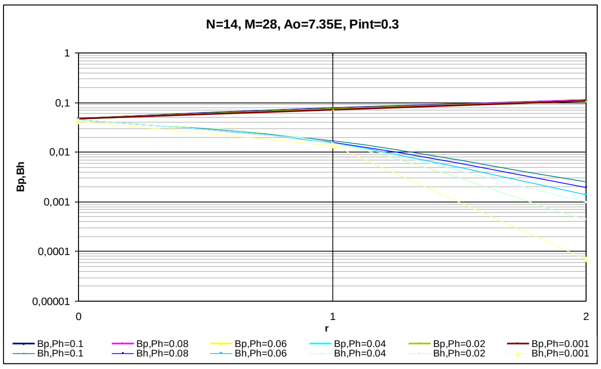

Fig. 5 – Primary (B_p) and handover (B_h) calls loss as a function of the number of reserved channels (r), handover traffic probability (P_h) as a parameter in the system with $N = 14$ channels, $M = 28$ users, totally offered traffic $A_o = 7.35$E and intra-cell traffic probability $P_{int} = 0.3$ (case 4).

The probability of handover calls P_h is a parameter for the graph in Fig. 5. The values of loss probabilities are presented as a function of the number of reserved channels. The graph is presented starting from $P_h = 0.001$ instead of $P_h = 0$, as is also in Fig. 4. According to the graph in Fig. 5, B_p decreases about two times when r is decreased from $r = 2$ to $r = 0$ (from $B_p \approx 0.1$ to $B_p \approx 0.045$), while B_h increases in a significantly greater extent: for P_h= 0.1 this increase is nearly 20 times (from $B_h \approx 0.0025$ to $B_h \approx 0.045$), while at very low values of P_h the increase is nearly 500 times (from B_h= 0.00007 to $B_h \approx 0.045$ at $P_h = 0.001$).

6. SIMULATION

The simulation program in this paper is realized in the program language C as Roulette or Monte Carlo simulation, starting from the principles of how it is realized in contributions [7, 8]. These two contributions have been used as a criterion for the initial verification of the developed program. Besides [7, 8], where the accent is on the traffic analysis of mobile systems as in this paper, Monte Carlo simulation is also used in several papers (as, for example, [19, 20]) where the necessary emission power of base stations is determined as a function of different traffic and other conditions.

Monte Carlo simulation is a universal procedure for analysis and verification of different system types, not only in mobile telephony, as in [21].

The complicated structure of the analyzed traffic process has led to the more demanding procedure for traffic event definition during simulation. The relation between the random number generated in the Monte Carlo process and the corresponding traffic event may be explained in Fig. 6.

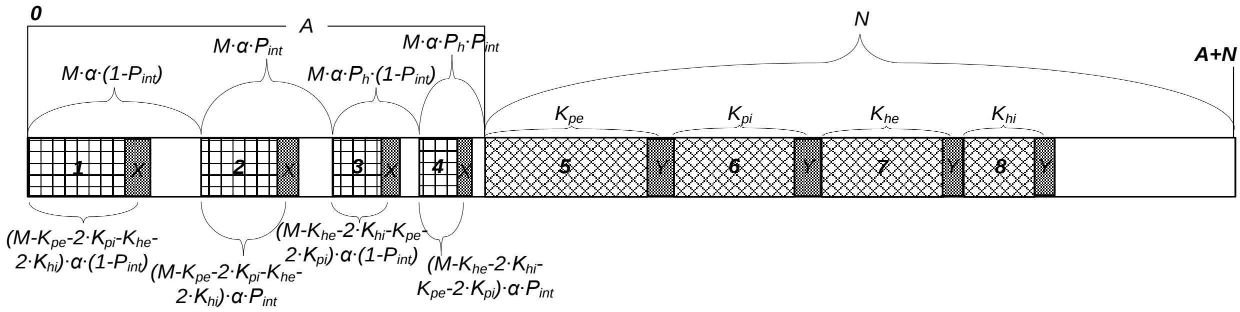

Fig. 6 – Generation of the events in the simulation model.

A new traffic request may appear if the generated random number is in the area symbolically designated by A (in Erlangs) in the complete set of uniformly distributed random numbers from the area of the dimension $A+N$. Traffic request is finished if the generated random number is in the area designated by N (where N is the number of available traffic channels).

The possible events during a simulation on the base of generated random number are enumerated by numbers 1–8, Fig. 6. These events are:

1 – generation of external primary call;
2 – generation of intra-cell primary call;
3 – arrival of external handover call to the cell;
4 – arrival of intra-cell call to the considered cell;
5 – end of external primary call;
6 – end of intra-cell primary call;
7 – end of external handover call;
8 – end of intra-cell handover call.

The size of the area where the generation of a call according to the events 1-4 is possible is designated by the curly brace „towards up "(for example, the new external primary call may be generated if the random number is around numbers 0 – $M\cdot\alpha\cdot(1–P_{int})$). But such a new call is not generated in the whole designated area. As the number of users (M) is comparable to the number of available channels (it is not significantly higher), the size of the random number area corresponding to the new external primary call is decreased depending on the number of instantaneously realized external primary calls (K_{pe}) and intra-cell primary calls (K_{pi}). According to this explanation, the new call will be generated if the random number is in the hatched area 1. The hatched area X beside area 1 symbolizes that area 1 has variable size during the simulation process. The variable α represents offered traffic per idle user. At the same time, P_{int} is the probability of primary intra-cell call in relation to the total primary call intensity (the relation between the handover intra-cell traffic and total handover traffic is established similarly). The method of random number generation for areas 2–4 is similar to area 1, and all important variables for the definition of these events are designated in Fig. 6. The designation K_{he} and K_{hi} in Fig. 6 represent the number of established external and intra-cell handover calls, respectively.

The probability of each established connection ending depends on the number of instantaneously realized connections of that type. For example, an external primary connection ends if the generated random number is in area 5 whose size is determined by the number of established external primary connections K_{pe}. The hatched area Y beside area 5 symbolically designates that the size of area 5 is variable during the simulation process. The end of the three remaining connection types is defined similarly if the random number is in one of the areas with the designation between 6 and 8.

The complexity of the simulation process is obvious also in the simulation program execution. The simulation must comprise both the generation of intra-cell calls (as in [8]) and handover calls (as in [7]), and then also the finite number of users. The flow-chart of the simulation program execution is the most complex in the case of handover calls analysis (the results may not be obtained on the base of only one simulation cycle but using an iterative procedure with more simulation cycles while successively approaching the exact value, as already explained in [7]). We have started from the simulation program realized in [7] and have upgraded this program by the internal traffic and variable size of areas 1-4 as a function of the number of realized connections, according to the simulation in [8].

7. CONCLUSION

The first and main contribution of this paper is to allow the traffic characteristics analysis of complicated mobile systems which comprise different traffic types in the mobile station cell. It is hard or even impossible to develop analytical models based on queueing theory in such situations. The second contribution is that our originally developed simulation program may be applied when input parameters gradually tend to their limiting or very small values. Small values of input parameters are an additional problem for the analytical approach. With these two contributions, the paper and its results are very useful for mobile network designers to estimate the characteristics of their systems before their practical implementation.

Intra-cell and handover traffic is comprised in this analysis besides the standard external traffic. Reserved traffic channels only for handover calls may exist in the mobile cell with the principle aim to decrease the probability of handover call loss. The classical Erlang system with a significant number of users about the total number of traffic channels is replaced by the Engset model with a limited number of users. The analytical model of such a system would be very complicated. That's why the initially developed simulation model is implemented. As there is no analytical model, we have verified the simulation program using several simplified versions where one or two traffic components do not exist, the number of users is significant, or the number of reserved channels is $r = 0$. The traffic loss probabilities are determined for the tested traffic types and compared to the analytically obtained results when simplified simulation models are selected. After such verification, simulation is performed for the cases where all important traffic elements do not have their limiting value: the number of users is not too high, both intra-cell and handover traffic exists, and reserved channels are used only for handover traffic. The graphs presented in the paper are obtained starting from some finite and not equal to zero value of a traffic parameter. After that, this parameter is successively changed towards its ultimate value, while other traffic parameters keep their unchanged, finite value. Several specificities have been noticed during simulation:

1. When r is decreased, the probability of primary traffic loss (B_p) and the probability of handover traffic loss (B_h) approach one to the other (B_p decreases and B_h increases). At the same time, they become equal for $r = 0$. This claim is also valid for very low probabilities of handover traffic (in the test in this paper for $P_h = 0.001$) before the handover traffic component drops to zero ($P_h = 0$) when it is $B_h = 0$;

2. When the part of intra-cell traffic is decreased, both B_p and B_h decrease, but the relative change of B_h is significantly greater than the relative change of B_p;

3. The values of B_p and B_h practically reach their ultimate value already when the number of users in the cell approaches the quadruple number of traffic channels.

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