Influence of Users' Moving Speed on Dimensioning of Traffic Channels Number in Mobile Systems

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Abstract—**In this paper it is analyzed the influence of call handover on the dimensioning of traffic channels in mobile telephony systems. Classical Erlang traffic model is modified using the variables, which are specific for mobile systems implementation: handover rate and call dwell time. Call dwell time is defined by users' moving velocity and mobile cell radius. New-call blocking probability and handover probability are determined on the base of state probabilities. It is proved that traffic capacity is decreased because some traffic channels are reserved only for handover. For new calls generation the considered system behaves as it has lower number of available traffic channels than it is in reality.**

Keywords-*mobile systems; traffic channels dimensioning; handover; handover dropping probability; new-call blocking probability;*

I. Introduction

Different types of mobile systems, from the simplest ones (GSM systems) implemented in 2G networks to the more complicate ones intended for 4G networks, are surrounding us. Their dimensioning, especially when the number of traffic channels is concerned, is based on the knowledge from classic telephony system dimensioning. Although the formulas for traffic loss calculation in classic telephony are well known a long while ago and studied in detail [1], they are not enough for mobile systems analysis. Besides determination of traffic channels number, there is one additional element, which was not important in classic telephony systems: the necessary emission power. This power is mainly dependent on the distance between base station (BS) and mobile user (mobile station - MS) [2], distribution of users in the mobile cell [3], [4], implemented traffic model, i.e. the number of users, who generate traffic in mobile cell [5] and the ratio of different traffic types [6]. The implementation of discontinuous transmission (DTX) is also the method for BS power and traffic channel number saving [7]. When the number of necessary traffic channels is analyzed, the important factors are the implemented codec type [8], traffic type and the number of users in the cell [9], and sometimes the implemented order of channel seizure [10]. Users' moving changes the distribution of users in the cell, thus contributing to the variations of necessary BS emission power [11]. As a consequence of users' moving, the BS, which controls the considered user, is changed. Until now we haven't analyzed influence of this factor (handover) on the necessary number of traffic channels. Such an analysis is the subject of this paper.

The aspects of mobile systems analysis which are emphasized in the introductory first paragraph contribute to adequate quality of service, on one side, or to energy saving, on the other side. It may be said that the aim in mobile system dimensioning is environment protection by limiting BS emission power while, in the same time, satisfying recommendations in traffic and signal quality field.

Various aspects of handover are studied in [12]. The analysis in [12] defines, at first, hard and soft handover as two processes how handover is performed. It is also defined in [12] under what conditions happens handover from BS macrocell to microcell and vice versa. The specific problems, which lead to more frequent handover between microcells, are defined in one section of paper [12]. Handovers may be also divided to intra-cell and inter-cell type and inter-cell handovers are realized in the same or between different BSs [13]. The possible criteria for handover realization intended to avoid ping-pong effect at handover location are explained in [12].

In order to achieve satisfactory quality of service in mobile systems, it is necessary to keep enough low value of handover dropping probability as a consequence of successful handover omission. This value is usually assumed to be order of magnitude lower (for example, 0.2%) than new-call blocking probability (1% or 2%) [12]. Low value of handover dropping probability may be achieved by implementing several techniques [14]: 1. reserving a number of channels exclusively for handovers, 2. queueing handover requests and 3. sub-rating an existing call to accommodate a handover call.

II. Model, Designations and Assumptions

Let us consider a model of mobile cell, in which traffic generated by call handover is considered besides new calls generation in a cell [15], [16]. The distribution of elapsed time between two new calls generation, as also the time between two realized handovers is supposed to be exponential. The call duration time and the call residence in the considered BS cell (dwell time), if there is handover, are also exponentially distributed with the mean value t_c and t_h, respectively. The variables, defined on the base of this consideration, are:

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- λ_c – the mean new call generation rate;
- λ_h – the mean rate of realized handovers into the considered cell;
- $t_c=1/\mu_c$ – the mean call duration;
- $t_h=1/\eta$ – the mean call dwell time.

On the base of these definitions, the offered traffic of new calls is $A=\lambda_c/\mu_c$. The traffic of calls, which are generated by handover, is $A_h=\lambda_h/\eta$. (Besides the dwell time definition in this paper as the time of call residence in the cell before the handover, there is a number of other definitions. For example, in [17] this time is defined as the time when the call is under the control of two neighbour BSs during the handover).

The satisfactory quality of service in mobile cells supposes that handover dropping probability is very low [12]. It means that this probability is negligible. On the contrary, new-call blocking probability may be greater. Only the method 1. between the methods emphasized in [14] for handover dropping probability decreasing is analyzed in this paper on the base of formulas from [15], [16]. The most important parameter for the application of this handover strategy is the threshold number of channels (g of total N channels) when new calls begin to get blocked. It means that new calls are blocked if the number of busy channels is $i\geq g$. For $g\leq i<N$ only handover may be realized. The total number of busy channels which are reserved only for handover is, therefore, N-g. The systems with the reservation of some channels for serving requests of higher priority are already analyzed in queueing theory, for example in [18].

The mean channel holding time in one BS cell is $t=1/\mu=\min(t_c,t_h)$. On the base of [15], [19], the value of μ may be calculated from

$$\frac{1}{\mu}=\frac{1}{\mu_c+\eta}\,. \tag{1}$$

The value of η depends on the user's moving velocity (v) and the cell radius (r). We consider only handovers between different BSs realized as the consequence of user's moving. Such handovers (inter-cell handovers) are dominant in relation to other handover types. They are about 75% of all handovers, according to data collected from three practically realized mobile networks [13].

The value of cell radius depends on several factors. Among them, dominant is the influence of environment propagation coefficient γ. The value of γ may be between 2 and 5 [20]. According to different available references, the cell radius is between 200m (when γ has its maximum value) and even 30km (when value of γ is minimal), as the result of the influence of γ and other contributing factors [21]-[26]. In our analysis we are focused on the minimum value of r.

The value of η is, according to formula from [15]

$$\eta=\frac{v\cdot L}{\pi\cdot S}\,, \tag{2}$$

where S and L are, respectively, the area and the perimeter of the figure, which model the mobile cell. Mobile cells are usually modelled as regular hexagon. In such a case the formula (2) is changed to

$$\eta=\frac{v\cdot L}{\pi\cdot S}=\frac{v\cdot 6\cdot r}{\pi\cdot 6\cdot\frac{r^2\cdot\sqrt{3}}{4}}=\frac{4\cdot v}{\pi\cdot r\cdot\sqrt{3}}\,. \tag{3}$$

Such a model we are going to implement in this paper.

The rates of requests generation (λ_c and λ_h) are related by the formula, also from [15]

$$\lambda_h\approx\lambda_c\cdot\frac{\eta}{\mu_c}\,. \tag{4}$$

Fig. 1 presents the queueing system model of mobile system with applied handover. In this system the number of traffic sources M (mobile users) is significantly greater than the number of available traffic channels N in a cell ($M>>N$). The model is the modified classical Erlang model, which may be found in many books from classic queueing theory (for example, [1]). The modification is in the rate of new requests generation from the state i to the state i+1. As it is $M>>N$, in classical Erlang model this rate is always the same between any pair of states. In our model it is equal $\lambda_c+\lambda_h$ till the state g (new calls are generated and handover is possible). After that the requests generation rate is λ_h (only handover is allowed).

$$\begin{aligned}
&(\lambda_c+\lambda_h)\cdot p_0=\mu\cdot p_1\\
&(\lambda_c+\lambda_h+\mu)\cdot p_1=(\lambda_c+\lambda_h)\cdot p_0+2\cdot\mu\cdot p_2\\
&(\lambda_c+\lambda_h+2\cdot\mu)\cdot p_2=(\lambda_c+\lambda_h)\cdot p_1+3\cdot\mu\cdot p_3\\
&\ldots\\
&(\lambda_c+\lambda_h+(g-1)\cdot\mu)\cdot p_{g-1}=(\lambda_c+\lambda_h)\cdot p_{g-2}+g\cdot\mu\cdot p_g\\
&(\lambda_h+g\cdot\mu)\cdot p_g=(\lambda_c+\lambda_h)\cdot p_{g-1}+(g+1)\cdot\mu\cdot p_{g+1}\\
&(\lambda_h+(g+1)\cdot\mu)\cdot p_{g+1}=\lambda_h\cdot p_g+(g+2)\cdot\mu\cdot p_{g+2}\\
&\ldots\\
&(\lambda_h+(N-1)\cdot\mu)\cdot p_{N-1}=\lambda_h\cdot p_{N-2}+N\cdot\mu\cdot p_N\\
&p_0+p_1+p_2+\ldots+p_{g-1}+p_g+p_{g+1}+\ldots+p_{N-2}+p_{N-1}+p_N=1
\end{aligned} \tag{5}$$

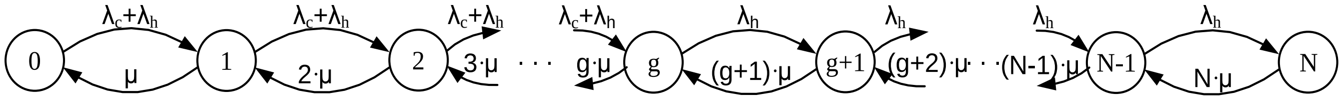

Figure 1. The queueing system model of mobile system with applied handover

The system of equations (5) is defined for the stationary state of the system from Fig. 1. It means that it is necessary to equate the traffic flow from each state with the flow into the same state. The system (5) is used, first, to determine the busy channels number probabilities. There are $N+1$ equations in system (5), as there are total $N+1$ states. As it is usual in each such an analysis, the last equation includes all system states probabilities, which allows us to obtain the values of all state probabilities in the explicit form. The solution of (5) while considering (1) is now expressed, separately, for the states $i \leq g$ and for the states $g < i \leq N$ as:

$$p_i = \frac{\dfrac{(\lambda_c+\lambda_h)^i}{(\mu_c+\eta)^i \cdot i!}}{\sum\limits_{l=0}^{g}\dfrac{(\lambda_c+\lambda_h)^l}{(\mu_c+\eta)^l \cdot l!}+\dfrac{(\lambda_c+\lambda_h)^g}{(\mu_c+\eta)^g}\cdot\sum\limits_{l=g+1}^{N}\dfrac{\lambda_h^{\,l-g}}{(\mu_c+\eta)^{l-g}\cdot l!}},\ i=0,1,\ldots,g \tag{6}$$

$$p_i = \frac{\dfrac{(\lambda_c+\lambda_h)^g}{(\mu_c+\eta)^g \cdot i!}\cdot\dfrac{\lambda_h^{\,i-g}}{(\mu_c+\eta)^{i-g}}}{\sum\limits_{l=0}^{g}\dfrac{(\lambda_c+\lambda_h)^l}{(\mu_c+\eta)^l \cdot l!}+\dfrac{(\lambda_c+\lambda_h)^g}{(\mu_c+\eta)^g}\cdot\sum\limits_{l=g+1}^{N}\dfrac{\lambda_h^{\,l-g}}{(\mu_c+\eta)^{l-g}\cdot l!}},\ i=g+1,\ldots,N\ . \tag{7}$$

It is possible to simplify (6) and (7) using the equations:

$$\frac{\lambda_c+\lambda_h}{\mu_c+\eta} = \frac{\lambda_c\cdot(1+\dfrac{\eta}{\mu_c})}{\mu_c\cdot(1+\dfrac{\eta}{\mu_c})} = \frac{\lambda_c}{\mu_c} = \lambda_c\cdot t_c = A \tag{8}$$

$$\frac{\lambda_h}{\mu_c+\eta} = \frac{\lambda_c\cdot\dfrac{\eta}{\mu_c}}{\mu_c\cdot(1+\dfrac{\eta}{\mu_c})} = A\cdot\frac{\dfrac{\eta}{\mu_c}}{1+\dfrac{\eta}{\mu_c}}\ . \tag{9}$$

Now (6) and (7) may be written as

$$p_i = \frac{\dfrac{A^i}{i!}}{\sum\limits_{l=0}^{g}\dfrac{A^l}{l!}+\sum\limits_{l=g+1}^{N}\dfrac{A^l\cdot\left(\dfrac{K}{1+K}\right)^{l-g}}{l!}},\ i=0,1,\ldots,g \tag{10}$$

$$p_i = \frac{\dfrac{A^i\cdot\left(\dfrac{K}{1+K}\right)^{i-g}}{i!}}{\sum\limits_{l=0}^{g}\dfrac{A^l}{l!}+\sum\limits_{l=g+1}^{N}\dfrac{A^l\cdot\left(\dfrac{K}{1+K}\right)^{l-g}}{l!}},\ i=g+1,\ldots,N\ , \tag{11}$$

where it is

$$K = \frac{\eta}{\mu_c} = \frac{4\cdot v}{\pi\cdot r\cdot\mu_c\cdot\sqrt{3}}\ . \tag{12}$$

It is possible to calculate the probability that a new call is lost (new-call blocking probability - p_c) and that the call in handover is dropped (handover dropping probability - p_h). The new call is blocked in the case that there is g or more busy channels. Thus it is

$$p_c = \frac{\sum\limits_{l=g}^{N}\dfrac{A^l\cdot\left(\dfrac{K}{1+K}\right)^{l-g}}{l!}}{\sum\limits_{l=0}^{g}\dfrac{A^l}{l!}+\sum\limits_{l=g+1}^{N}\dfrac{A^l\cdot\left(\dfrac{K}{1+K}\right)^{l-g}}{l!}}\ . \tag{13}$$

The call in handover is dropped if there are N busy channels. The handover dropping probability is then

$$p_h = \frac{\dfrac{A^N\cdot\left(\dfrac{K}{1+K}\right)^{N-g}}{N!}}{\sum\limits_{l=0}^{g}\dfrac{A^l}{l!}+\sum\limits_{l=g+1}^{N}\dfrac{A^l\cdot\left(\dfrac{K}{1+K}\right)^{l-g}}{l!}}\ . \tag{14}$$

III. THE RESULTS OF CALCULATION

Handover dropping probability (p_h) as a function of the mean MS velocity when there are N=6 available traffic channels is presented in Fig. 2. The results are calculated using (14). The parameters for the presented curves are the threshold number of channels (g) when new calls begin to get blocked and the offered traffic (A).

New-call blocking probability (p_c) as a function of the mean MS velocity when there are N=6 available traffic channels is presented in Fig. 3. The results are calculated using (13). The parameters for the curves in Fig. 3 are the same as for Fig. 2. For the case that it is $g=N$ (classical Erlang model) the values of p_h and p_c are mutually equal and they do not depend on MS velocity.

Handover dropping probability (p_h) as a function of the mean MS velocity when there are N=14 available traffic channels is presented in Fig. 4. The results are calculated using (14). The parameters for the presented curves are the threshold number of channels (g) when new calls begin to get blocked and the offered traffic (A).

New-call blocking probability (p_c) as a function of the mean MS velocity when there are N=14 available traffic channels is presented in Fig. 5. The results are calculated using (13). The parameters for the curves in Fig. 5 are the same as for Fig. 4.

It is very important to choose optimum value for g, according to the requested values of p_c and p_h. If the value of g is too small, all traffic channels, which are reserved for possible handover, are never busy. The number of channels, which may be used for serving new generated calls, is decreased more than it is necessary. On the contrary, the higher value of g means that calls in handover are dropped more often than it is allowed. When considering the example illustrated in the figures 4 and 5 for 14 traffic channels, optimum choice is g=12. In such situation for A=6E and the great velocity v=60km/h, handover dropping probability is p_h=0.17% (Fig. 4) and new-call blocking probability is $p_c \approx 1.7\%$ (Fig. 5). These values are well matched and satisfy the recommendation from the Introduction (i.e. from [12]). If we choose the value g=11 instead of g=12, new-call blocking probability will even reach the value $p_c \approx 3.8\%$, which is unsatisfactory result.

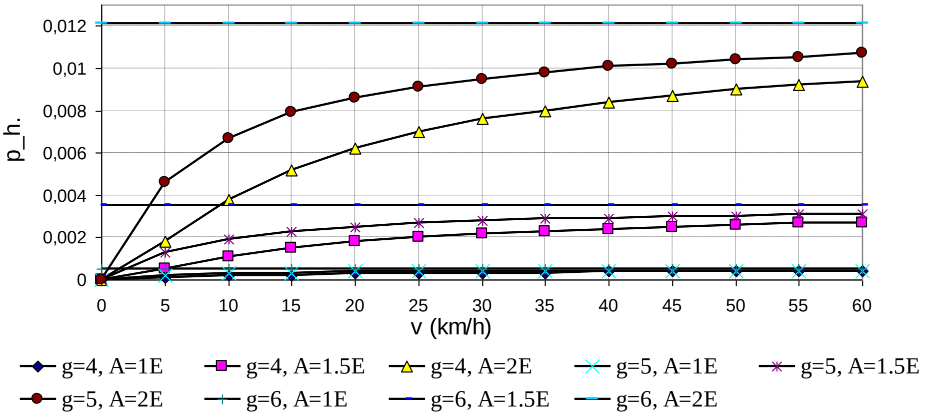

Figure 2. Handover dropping probability (p_h) as a function of mean mobile user velocity (v) for N=6 channels

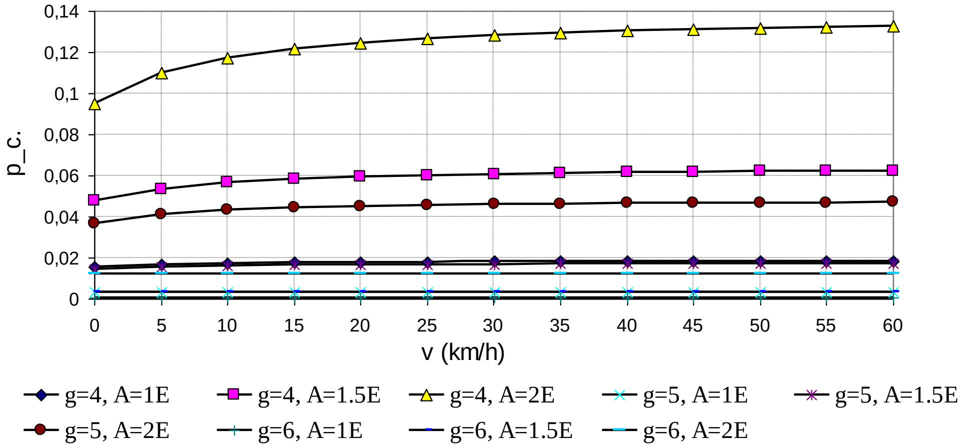

Figure 3. New-call blocking probability (p_c) as a function of mean mobile user velocity (v) for N=6 channels

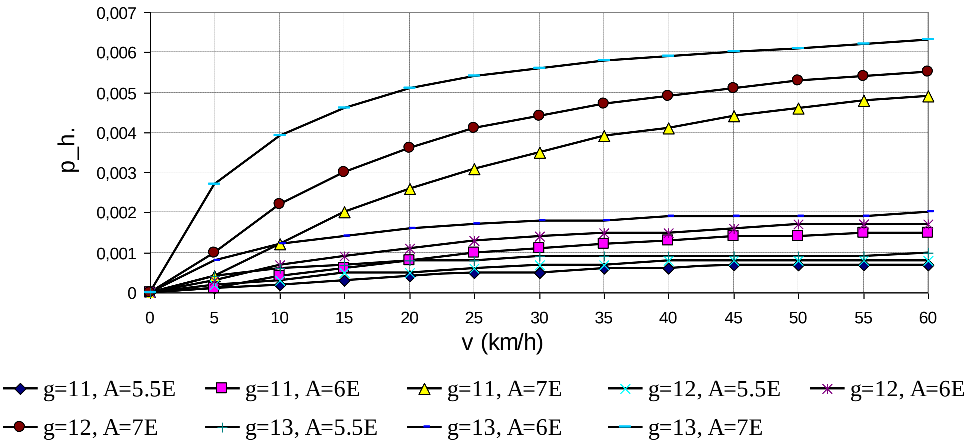

Figure 4. Handover dropping probability (p_h) as a function of mean mobile user velocity (v) for N=14 channels

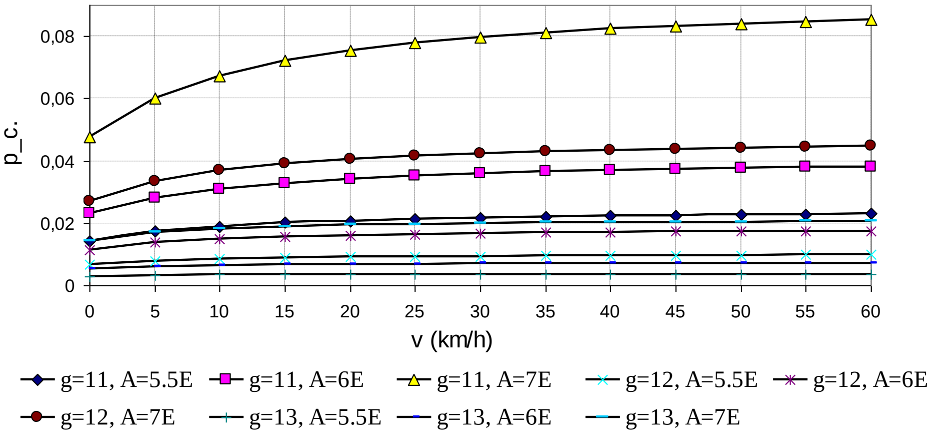

Figure 5. New-call blocking probability (p_c) as a function of mean mobile user velocity (v) for N=14 channels

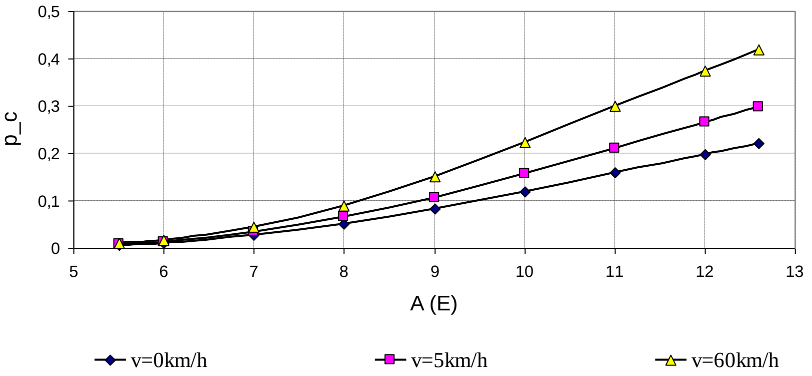

Figure 6. New-call blocking probability (p_c) as a function of offered traffic (A) for N=14 channels and g=12 channels

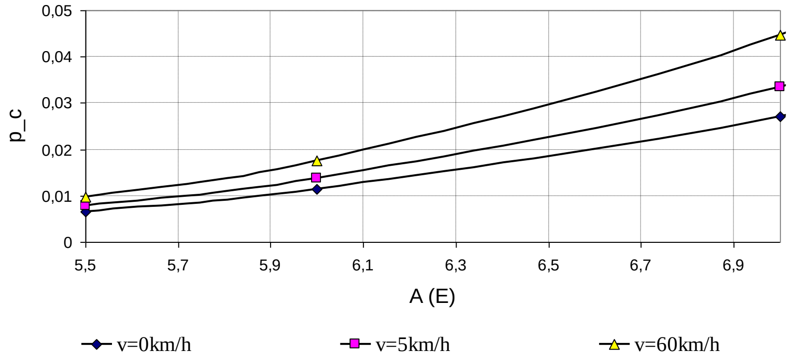

Figure 7. New-call blocking probability (p_c) as a function of offered traffic (A) for N=14 channels and g=12 channels, detail from Fig. 6

The analysis from this paper is valid for all types of mobile systems, because handover is universal principle in mobile call control. The values of 6 and 14 are specific number of traffic channels in GSM systems when they have one or two frequency carriers in practical realization. According to [27], such relatively small systems have been about 70% of total number of GSM systems in the considered very developed country.

Fig. 6 presents new-call blocking probability (p_c) as a function of offered traffic (A) when there are N=14 traffic channels available. The threshold channels number is 12. The parameter on Fig. 6 is user velocity (v). This figure may be used for evaluating to what extent users' moving reduces the ability of the system to serve traffic. Starting from the value of 11E when users are not moving (mean users' velocity is 0km/h), we may conclude that the same new-call blocking probability (p_c) is obtained for the offered traffic 10E when the mean users' velocity is small (5km/h). When users' mean velocity is great (60km/h), the same p_c is obtained for offered traffic 9.1E.

Traffic capacity decreasing is lower when offered traffic is lower. According to the graph in Fig. 7, which is the detail of the Fig. 6, it is possible to serve the offered traffic of A=6.6E with p_c=0.02 when users are not moving. The same value of p_c is achieved when it is A=6.36E when mean users' moving velocity is v=5km/h, or A=6.1E when it is v=60km/h.

IV. CONCLUSION

In this paper we have analyzed the influence of users' moving on BS traffic capacity. This influence is expressed over existing calls handover between two adjacent cells. Handover decreases BS traffic capacity as a consequence of the requirement to reserve some number of traffic channels only for handover in order to achieve low handover dropping probability. Thus mobile system effectively behaves in relation to new call serving as it has lower number of available traffic channels than it is in reality. In the example from the paper, the number of traffic channels for new calls serving is decreased from 14 to 12.

In this paper we have presented the one-dimensional model intended for the analysis of the system with two different traffic components in mobile cell. The traffic generated by handover has higher priority. The goal of our further study is to develop two-dimensional model of such a system.

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