Simulation of Traffic Process in Mobile Telephony Systems

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Paper devoted to the 50th anniversary of Institute IRITEL

***Abstract*—This paper presents simulation programs for four traffic models, implemented in mobile telephony. These models differ according to the traffic type in the mobile cell. The first one is the ordinary model, where only external connections exist. The second one is model, which includes some percent of intra-cell connections (internal connections between two users from the same cell). In the third model two types of connections are established: full-rate connections, which seize one traffic channel and half-rate connections, which seize half a traffic channel. And, finally, the fourth one is model with intra-cell and external connections, but with limited number of mobile users in the system. Flow-charts of these simulation programs are explained. The simulation programs are originally developed, based on simulation programs for switching systems, which are also developed in IRITEL. The main purpose of simulation programs is to approve the results, obtained by mathematical analysis. In complicate situations, where mathematical equations for calculating important system parameters may not be easily determined, simulation results may replace calculation.**

***Index Terms*—Mobile telephony; traffic simulation; intra-cell traffic; half-rate connection; Engset system.**

I. Introduction

SYSTEMS of mobile telephony (GSM) are very complex. This complexity refers not only on its functionality, but also on its traffic analysis. There are various types of connections, which can be established, various codec types with different data rate are implemented, the number of mobile users situated in the area covered by one cell can be different (very great – infinite, or limited comparing to the number of available traffic channels), and so on. Besides, dimensioning of traffic resources (traffic channels) is very important for the calculation of base station emission power, [1], [2]. The results of such analysis are used in projecting systems of mobile telephony, i.e. their base stations, which is one of the activities in the Department of Radio Communications in IRITEL. Origination of traffic analysis, implemented in radio communications, is in traditional switching systems, where these type of analysis where first implemented. On the basis of traffic analysis intended for switching systems was developed digital switching system DKTS, which was one of the main development projects in IRITEL during years, intended, primarily, for telephone network of Telekom Serbia, [3]. Also development of various switching systems for Electric Power Utility, which is realized in IRITEL, is based on traffic modelling of switching systems. In these systems both-way trunks are used between telephone exchanges, and calculation of collision probability on them is very important, [4].

Some of traffic models, developed long ago for switching systems analysis, are also implemented today in the analysis of radio communication systems. Perhaps the most interesting are models for Private Branch Exchanges (PBX), whose very important element is existence of two traffic types: internal traffic (connections established between the two users in the exchange) and external traffic (connections established between the user in the exchange and the user outside the exchange), [5]. External connections include outgoing and incoming connections. The internal connections are also implemented for the dimensioning of systems in mobile telephony. In mobile telephony they are called intra-cell connections, [6].

Traffic analysis in telecommunication systems (switching systems and systems of mobile telephony) is part of queueing theory. Mathematical analysis of such systems is often very complicate. That's why simulation is implemented in such situations. In IRITEL simulation in telephony is implemented first to model switching systems, [7]. Based on this experience, it is implemented to model systems in mobile telecommunications, [8]-[11]. In this paper we shall limit our analysis to the simulation of traffic process in the systems of mobile telephony.

Modern telecommunication systems are migrating today more and more to packet switching. Important characteristic of packet switching systems is that they are not connection oriented. It is the reason to calculate (and simulate) such systems as waiting queueing systems, usually with one channel. Various voice packets of one connection may be transmitted over different routes. That's why traffic conditions for various packets, devoted to one connection, need not be the same. Even more, one packet may contain voice data for more connections. The other important characteristic of packet switching systems is that there is no connection blocking in such systems. A connection is always realized and it is only possible that some packets are lost due to successive delay. This situation leads to connection quality decrease, not

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to connection loss. The method to estimate voice connection quality in such situations is presented in [12], [13]. As a consequence of differences between mobile and packet switching systems, traffic simulation programs presented in this paper may not be implemented in this or similar form for packet switching systems analysis.

II. Simulation Process for Telecommunication Systems

One possible method for generating events in telecommunication systems is *roulette* or *Monte Carlo* method, [14]. It is intended for simulation of circuits oriented switching systems (i.e. systems with traffic loss). Method is based on generating random numbers (RN) with uniform distribution in the range (0, $A+N$), where A is traffic offered to the group of N resources (channels), block 1 in Fig. 1, [15]. After that, in block 2 the value of generated RN is tested. If it is less than A, new request (call) is generated, in the case that the number of busy channels (j) is less than N (blocks 3 and 4). If all channels are busy, the call is lost (block 5).

The call is candidate for termination in the case that the test in block 2 shows that generated RN is not less than A. The call is really terminated if the condition in block 6 is satisfied. This test may be formulated in two ways. The first one is that the call is terminated if the generated RN is in the range (A, $A+n_t$), where n_t is the number of instantaneously busy channels. The second one is to consider the serial numbers of busy channels. If the generated RN is in the range ($A+k-1$, $A+k$) and the channel with serial number k is busy, the call is terminated (block 7).

The simulation process is continued until the number of generated RNs does not reach the predefined limit.

In this simulation model it is supposed that the number of possible traffic sources (M) is $M>>N$. With this assumption, the request arrival rate is always the same, regardless of the number of already realized connections (Erlang systems).

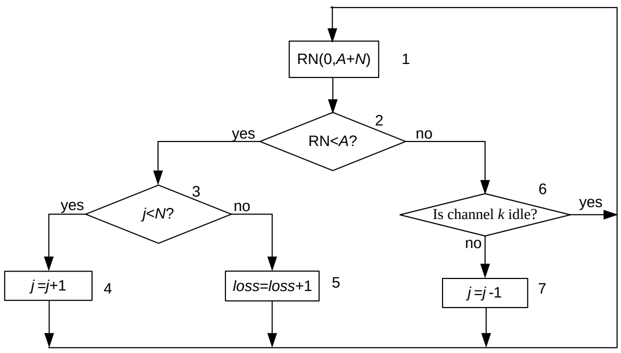

Fig. 1. Principle block-scheme of telecommunication traffic simulation

III. Traffic Types in Mobile Telephony

Intra-cell connections are one specific type of connections in mobile telephony, [16]. They are established between the users belonging to the same mobile cell (mobile station). That’s why it is necessary to seize two channels in order to establish intra-cell connection. The percent of these connections in relation to the total number of connections in mobile systems usually is not great. But in some cases, as in some private mobile networks, [17], networks covering one company, [9], or in rural areas, [18], this traffic component can be significant, even 30-40% of the total traffic.

Available frequency capacity for mobile communications is limited. That’s why it is very important to save this capacity whenever it is possible. One possible method is implementation of low-rate codecs. Among this codecs, half-rate codec is subject of our interest in this paper. Its main characteristic is that it reduces necessary channel capacity at one half of the full-rate channel capacity, thus increasing the number of traffic channels, which can be transmitted and decreasing the blocking probability. Besides its contribution to system traffic characteristics, implementation of half-rate codec also contributes to decreasing of BTS emission power, [10]. The negative effect of half-rate codec implementation is lower connection quality. In order to allow better connection quality to the greater number of connections, it is usual to establish only full-rate connections until some threshold of the number of busy channels. After that, connections are established mixed: full-rate and half-rate. It is possible to realize half-rate connections only between mobile stations, which have possibility to realize such connections. It is not easy to analytically solve the system with the threshold to start half-rate connection realization. Analytical solutions can be found only for the system, which realizes half-rate connections in each case (without considering the threshold for starting its implementation) for the mobile users, who have this possibility, [19] and for the system, where only half rate connections are realized, [20]. When threshold for starting half-rate connections realization is implemented, satisfactory results can be obtained only by simulation.

It is supposed in the systems, which are already presented in this section, that the number of traffic sources is $M>>N$. If this condition is not satisfied (Engset systems), the call arrival rate is variable (it decreases when the number of realized connections increases). Such systems are not often analyzed in mobile telephony, [21], but they can be found in rarely populated areas, or areas, where many inhabitants do not have mobile phones.

IV. Simulation Models

All simulated systems start from RNs with uniform distribution in the range (0,1). These numbers are then multiplied by the spreading factor, which is in each case different, depending on the parameters of simulated system. The base of these systems is always flow-chart, presented in Fig. 1. This flow-chart is upgraded for each system type, according to the characteristics of simulated system.

A. Ordinary system (system with only external traffic)

Mobile telephony system, in which only external connections are realized, is simulated according to flow-chart in Fig. 1. The generated RNs (in the range (0,1) are multiplied by the normalization factor $A+N$ to obtain the appropriate range for the simulation, [11].

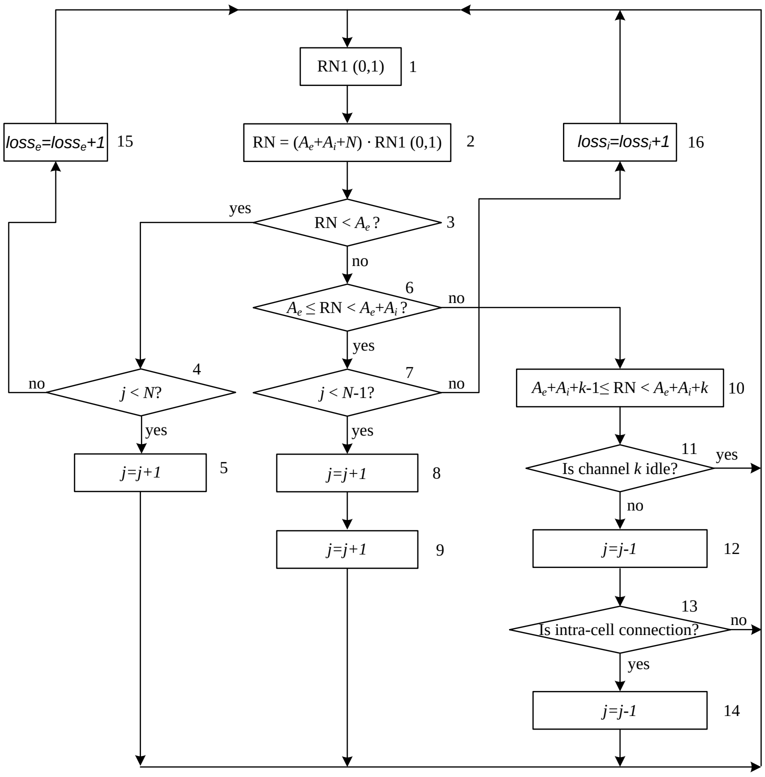

Fig. 2. Flow-chart of simulation program, in which external and intra-cell connections may be realized

B. System with intra-cell traffic

Flow-chart for the simulation of system, in which external and intra-cell connections may be realized, is presented in Fig. 2, [9]. In this case the value of normalization factor is A_e+A_i+N, where A_e is the value of offered external traffic and A_i the value of offered intra-cell traffic (block 2 in Fig. 2).

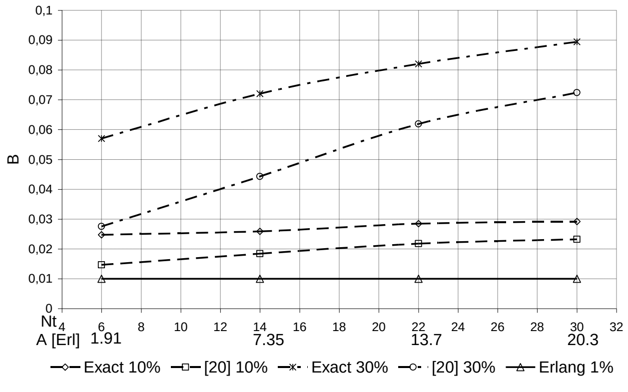

Fig. 3. Influence of intra-cell traffic component on traffic loss – results compared to approximate calculation method

The range, where the generated RN is situated, is determined in blocks 3 and 6. If it is RN<A_e, in block 4 is tested whether some idle channel exists. In the case that there are no idle channels, blocking of external call is declared in block 15. If there is at least one idle channel, it is seized in block 5.

The similar steps exist for intra-cell connection, if the generated RN is between A_e and A_e+A_i, as is presented in block 6. The differences, comparing to the steps for external connection, are that intra-cell connection can be realized if there are at least two idle channels (block 7) and that two channels are seized in blocks 8 and 9. If there are not at least two idle channels, internal blocking is declared in block 16.

The test in blocks 10 and 11 is intended to determine whether it is necessary to release the channel. It is same as the corresponding test in Fig. 1. The channel is released in block 12, if it is busy. The remaining test in block 13 is necessary to determine whether the channel, released in block 12, belongs to the intra-cell connection. The second channel is released in block 14, if intra-cell connection ends.

The simulation program is proved by the results presented in [9], [16]. In principle, all simulation programs may be implemented for traffic analysis, [16] and to estimate base station emission power in various conditions, [9]. When considering traffic component, it is interesting to perceive the rate of traffic loss increase when intra-cell traffic component is included in the analysis. This rate increase is presented in Fig. 3. In this figure the traffic value (line 1), which produces loss of 1% when pure external traffic (Erlang system) is considered, is the reference one. After that, corresponding traffic loss is calculated (and estimated by simulation) for different percent of intra-cell traffic in total traffic equal to the traffic, whose effect is 1% loss when there is no intra-cell traffic. The results of analysis from [16], and especially their proof after implementing simulation program, are important, because they indicated that the results, obtained by simplified, approximate method from [22], underestimate real traffic loss (in some cases for 30% of intra-cell traffic at even half the real value).

C. System with half-rate connections

Flow-chart for the simulation of the system, in which external full-rate and half-rate connections may be realized, is presented in Fig. 4, [10]. In this case the normalization factor in block 2 is $A+N\cdot(1+\pi_h)$, where π_h is probability that half-rate connection is established.

In the system with the possibility to realize half-rate connections there is one traffic component (A) and the new call may be started if the generated RN is RN<A (block 3). In that case, it is necessary to test whether the instantaneous number of busy channels is smaller than the threshold K, when realization of half-rate connections starts. As one half-rate connection occupies half a channel, the condition for testing the number of busy channels in block 4 is $n_f+n_h/2<K$, where n_f is the number of instantaneously realized full-rate connections and n_h is the number of realized half-rate connections.

Full-rate connection is realized in block 7, if the condition in block 4 is satisfied. If this condition is not satisfied, the previously generated RN is tested again in block 8. If the generated RN is RN<$A\cdot\pi_h$, it is necessary to consider the possibility to generate half-rate connection. This connection will be realized (block 11) if there is at least half a channel idle, according to the test in block 9. In the case that all channels are completely busy, loss of a half-rate connection will be declared in block 10.

The realization of full-rate connection is considered if the condition in block 8 is not satisfied. Generation of the new full-rate connection or declaration of full-rate connection loss is realized in blocks 5, 6 and 7 in the same way as it is explained for half-rate connection, with the single difference that new full-rate connection may be established if there is at least one full channel idle (block 5).

In the simulation program it is supposed that two half-rate connections are not split in two partially busy channels, i.e. that two half-rate connections are always accompanied in one busy channel. It means that algorithm for channel assignment functions in such a way that channels are optimally grouped: two half-rate channels in two separate channels after channel release are always repacked to seize one full-rate channel, as explained in [20]. In practice, mobile systems are realized including this possibility, because in this way the traffic capabilities of the system are increased. Mobile systems, which are analyzed in this paper, are modernized by the implementation of a new, VAMOS technology. The main feature of such systems is that each full-rate or half-rate channel may be used to transmit two voice signals. In this way mobile system capacity may be even quadrupled by the implementation of half-rate and VAMOS technics. This is one, significantly greater possibility to increase mobile systems capacity, than joining two half-rate channels, which remain in separate full-rate channels after connection release, into one full-rate channel.

Connection release is realized in blocks 12-15. Full-rate connection ends if the RN, generated in the beginning in the block 2, is between A and $A+n_f$ (blocks 12 and 14). Half-rate connection is released in blocks 13 and 15, if the generated RN is between $A+n_f$ and $A+n_f+n_h$.

The traffic loss results for various values of half-rate connection rate (π_h) and different threshold (K) in one case when considering traffic and the number of available channels are presented in Fig. 5. Programs for simulation are very important in half-rate traffic analysis, because the results may be obtained only by simulation. It is already stated that analytical models do not exist in this case, [19], [20].

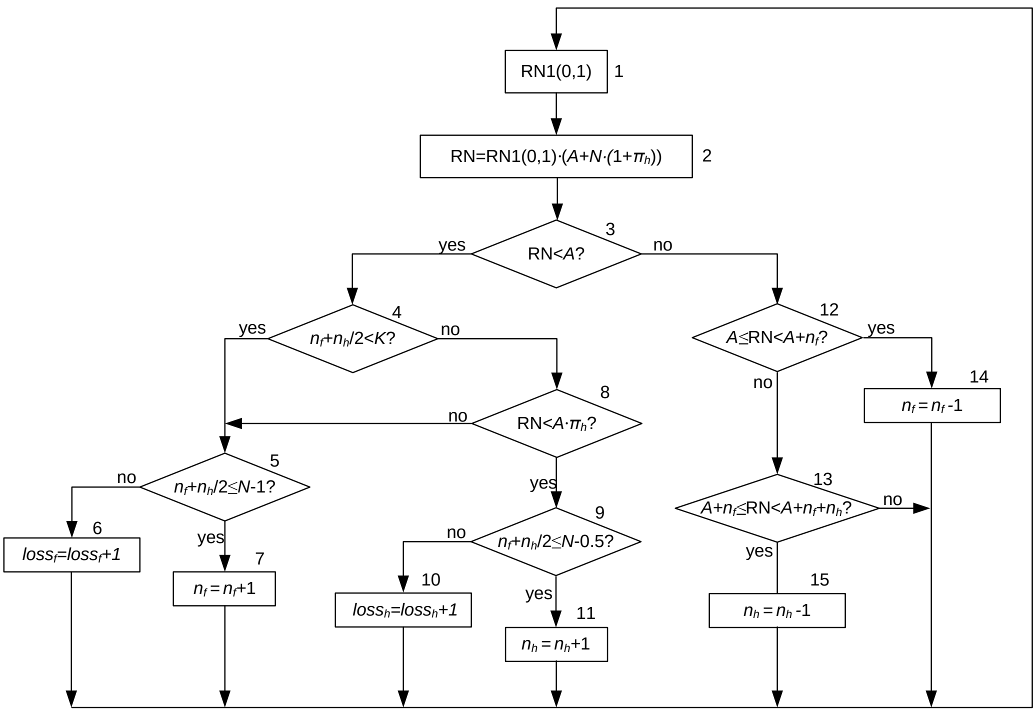

Fig. 4. Flow-chart of simulation program, in which external full-rate and half-rate connections may be realized

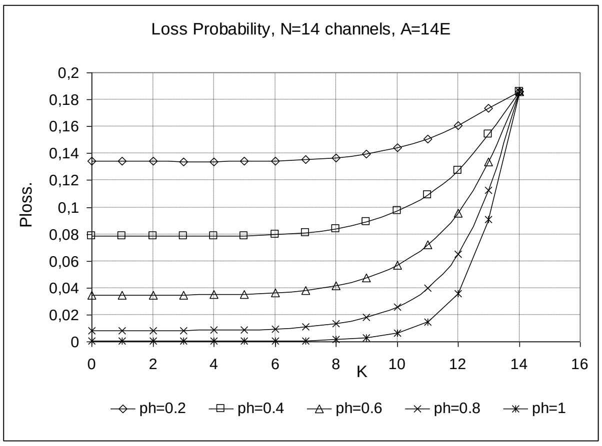

Fig. 5 Traffic loss as a function of threshold number of channels for starting half-rate connections realization in the system with half-rate possibility

D. System with limited number of traffic sources

Flow-chart of the simulation program for the system with limited number of users (Engset system) is presented in Fig. 6. In this system external and intra-cell connections may be established.

Normalization factor for generated RN in this case (block 2) is $M\cdot(a_i+a_e)+N$, where a_i is intra-cell offered traffic per each user in the system, a_e is external traffic per each user and M is the number of users in the system. After that, intra-cell connection may be established if RN is smaller than $(M\text{-}2\cdot n_i\text{-}n_e)\cdot a_i$ (block 3), where n_i and n_e are the numbers of instantaneously realized intra-cell and external connections, respectively. It means that offer of internal traffic is proportional only to the internal traffic per user (a_i), and the factor of proportionality is total number of idle users ($M\text{-}2\cdot n_i\text{-}n_e$). It is important to emphasize that probability of generating the new request is variable: it decreases as the number of realized intra-cell and external connections increases (factor $M\text{-}2\cdot n_i\text{-}n_e$ decreases when n_i and n_e increase). The second condition, which must be fulfilled to start a new intra-cell connection in block 5, is that there are at least two idle channels in the system (test $2\cdot n_i + n_e < N\text{-}1$ in block 4). In the case that this last condition is not fulfilled, the loss of intra-cell connection is declared in block 13.

Simulation steps 6, 7, 8 and 14 are reserved for the simulation of new external request. The range of generated RN, which must be satisfied for this case, is presented by the block 6. After that, external connection may be realized, if there is at least one idle channel (block 7). In such a situation, new external connection is established in block 8. If there are no idle channels, generated external request is lost (block 14).

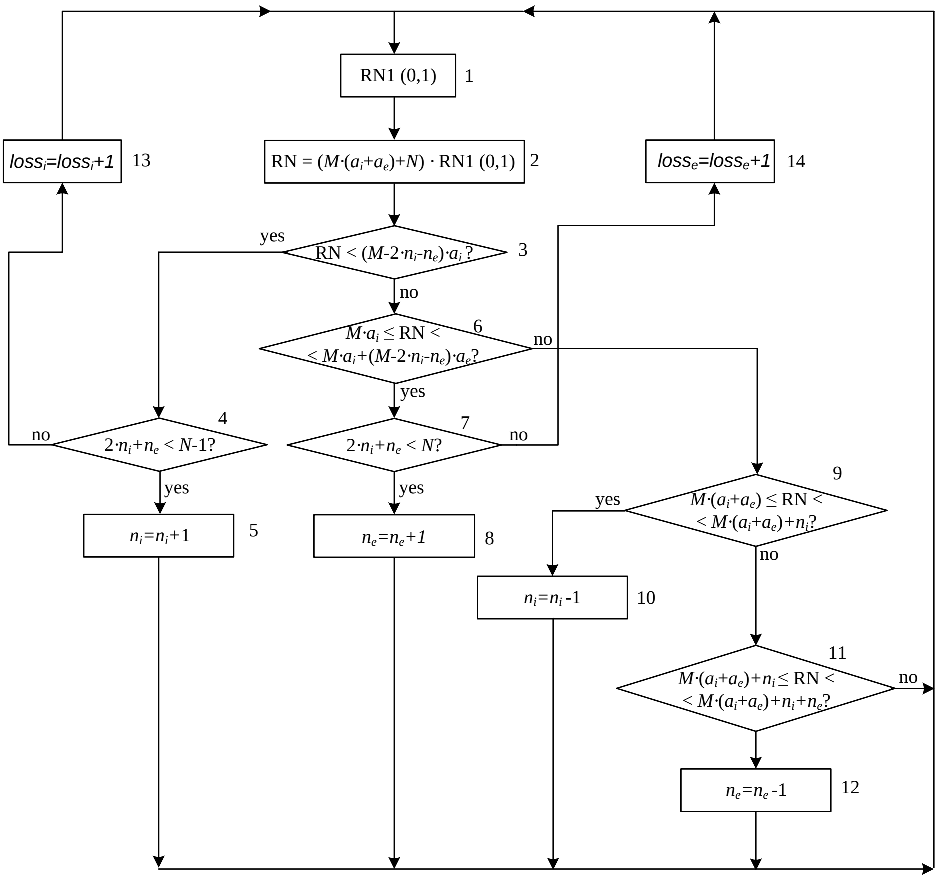

Fig. 6. Flow-chart of simulation program for the system with limited number of users, in which external and intra-cell connections may be realized

The range of generated RNs, which is presented in block 9, corresponds to release of intra-cell connection (block 10). The dimension of this range corresponds to the number of instantaneously realized intra-cell connections. Similar steps are executed in blocks 11 and 12 in order to release an external connection.

The effect of limited number of users in one system is that it decreases traffic loss rate, comparing to the pure Erlang system. But, generally, the effect of intra-cell traffic to the traffic loss is dominant comparing to the effect of limited number of users, [21]. Only in the case of very small component of intra-cell traffic (5%) it is possible that traffic loss becomes smaller for the system with limited number of users than in the pure Erlang system. In order to come into such a situation, it is necessary that the number of users in the analyzed system does not overcome three times the number of available traffic channels, as it can be concluded from Fig. 7 (M/N=3). Such a complicate analysis, when two opposite effects are considered, may not be also performed by analytical methods.

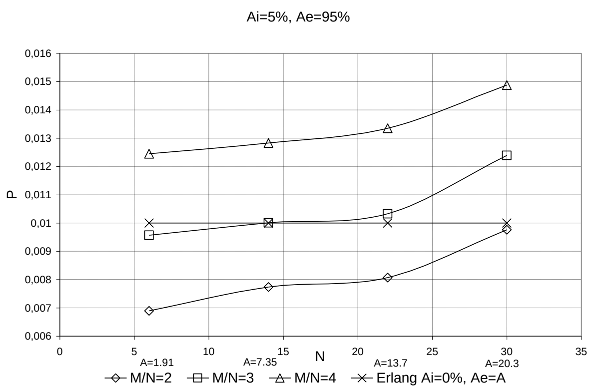

Fig. 7. Comparing the effect of limited number of users and intra-cell traffic to the traffic loss

V. Conclusion

In this paper we present traffic simulation programs developed in IRITEL for analysis of mobile telecommunication systems. These programs are based on simulation programs, intended for switching systems, which are also developed in IRITEL. They allow us to model relatively complicate systems, for which analytical solutions can't be obtained (as systems with half-rate connections). In the case that analytical solutions can be obtained, these models may approve calculated results. The results can be obtained by simulation easier and faster, than by measurement of real traffic process, [15].

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