Simulator of Multi-service Switching Networks with Multi-service Sources

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***Abstract*—In this paper, we present a simulator of multi-service switching networks with various resource management mechanisms. The network can be offered three types of traffic streams: Erlang, Engset and Pascal, generated by multi-service sources. Each multi-service source can generate calls of a number of traffic classes. In addition, the paper presents an analysis of the influence of different parameters upon the traffic characteristics of switching networks.**

Keywords–multi-service sources; Erlang; Engset; Pascal; switching network; simulation.

I. INTRODUCTION

Working out effective and efficient methods for managing resources in nodes of communication networks, especially in the case of multi-service networks that rely on virtualization of resources, is a complex issue. One of the fundamental difficulties arises from the necessity of servicing by switching nodes of the networks different classes of traffic streams [1][2][3]. In order to obtain a desirable admission policy for calls of different traffic classes as well as a desirable level of usage of resources, many different strategies of resource management in multi-service network have been elaborated. The ones of the most effective strategies can be reservation mechanisms of resources, both dynamic (executed on-line and securing well-balanced access to network resources) [4], and static (executed appropriately ahead of time with time advancement) [4], as well as threshold [4][5] and priority mechanisms [4].

In order to fully determine the influence of resource management mechanisms on the effectiveness of switching nodes of telecommunications networks we have to determine their influence on switching networks that are the key element of each node in the network. In this paper we describe an original simulation program for a determination of traffic characteristics of switching networks with various resource management mechanisms and multi-service traffic sources.

The paper is structured as follows. Section 2 presents the structure of traffic offered to the multi-service switching network. Section 3 describes the control mechanisms used in switching networks to control access to resources. Section 4 includes a description of the simulator and presents methods for a simulation of different types of traffic (Erlang, Engset and Pascal traffic). Section 5 presents the results of the simulation experiments. Finally, the conclusions and summary of the paper are provided in Section 6.

II. RELATED WORK

The influence of resource management mechanisms on the effectiveness of multi-service communications systems can be determined on the basis of both analytical methods [6][7] and simulation tools [8]. In the case of the analytical methods, we can obtain a limited number of traffic characteristics, under limited assumptions. For example, none of methods of switching networks analysis, known to the authors, take into account other than random algorithms of link selection in outgoing directions or interstage links. So far, no analytical methods have been developed that allow switching network modeling with any given number of attempts to set up a new connection, and with traffic streams other than Erlang streams. The existing limitations of analytical methods have led to the development of a switching networks simulator [8]. The simulation model of switching network with traffic management mechanisms developed in [8], however, was limited to multi-service switching networks with single-service sources [8][9][10]. Consequently, in order to determine the influence of many parameters not taken into account in existing analytical models, and, additionally, the multi-service sources (a multi-service traffic source is the source that can generate calls of different classes [6][11]), the simulation model of the multi-service switching networks with multi-service sources is presented in the paper. According to the authors' knowledge, this is the first simulator of the switching networks with multi-service traffic sources.

III. STRUCTURE OF OFFERED TRAFFIC

In the considered model, m traffic classes that belonged to the set $\mathbb{M} = \{1, 2, ..., m\}$ were defined. A given class c is defined by the number t_c of demanded BBUs (Basic Bandwidth Units) required to set up a new connection of class c and the parameter μ_c of the exponential distribution of the service time of calls of class c [11]. The switching network is offered three types of traffic streams - Erlang, Engset and Pascal traffic streams. Each stream is generated by a source that belongs to an appropriate set of traffic sources: $\mathbb{Z}_{\text{Er},i}$, $\mathbb{Z}_{\text{En},j}$ and $\mathbb{Z}_{\text{Pa},k}$. In the considered system, s_I sets of traffic sources generating Erlang traffic streams, s_J sets of traffic sources generating Engset traffic streams and s_K sets of traffic sources generating Pascal traffic streams were defined. The total number of the sets of traffic sources in the system is $S = s_I + s_J + s_K$. The sources that belong to the set $\mathbb{Z}_{\text{Er},i}$ can generate Erlang call streams from the set $\mathbb{C}_{\text{Er},i} = \{1, 2, ..., c_{\text{Er},i}\}$ according to the available set of services. The sources that belong to the set $\mathbb{Z}_{\text{En},j}$ can generate Engset call streams from the set $\mathbb{C}_{\text{En},j} = \{1, 2, ..., c_{\text{En},j}\}$, whereas the sources that belong to the set $\mathbb{Z}_{\text{Pa},k}$ can generate Engset call streams from the set $\mathbb{C}_{\text{Pa},k} = \{1, 2, ..., c_{\text{Pa},k}\}$.

The participation of class c (from the set $\mathbb{M}$) in the structure of traffic generated by sources from the appropriate sets $\mathbb{Z}_{\text{Er},i}$, $\mathbb{Z}_{\text{En},j}$ and $\mathbb{Z}_{\text{Pa},k}$ can be determined by the parameter $\eta_{\text{Er},i,c}$, $\eta_{\text{En},j,c}$ and $\eta_{\text{Pa},k,c}$:

$$\sum_{c=1}^{c_{\text{Er},i}} \eta_{\text{Er},i,c} = 1, \quad \sum_{c=1}^{c_{\text{En},j}} \eta_{\text{En},j,c} = 1, \quad \sum_{c=1}^{c_{\text{Pa},k}} \eta_{\text{Pa},k,c} = 1. \quad (1)$$

IV. Resource access control mechanisms

A. Bandwidth Reservation

Bandwidth reservation in the switching network consists in introducing the reservation threshold R_c [1][9][12][13]. R_c determines the borderline state of the link (or the group of links), in which servicing the class c calls is still possible. All states higher than R_c belong to the reservation space S_c in which the class c calls are blocked: $S_c = V - R_c$, where V is the total capacity of the group. The reservation mechanism was introduced to the classes that belonged to the set $\mathbb{R}$ which is a sub-set of the set $\mathbb{M}$.

B. Threshold Mechanisms

In switching networks with the applied threshold mechanism the parameters of the offered traffic change depending on the load of the system [6][9][14]. In the algorithm, the threshold mechanism is introduced to outgoing directions only [6]. According to this algorithm, for each class of calls a set of thresholds is individually introduced. For example, for class c we have a set $(Q_{c,1}, Q_{c,2}, \ldots, Q_{c,q})$. In each threshold area u of class c $\{Q_{c,u} < n \leq Q_{c,u+1}\}$ a traffic stream of class c, defined by own set of parameters $\{t_{c,u}, \mu_{c,u}\}$, is offered. Additionally, we assume that $t_{c,0} > t_{c,1} > \ldots > t_{c,u} > \ldots > t_{c,q}$ and $\mu_{c,0}^{-1} \leq \mu_{c,0}^{-1} \leq \ldots \leq \mu_{c,u}^{-1} \leq \ldots \leq \mu_{c,q}^{-1}$.

C. Hysteresis Mechanism

The hysteresis mechanisms also change traffic parameters of carried traffic in relation to the occupancy state of a system [7][9]. In hysteresis algorithm, when the load of the system exceeds the pre-defined limit Q_1, a decrease in the number of assigned BBUs for calls (currently offered and serviced) of classes belonging to the set $\mathbb{H}$ ensues and the average holding time of the call may be increased. When the load of the system is below the hysteresis limit Q_2, this situation is followed by an increase in the number of BBUs allocated to the compressed calls from the set $\mathbb{H}$ and a decrease in the holding time of these calls.

V. General Assumptions

The developed simulator of switching networks was written in C++ using the object programming technique. The process interaction method was used to develop the simulation model. Thus developed simulator allows us to determine values of the blocking probability, loss probability, as well as values of traffic serviced by calls of individual traffic classes, depending on the threshold mechanism involved, in switching networks with point-to-point selection, point-to-group selection and point-to-group selection with a number of attempts to set up a connection. The input data of the simulator are: the capacity and the structure of the switching network. For each traffic class, the number of demanded BBUs, service time and the parameters related to the introduced threshold mechanisms (the demanded number of BBUs in particular threshold areas, threshold boundaries) are given. The sets of traffic sources and their type (Erlang, Engset, Pascal) are defined. In addition, the average value of traffic offered to a single BBU of the system is also given.

In order to perform simulation experiments for a system with the capacity V and composed of switches $\upsilon \times \upsilon$ of links in which the capacity of a single link is f BBU, the values of the following parameters have to be introduced: the number of defined traffic classes m, the number t_c of demanded BBUs necessary to set up a connection of class c and the average service time μ_c^{-1} for a call of class c, the number of sets of traffic sources s_I, s_J, s_K, the sets $\mathbb{Z}_{\text{Er},i}$, $\mathbb{Z}_{\text{En},j}$ and $\mathbb{Z}_{\text{Pa},k}$ of traffic sources, the number of classes $c_{\text{Er},i}$, $c_{\text{En},j}$ and $c_{\text{Pa},k}$ that belong respectively to the sets $\mathbb{C}_{\text{Er},i}$, $\mathbb{C}_{\text{En},j}$ and $\mathbb{C}_{\text{Pa},k}$ of traffic classes, the participation $\eta_{\text{Er},i,c}$, $\eta_{\text{En},j,c}$ and $\eta_{\text{Pa},k,c}$ of calls of class c in traffic generated by sources that belong respectively to the sets $\mathbb{Z}_{\text{Er},i}$, $\mathbb{Z}_{\text{En},j}$ and $\mathbb{Z}_{\text{Pa},k}$ of traffic sources and the number $N_{\text{En},j}$ or $S_{\text{Pa},k}$ of Engset traffic sources from the set $\mathbb{Z}_{\text{En},j}$ and Pascal traffic sources from the set $\mathbb{Z}_{\text{Pa},k}$, threshold boundaries $Q_{c,u}$, defined in the output directions for calls of class c, the number of BBUs $t_{c,u}$ demanded by calls of class c in the threshold area u and the average service time $\mu_{c,u}^{-1}$ for a call of class c in area u.

Additionally, the average traffic a offered to a single BBU in the system is given. On the basis of the above parameters it is possible to determine in the simulator the intensity $\lambda_{\text{Er},i}$, $\gamma_{\text{En},j}$ or $\gamma_{\text{Pa},k}$ of calls generated by the sources of a given type of the traffic stream. In the case of the Engset and Pascal streams, the intensities $\gamma_{\text{En},j}$ and $\gamma_{\text{Pa},k}$ determine the call intensity for calls generated by a single free source. Thus, the parameters $\lambda_{\text{Er},i}$, $\gamma_{\text{En},j}$ and $\gamma_{\text{Pa},k}$ can be determined, depending on the average traffic offered to a single BBU:

$$\lambda_{\text{Er},i} = \frac{aV\upsilon}{S\left[\sum_{c=1}^{c_{\text{Er},i}} t_c\eta_{\text{Er},i,c}\right]\left[\sum_{c=1}^{c_{\text{Er},i}} \mu_c\eta_{\text{Er},i,c}\right]}, \quad (2)$$

$$\gamma_{\text{En},j} = \frac{aV\upsilon}{S\left[\sum_{c=1}^{c_{\text{En},j}} t_c\eta_{\text{En},j,c}\right]\left[\sum_{c=1}^{c_{\text{En},j}} \mu_c\eta_{\text{En},j,c}\right]N_{\text{En},j}}, \quad (3)$$

$$\gamma_{\text{Pa},k} = \frac{aV\upsilon}{S\left[\sum_{c=1}^{c_{\text{Pa},k}} t_c\eta_{\text{Pa},k,c}\right]\left[\sum_{c=1}^{c_{\text{Pa},k}} \mu_c\eta_{\text{Pa},k,c}\right]S_{\text{Pa},k}}. \quad (4)$$

The parameters determined on the basis of (2), (3), and (4) can be treated as the parameters for the exponential distribution that describes the new call arrival process.

With a determination of the blocking probability, the condition for the termination of the simulation experiment is the duration time for individual series necessary to generate a given number of calls of the least active class (most frequently this is a class with the highest number of demanded BBUs). In the case of the loss probability, the condition for the termination of the simulation experiment is the appropriate aggregated number of generated calls of the least active class. The time required to generate a given number of calls is chosen in such a way as to obtain 95% confidence interval. Conventionally, the average result is calculated on the basis of 5 series. In practice, to obtain the confidence interval at the level of 95% it is necessary to generate about 1,000,000 calls of the least active class.

The algorithm according to which the simulation program operates can be written on the basis of the following steps: **1.** Initial configuration of the simulation model – creation of all sources that generate calls of different traffic classes. **2.** Setting the system time to zero. **3.** Activation of traffic sources and events display (call arrival) in the list. **4.** Checking of the simulation termination condition. If the condition is satisfied, then the simulation is terminated and the results are recorded in a file. **5.** Updating of the system time to the time of the appearance of the first event from the list. **6.** Execution of the first event item from the list. **7.** Removal of the first event item from the list and return to step 2.

Two events were defined in the simulation model of the switching network: *the arrival of a new call* and *the termination of call service*. According to the process interaction method, these events are serviced by one function. This function has a different form for each type of Erlang, Engset and Pascal traffic stream. The approach described above makes it possible to define many different traffic classes in the system and to allocate (assign) them to different types of sets of traffic sources. In the initial configuration of the simulation model it is essential to create all sources that generate calls of different traffic classes.

A. Simulation of a system with the sets of Erlang sources

Consider a system in which the set i of Erlang traffic sources $\mathbb{Z}_{\mathrm{Er},i}$ has been defined. In the system, also the set $\mathbb{C}_{\mathrm{Er},i} = \{1, 2, ..., c_{\mathrm{Er},i}\}$ of traffic classes whose calls can be generated by sources from the set $\mathbb{Z}_{\mathrm{Er},i}$ has been defined. In the initial configuration of the system it is necessary to plan ahead the arrival of a call of class c from the set $\mathbb{C}_{\mathrm{Er},i}$. The function that executes events related to the set of Erlang traffic sources can be described in the following way: **1.** Planning of the arrival (appearance) of a new call generated by a source that belongs to the set $\mathbb{Z}_{\mathrm{Er},i}$ according to the exponential distribution where the parameter is the intensity $\lambda_{\mathrm{Er},i}$. Allocation of a given call to class c from the set $\mathbb{C}_{\mathrm{Er},i}$, on the basis of the parameter $\eta_{\mathrm{Er},i,c}$, according to the uniform distribution. Recording the event in the list. **2.** Checking whether the system has sufficient resources to admit a call for service: **a)** Checking whether any of the links of the demanded output direction has at least t_c free BBUs. If not, the call is lost due to the external blocking. **b)** Checking whether there is a path between the input link, at which a call appeared, and the output link of the demanded direction that has at least t_c unoccupied BBUs. If not, the call is lost due to the internal blocking. If any of the conditions (a) or (b) is not satisfied, next steps are omitted. **3.** Occupation of the resources demanded by a call of class c. **4.** Planning of the termination of service according to the exponential distribution where the parameter is the intensity μ_c. Recording the event in the list. **5.** Termination of service and release of resources.

B. Simulation of a system with the sets of Engset sources

Consider a system in which the set j of Engset traffic sources $\mathbb{Z}_{\mathrm{En},j}$ has been defined. In the system, calls from the set $\mathbb{C}_{\mathrm{En},j} = \{1, 2, ..., c_{\mathrm{En},j}\}$ of traffic classes can be generated by $N_{\mathrm{En},j}$ sources from the set $\mathbb{Z}_{\mathrm{En},j}$. It is necessary to plan in the initial configuration of the system an appearance (arrival) of a call of class c from the set $\mathbb{C}_{\mathrm{En},j}$ generated by each of $N_{\mathrm{En},j}$ sources. Hence, the function executing the events related to the set of Engset traffic sources can be presented as follows: **1.** Checking whether the system has sufficient resources to admit a call for service: **a)** Checking whether any of the links of the demanded output link has at least t_c free BBUs. If not, the call is lost due to the external blocking. **b)** Checking whether there is a path between the input link at which a call appears and the output link of the demanded direction that has at least t_c free BBUs. If not, the call is lost due to the internal blocking. If any of the conditions (a) or (b) cannot be satisfied, pass on to step 5. **2.** Occupation of the resources demanded by a call of class c. **3.** Planning of the termination of service according to the exponential distribution where the parameter is the intensity μ_c. Recording the event in the list. **4.** Termination of service and release of resources. **5.** Planning of the appearance (arrival) of a new call generated by a free source from the set $\mathbb{Z}_{\mathrm{En},j}$ of traffic sources according to the exponential distribution where the parameter is the intensity $\gamma_{J,j}$. Allocation of the generated call to class c from the set $\mathbb{C}_{\mathrm{En},j}$ on the basis of the parameter $\eta_{\mathrm{En},j,c}$ according to the uniform distribution. Recording the event in the list.

Unlike the system with the sets of Erlang sources, in the system with the sets of Engset sources a generation of a new call is possible only when there is a free source (from among $N_{\mathrm{En},j}$ sources) capable of generating this call. This condition will be satisfied in a situation when the call service process for another call is completed. Hence, in the function related to event service, a termination of service for a call is immediately followed by a possibility to plan an arrival of another call.

C. Simulation of a system with the sets of Pascal sources

Consider a system in which a set of Pascal traffic sources $\mathbb{Z}_{\mathrm{Pa},k}$ has been defined. The system also has a defined set $\mathbb{C}_{\mathrm{Pa},k} = \{1, 2, ..., c_{\mathrm{Pa},k}\}$ of traffic sources whose calls can be generated by $S_{\mathrm{Pa},k}$ sources from the set $\mathbb{Z}_{\mathrm{Pa},k}$. In the initial configuration of the system it is necessary to plan the appearance (arrival) of a call of class c from the set $\mathbb{C}_{\mathrm{Pa},k}$, generated by each of $S_{\mathrm{Pa},k}$ sources. Therefore, the function executing the events related to the set of Pascal traffic sources leads to the execution of the following task: **1.** Planning of the arrival of a new call, generated by a source from the set $\mathbb{Z}_{\mathrm{Pa},k}$, according to the exponential distribution where the parameter is the intensity $\gamma_{\mathrm{Pa},k}$. Allocation of the call to class c from the set $\mathbb{C}_{\mathrm{Pa},k}$, on the basis of the parameter $\eta_{\mathrm{Pa},k,c}$, according to the uniform distribution. Recording the event in the list. **2.** Checking whether the system has sufficient resources to service the call: **a)** Checking whether any of the links of the demanded output direction has at least t_c free BBUs. If not, the call is lost due to the external blocking. **b)** Checking whether there is a path between the input link at which a call appears (arrives) and the output link of the demanded output direction that has at least t_c free BBUs. If not, the call is lost due to the internal blocking. If any of the conditions (a) or (b) is not satisfied, the next steps are omitted. **3.** Occupation of the resources that are demanded by a call of class c. **4.** Planning of the termination of service according to the exponential distribution where the parameter is the intensity μ_c. Recording the event in the list. **5.** Addition of two sources (at the moment of the admittance of a given call). Planning of the arrival of new calls generated by new sources from the set $\mathbb{Z}_{\mathrm{Pa},k}$ according to the exponential distribution where the parameter is the intensity $\gamma_{\mathrm{Pa},k}$. Allocation of new calls to class c from the set $\mathbb{C}_{\mathrm{Pa},k}$ on the basis of the parameter $\eta_{\mathrm{Pa},k,c}$ according to the uniform distribution. Recording the event in the list. **6.** Termination of service and release of resources. **a)** Removal of two sources, currently not serviced, at the moment of a termination of service of a given call. **b)** Removal of the events related to the removed source.

VI. Simulation experiments of switching networks with threshold mechanisms

The simulator makes it possible to examine the influence of different factors on the values of the blocking probability and on the values of carried traffic. The factors involved include: the number of attempts to set up a connection and the link occupation strategy. This section presents an extensive set of results that determine the influence of different parameters on the characteristics of switching networks such as, for example, the applied threshold mechanism, the number of attempts to set up a connection, and the link occupation strategy. The results of the simulation experiments are presented in the from of graphs with confidence intervals that have been determined on the basis of the t-Student distribution (with 95-percent confidence interval) for 5 series. The duration time for each of the series has been determined on the basis of the time required to generate 1,000,000 calls of the least active class. In each case, the confidence interval does not exceed 5% of the average value of the result of the simulation experiment.

A. Influence of the applied threshold mechanism

To examine the influence of the applied resource access control mechanism on the values of carried traffic and the blocking probability simulation experiments were performed. Three types of mechanisms were considered: reservation, threshold and hysteresis mechanisms.

The study was carried out for the following parameters: **structure of switching network**: $\upsilon = 4$, $f = 32$ PJP, $V = 128$ PJP; **structure of offered traffic**: traffic classes: $m = 3$, $t_{1,0} = 1$ PJP, $\mu_{1,0}^{-1} = 1$, $t_{2,0} = 4$ PJP, $\mu_{2,0}^{-1} = 1$, $t_{3,0} = 8$ PJP, $\mu_{3,0}^{-1} = 1$; sets of traffic sources: $S = 3$, $\mathbb{C}_{\mathrm{Er},1} = \{1\}$, $\eta_{\mathrm{Er},1} = 1$, $\mathbb{C}_{\mathrm{En},2} = \{2\}$, $\eta_{\mathrm{En},2} = 1$, $N_{\mathrm{En},2} = 128$, $\mathbb{C}_{\mathrm{Pa},3} = \{3\}$, $\eta_{\mathrm{Pa},3} = 1$, $S_{\mathrm{Pa},3} = 128$; **reservation mechanism**: $R_1 = R_2 = 90$ PJP, $\mathbb{R} = \{1, 2\}$; **threshold mechanism**: $t_{2,1} = 2$ PJP, $\mu_{2,1}^{-1} = 2$, $t_{3,1} = 4$ PJP, $\mu_{3,1}^{-1} = 2$, $q_3 = 1$, $Q_{3,1} = 90$ PJP; **hysteresis mechanism**: $t_{2,1} = 2$ PJP, $\mu_{2,1}^{-1} = 2$, $t_{3,1} = 4$ PJP, $\mu_{3,1}^{-1} = 2$, $Q_1 = 100$ PJP, $Q_2 = 80$ PJP, $\mathbb{H} = \{2, 3\}$;

In the case when the hysteresis mechanism or the threshold mechanism have been applied to the switching networks under consideration we can observe the highest values of carried traffic as compared to a switching network without those mechanisms being introduced. A reverse situation is to be found in the case of switching networks with reservation mechanisms (Figure 1).

In switching networks in which a proper threshold mechanism or a threshold mechanism with hysteresis have been introduced it was observable that in the case of classes that did not undergo these mechanisms the blocking probability for low intensities of traffic was lower than the blocking probability in networks without the introduced mechanisms. With

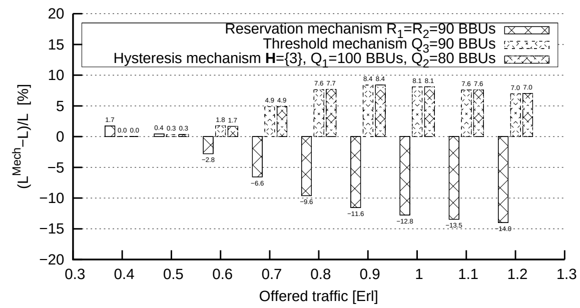

Figure 1. Percentage change in the value of carried traffic in relation to the applied resource access control mechanism

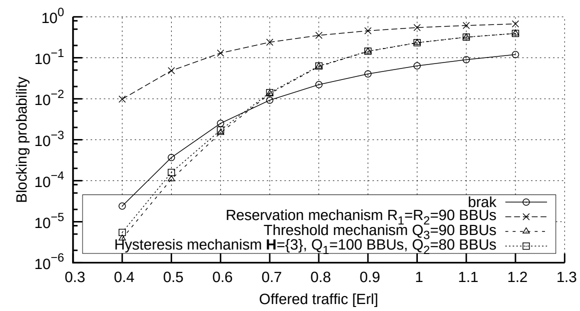

Figure 2. Blocking probability for calls of class 2 in relation to the applied resource access control mechanism

the traffic intensity being increased, a reverse situation was observed (Figure 2). For classes that undergo the introduced proper threshold mechanisms or threshold mechanisms with hysteresis, it was observed that the blocking probability was always lower than the blocking probability in networks without introduced relevant mechanisms (Figure 3). This behavior of the system results from the fact that calls of classes that undergo the threshold mechanisms are allocated the number of BBUs that is not higher, and in many cases lower, than in the case of switching networks without threshold mechanisms.

The blocking probability in switching networks with reservation mechanisms for traffic classes that undergo these mechanisms is always higher than the blocking probability in networks with no introduced mechanisms (Figure 2). Whereas in the case of classes that do not undergo reservation mechanisms (privileged classes), the blocking probability is always lower than the blocking probability in networks without new call admission control mechanisms (Figure 3). Such a behavior of

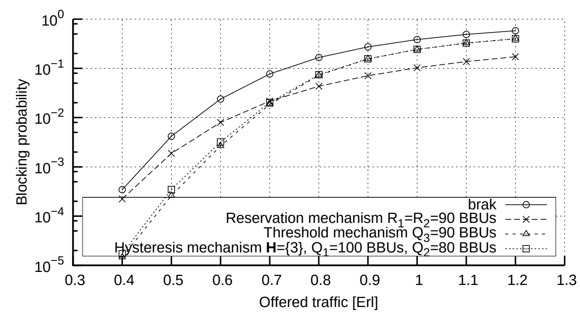

Figure 3. Blocking probability for calls of class 3 in relation to the applied resource access control mechanism

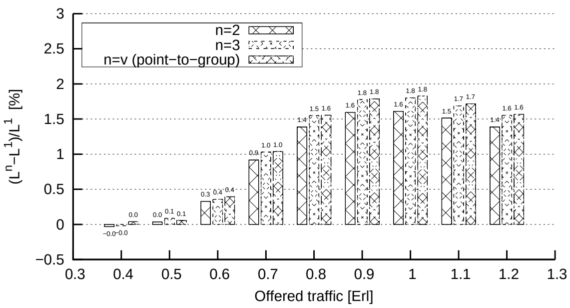

Figure 4. Percentage change in the value of carried traffic in relation to the number of attempts to set up a connection

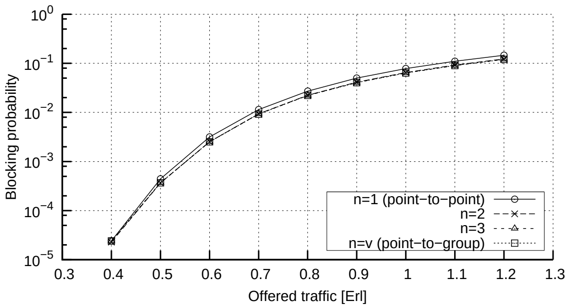

Figure 5. The blocking probability for calls of class 2 in relation to the number of attempts to set up a connection

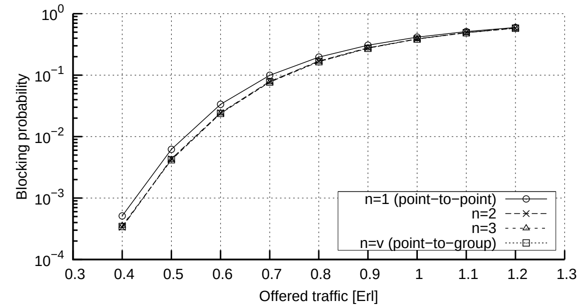

Figure 6. The blocking probability for calls of class 3 in relation to the number of attempts to set up a connection

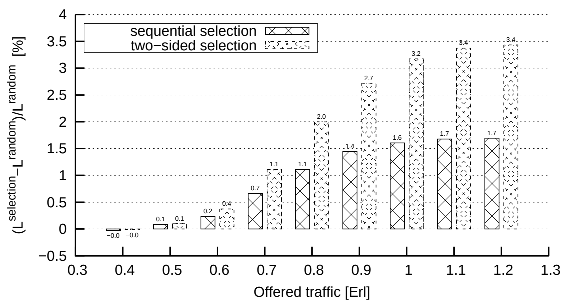

Figure 7. Percentage change in the value of carried traffic in relation to the link occupation strategy

the system results from the fact that for classes for which reservation boundaries have been defined the area of available network resources has been thus limited (decreased). In turn, for classes that do not undergo the reservation mechanism the whole capacity of the system is available.

B. *Influence of the number of attempts*

As a result of the simulation experiments carried out in the course of the study it was possible to examine the influence of the number of attempts to set up a connection inside the switching network on the values of carried traffic and the blocking probability. The maximum number of attempts to set up a connection in the network is equal to the number of links of a given output direction and is υ. The number of attempts is equal to 1 and corresponds to the point-to-point selection in the switching network, while υ attempts correspond to the point-to-group selection.

The study was performed for the following structure of the switching network: structure of switching network: $\upsilon = 4$, $f = 32$ PJP, $V = 128$ PJP; traffic classes: $m = 3$, $t_{1,0} = 1$ PJP, $\mu_{1,0}^{-1} = 1$, $t_{2,0} = 4$ PJP, $\mu_{2,0}^{-1} = 1$, $t_{3,0} = 8$ PJP, $\mu_{3,0}^{-1} = 1$; sets of traffic sources: $S = 3$, $\mathbb{C}_{\text{Er},1} = \{1\}$, $\eta_{\text{Er},1} = 1$, $\mathbb{C}_{\text{En},2} = \{2\}$, $\eta_{\text{En},2} = 1$, $N_{\text{En},2} = 128$, $\mathbb{C}_{\text{Pa},3} = \{3\}$, $\eta_{\text{Pa},3} = 1$, $S_{\text{Pa},3} = 128$;

While analyzing the systems under consideration in view of the influence of the number of attempts to set up a connection in the network on the value of carried traffic and the values of blocking probabilities, a number of interesting observations can be drawn up.

In many cases, only one attempt to set up a connection between a given input and a given output is not sufficient to determine a free connection path. The probability of finding a free connecting path increases with the increase in the number of attempts of setting up a connection. The highest values of carried traffic have been then observed for networks in which the number of attempts to set up a connection is υ (Figure 4). The blocking probability is the lowest in networks in which the number of attempts to set up a connection is υ. The biggest differences in the values of the blocking probabilities were observed between 1 and 2 attempts (Figures 5-6).

C. *Influence of the link occupation strategy*

The last factor influencing the changes in the values of carried traffic and the values of blocking probabilities to be examined in the study was the link occupation strategy. The relevant simulation experiments were performed to evaluate the influence of the adopted link occupation strategy on the values of carried traffic and the blocking probability. The experiments involved the following strategies: random selection (inter-stage links and output links of the switching network are randomly selected), sequential selection (the selection of inter-stage links of the network and output links begins with the first free link, while links are numbered from 1 to υ), and the so-called two-sided selection (calls of classes with lower demands begin the occupation of links from the numbers $1, 2, ...$, whereas calls of classes that demand the highest number of BBUs to set up a connection occupy links starting from the numbers $\upsilon, \upsilon-1, ...$).

The study was performed for the following structure of the switching network: structure of switching network: $\upsilon = 4$, $f = 32$ PJP, $V = 128$ PJP; traffic classes: $m = 3$, $t_{1,0} = 1$ PJP, $\mu_{1,0}^{-1} = 1$, $t_{2,0} = 4$ PJP, $\mu_{2,0}^{-1} = 1$, $t_{3,0} = 8$ PJP, $\mu_{3,0}^{-1} = 1$; sets of traffic sources: $S = 3$, $\mathbb{C}_{\text{Er},1} = \{1\}$, $\eta_{\text{Er},1,1} = 1$, $\mathbb{C}_{\text{En},2} = \{2\}$, $\eta_{\text{En},2,2} = 1$, $N_{\text{En},2} = 128$, $\mathbb{C}_{\text{Pa},3} = \{3\}$, $\eta_{\text{Pa},3,3} = 1$, $S_{\text{Pa},3} = 128$;

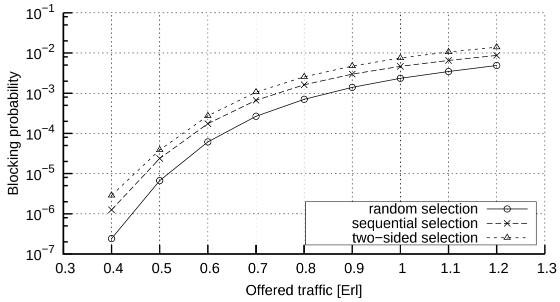

Figure 8. Blocking probability for calls of class 1 in relation to the link occupation strategy

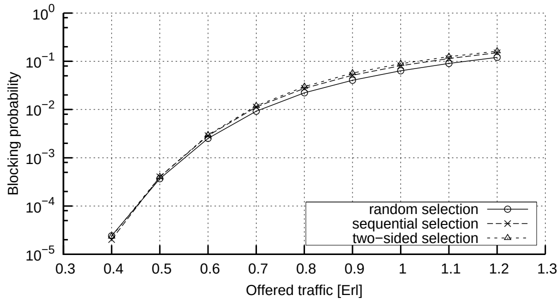

Figure 9. Blocking probability for calls of class 2 in relation to the link occupation strategy

The highest values of carried traffic in the switching network with point-to-group selection were observed for networks with the two-sided selection, whereas the lowest values for networks with the random selection of links (Figure 7). In the analysis of the influence of the link occupation strategy on the blocking probability, for the classes that demanded the highest number of BBUs, the lowest values were observed in the networks with two-sided selection (Figure 10). A reverse situation was recorded for the remaining traffic classes (Figures 8, 9).

VII. CONCLUSION

The papers presents the structure of the simulator of multi-service switching networks with multi-service sources. The developed simulator allows us to determine an influence of the number of attempts to set up a connection and the link occupation strategy on the values of the blocking probability and on the values of carried traffic. In the simulator, a selection of various resource management algorithms has been implemented. The obtained results makes it possible to select the right resource management mechanism to realize an assumed policy (e.g., equalisation of blocking probability of different traffic classes, maximization of the value of carried traffic, etc.). The simulator is also an indispensable tool for evaluation of analytical models of multi-service switching networks with multi-service sources.

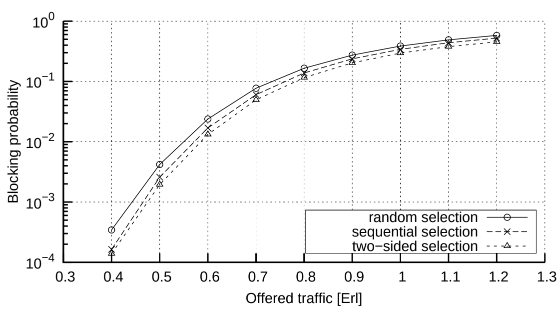

Figure 10. Blocking probability for calls of class 3 in relation to the link occupation strategy

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