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Modelling Pascal traffic in overflow systems

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***Abstract*—In this paper, impact of changes in parameters of offered traffic on the accuracy of determining the parameters of overflow traffic in hierarchical systems with multi-service traffic was presented. Pascal type traffic streams were offered to the considered systems. The study investigated the impact of changes in the number of sources, intensity of traffic offered by individual classes, as well as changes in the traffic offered by a single free source. The presented results are based on determined relative errors of the values of overflow traffic obtained in simulations and on the basis of calculations.**

***Keywords*—negative binomial distribution, Pascal traffic, multiservice traffic, overflow system**

I. INTRODUCTION

THE overflow mechanism is one of the oldest techniques used for optimizing the load of the network resources for the telecommunications traffic. It has gained its popularity because of its ability to maintain the required quality parameters while minimizing the number of required network resources.

The traffic overflow mechanism assumes the division of network resources into two types. The first type includes primary resources, also called direct resources, where the traffic calls offered to the resources origin directly from the users. The second type includes secondary resources, called alternative resources, that serve traffic which was blocked in primary resources (i.e., when all primary resources are occupied).

In general, the first type of the resources has a high level of usage, because it serves the traffic whose intensity results in exceeding the assumed system loss factor. The calls rejected by primary resources, due to their occupancy level, or applied handling policy, are redirected to the second type of resources. These in turn, are characterized with small losses. However, in the case when the current status of secondary resources also does not allow for the redirected calls to be served, then these calls are lost [1], [2].

The first telecommunication systems using traffic overflow were single-service single-channel hierarchical networks [3], [4], [5], [6], [7], [8], [9], [10], [11], [2], [12]. The futher interest on the topic of overflow systems appeared along with networks using the integration of services, for example ISDN (Integrated Services Digital Network) or wireless networks UMTS (Universal Mobile Telecommunications System). Currently, this mechanism has gained its popularity and found many applications, which among others include: optical networks (e.g. in Optical Burst Switching Networks) [13], [14], mobile networks 2G, 3G, 4G [15], [16], [17], [18], [19], [20], [1], [21], packet networks [22], [23], [24] as well as commutation fields [25], [26], [27]. In computer networks, this mechanism is used to improve the performance of cloud computing [28], file organization [29], load balancing [30], [31] and even to reduce energy consumption [32], [33].

The dominant area in the nowadays state of the art literature is the analysis of systems with overflow traffic in the contents of multi-service systems. Multi-service systems with fully available primary resources supporting Erlang traffic are discussed in [34], [35], and serving traffic Engset, Erlang and Pascal in [36], [37], [4]. In addition, the models with flexible traffic services were considered in [22], [24], [38], [39] and adaptive traffic services are discussed in [39], [38], [39]. Single-service and multi-service overflow systems with queues were analyzed in [40], [41], [42], [38], [43].

It can be clearly seen, that such a widely used mechanism requires accurate analytical models. Equivalent Random Traffic (ERT) models [2], [44] and Fredricks-Hayward (FH) [4] have proved to be the most relevant in the field of traffic engineering. Both models are based on the values of the first two moments, i.e. the value of the average intensity of the overflow traffic as well as its variance, which determined based on the so-called Riordan formulas. The values of these two moments are then used to describe non-Erlang traffic streams. The accuracy with which these parameters are determined has a significant impact on the resulting values of the blocking probability in secondary resources.

It can be further noted, that the observed traffic flows in today's multilayer networks are increasingly showing the nature of a negative binomial distribution called the Pascal distribution. The approximation methods for this type of traffic were proposed in [11], [45], [46], [47].

The assessment of the methods used to estimate the parameters of multi-service Pascal traffic overflowing from the primary resources, is essential to determine the accuracy of the entire model.

This paper presents a simulation model of a multi-service system that serves the overflow Pascal traffic. The model is used to determine the impact of the number of traffic sources, the intensity of offered traffic and the intensity of traffic offered by one free source on the traffic characteristics of the systems as well as the accuracy of analytical models. The article is organized as follows. In Section II hierarchical system with overflow traffic is shown. Section III contains the results of simulation tests carried out. In Section IV analysis of the results obtained is included. The last section contains the summary of the article.

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II. HIERARCHICAL NETWORKS WITH OVERFLOW TRAFFIC

A. *The characteristics of the primary resource traffic*

The diagram of the fully available multi-service, overflow system supporting Pascal-type traffic is presented in Fig. 1. The presented system consists of K primary resources, which are offered with the traffic streams of m classes. Each j $(0 < j \leq K)$ resource has a specific capacity of $C_{v,j}$.

The calls are defined as packet streams [48], [49]. The average value of the intensity of the calls of a single free source $\gamma_{i,j}$ of each class i $(0 < i \leq m)$ in the j^{th} resource as well as the average value of the intensity of the service stream $\mu_{i,j}$, are consistent with the exponential distribution. Each call requests t_i allocation units, which are equivalent to the largest common divisor of requested bit rates (e.g. 1 bps, 1 kbps, 1 Mbps).

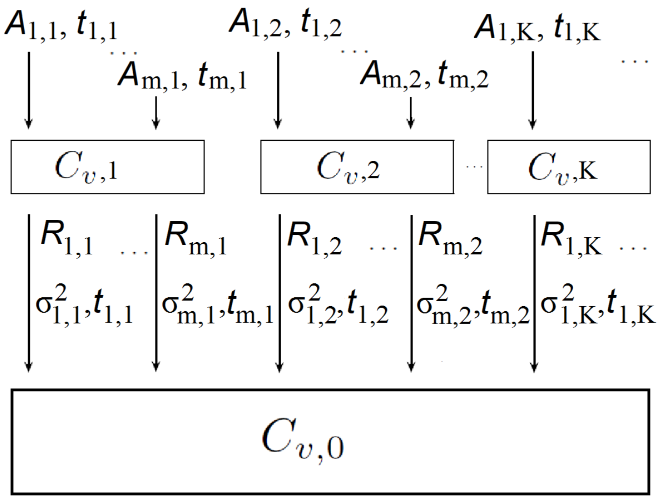

Fig. 1. Diagram of a multiservice system with overflow traffic.

The average intensity of the traffic of class i offered to the j^{th} primary resource in the system with occupancy state equal to n is defined as:

$$\forall_{(1 \leq j \leq K)} \forall_{(i \in M_K)} \;\; A_{i,j}(n) = \alpha_{i,j}[S_{i,j} + n_{i,j}(n)] \qquad (1)$$

where:

- $\alpha_{i,j} = \gamma_{i,j}/\mu_{i,j}$ is the average traffic offered by one free source of class i to the j^{th} resource,
- $\gamma_{i,j}$ is the average intensity of calls generated by one free source of class i and offered to the j^{th} resource,
- $S_{i,j}$ is the number of i^{th} class traffic sources generating the traffic offered to the j^{th} resource,
- $n_{i,j}(n)$ is the average number of i^{th} class traffic sources served by the system in the occupancy state n.

The calls are overflown to the secondary resources when the occupancy status of the primary resource does not allow for their handling. The probability of such an event is determined on the basis of the distribution of the allocation units in primary resources. For resources with a finite number of sources, this distribution can be determined by the MIM-NSD-BPP method (Multiple Iteration Method - Not State Dependent - BPP) [16], taking into account the current number of busy sources in the specific system occupancy states:

$$n[P_n]_{C_j} = \Sigma_{i \in M_K} \alpha_{i,j}[S_{i,j} + n_{i,j}(n - t_{i,j})] t_{i,j} [P_{n-t_{i,j}}]_{C_j} \quad (2)$$

B. *The characteristics of the secondary resource traffic*

The qualitative parameters of secondary resources traffic are determined on the basis of overflow traffic parameters. The calls of the i^{th} class overflown to the secondary resources can be characterized by the following parameters:

- $R_{i,j}$ - the average traffic intensity of class i that overflows from resource j to the secondary resources,
- $\sigma^2_{i,j}$ - variance of traffic intensity of class i that overflows from resource j to the secondary resources.

The calls are lost in the case where there are no sufficient secondary resources available.

Both the average value of the overflow traffic and its variance are determined by the Riordan formulas [2]:

$$R_{i,j} = A_{i,j} E_{C_{v,j}}(A_{i,j}) \qquad (3)$$

$$\sigma^2_{i,j} = R_{i,j}\left[\frac{A_{i,j}}{C_{v,j} + 1 - A_{i,j} + R_{i,j}} + 1 - R_{i,j}\right] \qquad (4)$$

where:

- $A_{i,j}$ is the average traffic intensity of class i offered to the resource j,
- $C_{v,j}$ is the capacity of the resource j,
- $E_v(A)$ is the blocking probability determined by the B-Erlang Formula:

$$E_C(A) = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}} \qquad (5)$$

However, the formulas above were defined for systems that support only one class of Erlang traffic with requests equal to 1 BBU (Basic Bandwidth Unit). Therefore to adopt these formulas to the multi-service traffic, additional operations are necessary [39] as shown in Fig. 2.

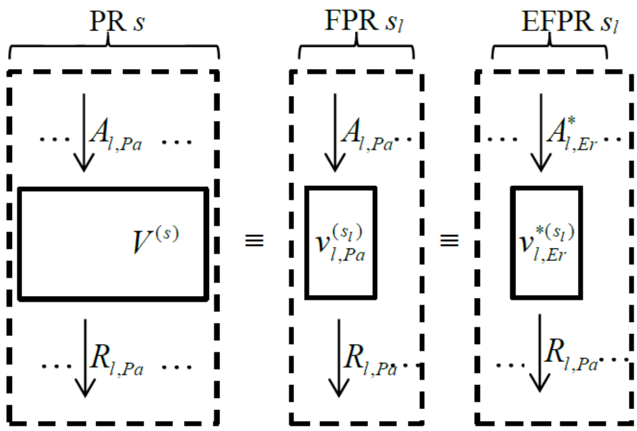

Fig. 2. Decomposition of the primary resource

The procedure shown in Fig. 2 is as follows. First, the primary resource (PR) is divided into smaller resources which number is equal to the number of classes of offered traffic. These resources are called fictitious primary resources (FPR). Each newly created resource supports only one class of traffic with a certain virtual capacity, allowing to obtain the same blocking probability as in the case of multi-service resource. Next the classes that are not of Erlang type are changed to that type using the ERT (Equivalent Random Traffic) method [45].

C. Simulation model

In order to analyze the accuracy of the presented system model, a simulator implementing the above assumptions has been designed. The source code was written in the programming language $C\#$ using a discrete-event simulation models. The simulator works as a discrete system with continuous time. This means that the occupation of resources as well as the activity of sources change in an abrupt manner, but at any time. Acceptance of a call request is a conditional event, because it depends on the state of currently free system resources, while call service is a time-dependent event, because while releasing resources, it is not necessary to meet additional conditions. The calls (events) are offered to the primary resources, and in the event of their blocking, subsequently overflown to the secondary resource. The probability of blocking of the secondary resources is determined as the ratio of the time during which the system is in the busy state and does not allow the calls of the given class to be accepted to the whole simulation time.

The simulator's operation is based on the list ordered in time with information about the planned occurrence of calls and their termination. Adding a new item to the list requires the list to be sorted again in time. The conditions for accepting a given call for service must be met at the time of its scheduled occurrence. Starting the service causes an occupancy of required system resources and generation of random service time. When the call is served, the occupied resources are released. Once the operation related to the given element of the list is completed, it is removed from the list and the program goes to the next event.

D. Model of Pascal traffic

Pascal traffic type assumes a finite number of sources. The number of sources being able to generate a new call increases when the call of a given class is accepted for service. As a result, the maximum number of sources is equal to the sum of the initial number of sources and the number of calls of a given class that can be handled by the system at a given time.

In the elaborated simulator, the initial number of sources generates the times of upcoming events. Processing an event, i.e., accepting a new call for service, generates two time-events: a standard one and the one related with its derivative event. The same rule applies to derivative events, so the overall relationships can be multi-level. The termination of service deletes the event from the list and all associated derivative events that have not yet been accepted for service.

III. Results of the simulation experiments

The simulator was used to study the effectiveness of overflow systems supporting Pascal traffic. In the article, the results obtained for three multi-service systems are presented. The evaluations were carried out for each of the systems using different number of traffic sources. For a given value of traffic a offered to one Basic Bandwidth Unit (BBU), such a change directly resulted in a change in the intensity of traffic offered by one free source. The parameters of the evaluated systems are as follows:

1) System No. 1
   a) Primary resources:
      - $C_{v,1} = 60$ BBU,
      - offered traffic: $t_{1,1} = 1$ BBU, $t_{2,1} = 2$ BBU,
      - proportions of offered traffic: $A_{1,1}t_{1,1} : A_{2,1}t_{2,1} = 1 : 1$,
   b) Secondary resources:
      - $C_{v,0} = 10$ BBU,
   c) Number of traffic sources:
      - $S_{1,1} = 40$, $S_{2,1} = 30$,
      - $S_{1,1} = 20$, $S_{2,1} = 15$,
      - $S_{1,1} = 80$, $S_{2,1} = 60$.
2) System No. 2
   a) Primary resources:
      - $C_{v,1} = 50$ BBU,
      - offered traffic: $t_{1,1} = 1$ BBU, $t_{2,1} = 2$ BBU, $t_{3,1} = 4$ BBU,
      - proportions of offered traffic: $A_{1,1}t_{1,1} : A_{2,1}t_{2,1} : A_{3,1}t_{3,1} = 1 : 1 : 1$,
   b) Secondary resources:
      - $C_{v,0} = 20$ BBU,
   c) Number of traffic sources:
      - $S_{1,1} = 40$, $S_{2,1} = 20$, $S_{3,1} = 10$,
      - $S_{1,1} = 20$, $S_{2,1} = 10$, $S_{3,1} = 5$,
      - $S_{1,1} = 80$, $S_{2,1} = 40$, $S_{3,1} = 20$.
3) System No. 3
   a) Primary resources:
      - $C_{v,1} = 45$ BBU,
      - offered traffic: $t_{1,1} = 1$ BBU, $t_{2,1} = 3$ BBU,
      - proportions of offered traffic: $A_{1,1}t_{1,1} : A_{2,1}t_{2,1} = 1 : 1$,
   b) Secondary resources:
      - $C_{v,0} = 10$ BBU,
   c) Number of traffic sources:
      - $S_{1,1} = 50$, $S_{2,1} = 20$,
      - $S_{1,1} = 25$, $S_{2,1} = 10$,
      - $S_{1,1} = 100$, $S_{2,1} = 40$.

IV. Analysis of the obtained results

Figures 3–5 show the results of the probability of blocking in alternative resources for System No. 1, 2 and 3.

In the article, the relative error between analytical results and simulation data was used as the basis for analyzing the accuracy of the discussed method (Equation 3). Figure 6

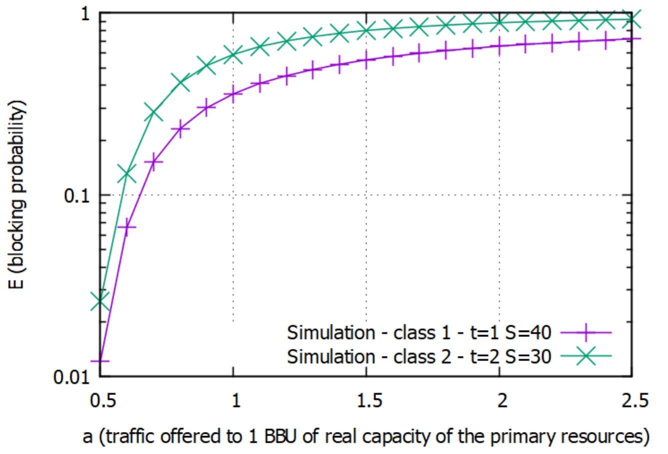

Fig. 3. The blocking probability of individual traffic classes in the secondary resources of the considered overflow system No. 1 for $S_{1,1} = 40$, $S_{2,1} = 30$.

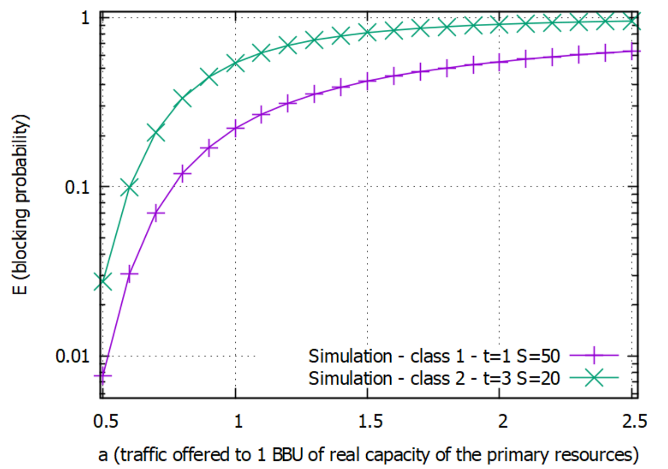

Fig. 5. The blocking probability of individual traffic classes in the secondary resources of the considered overflow system No. 3 for $S_{1,1} = 50$, $S_{2,1} = 20$.

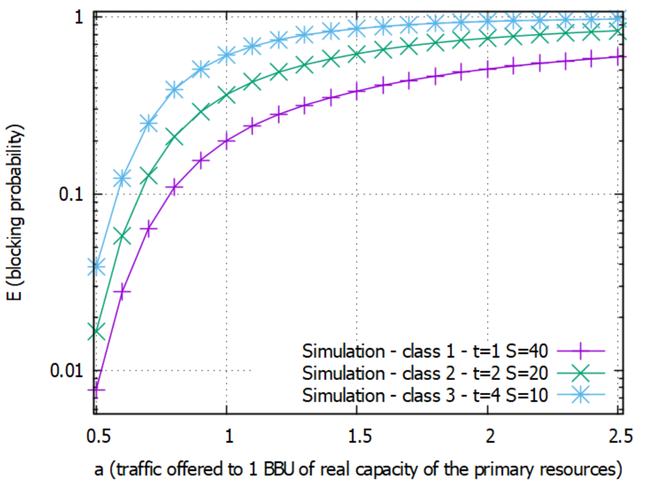

Fig. 4. The blocking probability of individual traffic classes in the secondary resources of the considered overflow system No. 2 for $S_{1,1}$ = 40, $S_{2,1}$ = 20, $S_{3,1} = 10$.

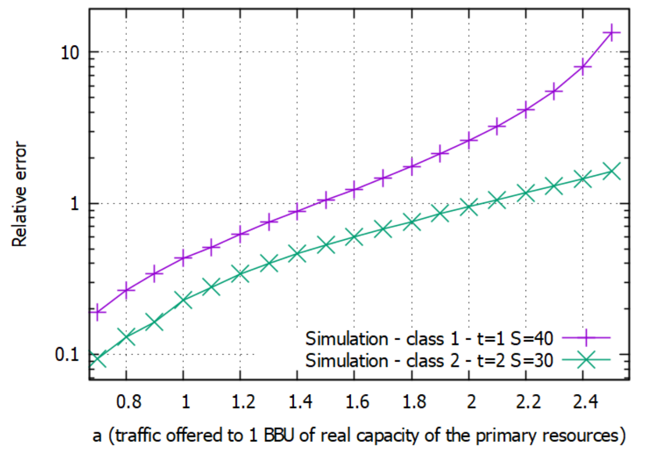

Fig. 6. Change in the relative error of the average value of overflow traffic against of the average value of traffic offered to one BBU a.

presents changes in the relative error of the average value of the overflow traffic R for both classes of system No. 1. As the offered traffic increases, one can notice a decrease in the accuracy of the calculated average value of the transferred traffic. Figure 7 shows the same dependency in system 3.

Figure 8 shows the result obtained in System No. 2 for the third class ($t_{3,1} = 4$ BBU) for different number of S traffic sources. The class with $S = 10$ sources showed the lowest accuracy of calculations in relation to the obtained simulation results. The graph shows that in this particular case an increase or decrease in the number of sources has a positive effect on the relative error of the calculated average values of transferred traffic. The reason here is the average traffic intensity offered by one free source α. In this example it was in the range of 0.5-1.0 Erl. As confirmed by additional simulations, this range introduces the largest errors in the discussed method. At a constant value of a, the α depends only on the number of sources S.

The same dependence can be observed in Figure 9, presenting the results obtained in System No. 3 for the second class ($t_{2,1} = 3$ BBU), for different number of traffic sources. In this case, the class with the smallest number of sources for the presented range had the average traffic intensity offered by one free source α in the range 0.5-1.0 Erl.

Figure 10 shows the results obtained for class 2 of System No. 1 for different values of traffic offered by a single source.

As we can notice, the number of sources has a direct influence on the accuracy of calculations of the average value of overflow traffic R. For the lower number of sources the value of relative error of the calculated average value of the overflow traffic R is lower. However, this parameter has much less effect than the α parameter value. The same dependence can be observed in Figure 11 presenting the results for class 1 of System No. 2.

The study was conducted for the traffic offered to one Basic Bandwidth Unit with intensity values range from $0.5 \div 2.5$ Erl.

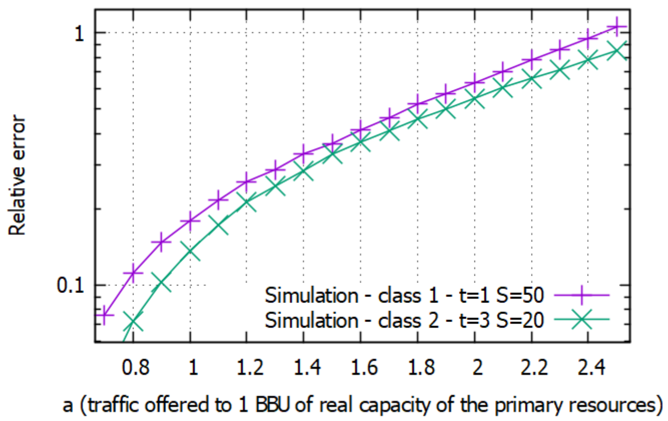

Fig. 7. Change in the relative error of the average value of overflow traffic against of the average value of traffic offered to one BBU a.

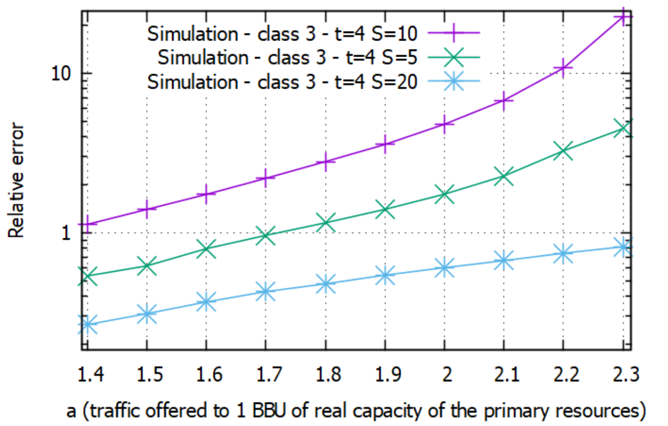

Fig. 8. Change in the relative error of the average value of overflow traffic against of the average value of traffic offered to one BBU a.

The simulation for each value was conducted in five series, counting 1,000,000 applications for each of them.

V. Summary

The article presents the simulation model of a multi-service system with overflow traffic. In the considered system, traffic was generated by Pascal-type traffic. A detailed analysis of the obtained results allowed to determine the impact of changes in individual traffic parameters (intensity of offered traffic, number of sources, intensity of traffic offered by one free source) of the considered systems on the accuracy of determining the average value of traffic overflown to the secondary resources. The result data sets were presented as relative errors and percentage of relative errors between analytical and simulation values. The obtained results can be used to identify the limitations of the analytical models. This, in turn, allows us for more efficient use of the model and at the same time gives a solid foundation for the future work on this topic.

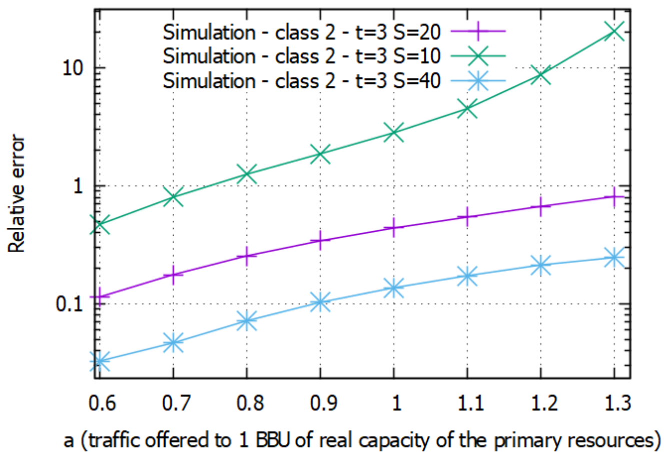

Fig. 9. Change in the relative error of the average value of overflow traffic against of the average value of traffic offered to one BBU a.

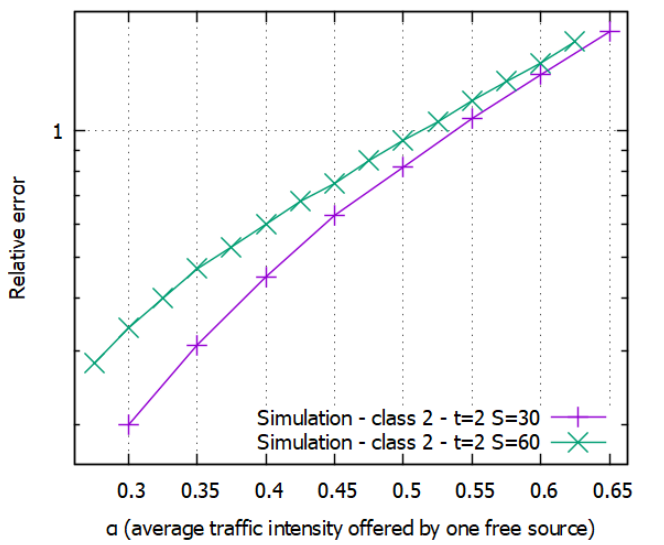

Fig. 10. Change in the relative error of the average value of overflow traffic against of the traffic offered by one free source α.

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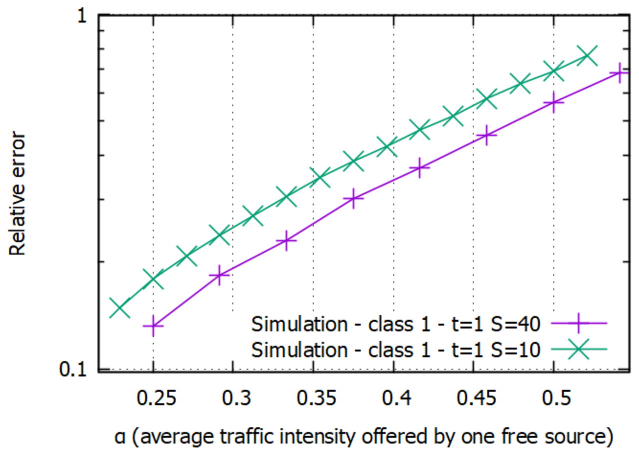

Fig. 11. Change in the relative error of the average value of overflow traffic against of the traffic offered by one free source α.

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