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OVERFLOWS OF ELASTIC TRAFFIC

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Abstract. This article presents the results of a study on hierarchical multiservice traffic overflow systems. The systems under investigation were composed of a number of primary resources and one alternative resource. Traffic in the considered systems was generated with the assumption that there was a finite number of traffic sources in individual classes. Further assumption was that offered traffic is elastic traffic for which – with an increase of the load of the system – a change in the volume of allocated resources is possible followed by concurrent extension of their service time. The article includes the results that present the blocking probability in the sample elastic traffic overflow systems. The study focuses on a determination of the influence of the traffic intensity, volume of resources, degree of compression, resource with compression (primary resources, alternative resources) and the cardinality of traffic sources on values of the blocking probability in individual call classes and on the number of calls that overflow to the alternative resource.

1 Introduction

The traffic overflow mechanism is applied in optimization of network resources, irrespective of the actual networking technology involved. The possibility to limit the amount of network resources being used offered by the operation of the mechanism, simultaneously with guaranteed demanded quality parameters being retained, has resulted in its wide application in both Public Switched Telephone Networks [2, 5, 25–27, 29, 32], 2G, 3G, and 4G mobile networks [4, 9, 17, 19, 20, 28, 30, 31] and packet networks [6, 8, 10].

In traffic overflow systems, irrespective of the technology used, we can always distinguish the so-called primary resources, called primary groups or direct groups in traffic engineering, and alternative resources, otherwise known as secondary groups or alternative groups. Call streams are offered as first to primary resources. In a situation where a given primary resource cannot service a call of a given traffic class, this call is transferred, i.e. "overflows", to the alternative resource. Only when it cannot be serviced in the alternative resources, the call is lost [32]. The main reason for the lack of possibility of servicing a call of a given class in primary or alternative resources is most frequently full occupancy of resources or implemented specific call admission policy that bases its acceptance decisions on predefined rules according to which even if free resources are available, no calls of a given class can be admitted. One of the most widely used mechanisms that influence the call admission process are resource reservation mechanisms [12, 14, 15] and threshold mechanisms [7, 13, 21, 22].

To analyze the effectiveness of systems with traffic overflow, simulation and analytical methods are capable enough and can be used alike. In the case of single-service systems, one of the most effective analytical methods include: Equivalent Random Traffic (ERT) method [32] and Hayward's method [5]. High accuracy of these methods makes it possible to omit time-consuming simulation studies. In the ERT method, to describe overflow traffic two moments are used, i.e. the average value of overflow traffic and its variance. These moments allow equivalent systems servicing call streams with Poisson distribution to be constructed. Modelling of single-service overflow systems in Hayward's method is, in turn, based on the proposed modification to Erlang's formula that takes into consideration variance of overflow traffic.

An introduction of the multirate-network (with integrated services), the first multi-service wireless networks (UMTS) in particular, has revived the interest in the traffic overflow mechanism and aspirations in the pursue to develop accurate methods for the analysis of multi-service network systems with traffic overflow, which is documented, for example, in [3, 4, 16, 18–20, 28, 30, 31]. Perhaps one of the most effective methods in this group of methods is the one based on Hayward's generalization and proposed in [11] and [17]. This method, the so-called multi-service Hayward approximation, allows quick analytical determination of the blocking probability in alternative groups to be achievable, without any necessity to carry out time-consuming simulation experiments. At the same time, the accuracy of calculations offered by the method makes the method fully applicable in engineering practice at the stage of dimensioning and designing multi-service overflow systems.

The gradual migration of wireless networks from the solutions based on the ATM technology (Asynchronous Transfer Mode) towards those based on the TCP/IP protocol pile has effected in elastic traffic streams, i.e. traffic streams with variable bit rate – in line with the operation of the TCP protocol – depending on the load of the network, to be taken into consideration in the process of modelling of multi-service overflow systems. Initial work on modelling these systems is presented in [6] and [10]. The solutions obtained in the process make analytical determination of the blocking probability possible in systems with elastic overflow traffic generated with assumption of infinite number of traffic sources of individual classes, i.e. with the assumption that call streams are of Poisson nature.

To the best knowledge of the authors, until now the literature of the subject has not addressed overflow systems in which elastic traffic would be generated with the assumption of a finite number of traffic sources. The present article presents a novel simulation model of a multi-service overflow system that services elastic traffic in both primary and secondary resources and that is generated with the assumption of a finite number of traffic sources. The results of the study presented in the article make it possible to determine the influence exerted on the traffic characteristics of systems by such parameters as: the number of traffic sources, degree of acceptable compression of traffic streams, possibility of compression in primary and secondary resources and the volume (size) of systems.

The article is structured as follows. In Section 2, the analyzed system with elastic traffic generated with the assumption of a finite number of traffic sources and with call overflow to alternative resources is characterized. Section 3 presents the results of the conducted simulation experiments. Section 4 provides the reader with a detailed analysis of the obtained results. Section 5 concludes the paper.

2 Hierarchical system with elastic overflow traffic

2.1 Parameters of traffic offered to primary resources

Figure 1 shows a diagram of a multi-service overflow system with elastic traffic. With elastic traffic streams it is possible to decrease the volume of allocated resources (most frequently bit rate) in states of a high load of the network (compression) with concurrent extension of their service time [33, 34]. The basic protocol that would make dynamic adjustment of bit rates of a traffic stream to the current load of the network possible, is the TCP protocol [24].

In the case of the considered system with overflow traffic we can distinguish K primary resources. The primary resources j $(0 < j \leq K)$ have real capacity $C_{r,j}$. Each of the resources can service m classes of elastic traffic. Calls of class i $(0 < i \leq m)$ are carried with the average intensity of λ_i and demand initially t_i the so-called allocation units (AU) for service, while the intensity of the service stream (consistent with the exponential distribution) of one demand t_i is μ_i. The average intensity of offered traffic of class i offered to the primary resources j $(0 < j \leq K)$ can be then expressed with the following formula:

$$A_{i,j} = \lambda_i / \mu_i. \tag{1}$$

When there are no t_i unoccupied resources in the primary group, in order to service a call of class i a compression of all serviced calls in the system has to be introduced. This means a decrease in the bit rate of serviced calls to the values that would make service of a new call possible, i.e. with the same level of compression as the calls that are being serviced in the system. The assumption adopted in the article is that the compression of resources allocated to individual calls will be taken into consideration thanks to the introduction of the so-called virtual capacities $C_{v,j}$, corresponding to appropriate (relevant) real capacities $C_{r,j}$. A degree of compression can be thus defined as the ratio of the virtual capacity of a resource to the real capacity: $C_{v,j}/C_{r,j}$. If, despite compression of demands (and the extension of their service time), a new call cannot be admitted in the primary resources, then it overflows – in its uncompressed form – to the secondary resources with the real capacity $C_{r,0}$ AUs and virtual capacity $C_{v,0}$. A call of class j that overflows from the primary resources to the secondary resources can be described with the following parameters:

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

Calls that cannot be serviced by secondary resources due to a lack of free AUs will be dropped (lost).

3 Results of the simulation experiments

The study on the effectiveness of systems with elastic traffic overflow (with compression) was carried out for three sample multi-service systems. Studies were performed for each of the systems for different values of virtual resources that determined a degree of compression, in both primary and secondary resources. The virtual capacities of both, primary and secoundary resources used in the

It is adopted in the article that a *call* (otherwise known in literature as flow or stream) is defined as a packet stream or its fragment related to a service executed in the network [1, 23]. In engineering considerations, it is the bit rate unit appropriate for a system under consideration that is often chosen as AU (allocation unit) (e.g. 1 bps, 1 kbps, 1Mbps).

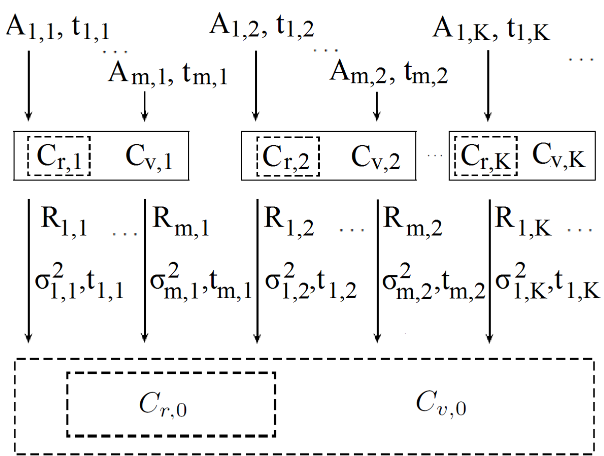

Fig. 1: Diagram of a multi-service overflow system with elastic traffic

systems were: 0 (no compression), 20, 40, 60, and 80 AU. The parameters for the systems under investigation were as follows:

1. System nr 1
   (a) Primary resources 1:
      - $C_{r,1}$ = 40 AU,
      - offered traffic: t_1 = 10 AU, t_2 = 6 AU, t_3 = 8 AU,
      - proportions of offered traffic: $A_1 t_1 : A_2 t_2 : A_3 t_3 = 1 : 1 : 1$,
      - number of traffic sources: n_1 = 40, n_2 = 80, n_3 = 60;
   (b) Primary resources 2:
      - $C_{r,2}$ = 80 AU,
      - offered traffic: t_1 = 6 AU, t_2 = 4 AU, t_3 = 8 AU,
      - proportions of offered traffic: $A_1 t_1 : A_2 t_2 : A_3 t_3 = 1 : 1 : 1$,
      - number of traffic sources: n_1 = 80, n_2 = 80, n_3 = 60;
   (c) Primary resources 3:
      - $C_{r,3}$ = 60 AU,
      - offered traffic: t_1 = 10 AU, t_2 = 6 AU, t_3 = 8 AU,
      - proportions of offered traffic: $A_1\ t_1 : A_2\ t_2 : A_3\ t_3 = 1 : 1 : 1$,
      - number of traffic sources: n_1 = 40, n_2 = 80, n_3 = 60;
   (d) Secondary resources:
      - $C_{r,0}$ = 100 AU.
2. System 2
   (a) Primary resources 1:
      - $C_{r,1}$ = 40 AU,
      - offered traffic: t_1 = 5 AU, t_2 = 3 AU, t_3 = 4 AU,
      - proportions of offered traffic: $A_1\ t_1 : A_2\ t_2 : A_3\ t_3 = 1 : 1 : 1$,
      - number of traffic sources: n_1 = 20, n_2 = 60, n_3 = 40;
   (b) Primary resources 2:
      - $C_{r,2}$ = 80 AU,
      - offered traffic: t_1 = 3 AU, t_2 = 2 AU, t_3 = 4 AU,
      - proportions of offered traffic: $A_1\ t_1 : A_2\ t_2 : A_3\ t_3 = 1 : 1 : 1$,
      - number of traffic sources: n_1 = 60, n_2 = 60, n_3 = 40;
   (c) Primary resources 3:
      - $C_{r,3}$ = 60 AU,
      - offered traffic: t_1 = 5 AU, t_2 = 3 AU, t_3 = 4 AU,
      - proportions of offered traffic: $A_1\ t_1 : A_2\ t_2 : A_3\ t_3 = 1 : 1 : 1$,
      - number of traffic sources: n_1 = 20, n_2 = 60, n_3 = 40;

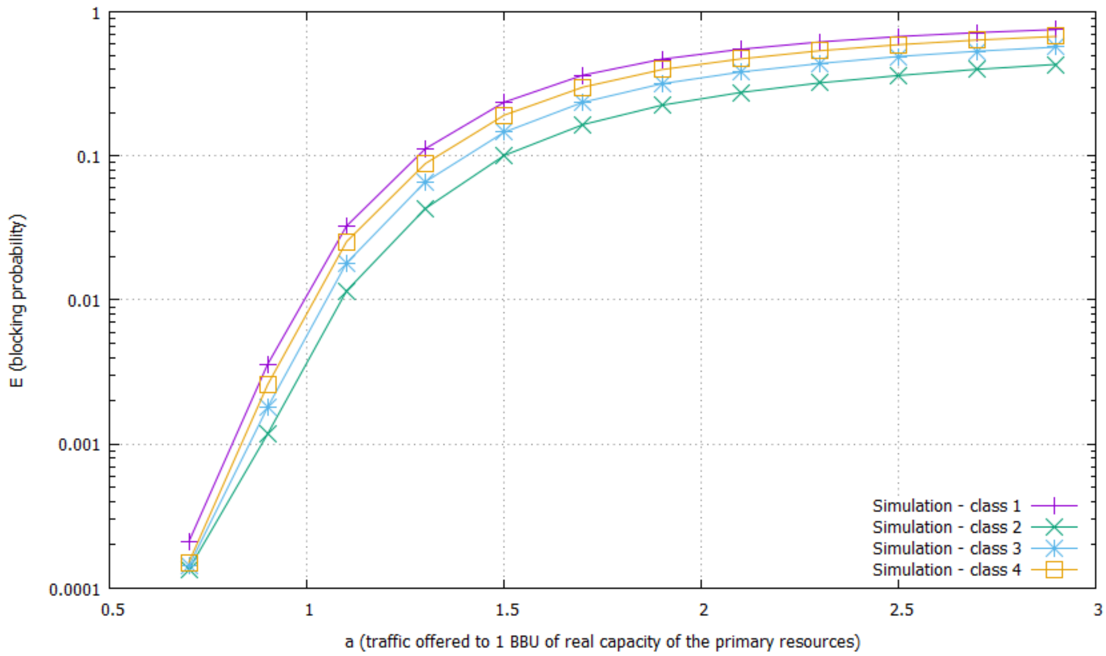

Fig. 2: Blocking probability of particular traffic classes in the alternative resources of the considered overflow System 1 without compression.

(d) Secondary resources:

- $C_{r,0}$ = 100 AU.

3. System 3

(a) Primary resources 1:

- $C_{r,1}$ = 40 AU,
- offered traffic: t_1 = 5 AU, t_2 = 3 AU, t_3 = 4 AU,
- proportions of offered traffic: $A_1 t_1 : A_2 t_2 : A_3\ t_3$ = 1 : 1 : 1,
- number of traffic sources: n_1 = 10, n_2 = 20, n_3 = 30;

(b) Primary resources 2:

- $C_{r,2}$ = 80 AU,
- offered traffic: t_1 = 3 AU, t_2 = 2 AU, t_3 = 4 AU,
- proportions of offered traffic: $A_1\ t_1 : A_2\ t_2 : A_3\ t_3$ = 1 : 1 : 1,
- number of traffic sources: n_1 = 20, n_2 = 30, n_3 = 30;

(c) Primary resources 3:

- $C_{r,3}$ = 60 AU,
- offered traffic: t_1 = 5 AU, t_2 = 3 AU, t_3 = 4 AU,
- proportions in offered traffic: $A_1\ t_1 : A_2\ t_2 : A_3\ t_3$ = 1 : 1 : 1,
- number of traffic sources: n_1 = 10, n_2 = 20, n_3 = 30;

(d) Secondary resources:

- $C_{r,0}$ = 100 AU.

4 Analysis of the obtained results

Figures 2– 4 show the results for the blocking probability in the alternative resources with the assumption that in each of the considered systems no compression has

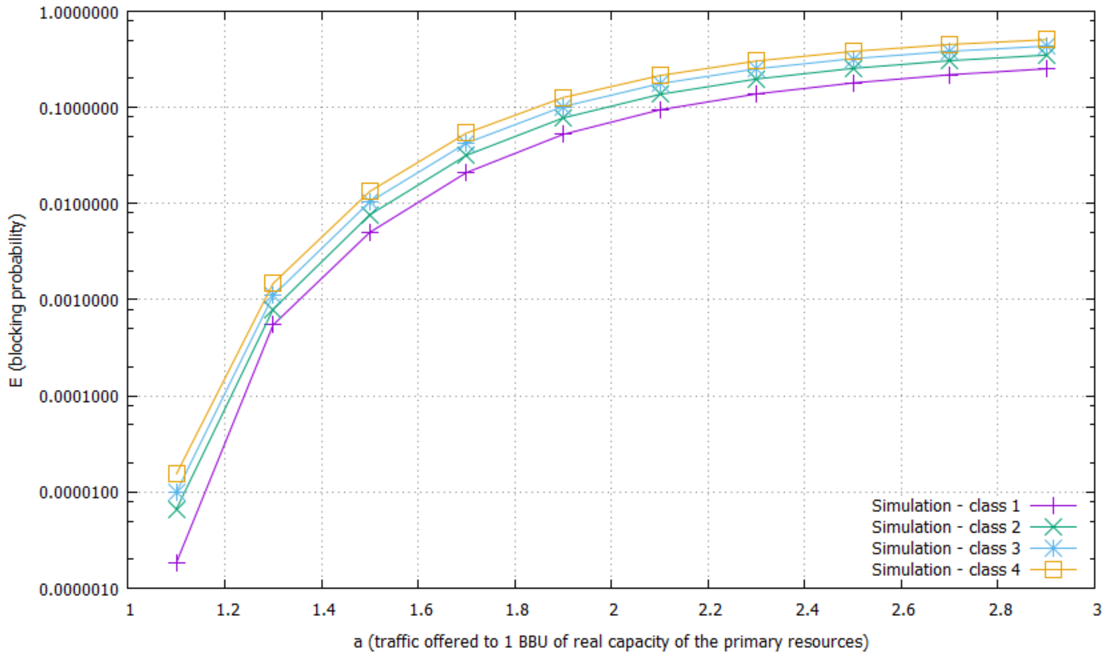

Fig. 3: Blocking probability of particular traffic classes in the alternative resources of the considered overflow System 2 without compression.

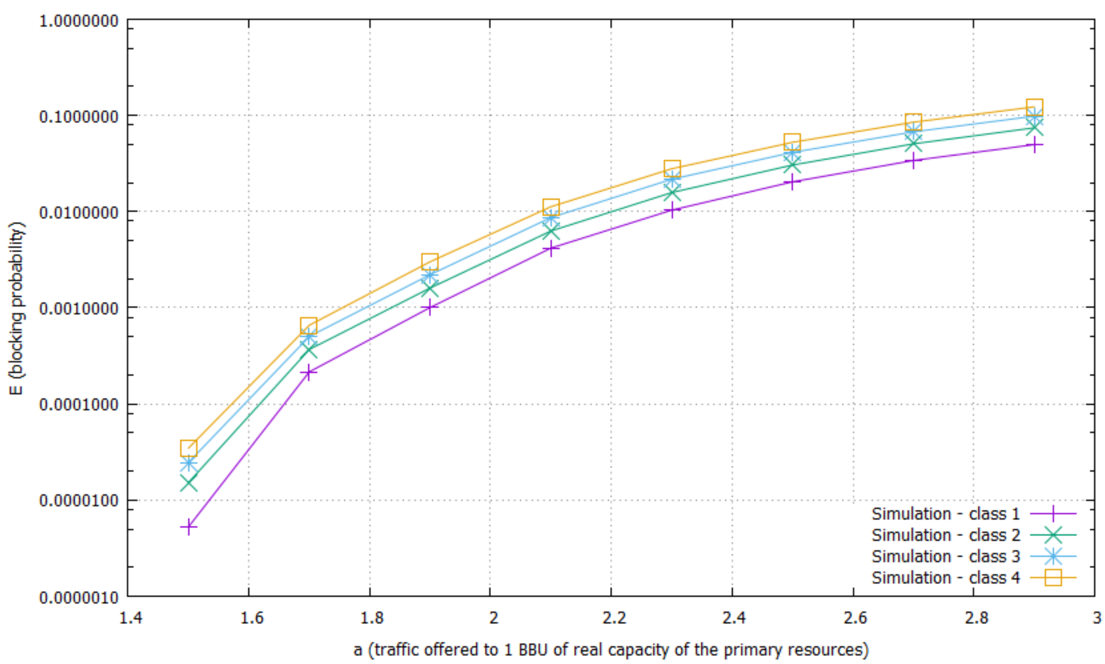

Fig. 4: Blocking probability of particular traffic classes in the alternative resources of the considered overflow System 3 without compression.

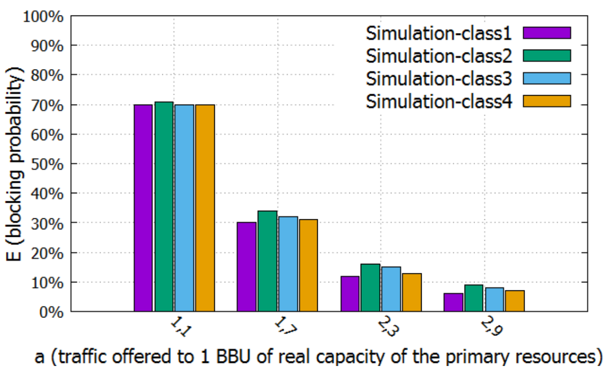

Fig. 5: Percentage change in the blocking probability for System 1 effected by the introduction of compression in one of the primary resources. The virtual capacity used in the system was equal to 40 AU.

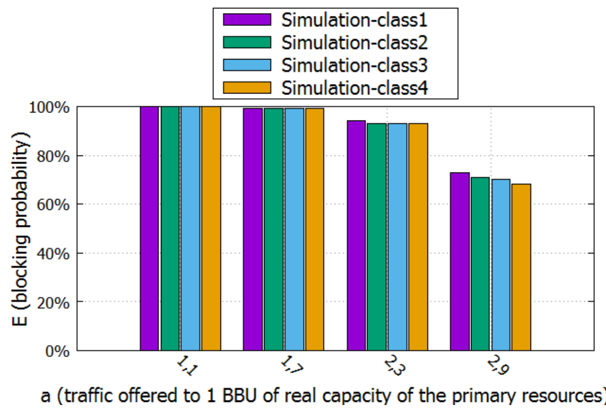

Fig. 6: Percentage change in the blocking probability for System 2 effected by the introduction of compression in each of the primary resources and in the secondary resources. The virtual capacities used in the system were equal to 20 AU.

been introduced to any of its resources (primary or secondary). Then, Figures 5– 8 present the simulation results for particular increasing values of virtual areas (defining a degree of compression) that correspond to the results obtained for the same system with real capacities only. A comparison that shows the changes in the blocking probability in the alternative resources resulting from the application of compression of allocated resources is presented in Figures 9– 18. A detailed comparative analysis for the obtained results allows us to formulate the following conclusions:

1. An introduction of compression in any of the resources is followed by a decrease in the blocking probability of calls in alternative resources. Along with an increase in the intensity of offered traffic, the influence of the virtual capacity used in the system on a decrease in the blocking probability of individual traffic classes in alternative resources decreases (Figures 5– 8).

2. Irrespective of the primary resource to which compression was introduced, it has a similar effect on the values of blocking for all traffic classes that overflow to the secondary group (Figures 5– 8). This dependence makes it possible to compare the values of the

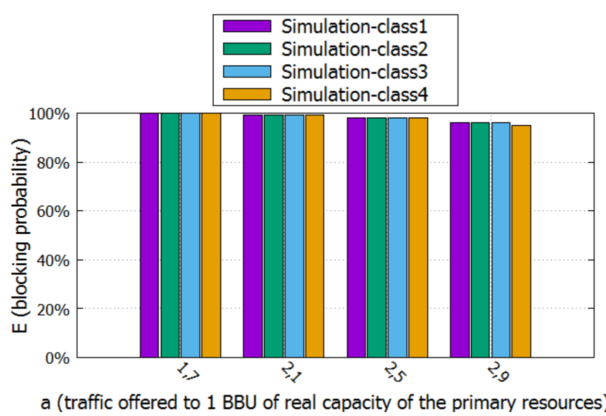

Fig. 7: Percentage change in the blocking probability for System 3 effected by the introduction of compression in the secondary resources. The virtual capacity used was equal to 40 AU.

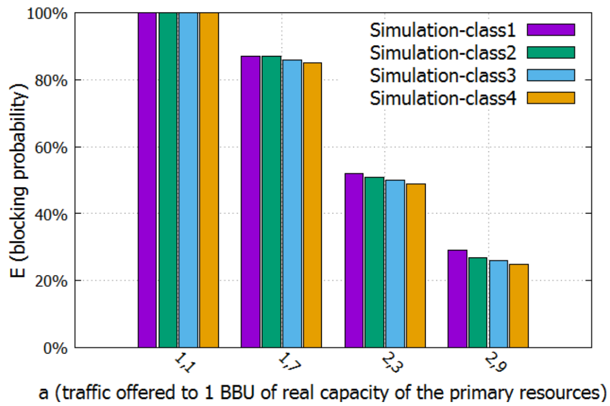

Fig. 8: Percentage change in the blocking probability for System 2 effected by the introduction of compression in one of the primary resources. The virtual capacity used was equal to 40 AU.

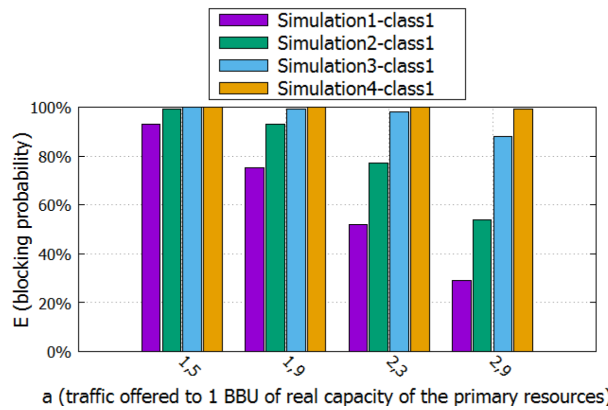

Fig. 10: Percentage change in the blocking probability effected by the introduction of compression for System 2. In simulation 1, the virtual capacity was 40 AU in the primary group; in simulation 2, the virtual capacity was 40 AU in the secondary group; in simulation 3, the virtual capacity was 40 AU in each of the primary groups; in simulation 4, the virtual capacity was 40 AU in each of the primary groups and in the secondary group.

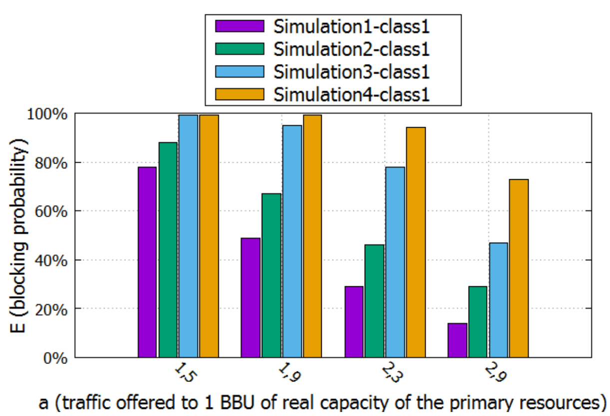

Fig. 9: Percentage change in the blocking probability effected by the introduction of compression for System 2. In simulation 1, the virtual capacity was 20 AU in the primary group; in simulation 2, the virtual capacity was 20 AU in the secondary group; in simulation 3, the virtual capacity was 20 AU in each of the primary groups; in simulation 4, the virtual capacity was 20 AU in each of the primary groups and in the secondary group.

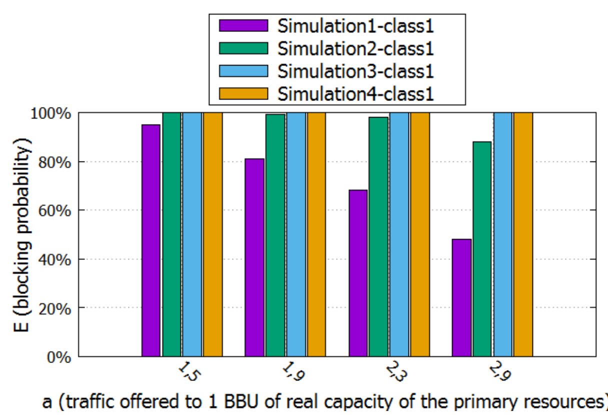

Fig. 11: Percentage change in the blocking probability effected by the introduction of compression for System 3. In simulation 1, the virtual capacity was 80 AU in the primary group; in simulation 2, the virtual capacity was 80 AU in the secondary group; in simulation 3, the virtual capacity was 80 AU in each of the primary groups; in simulation 4, the virtual capacity was 80 AU in each of the primary groups and in the secondary group.

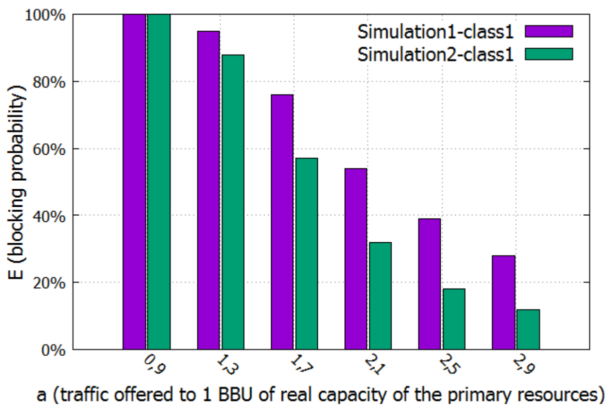

Fig. 12: Percentage change in the blocking probability effected by the introduction of compression for System 1. In simulation 1, the virtual capacity was 60 AU in the secondary group; in simulation 2, the virtual capacity was 20 AU in each of the primary groups.

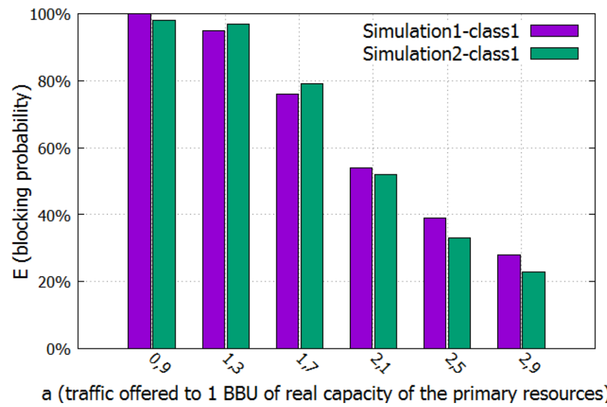

Fig. 14: Percentage change in the blocking probability effected by the introduction of compression for System 1. In simulation 1, the virtual capacity was 60 AU in the secondary group; in simulation 2, the virtual capacity was 20 AU in each of the primary groups and in the secondary group.

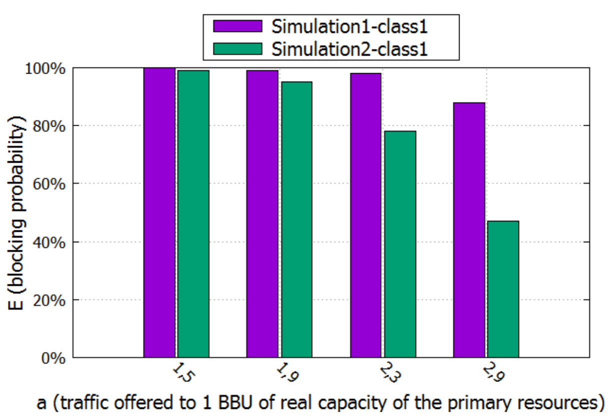

Fig. 13: Percentage change in the blocking probability effected by the introduction of compression for System 2. In simulation 1, the virtual capacity was 80 AU in the secondary group; in simulation 2, the virtual capacity was 20 AU in each of the primary groups.

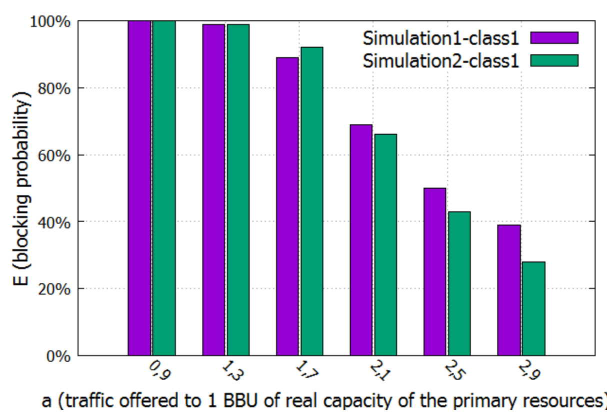

Fig. 15: Percentage change in the blocking probability effected by the introduction of compression for System 1. In simulation 1, the virtual capacity was 80 AU in the secondary group; in simulation 2, the virtual capacity was 40 AU in each of the primary groups.

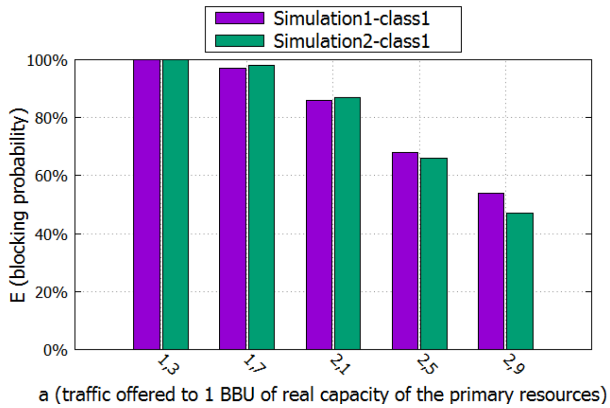

Fig. 16: Percentage change in the blocking probability effected by the introduction of compression for System 2. In simulation 1, the virtual capacity was 40 AU in the secondary group; in simulation 2, the virtual capacity was 20 AU in each of the primary groups.

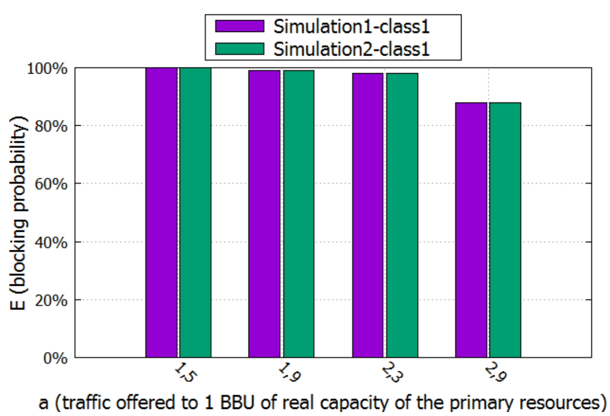

Fig. 17: Percentage change in the blocking probability effected by the introduction of compression for System 2. In simulation 1, the virtual capacity was 80 AU in the secondary group; in simulation 2, the virtual capacity was 40 AU in each of the primary groups.

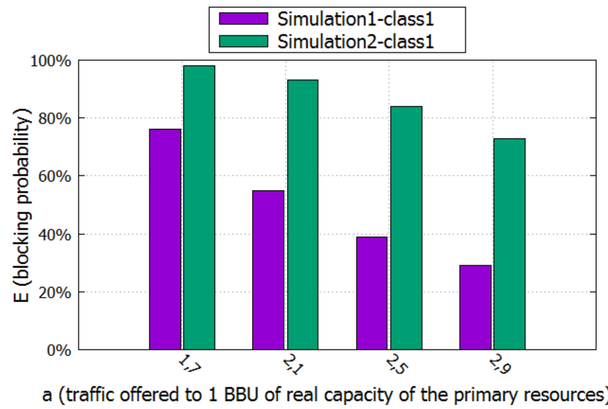

Fig. 18: A comparison showing the changes in the blocking probability with relation to the number of sources. Shown are the differences between System 2 (simulation 1) and 3 (simulation 2) in which the virtual capacity of 20 AU in the secondary group was used.

blocking probability in only one of the classes between the systems in subsequent diagrams.

3. Irrespective of a system type under investigation, the most effective (i.e. one that leads to lower values of the blocking probability) is the application of virtual resources in the secondary group than in any of the primary groups (Figures 9– 11).

4. An introduction of compression in all of the primary groups makes it possible to obtain a lower blocking probability in the alternative resources as compared to an introduction of compression in the secondary group only (Figures 9– 11).

5. The comparison of the systems in which similar values of virtual capacities in the secondary group and primary groups are separated shows that if we have a possibility of introducing compression to one of the types of resources only, then the introduction of compression to secondary resources will be more effective (Figures 12– 13).

6. A gradual increase in the level of compression (virtual capacities) in primary resources allows the

blocking probability for individual classes in the alternative group to be reduced. In the case where the virtual capacity used in primary resources (or primary and secondary) is higher by about 50% than the virtual capacity used in secondary resources, it equalizes their influence upon the system. Even though blocking probabilities are similar, it is observable that for lower traffic intensities the application of capacities in primary resources has a more favourable effect, though with an increase in the traffic intensity this situation is reversed (Figures 14–17).

7. An increase in the number of traffic sources is followed by an increase in the blocking probability of the system, and an increase in the number of calls that overflow to the secondary resource, with the same average value of traffic intensity offered to one allocation unit (Figures 18).

8. When compression is introduced to one of the primary resources only, the best effect (percentage decrease in the blocking probability in the alternative group) is obtained when this compression is used in the resources with the lowest value of $\sum(t_i N_i)$.

5 Conclusion

This article presents a simulation model of a multi-service overflow system with elastic traffic in which both the primary resources and secondary resources are fully available. Traffic in the considered systems was generated with the assuption of a finite number of traffic sources. A detailed analysis of the obtained results have made it possible to determine the influence of changes in particular traffic parameters of the considered systems (compression level, traffic intensity, demands of particular traffic classes and the volume of the system) on the blocking probability of serviced traffic classes. These comparisons have been effected following a juxtaposition of percentage changes in the blocking probability resulting from the introduced compressions. The simulation model presented in the article will open up avenues for further research in the field, in particular on such an analytical model that would make quick and effective dimensioning of hierarchical multi-service systems with both elastic and adaptive traffic possible.

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