UDC 621.39, 004.7

PERFORMANCE EVALUATION OF COMMUNICATION GRIDS WITH CUT-THROUGH SWITCHING NODES

Shmeleva T.R.

A.S. Popov Odessa National Academy of Telecommunications,
1 Kuznechna St., Odessa, 65029, Ukraine.
t.shmeleva@onat.edu.ua

ОЦЕНКА ПРОИЗВОДИТЕЛЬНОСТИ КОММУНИКАЦИОННЫХ РЕШЕТОК С УЗЛАМИ СКВОЗНОЙ КОММУТАЦИИ

Шмелёва Т.Р.

Одесская национальная академия связи им. А.С. Попова,
65029, Украина, г. Одесса, ул. Кузнечная,1.
t.shmeleva@onat.edu.ua

ОЦІНКА ПРОДУКТИВНОСТІ КОМУНІКАЦІЙНИХ ҐРАТОК З ВУЗЛАМИ НАСКРІЗНОЇ КОМУТАЦІЇ

Шмельова Т.Р

Одеська національна академія зв'язку ім. О.С. Попова,
65029, Україна, м. Одеса, вул. Кузнечна,1.
t.shmeleva@onat.edu.ua

Abstract. For the performance evaluation of communication and computing rectangular grids of arbitrary size with a node that implements the cut-through packet switching technology, a model is constructed in the form of a reenterable colored Petri net. The grid model consists of three main parts: a grid structure model, a switching node model, and a terminal device model that generates a user's traffic. The listed models are presented in a single copy, in accordance with the rules of reenterable models construction, the main parameters of the models are the grid topology, traffic intensity and packet processing time. The advantages of a reenterable model for the properties investigation and the design of complex systems are shown. Models of guns were added for the investigation of ill-intentioned traffic influence. The results of the grid performance estimation and the average packet delivery time for nodes with different packet switching technology under working load conditions are presented. The behavior of the communication grid model under workload conditions and ill-intentioned traffic is investigated. The quality of service parameters were estimated and the efficiency of real-size communication and computing grids was investigated for different types and intensities of ill-intentioned traffic. It is shown that the Focus configuration leads the grid, with the node that implements the technology of cut-through packet switching, to a complete deadlock under workload conditions. The other configurations lead the grid to a complete deadlock only under peak load conditions, while in the workload environment the Side shot and Crossfire configurations reduce the average packet delivery time.

Key words: communication grid, performance evaluation, reenterable colored Petri net, cut-through switching, traffic attack.

Аннотация. Для оценки производительности коммуникационных и вычислительных прямоугольных решеток произвольного размера с узлом, реализующем технологию сквозной коммутации пакетов, построена модель в форме реентерабельной раскрашенной сети Петри. Модель решетки состоит из трех основных частей: модели структуры решетки, модели узла коммутации и модели терминального устройства, генерирующего пользовательский трафик. Перечисленные модели представлены в единичном экземпляре, в соответствии с правилами построения реентерабельных моделей, главными параметрами моделей являются топология решетки, интенсивность трафика и время обработки пакетов. Показаны преимущества реентерабельной модели при исследовании свойств и проектировании сложных систем. Для исследования влияния злонамеренного трафика добавлены модели «пушек». Приведены результаты оценки производительности решетки и среднего времени доставки пакета для узлов с различной технологией коммутации пакетов в условиях рабочей нагрузки. Исследовано поведение модели коммуникационной решетки в условиях рабочей нагрузки и злонамеренного трафика. Проведена оценка параметров качества обслуживания и исследована эффективность коммуникационных и вычислительных решеток реального размера при разных конфигурациях и интенсивностях злонамеренного трафика. Показано, что конфигурация Фокус приводит решетку с узлом, реализующим технологию сквозной коммутации пакетов, к полному тупику в условиях рабочей нагрузки. Остальные конфигурации приводят решетку к полному тупику только в условиях пиковой нагрузки, при этом в условиях рабочей нагрузки конфигурации Side shot и Crossfire уменьшают среднее время доставки пакета.

Ключевые слова: коммуникационная решетка, оценка производительности, реентерабельная раскрашенная сеть Петри, сквозная коммутация, злонамеренный трафик.

Анотація. Для оцінки продуктивності комунікаційних й обчислювальних прямокутних ґраток довільного розміру з вузлом, що реалізує технологію наскрізної комутації пакетів, побудована модель у формі реєнтерабельної розфарбованої сітки Петрі. Модель ґратки складається з трьох основних частин: моделі структури ґратки, моделі вузла комутації та моделі термінального пристрою, що генерує трафік користувача. Побудовані моделі надані в одиничному екземплярі, відповідно до правил побудови реєнтерабельних моделей, головними параметрами моделей є топологія ґратки, інтенсивність трафіка та час обробки пакетів. Показано переваги реєнтерабельної моделі при дослідженні властивостей і проектуванні складних систем. Для дослідження впливу зловмисного трафіка додані моделі «гармат». Надано результати оцінки продуктивності ґратки та середнього часу доставки пакета для вузлів з різною технологією комутації пакетів в умовах робочого навантаження. Досліджено поведінку моделі комунікаційної ґратки в умовах робочого навантаження і зловмисного трафіка. Проведено оцінку параметрів якості обслуговування і досліджено ефективність комунікаційних та обчислювальних ґраток реального розміру за різних конфігурацій та інтенсивності зловмисного трафіка. Показано, що конфігурація Фокус приводить ґратки з вузлом, якій реалізує технологію наскрізної комутації пакетів до повного тупика в умовах робочого навантаження. Інші конфігурації приводять ґратки до повного тупика тільки в умовах пікового навантаження, при цьому в умовах робочого навантаження конфігурації Side shot та Crossfire зменшують середній час доставки пакета.

Ключові слова: комунікаційна ґратка, оцінка продуктивності, реєнтерабельна розфарбована сітка Петрі, наскрізна комутація, зловмисний трафік.

Simulation modeling is a powerful method for the investigation of telecommunication systems, cloud technologies, communication and computing grids [1, 2]. For these complex systems and modern technologies, the choice of the type of a communication device and data transmission technology [3] is an open question. Investigation of the properties of these systems requires new simulation and optimization methods [4]. The model construction for these complex systems assumes various combinations of a large number of communication devices [3] and types of system topology [1].

A colored Petri net (CPN) [5] is a universal algorithmic system and a convenient tool [9] for modeling of networks and communication grid [6, 7]. The grid model construction via direct mapping of topological schemes is studied in [6]. Basic principles of reenterable models construction of telecommunication networks and computing grids via colored Petri nets [5] are presented in [7]. The modeling of grids with cut-through nodes and estimation of the workload influence on the grid functioning is studied in [8].

The aim of this paper is the performance evaluation of communication and computing grids with a node that implements the cut-through packet switching technology. The model of grids with an arbitrary size is constructed in the form of a reenterable [8] colored Petri net [5] in the environment of CPN Tools modeling system [9].

Optimization of models construction by reenterable colored Petri nets. Currently, modern telecommunications networks are very complex, and communication grids are an internal part of them. A performance evaluation and investigation of the network properties require the construction of complex models. From the above, it follows the need to integrate the use of simulation and optimization approaches, to merge the advantages of simulation and optimization methods [4]. The first step done in this paper is to study the problem of increasing the efficiency of simulation by using optimization methods and developing a methodology for determining the scope of their application in the process of constructing and operating simulation models.

The reenterable model of $n \times m$ computing grid consists of a constant number of vertices for a grid of an arbitrary size. The reenterable models of MPLS, PBB, IP networks also consist of a constant number of vertices and do not depend on the terminal and communication devices quantity. The models which were constructed by direct mapping consist of the greater number of vertices than the reenterable model. For example, the number of vertices in the computing grid reenterable model is 181 while there are 3656 vertices in the 8 × 8 computing grid model. In this case, a first criterion of optimization is the number of vertices which are used for modeling of the investigated system.

According to the first criterion of optimization, the size of file, which contains a reenterable model, is less than the size of file containing a model which was constructed by direct mapping. The loading of this file by the modeling system and the model checking require less time than for a file with a model constructed by the traditional method. For example, the size of a file which contains the reenterable model of $n \times n$ computing grid is 0,7 Mb and the loading time is 1 min. The size of the file is 4,5 Mb and the file loading time is 15 min for a file which contains the model of 8 × 8 computing grid. Thus, a second criterion of optimization is the size of the file which contains a model.

The third aspect of the modeling process optimization by reenterable models is the following: a disadvantage of the traditional method of constructing models is the necessity to reconfigure the model for each new topological scheme of a grid or network. This work requires time and computing resources. Reconfiguring of the computing grids and networks models by the reenterable modeling is a very simple procedure; a designer changes only a topology marking in corresponding places, declarations of variables and function.

Reenterable model of computing grids with cut-through switching nodes. In this paper we propose to use the reenterable grid model [7] with the store-and-forward switching nodes as a basis for the construction of reenterable rectangular communication grid model [8] with communication devices which implement the cut-through packet switching [3]. Fig. 1 shows the reenterable model of $n \times m$ computing grid structure for $n = m = 8$.

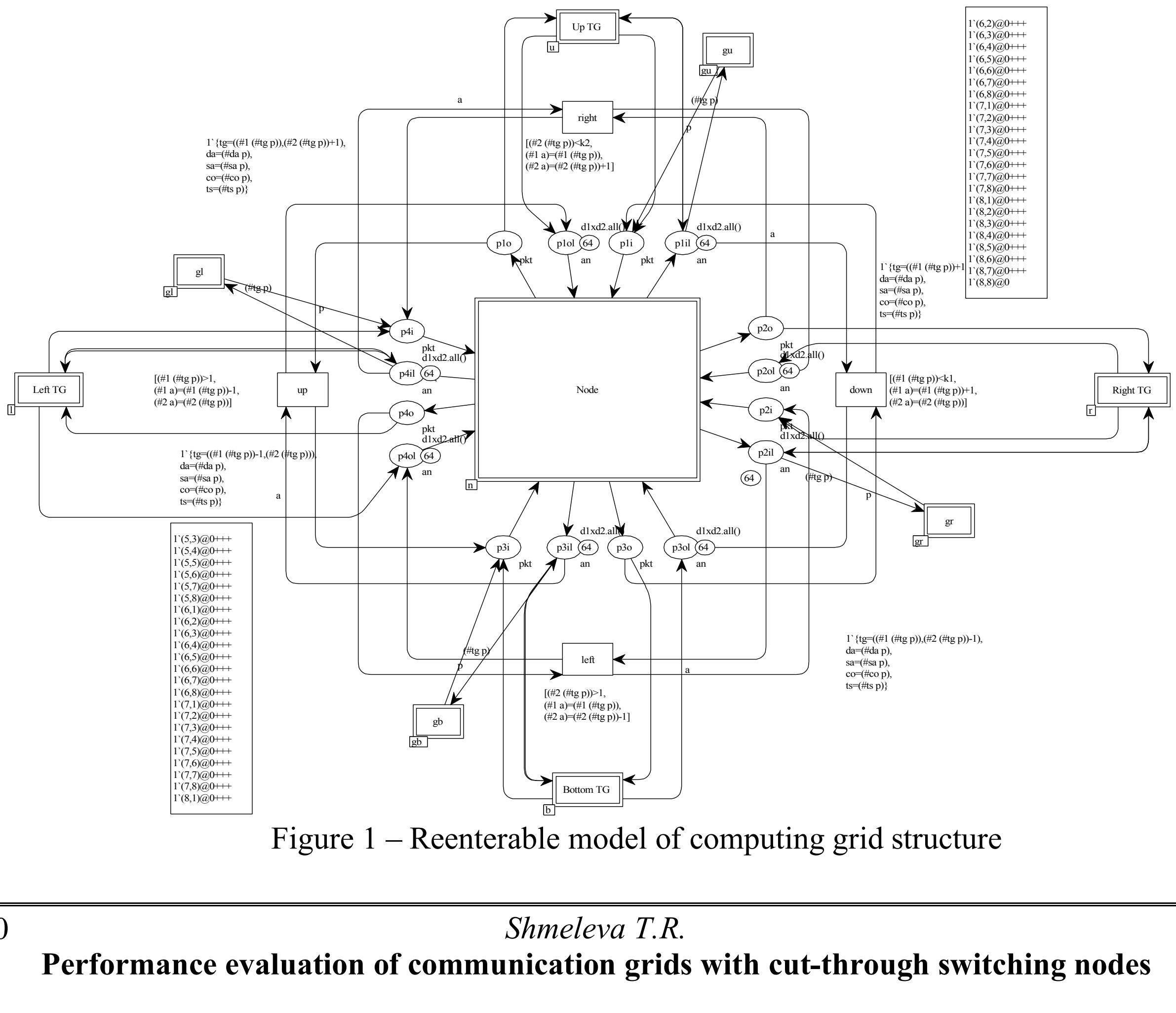
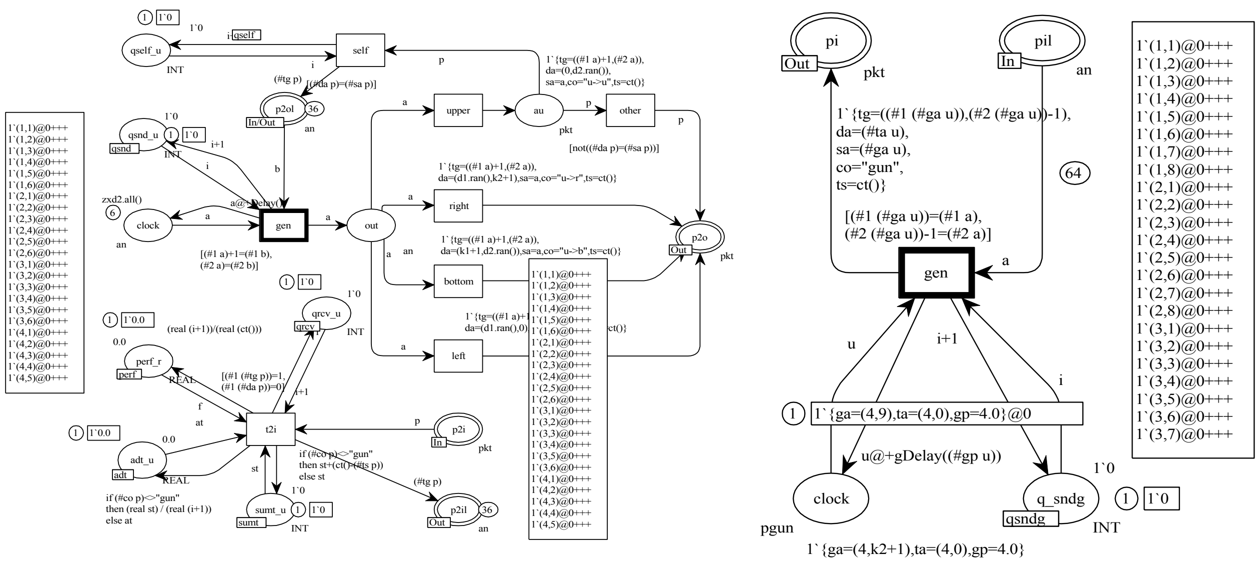


Figure 1 – Reenterable model of computing grid structure

In this case the model of a grid structure is the same for both types of communication devices, and for the efficiency estimation of computing grid model under traffic attacks, we add the model of a packet gun to the grid borders.

The model of computing grid was constructed and tested in the environment of CPN Tools modeling system [9]. According to basic principles of model construction of telecommunication networks and computing grids via reenterable colored Petri nets [7], the model of a grid structure contains a single submodel which represents all devices of a definite type for any their number. For example, the *Node* transition is a reenterable model of all cut-through switching nodes; the *Bottom TG*, *Up TG*, *Left TG,* and *Right TG* transitions are reenterable models of all user's terminal devices. The *gb*, *gu*, *gl*, and *gr* transitions are models of packet guns. A marking of the places describes the grid topology, and the places describe all ports of the communication nodes.

Models of the terminal nodes. In the grid model, there are two types of terminal nodes: nodes which generate users' traffic and packet guns which generate ill-intentioned traffic. The first one is used for performance and QoS parameters evaluation of grids under the conditions with a different intensity of workload. The second one defines security of a grid to attacks influence. Fig. 2 shows the models of terminal nodes; Fig. 2,*a* – reenterable model of user's traffic generators; Fig. 2,*b* – model of packet gun. These models are the same for both types of communication grids and switching devices [7].



a) *b*)

Figure 2 – Models of terminal devices:
a) user's traffic generators; *b*) packet gun

The reenterable model of user's terminal nodes consists of three parts: the first part is the packets generating according to a random distribution function of workload intensity; the second part is the receiving of incoming packets; the third part is the measuring fragment which processes the users' and guns' packets and calculates QoS parameters.

The main aim of the packet gun model is to generate ill-intentioned traffic with special source and destination addresses which simulates one type of traffic attack according to its configuration. We investigate four types of traffic attacks which are generated with different random distribution functions and their intensity.

Reenterable model of communication nodes with the cut-through switching mode. Reenterable model of communication node with the cut-through switching mode [8] is shown in Fig. 3. This model describes all communication nodes of a rectangular grid with an arbitrary size and consists of 4-ports which implement the full-duplex transmission mode. Each port is described by four places and three transitions; the output channel of a port is modeled by the two places *p*o* and *p*ol*, where symbol "*" is the port number. The place *p*o* contains packets or an empty symbol, the place *p*ol* represents the output port capacity limit and contains nodes' indexes with timestamp or an empty symbol.

The input channel of a port is modeled by the two places *p*i*, *p*il* and three transitions, where "*" is a port number. For example, place *p*1*i* is the first port and place *p*1*il* is the first port capacity limit. In the initial marking, all places *p*i* and *p*o* are empty, markings of all *p*il* and *p*ol* places contain nodes indexes with zero timestamp. The expression (1) demonstrates the marking of the first input port place *p*1*i* after 1000 000 Steps modeling.

```
1`{tg=(1,1),da=(0,1),sa=(8,0),co="l->u",ts=3747}@3763+++
1`{tg=(1,7),da=(0,7),sa=(7,0),co="l->u",ts=3737}@3763+++
1`{tg=(3,7),da=(0,7),sa=(9,3),co="b->u",ts=3743}@3763+++          (1)
1`{tg=(6,8),da=(3,9),sa=(6,9),co="r->r",ts=3761}@3763+++
1`{tg=(7,1),da=(4,0),sa=(9,1),co="b->l",ts=3759}@3763
```

There are five packets in this input port place, and according to field *tg* the five input ports of nodes with indexes (1,1), (1,7), (3,7), (6,8) and (7,1) are busy, the other 59 ports are empty. The expression (2) lists the marking of the limit place *p*1*il* of the first input port. There are no elements with indexes (1,1), (1,7), (3,7), (6,8) and (7,1) in this marking because there are five packets in the first input port of nodes with the same indexes. The marking of ports limits the place *p*1*il* contains 64 – 5 = 59 elements with indexes of nodes which the first input port is empty.

```
1`(1,2)@3709+++1`(1,3)@3715+++1`(1,4)@3746+++1`(1,5)@3744+++1`(1,6)@3731+++
1`(1,8)@3735+++1`(2,1)@3761+++1`(2,2)@3751+++1`(2,3)@3721+++1`(2,4)@3744+++
1`(2,5)@3757+++1`(2,6)@3753+++1`(2,7)@3632+++1`(2,8)@3696+++1`(3,1)@3759+++
1`(3,2)@3749+++1`(3,3)@3680+++1`(3,4)@3753+++1`(3,5)@3749+++1`(3,6)@3726+++
1`(3,8)@3694+++1`(4,1)@3757+++1`(4,2)@3747+++1`(4,3)@3738+++1`(4,4)@3751+++
1`(4,5)@3747+++1`(4,6)@3724+++1`(4,7)@3761+++1`(4,8)@3674+++1`(5,1)@3755+++
1`(5,2)@3745+++1`(5,3)@3747+++1`(5,4)@3723+++1`(5,5)@3745+++1`(5,6)@3722+++   (2)
1`(5,7)@3759+++1`(5,8)@3740+++1`(6,1)@3753+++1`(6,2)@3743+++1`(6,3)@3668+++
1`(6,4)@3750+++1`(6,5)@3760+++1`(6,6)@3720+++1`(6,7)@3757+++1`(7,2)@3658+++
1`(7,3)@3737+++1`(7,4)@3748+++1`(7,5)@3758+++1`(7,6)@3718+++1`(7,7)@3710+++
1`(7,8)@3721+++1`(8,1)@3761+++1`(8,2)@3722+++1`(8,3)@3735+++1`(8,4)@3764+++
1`(8,5)@3722+++1`(8,6)@3741+++1`(8,7)@3769+++1`(8,8)@3752
```

The name of a transition has the following form: *t_IndexInputPort_i_IndexOutputPort*. For example, transition *t1i*3 redirects a packet from the first input port – place *p*1*i* to the third output port – place *p*3*o*.Two indexes are added for describing the possible direction of transmission (upper, bottom, right, and left) from the input to the output port of a communication node. Auxiliary and basic *to*1*(p)*–*to*4*(p)* redirection predicates [6] are used for implementation of the packet switching algorithm. Also, we add to each transition a timestamp *rT()*, which describes the delay time of the packet receiving, and use it for the performance evaluation of the grid.

The rectangular communication grid composition rules, that determine the node's channels connection of opposite types, the numbering of ports contact places which locate on the sides of the node, the functions for sending and receiving packets, correspond to [7].

The rectangular grid model with dimension $n \times m$ is optimized by replacing all models of switching nodes of the grid, by one model which contains in the corresponding places a marking which is equal to the grid dimension. In our case, the grid dimension is $n \cdot m$, and for example, in an 8 × 8 grid there are 64 switching node models. They are replaced by a single node model in which the topology is wrapped using tag switching.

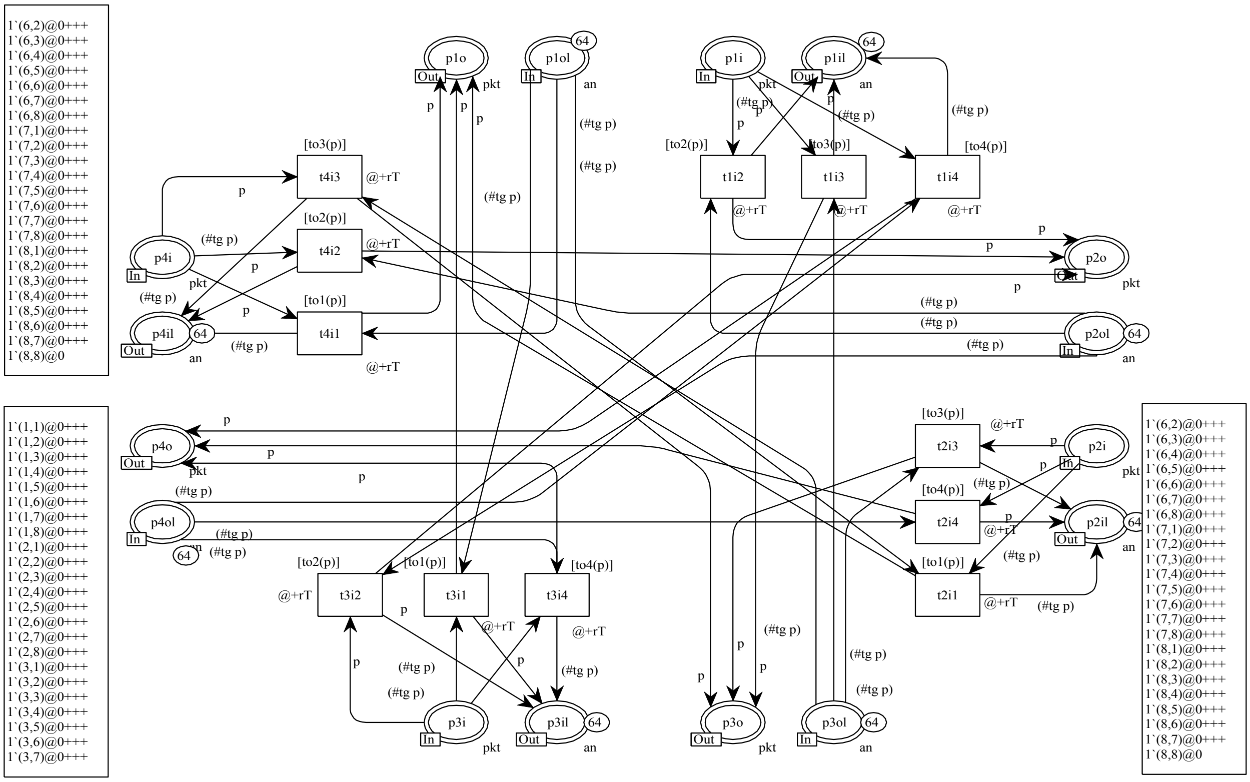
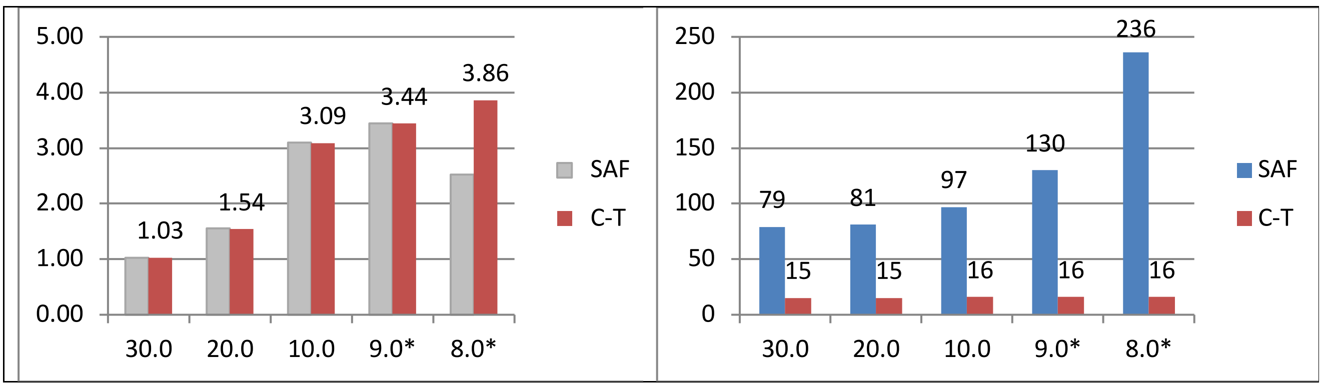


Figure 3 – Reenterable model of communication node

Efficiency estimation of rectangular computing grid model. The model of a computing grid was debugged under workload with various traffic types which the user's terminal devices generate. The estimation of the grid efficiency and QoS parameters has been done for an 8 × 8 rectangular grid under the workload and peak load conditions. The grid performance and average packet delivery time were studied for different intensity of Poisson distribution for two types of switching nodes.

Fig. 4 shows the results comparisons of the grid efficiency evaluation under regular workload for store-and-forward (SAF) and cut-through (C-T) nodes. The performance of the communication device is equal to the time parameter $rT = 5$ for SAF node and $rT = 2$ for C-T node. The symbol "*" – a communication grid comes to a full deadlock, there are no permitted transitions; MTU is a Model Time Unit.



a) *b)*

Figure 4 – Comparing parameters of grid efficiency:
a) grid performance (packets/MTU); *b*) average packet delivery time (MTU)

The grids performances are equal in regular workload conditions, but a grid with SAF technology is more stable in peak load conditions. The average packet delivery time of a grid with C-T technology is better than one with SAF switching nodes.

The comparisons of the grid efficiency evaluation for the direct and reenterable models, for SAF switching nodes [6] and cut-through switching nodes of a grid structure with size $n \times n$ were studied in [8] for different intensity of the Uniform distribution.

For the efficiency estimation of rectangular computing grid model under traffic attacks, we studied the following configurations of guns and targets: a traffic Duel (4,0) ↔ (4,9) between two nodes; the Focus (4,0) → (9,4), (4,9) → (9,4) consisting of three nodes; the Crossfire consisting of four nodes (4,0) → (9,8), (4,9) → (9,1); and two nodes in the Side shot (4,0) → (8,9). We estimate the 8 × 8 computing grid model; the intensity of the users traffic is wl = 30,0 and intensity of traffic gun is gl = 4,0. Fig. 5 shows the results of the computing experiments of the grid efficiency evaluation under different types of traffic attacks.

The communication grid with SAF nodes comes to a full deadlock if the workload intensity is wl = 30,0 and the type of gun attack is a traffic duel [6], the grid with C-T nodes processes in regular mode. Also, we study the influence of traffic, which is generated by guns, on the model behavior. The grid performance is increasing for the four types of traffic attack, and it is a regular situation.

a) *b*)

Figure 5 – Comparing parameters of grid efficiency:
a) average packet delivery time (MTU); *b*) grid performance (packets/MTU)

For the average packet delivery time we obtained interesting results. Fig. 5 shows that the Duel attack is more malicious and disguised, because the average packet delivery times are equal for the workload and Duel attack. The Focus attack increases the average packet delivery time twice, and the communication grid with C-T nodes comes to a full deadlock. The Side shot and the Crossfire attacks decrease the average packet delivery time.

Reenterable models in the colored Petri nets form optimize the investigation of the model behavior under a workload and traffic attacks. The performance evaluation of communication grids with an arbitrary size and different types of switching nodes is implemented in a feasible time now.

Acknowledgments. The author would like to thank prof. Jan W. Owsinski and the participants of "*Modeling Network with Infinite Petri Nets*" seminar in System Research Institute, Polish Academy of Sciences for discussion of some results presented in this paper.

REFERENCES:

1. Grid and Cloud Computing: Concepts, Methodologies, Tools and Applications, vol. 4. Information Resources Management Association (USA), IGI-Global. – 2012.
2. Berman, F., Fox, G C and Hey, A J G (Eds.) Grid Computing – Making the Global Infrastructure a Reality. Wiley and Sons. – 2003. – 1060 p.
3. Liberzon Daniel. Switching in Systems and Control. Published by Birkhäuser Boston, 2003, 230 p.
4. Modeling and Optimization in Science and Technologies. Series Editors: Patnaik, Srikanta, Sethi, Ishwar K., Li, Xiaolong. Springer International Publishing AG. – 2017. ISSN: 2196-7326.2018.
5. Jensen, K., Kristensen, L.M. Coloured Petri Nets: Modelling and Validation of Concurrent Systems. Springer-Verlag Berlin Heidelberg, Germany. – 2009. – 384 p.
6. W. Retschitzegger, B. Pröll, D. A. Zaitsev, T. R. Shmeleva. Security of grid structures under disguised traffic attacks. Cluster Computing. – 2016. – 19(3). – pp. 1183–1200.
7. Shmeleva T.R. Efficiency estimation of computing grids with various traffic types // A.S. Popov ONAT proceedings. – 2017. – No 2. – pp. 89-95.
8. Shmeleva T.R. Reenterable Model of Communication Grid with Cut-through Nodes. Transactions of IEEE 4th International Scientific-Practical Conference «Problems of Infocommunications. Science and Technology» (PIC S&T), October 10 - 13, 2017, Kharkiv, Ukraine, pp. 223 – 227.
9. Modelling system a CPN Tools http://www.cpntools.org.

ЛИТЕРАТУРА:

1. Grid and Cloud Computing: Concepts, Methodologies, Tools and Applications, vol. 4. Information Resources Management Association (USA), IGI-Global. – 2012.
2. Berman, F., Fox, G C and Hey, A J G (Eds.) Grid Computing – Making the Global Infrastructure a Reality. Wiley and Sons. – 2003. – 1060 p.
3. Liberzon Daniel. Switching in Systems and Control. Published by Birkhäuser Boston, 2003, 230 p.
4. Modeling and Optimization in Science and Technologies. Series Editors: Patnaik, Srikanta, Sethi, Ishwar K., Li, Xiaolong. Springer International Publishing AG. – 2017. ISSN: 2196-7326.2018
5. Jensen, K., Kristensen, L.M. Coloured Petri Nets: Modelling and Validation of Concurrent Systems. Springer-Verlag Berlin Heidelberg, Germany. – 2009. – 384 p.
6. D. A. Zaitsev , T. R. Shmeleva, W. Retschitzegger, B. Pröll Security of grid structures under disguised traffic attacks. Cluster Computing.– 2016. – 19(3). – pp. 1183–1200.
7. Shmeleva T.R. Efficiency estimation of computing grids with various traffic types // Сборник научных трудов ОНАС им. А.С. Попова. – 2017. – № 2. – С. 89-95.
8. Shmeleva T.R. Reenterable Model of Communication Grid with Cut-through Nodes. Transactions of IEEE 4th International Scientific-Practical Conference «Problems of Infocommunications. Science and Technology» (PIC S&T), October 10 - 13, 2017, Kharkiv, Ukraine, pp. 223 – 227.
9. Modelling system a CPN Tools http://www.cpntools.org.