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Simulation Model of System Enabled to Serve *n* Types of Messages

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Introduction

Last decades are characteristic in telecommunications for the rise of new services. Big part in them is taken by services associated with the use of supplementary information – Value Added Services VAS. They are specific for having different signaling realization algorithms used in creating messages for a network.

In the qualitative analysis of network nodes which give VAS they are presented as a system made of queues and processors responsible for servicing queues [1,2]. Different types of messages arrive to queues, and are serviced with different servicing times.

Either analytical [3] or simulation [1, 2] models are used in the analysis of probabilistic characteristics of such systems.

Markov chains is one of analytical methods, but if the system has many feedback connections or queues store a lot of different types of messages Markov chain analysis becomes inappropriate because of large number of states and transitions between them [4].

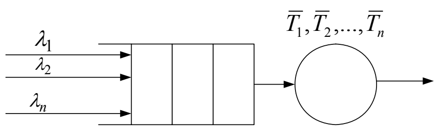

Fig. 1. System servicing different types of messages with different servicing times

Node simulation model

Analysis of network servicing complementary services behavior needs to take into account different interaction between many nodes. Firstly, to analyze such servicing, analytical or simulation models of individual VAS nodes needs to be done. Later they can be connected to a network. VAS node model is composed of one or several interconnected systems, which have a processor and a queue for message storage. Different type of messages arrives to such system and their servicing time depends on message type (Fig. 1).

That is why it is important to make a model of such system first, which later can be used to model a network composed of many nodes [1, 2]. In this paper simulation model of a system servicing different types of messages with different servicing times is presented (Fig. 2).

Model is built in OMNeT++ [5] environment, by defining distinct components and their interactions. It is made of the following components:

- Message generators „source1“, „source2“, „source3“, generate messages of corresponding type. Message interarrival times are distributed exponentially. Distribution parameters λ_1, λ_2, λ_3 are entered to each node. Messages are stored in a single queue.
- Element “queue” queues arriving messages while they wait for service. FIFO discipline is used in queue. When the message comes “queue” sends a query to the processor. If it is free message is sent to it for servicing, if it is busy message is put in queue. Queue size is entered before modeling. If newly arrived message sees “queue” full it is sent to element “losses”. Statistics about queue length, waiting time in queue are collected.
- Element “losses” destroys received messages and counts losses.
- Element “processor” serves received messages. Service time is distributed exponentially with mean T_i based on message type. Serviced message is sent to element “sink”. Statistics about number of messages in system are collected.
- Element “sink” calculates number of serviced messages and message time in system.

Sample size calculation based on desired simulation accuracy

When simulating a system it is important to determine simulation length or the sample size of generated messages which gives model characteristics with desired accuracy.

Fig. 3 shows mean time in systems dependance on sample size. Simulation was done with servicing times $T_1 = 0{,}039$ s, $T_2 = 0{,}003$ s, $T_3 = 0{,}034$ s and arrival intensities $\lambda_1 = 6{,}91$ messages/s, $\lambda_2 = 7$ messages/s, $\lambda_3 = 3$ messages/s.

Using methodology presented in [6] i‘th message type relative error of time in system dependence on sample size with confidence level $p = 0{,}99$. k‘th simulation i‘th type message absolute error of delay is determined by

$$\varepsilon_{p,k,i} = z_p \cdot \frac{\sigma_{D_{k,i}}}{\sqrt{N_{k,i}}}, \tag{1}$$

where z_p - normal distribution p- quantile, is selected from the table in [6], $\sigma_{D_{k,i}}$ - k‘th simulation i‘th message type standard deviation of time in system, $N_{k,i}$ - number of i‘th type messages in k‘th simulation. Relative error value of k‘th simulation i‘th message type time in system is

$$\Delta_{k,i} = \frac{\varepsilon_{p,k,i}}{\overline{D}_{k,i}}, \tag{2}$$

where $\overline{D}_{k,i}$ is k‘th simulation i‘th message type mean time in system.

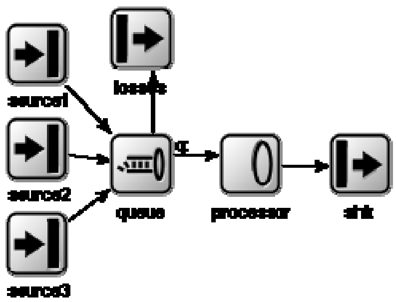

Fig. 2. Simulation model of the servicing system

Fig. 4 shows the dependence of relative error of message mean time in system on the number of generated messages. To achieve that the accuracy of empirical sample mean would be in 1% range of the theoretical mean with probability of 99% we need to generate at least 300000 messages of corresponding type. If such condition is applied mean time in system of all messages then model has to service more than 300000 messages all types combined.

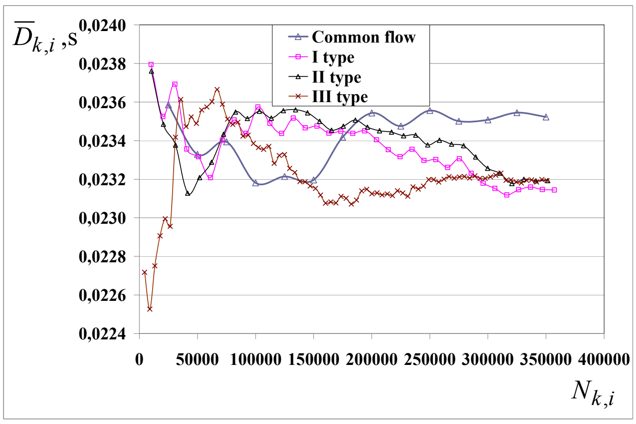

Fig. 3. Mean delay dependence on the number of serviced messages

System investigation using Markov chain method

Application of Markov chain method to complex systems is limited, but it can be used to test analytical or simulation models adequacy by applying some limitations (small queue size, few types of messages).

Results achieved in simulation will be compared ones calculated using Markov chain method, when there are only three types of messages, each with different exponential arrival and service distributions. Queue can store no more than five messages (Fig. 5). Messages are served using FIFO (First In, First Out) discipline.

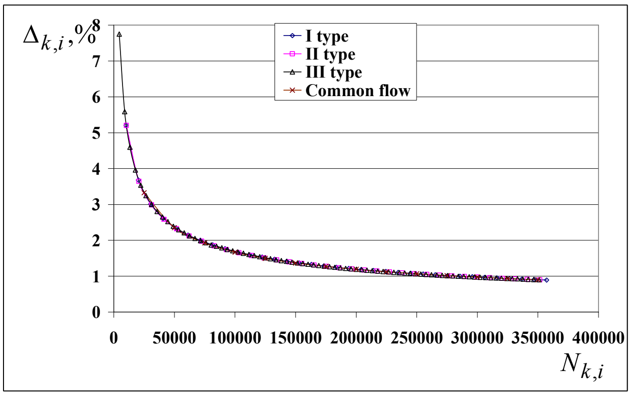

Fig. 4. Dependence of relative error of message mean time in system on the number of generated messages

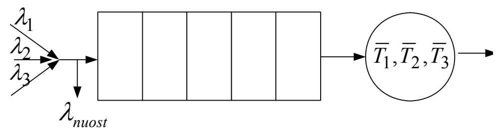

Fig. 5. Model of a system with queue length five and three types of messages

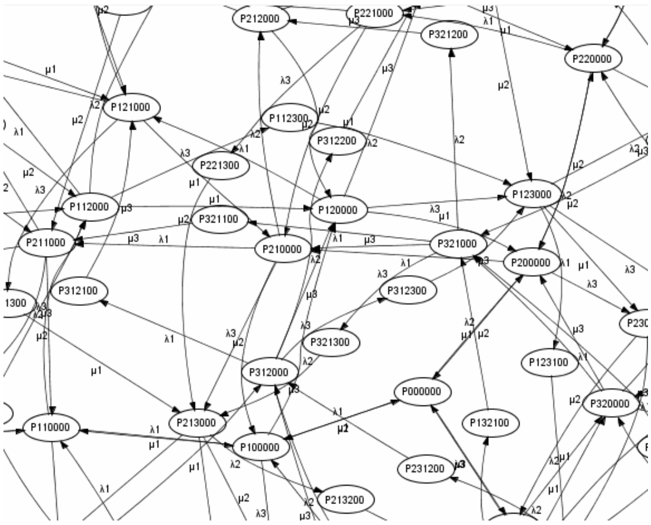

Fig. 6. Fragment of system states transition graph

Such system can be described using steady state distribution of the corresponding continuous time Markov chain. Each state is described with six parameters: A, B, C, D, E, F. Where A – state of processor, B – state of first place in queue, C – state of second place in queue, D – state of third place in queue, E – state of fourth place in queue, F – state of fifth place in queue. State parameter A can acquire values: 0 then the processor is idle, 1 then the processor is servicing message of first type, 2 then the processor is servicing message of second type, 3 then the processor is servicing message of third type. State parameters B, C, D, E, F can acquire values: 0 then the corresponding place in queue is empty, 1 then it stores message of first type, 2 then it stores message of second type, 3 then it stores message of third type. Name of each steady state is written as P_{ABCDEF}. At the beginning time t_0 system is in P_{000000} state. System has 1093 steady states and 2184 transition between them. Fig. 6 shows a fraction of the Markov chain state transition graph.

Based on state transition graph presented in Fig. 6 we can write a balance equation for every state. Equation system is obtained

$$\begin{cases} -(\lambda_1+\lambda_2+\lambda_3)\cdot P_{000000}+\mu_1\cdot P_{100000}+ \\ +\mu_2\cdot P_{200000}+\mu_3\cdot P_{300000}=0 \\ -(\lambda_1+\lambda_2+\lambda_3+\mu_1)\cdot P_{100000}+\lambda_1\cdot P_{00000}+ \\ +\mu_1\cdot P_{110000}+\mu_2\cdot P_{210000}+\mu_3\cdot P_{310000}=0 \\ \ldots \\ \sum P_{ABCDEF}=1, \end{cases} \qquad (3)$$

here A can be 0, 1, 2, 3; B equals 0 then A equals 0 and can aquire values 0, 1, 2, 3 then A is more then 0; C equals 0 then B equals 0 and can be 0, 1, 2, 3 then B is more then 0; D equals 0 then C equals 0 and can acquire values 0, 1, 2, 3 then C is more then 0; E equals 0 then D equals 0 and can acquire values 0, 1, 2, 3 then D is more then 0; F equals 0 then E equals 0 and can acquire values 0, 1, 2, 3 then E is more then 0.

Values of steady state probabilities P_{ABCDEF} are found then equation system (2). They are used to calculate probabilistic characteristics.

Probability that the message will not be serviced equals probability that the queue is full

$$P_{M,B}=\sum P_{ABCDEF}, \qquad (4)$$

here A, B, C, D, E, F values are more than 0.

Mean number of messages in queue

$$\overline{N}_M=\sum N_M\cdot P_{ABCDEF}, \qquad (5)$$

here A can be 1, 2, 3; B can be 1, 2, 3; C, D, E can get values 0, 1, 2, 3; N equals 1, then A, B are more then 0, but C, D and E equals 0; acquires value 2, then A, B and C are more than 0, but D and E equals 0; gets value 3, then A, B, C, D are more than 0, but E equals 0; acquires value 4, then A, B, C, D, E are more then 0, but F equals 0; gets value 5, then A, B, C, D, E, F are more then 0.

Mean waiting time of messages in queue can be found using Little‘s formula

$$W_M=\frac{\overline{N}_M}{\sum_{i=1}^{3}\lambda_i\cdot\left(1-P_{M,B}\right)}. \qquad (6)$$

Mean i‘th type message delays equals to the sum of mean message time in queue and i‘th message type service time

$$D_{M,i}=\overline{T}_{M,i}+W_M. \qquad (7)$$

Processor load equals to the sum of state probabilities showing that it is busy

$$\rho_M=\sum P_{ABCDEF}, \qquad (8)$$

where A can be 1, 2, 3; B, C, D, E, F can be 0, 1, 2, 3.

Probability, that the system is idle

$$P_{M,0}=P_{00000}. \qquad (9)$$

Evaluation of simulation model performance

Fig. 7 shows mean delay of messages obtained in both simulation model and Markov chain method dependence on processor load, when maximum queue length is five.

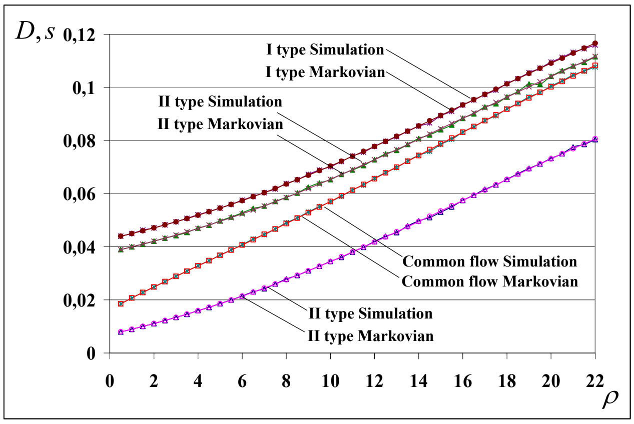

Fig. 7. Mean delay of messages obtained in both simulation model and Markov chain method dependence on processor load

In the simulation arrival intensities of second and third message types and all service types remain constant ($\lambda_2=7$ messages/s, $\lambda_3=3$ messages/s, $T_1=0{,}039$ s, $T_2=0{,}003$ s, $T_3=0{,}034$ s). Only the first message type arrival intensity changes ($\lambda_1\in[0{,}5;22]$ messages/s).

For the comparison of results obtained in both models we used Kolmogorov-Smirnov 2-sample goodness of fit test. Hypothesis H_0 „results obtained with simulation model and Markov chain model are identical“. So theirs function have to be close to each other. Maximal distance between each sample‘s empirical distribution function is found [6]:

$$R=\max\left|F_1(x)-F_2(x)\right|. \qquad (10)$$

Based on Kolmogorov-Smirnov test it can be stated that:

- if $R\in K$, then hypothesis H_0 contradicts observation (is incorrect);
- if $R\notin K$, then hypothesis H_0 is correct;

here K is critical region.

Table 1. Tests results

Characteristic	R	H_0
Mean delay	0.0178571	correct
Mean first type message delay	0.0178571	correct
Mean second type message delay	0.0178571	correct
Mean third type message delay	0.0267857	correct

For result comparison sample of 112 elements of each characteristic was used, significance level $\alpha = 0{,}05$. Critical region $K = [0{,}1141195; +\infty]$ is obtained.

Kolmogorov-Smirnov test confirms hypothesis that results obtained with simulation model and Markov chain model are identical.

Using expression (12), calculate relative error of delay in simulation model, can be

$$\Delta_{D_{I\_5,i}} = \frac{\left|D_{M,i} - D_{I\_5,i}\right|}{D_{M,i}} \cdot 100\%, \qquad (11)$$

here $D_{I\_5,i}$ i'th message type mean delay obtained in simulation with 5 places in queue.

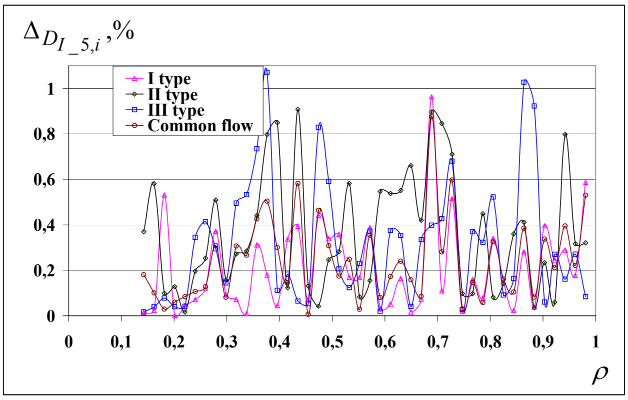

Fig. 8. Dependence of relative error of delay in simulation model, on processor load

Relative error of delay values are shown in Fig. 8. Most of the relative error is less 1%.

Conclusion

Simulation model results differ from corresponding Markovian model results less than 1% lets us conclude that simulation model correctly describes the system being modeled.

Sample size needed for desired simulation accuracy was calculated. For empirical mean delay of i'th type message to be within 1% of the real mean with probability 99%, at least 300000 i'th type messages needs to be generated

Suggested simulation model is more universal than Markov chain method used to find characteristics of VAS networks. It can be used to take into account different message processing algorithms, different service times, while changing system configuration.

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R. Gedmantas, A. Jarutis, J. Jarutis. Simulation Model of System Enabled to Serve *n* Types of Messages // Electronics and Electrical Engineering. – Kaunas: Technologija, 2007. – No. 8(80). – P. 35–38.

Analysis of value added complementary services pose a specific problem, because distinct servicing algorithms have to be taken into account, while generating messages with different service times. This problem can be solved using analytical or simulation methods. Analytical models are not suited to evaluate specific details of the system being modeled, because of their complexity therefore simulation model of the system servicing different types of messages with different service times is presented in this paper. Sample size needed for desired accuracy is calculated. Results obtained with simulation are tested with Kolmogorov-Smirnov test against results obtained using steady state distribution of corresponding Markov chain. Ill. 8, bibl. 6 (in English; summaries in English, Russian, Lithuanian).

Р. Гедмантас, А. Ярутис, Ё. Ярутис. Имитационая модель системы обслужевающей *н* типов заявок // Электроника и электротехника. – Каунас: Технология, 2007. – № 8(80). – С. 35–38.

Анализ обслуживания дополнительных услуг повышенной ценности является специфической задачей в силу того, что следует учесть разные алгоритмы предоставления услуг. При том создаются потоки заявок, обслуживемые разными временами. Для их исследования используются аналитические или имитационные методы. Аналитические методы из-за сложностей исследования таких систем не позволяют учесть всей специфики предоставления дополнительных услуг повышенной ценности. Поэтому в работе представлена имитационная модель, реализованная в среде OMNET++, учитывая разные типи заявок с разными временами их обслуживания. Определено число заявок, при котором полученные результаты имеют достаточную точность (<1%) по сравнению с аналитическим путём полученными результатами. Результаты имитационного моделирования сравнены с результатами, полученными аналитическим путём на основе Марковских цепей, по критерию Колмогорова-Смирнова. Ил. 8, библ. 6 (на английском языке; рефераты на английском, русском и литовском яз.).

R. Gedmantas, A. Jarutis, J. Jarutis. Sistemos, aptarnaujančios *n* skirtingų tipų paraiškų, imitacinis modelis // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 8(80). – P. 35–38.

Pridėtinės vertės papildomų paslaugų aptarnavimo analizė yra specifinis uždavinys, nes būtina įvertinti skirtingus paslaugų realizavimo algoritmus, sukuriant skirtingų paraiškų srautus su skirtingomis aptarnavimo trukmėmis. Tam gali būti naudojami analitiniai ar imitaciniai modeliai. Dėl sudėtingo tokių sistemų tyrimo analitiniais modeliais negalima įvertinti visos specifikos, todėl darbe sukurtas imitacinis modelis, aptarnaujantis skirtingo tipo paraiškas su skirtingomis aptarnavimo trukmėmis. Imitaciniam modeliui sukurti panaudota programa OMNET++. Parinkta aptarnautų paraiškų imtis, kuriai esant imitaciniu modeliu gauti rezultatai yra reikiamo tikslumo. Imitaciniu modeliu gauti rezultatai lyginami su rezultatais, gautais Markovo grandinių metodu, tam panaudojant Kolmogorovo ir Smirnovo kriterijų. Il. 8, bibl. 6 (anglų kalba; santraukos anglų, rusų, lietuvių k.).