ANALYTICAL MODELLING AND SIMULATION OF ADMISSION CONTROL SCHEME FOR NON-REAL TIME SERVICES IN LTE NETWORKS

Irina A. Gudkova
Ekaterina V. Markova
Pavel O. Abaev
Department of Applied Probability and Informatics
Peoples' Friendship University of Russia
Ordzhonikidze str. 3, 115419 Moscow, Russia
{igudkova, emarkova, pabaev}@sci.pfu.edu.ru

Veronika M. Antonova
Department of Communication Network and Switching Systems
Moscow Technical University of Communication and Informatics
Aviamotornaya str. 8 A, 111024 Moscow, Russia
xarti@mail.ru

KEYWORDS

LTE, radio admission control, non-real time service, non-guaranteed bit rate, degradation, queuing theory, simulation model, blocking probability, data transfer time.

ABSTRACT

In 4th generation LTE (Long Term Evolution) and LTE-Advanced networks, there are 9 types of services, which have different service priorities and generated traffics. Depending on the combination of services with different priorities, about 200 radio admission control schemes could be developed. However, international standards have no recommendations for the construction and analysis of methods for such schemes. Thereby, a need for admission control schemes development and selecting the most effective ones arises. The article proposes a scheme based on the bit rate degradation of non-real time services in proportion to the individual thresholds chosen in accordance with the network or consumer devices characteristics. A complex approach for analysing the model performance measures – blocking probability, mean data transfer time – is proposed. It is based on queuing theory via the development of a Markov model of the admission control scheme and on verifying the obtained results via simulation allowing arbitrary arrival process and file sizes. The results obtained in this paper could be used by mobile operators for 4th and 5th generation network planning to evaluate the quality of service level.

INTRODUCTION

Telecommunication companies from different countries are currently making the transition to the next stage of mobile communication development, namely, the transition to 4th generation (4G) mobile networks (Cisco Systems 2014), which allow to transfer data at rates exceeding 100 Mbps for mobile users (speed of motion is 10 km/h to 120 km/h) and 1 Gbps for stationary users (speed of motion is up to 10 km/h). However, according to Cisco Systems analysts (Cisco Systems 2014) by 2018 only 15% of all consumer devices will be capable of supporting 4G communication standards, while the volume of traffic generated in 4G networks will have exceeded 50% of the total traffic generated in mobile networks.

LTE-Advanced technology that underlies 4G networks allows increasing the bit rate and efficiency of data transfer, reducing operators' costs, and improving the quality of service (QoS). In accordance with the recommendations (TS 36.300, TS 23.401, TS 23.203) of 3GPP consortium (3rd Generation Partnership Project), which standardizes LTE networks, 9 types of services are specified in LTE networks (Table 1). The services differ from each other in priority level and requirements for QoS expressed as constraints on the delay and data bit rate.

All services are divided into two types depending on the network resource requirements: services with guaranteed bit rate (GBR), i.e. real-time services, e.g., voice or video telephony, real time gaming; services without guaranteed bit rate (non-GBR), e.g., e-mail, web browsing, interactive games.

Increasing or decreasing bit rate from the minimum value (GBR) to the maximum one (maximum bit rate, MBR) does not affect the value of mean data transfer time for GBR services. While varying bit rate results in changing the mean data transfer time for Non-GBR services.

One of the most important and actual problems in the planning and development of LTE networks is the optimal configuration of a radio access network including optimal radio resource management which includes the following tasks: radio bearer control, radio admission control (RAC), connection mobility control, dynamic resource allocation, and inter-cell interference coordination. One of the tasks is RAC the main purpose of which is to form RAC schemes while taking into account the limited frequency range of mobile networks and different requirements for QoS parameters.

Proceedings 29th European Conference on Modelling and Simulation ©ECMS Valeri M. Mladenov, Petia Georgieva, Grisha Spasov, Galidiya Petrova (Editors)
ISBN: 978-0-9932440-0-1 / ISBN: 978-0-9932440-1-8 (CD)

Table 1: Characteristics of LTE Service Types (TS 23.203)

<table>
<tr><th>QCI</th><th>Resource type</th><th>Priority level</th><th colspan="2">Example services</th></tr>
<tr><td>1</td><td rowspan="4">GBR</td><td>2</td><td colspan="2">Conversational voice</td></tr>
<tr><td>2</td><td>4</td><td colspan="2">Conversational video (live streaming)</td></tr>
<tr><td>3</td><td>3</td><td colspan="2">Real time gaming</td></tr>
<tr><td>4</td><td>5</td><td colspan="2">Non-conversational video (buffered streaming)</td></tr>
<tr><td>5</td><td rowspan="5">Non-GBR</td><td>1</td><td colspan="2">IMS signalling</td></tr>
<tr><td>6</td><td>6</td><td colspan="2">Video (buffered streaming), TCP-based (e.g., WWW, e-mail, chat, FTP, P2P file sharing, progressive video, etc.) (for multimedia priority services subscribers)</td></tr>
<tr><td>7</td><td>7</td><td colspan="2">Voice, video (live streaming), interactive gaming</td></tr>
<tr><td>8</td><td>8</td><td rowspan="2">Video (buffered streaming), TCP-based (e.g., WWW, e-mail, chat, FTP, P2P file sharing, progressive video, etc.)</td><td>for premium subscribers</td></tr>
<tr><td>9</td><td>9</td><td>for non-privileged subscribers</td></tr>
</table>

Simulation and mathematical modelling are used for research and analysis of RAC schemes. Mathematical teletraffic and queuing theories are the instruments of mathematical modelling (Basharin et al. 2013), (Basharin et al. 2009). In accordance with the mathematical teletraffic theory, GBR services generate streaming traffic (Gudkova and Plaksina 2010) characterized by a fixed bit rate and transfer time, non-GBR services generate elastic traffic (Bonald and Tran 2007) which is characterized by a fixed file size and variable transfer time.

To ensure the required QoS, mobile operators need to develop various RAC schemes (Qian et al. 2009), (Khabazian et al. 2012), (Chowdhury et al. 2013), (Gudkova and Samouylov 2012), (Samouylov and Gudkova 2013), (Borodakiy et al. 2014) and choose the most effective ones. Due to the fact that the proportion of data (non-GBR) traffic is a sufficiently large part of the total traffic generated by different services (Cisco Systems 2014), in this article we propose a model of RAC scheme with two non-GBR services generating elastic traffic. Mathematical and simulation modelling is performed for analysing model performance measures. Note that the file fransfer bit rate depends not only on the technical characteristics of the base station and radio access network, but also on the characteristics of consumer devices resulting in different values of MBR (the so-called individual thresholds of bit rate) (Bonald and Virtamo 2005). However, unlike the previously known teletraffic theory models with the discriminatory processor sharing (DPS) (Yashkov 1992), for this model a threshold of the maximum number of transferred files is introduced (Bonald and Tran 2007), which is necessary to guarantee data transfer time. Our RAC scheme is constructed in the way that in case of the network congestion the bit rate reduction is carried out in proportion to individual thresholds of bit rates, i.e. service degradation, which is also called partial pre-emption, takes place (Khabazian et al. 2012).

The paper is organized as follows. We propose a functional model of the LTE network cell with individual thresholds of the file transfer bit rate and a threshold of the number of transferred files. Then, we propose a corresponding mathematical model with the assumption of the exponential distribution of file sizes and Poisson arrival process. We propose a simulation model of the described RAC scheme which takes into account arbitrary arrival process and file sizes. We analyse the model performance measures such as blocking probability adnd mean data transfer time.

OBJECT TO SIMULATE

We consider the LTE network cell with a total capacity C Mpbs and two types of files. Note that the time between arrives of first and second type files are random variables with arbitrary distribution function $A(x)$ and parameters λ_1 and λ_2 respectively. The main difference between different types of files is their sizes, which affects the mean transfer time. In this case, the sizes of the first and second type files are also random variables with an arbitrary distribution function $B(x)$ and the mean values θ_1 and θ_2 MB. The file transfer time is influenced by technical characteristics of networks, specifications used by consumer devices, which do not necessarily support the 4G LTE standard. All these factors limit the MBR for first and second types files – d_1 and d_2 Mpbs. We assume $d_1 > d_2$. Therefore, to determine the values of individual thresholds of bit rate required for numerical experiment, we divide all the subscribers into two categories, namely for 3G and 4G networks, i.e. we assume that the first type files are transferred in accordance with 4G technology, and the second type files are transferred in accordance with 3G technology as $d_1 > d_2$. 2G network connections in this case is not taken into account.

Admission control is organized as follows: depending on the cell load the file transfer bit rate can dynamically vary from MBR to GBR sufficient for the compliance with the transfer time requirements, i.e. the bit rate depends on the number of transferred files of the first n_1 and second n_2 types. To determine the minimum requirements needed to transfer files, we introduce the threshold value N of the total number of transferred files. To realize the service degradation mechanism we introduce the degradation factor, which is defined by the formula

$$g(n_1, n_2) = \begin{cases} 1, & n_1 d_1 + n_2 d_2 \le C, \\ \dfrac{C}{n_1 d_1 + n_2 d_2}, & n_1 d_1 + n_2 d_2 > C. \end{cases} \quad (1)$$

When k -type file arrives three situations are possible:

- if the file finds the cell having greater than or equal to d_k Mbps free, then the file will be accepted at bit rate d_k Mbps;
- if the file finds the cell having less than d_k Mbps free and number of transferred files less than N, then the file will be accepted at bit rate $d_k \cdot \dfrac{C}{n_1 d_1 + n_2 d_2}$ Mbps;
- otherwise the file will be blocked without any after-effect on the corresponding Poisson process arrival rate.

We explain the principle of the file bit rate degradation mechanism proportional to the individual thresholds by an example (Figure 1). Let be $C = 7$ Mpbs, $N = 6$, $d_1 = 3$ Mpbs, and $d_2 = 2$ Mpbs. We assume that one first type file and one second type file are transferred at MBR at the initial moment of time t_0 in the system, i.e. $n_1 = 1$ and $n_2 = 1$, and then 5 out of 7 Mbps are occupied. At the time t_1, a second type file arrives and since the number of free Mbps is 2, the file is accepted at MBR after that the number of free Mbps is 0, and the number of transferred files is $n_1 + n_2 = 3$. Sometime later, at t_2 one more second type file arrives, it is accepted as the number of files does not exceed N, but it cannot be transferred at MBR and the bit rate degradation mechanism is applied. This degradation is performed in accordance with degradation factor $g(1,3) = \dfrac{7}{1 \cdot 3 + 3 \cdot 2} \approx 0.778$ proportional to the individual thresholds – the bit rates become equal to $d_1 g(1,3) \approx 2.333$ Mpbs for the first type files and $d_2 g(1,3) \approx 1.556$ Mpbs for the second type files. Further, at the time t_3 and t_4, there are similar situations – a second type files arrive, they are accepted with bit rates degraded in proportion to the individual thresholds, namely, at the time t_3 the degradation factor is equal to $g(1,4) \approx 0.636$, at the time t_4 it is $g(1,5) \approx 0.538$.

At the last considered moment of time t_5, a second type file arrives, but since the number of transferred files at t_4 has reached the threshold value 6, the file will be blocked without any after-effect on the corresponding Poisson process arrival rate.

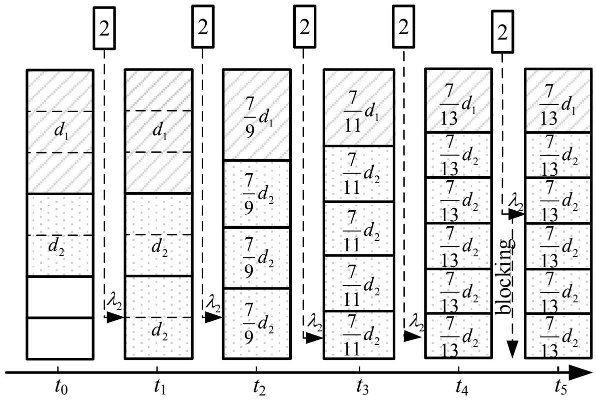

Figure 1: Degradation Mechanism

The main performance measures of the model are: blocking probabilities B_1 and B_2 for the first and second type files, respectively; mean degradation factor $\bar{g}$; mean transfer time T_1 and T_2 for the first and second types files, respectively. We note that the blocking probabilities for the first and the second type files are the probabilities of being in states (n_1, n_2), where $n_1 + n_2 = N$, and consequently $B_1 = B_2$.

MATHEMATICAL MODEL

Thus, the RAC scheme with individual thresholds of file transfer bit rates and a threshold control has been described in the previous section. Further the simulation modelling will be held but beforehand we are going to construct a mathematical model on the assumption that arrival process are Poisson and file sizes are exponentially distributed. The process representing the system states is described by the systems of equilibrium equations (2)

$$\begin{aligned} & p(n_1, n_2) \cdot \Bigg\{ (\lambda_1 + \lambda_2) \cdot 1\{n_1 + n_2 < N\} \\ & + \left(\frac{n_1}{\theta_1} \cdot d_1 + \frac{n_2}{\theta_2} \cdot d_2 \right) \cdot \Bigg[1\{n_1 d_1 + n_2 d_2 \le C\} \\ & + \frac{C}{n_1 d_1 + n_2 d_2} \cdot 1\{n_1 d_1 + n_2 d_2 > C\} \Bigg] \Bigg\} \\ & = p(n_1 - 1, n_2) \cdot \lambda_1 \cdot 1\{n_1 > 0\} \\ & + p(n_1, n_2 - 1) \cdot \lambda_2 \cdot 1\{n_2 > 0\} \\ & + \Bigg\{ p(n_1 + 1, n_2) \cdot \Bigg[\frac{n_1 + 1}{\theta_1} \cdot \Bigg(d_1 \cdot 1\{(n_1 + 1) d_1 + n_2 d_2 \le C\} \\ & + \frac{C d_1}{(n_1 + 1) d_1 + n_2 d_2} \cdot 1\{(n_1 + 1) d_1 + n_2 d_2 > C\} \Bigg) \Bigg] \end{aligned} \quad (2)$$

$$+p\left(n_1,n_2+1\right)\cdot\left[\frac{n_2+1}{\theta_2}\cdot\left(d_2\cdot 1\left\{n_1d_1+\left(n_2+1\right)d_2\le C\right\}\right.\right.$$

$$\left.\left.\left.+\frac{Cd_2}{n_1d_1+\left(n_2+1\right)d_2}\cdot 1\left\{n_1d_1+\left(n_2+1\right)d_2>C\right\}\right)\right]\right\}$$

$$\times 1\left\{n_1+n_2<N\right\},\quad n_2=0,\ldots,N-n_1,\ n_1=0,\ldots,N,$$

where $1\{\bullet\}$ – indicator function.

Having found the probability distribution $p\left(n_1,n_2\right)$ one could compute performance measures of model, which have been defined above, namely:

- blocking probability

$$B_1=B_2=B=\sum_{n_1=0}^{N}p\left(n_1,N-n_1\right),$$

- mean degradation factor

$$\overline{g}=\sum_{n_1=0}^{N}\sum_{n_2=0}^{N-n_1}g\left(n_1,n_2\right)\cdot p\left(n_1,n_2\right),$$

- mean data transfer time

$$T_1=\frac{\sum_{n_1=1}^{N}\sum_{n_2=0}^{N-n_1}n_1\cdot p\left(n_1,n_2\right)}{\lambda_1\left(1-B\right)},$$

$$T_2=\frac{\sum_{n_2=1}^{N}\sum_{n_1=0}^{N-n_2}n_2\cdot p\left(n_1,n_2\right)}{\lambda_2\left(1-B\right)}.$$

It could be simply proved that the process representing the system states is not a reversible Markov process and it is possible to determine the system probability distribution and the performance measures only by means of numerical methods for solving systems of equilibrium equations.

SIMULATION TOOL

Thereby, the mathematical model given in the previous section describes the system we are going to simulate but it has two simplifications: the first one is the Poisson arriving process and the second one is exponential file sizes. To enhance the capabilities of our complex we use a simulation tool that considers various laws of the arriving process and file sizes as well. Simulation tool is a discrete event simulator written in JavaScript.

Figure 2 illustrates the simulation tool classes as well as basic steps of the simulation algorithm. The simulation model consists of the following classes: simulator, cell, and file (see Figure 2.A). Each of them has fixed and variable attributes. Fixed attributes are equal to the model parameters whereas variable attributes are changing during the simulation process. Namely, dynamic changing of the number of files results in the corresponding changing of the degradation factor. The more files are in the cell, the less the degradation factor is. This degradation factor varying influences on the files transfer conditions, therefore, the current bit rates, remaining file sizes, and estimated time of file transfer completion.

The main element of the event-driven simulation tool is the queue of events containing the information about the file arrivals (Figure 2.C) and file transfer completions (Figure 2.D). At the initial moment of time (Figure 2.B), two files – of the first and second types – are generated and then they enter the queue. Their current bit rates are initially set to be MBR. Then the cycle selecting from the queue the event with minimum time.

NUMERICAL EXAMPLE

To carry out the numerical analysis we assume the Cisco Systems's global mobile data traffic forecast for 2015-2018. According to the forecast, in 2015 the data traffic will reach 38% of the total mobile traffic and by 2018 this value will have been equal to 25%. Our numerical experiment does not consider the overall peak cell bit rate (100 Mbps) and deals with the part of it which corresponds to data traffic (Table 2). All users are divided into two groups according to the type of technology they use (3G or 4G). Considering these two technologies and owing to limitations imposed by consumer devices (phones, smartphones, and tablets) we select the corresponding MBR d_k. We denote by α the ratio of 4G traffic to overall 3G and 4G traffics, by d^* the minimum bit rate (GBR) sufficient to satisfy the QoS for requirement file transfer time. Arriving flow is considered Poisson, file sizes have exponential (e.g., e-mail) and Pareto distributions (IP-applications).

Table 2: Input Data

$\omega_1+\omega_2\in\left(0,30\right)$ Mbps, $d^*\approx 2$ Mbps, $\theta_1=\theta_2=10$ MB				
	C	α	d_1	d_2
2015	38 Mbps	0.39	6 Mbps	4 Mbps
2018	25 Mbps	0.53	7 Mbps	5 Mbps

Figure 3 ilistrates blocking probability (A), mean degradation factor (B), and mean data transfer times (C and D). The results show that mathematical model could be used to calculate the upper bound of blocking probability and mean degradation factor and the lower bound of mean data transfer time for the Pareto distributed file sizes.

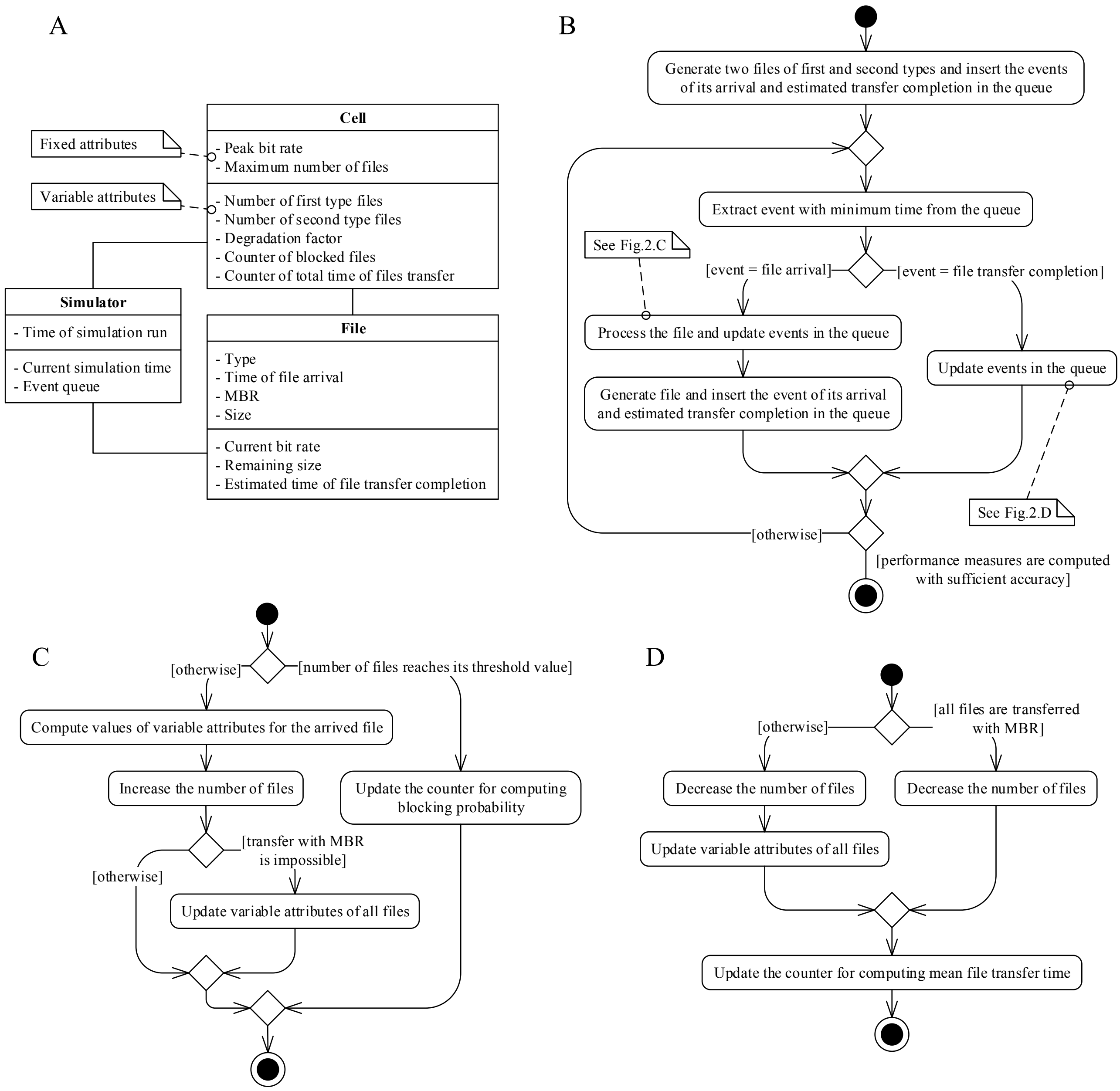

Figure 2: Main classes and algorithms of the simulation tool:
A: Classes. B: Inserting in and extracting events from the queue.
C: Processing events of file arrival. D: Processing events of file transfer completion

CONCLUSIONS

In this paper, we addressed an admission control problem for a multi-service LTE radio network, namely we presented a multi-rate model with two types of files and a complex approach for analysing it performance measures. The RAC scheme is based on the quality degradation proportionally to the individual thresholds of bit rates. We propose the mathematical model with the Poisson arriving process and exponential file size and simulation tool with arbitrary distributions. Results show that performance measures calculated by simulation are reasonably close to the analytical ones, but they also remain slightly lower due to the increasing influence of the realistic LTE performance factors not captured by the current analysis. The results of numerical analysis can be used for planning standards for 5G wireless cellular networks. They can be used for developing software that is responsible for radio resources management, namely for developing RAC schemes.

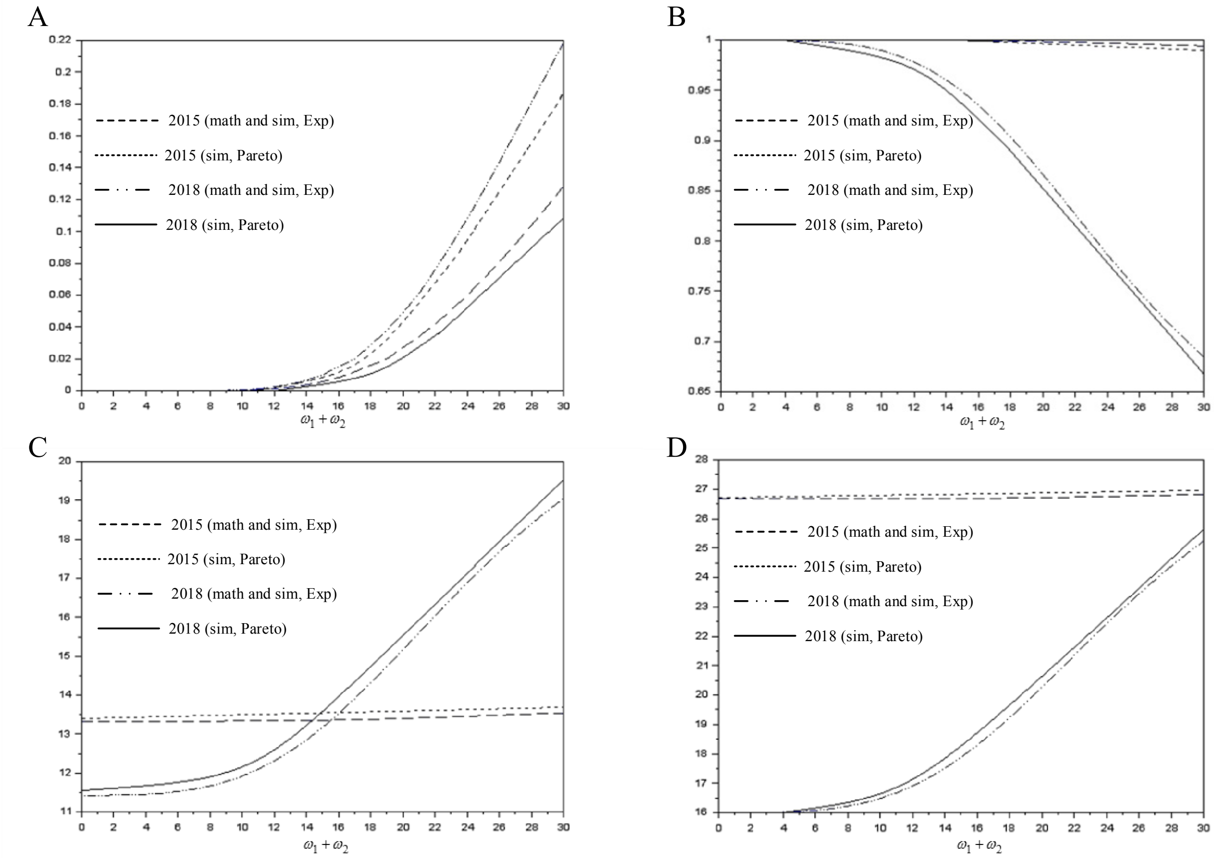

Figure 3: Performance measures:
A: Blocking probability. B: Mean degradation factor.
C: Mean data transfer time for the first type files. D: Mean data transfer time for the second type files

Notes and Comments. This work was supported in part by the Russian Foundation for Basic Research (research project No. 13-07-00953).

REFERENCES

Stasiak, M.; M. Glabowski; A. Wisniewski; and P. Zwierzykowski. 2010. “Modelling and dimensioning of mobile wireless networks: from GSM to LTE.” Willey, 1-340.

Cisco Systems. 2014. Cisco visual networking index: Global Mobile Data Traffic Forecast Update, 2013–2018: usage: White paper.

Gudkova, I.A. and O.N. Plaksina. 2010. “Performance measures computation for a single link loss network with unicast and multicast traffics.” *Lecture Notes in Computer Science*, Vol. 6294, 256–265.

Bonald, T. and M.-A. Tran. 2007. “Balancing elastic traffic sources.” *IEEE Communications Letters*, Vol. 11, No. 8, 692–694.

Basharin, G.P.; Y.V. Gaidamaka; and K.E. Samouylov. 2013. “Mathematical theory of teletraffic and its application to the analysis of multiservice communication of next generation networks.” *Automatic Control and Computer Sciences*, Vol. 47, No. 2., 62–69.

Basharin, G.P.; K.E. Samouylov K.E.; N.V. Yarkina; and I.A. Gudkova. 2009. “A new stage in mathematical teletraffic theory.” *Automation and Remote Control*, Vol. 70, No 12, 1954–1964.

Qian, M.; Y. Huang; J. Shi; Y. Yuan; L. Tian; and E. Dutkiewicz. 2009. “A novel radio admission control scheme for multiclass services in LTE systems.” *Proc. of the 7th IEEE Global Telecommunications Conference GLOBECOM-2009* (November 30 – December 4, 2009, Honolulu, Hawaii, USA), IEEE, 1-6.

Khabazian, M.; O. Kubbar; and H. Hassanein. 2012. “A fairness-based pre-emption algorithm for LTE-Advanced.” *Proc. of the 10th IEEE Global Telecommunications Conference GLOBECOM-2012* (December 3–7, 2012, Anaheim, California, USA), IEEE, 5320-5325.

Chowdhury, M.; M. Jang; and Z. Haas. 2013. “Call admission control based on adaptive bandwidth allocation for multi-class services in wireless networks.” *Communications and Networks*, Vol. 15, 15-24.

Gudkova, I.A. and K.E. Samouylov. 2012. “Modelling a radio admission control scheme for video telephony service in wireless networks.” *Lecture Notes in Computer Science*, Vol. 7469, 208-215.

Samouylov, K.E. and I.A. Gudkova. 2013. “Analysis of an admission model in a fourth generation mobile network with triple play traffic.” *Automatic Control and Computer Sciences*, Vol. 47, No. 4, 202-210.

Borodakiy, V.Y.; I.A. Gudkova; E.V. Markova; and K.E. Samouylov. 2014. “Modelling and performance analysis of pre-emption based radio admission control scheme for video conferencing over LTE.” *Proc. of the 2014 ITU*

Kaleidoscope Academic Conference (June 3-5, 2014, St. Peterburg, Russian Federation), 53-59.

Bonald, T. and J. Virtamo. 2005. "A recursive formula for multirate systems with elastic traffic." *IEEE Communications Letters*, vol. 9 no. 8, 753–755.

Yashkov, S.F. 1992. "Mathematical problems in the theory of shared-processor systems." *Journal of Soviet Mathematics*, Vol. 58, No. 2, 101–147.

Bonald, T. and M.-A. Tran. 2007. "Balancing elastic traffic sources." *IEEE Communications Letters*, Vol. 11, No. 8, 692–694.

AUTHOR BIOGRAPHIES

IRINA A. GUDKOVA received her B.Sc. and M.Sc. degrees in applied mathematics from the Peoples' Friendship University of Russia in 2007 and 2009, respectively. In 2007, she was awarded a scholarship of the Government of the Russian Federation. In 2011, she received her Ph.D. degree in applied mathematics and computer sciences from the PFUR. Since 2008, Irina Gudkova works at the Telecommunication Systems Department of PFUR, now she is an Associate Professor at the Department of Applied Probability and Informatics of PFUR. Her current research interests lie in the area of performance analysis of radio resource management techniques in LTE networks and teletraffic of triple play networks. In these areas, she has published several papers in refereed journals and conference proceedings. Her e-mail address is: `igudkova@sci.pfu.edu.ru`.

EKATERINA V. MARKOVA received her B.Sc. and M.Sc. degrees in applied mathematics from the Peoples' Friendship University of Russia in 2009 and 2011, respectively. She is currently a Ph.D. student at PFUR. Since 2012, she works at the Telecommunication Systems Department of PFUR, now she is a Senior Lecturer at the Department of Applied Probability and Informatics of PFUR. Her current research interests lie in the area of performance analysis of radio resource management techniques in LTE networks. Her e-mail address is: `emarkova@sci.pfu.edu.ru`.

VERONIKA M. ANTONOVA was born in Moscow, Russia. In 2012 she graduated from Moscow State Technical University named after Bauman with specialization on computer technologies. She is a postgraduate student of Communications Networks and Systems Faculty of the MTUCI where she is working at the moment. She studies the ratio of information traffic to signalling one in LTE networks. Her e-mail address is: `xarti@mail.ru`.

PAVEL O. ABAEV received his Ph.D. in Computer Science from the Peoples' Friendship University of Russia in 2011. He is an Assistant Professor in the Department of Applied Probability and Informatics at Peoples' Friendship University of Russia since 2014. His current research focus is on signalling networks congestion control, performance analysis of wireless 4G/5G networks and M2M communications, applied probability and queuing theory, and mathematical modelling of communication networks. His email address is: `pabaev@sci.pfu.edu.ru`.