SIMULATION OF THE LIMITED RESOURCES QUEUING SYSTEM FOR PERFORMANCE ANALYSIS OF WIRELESS NETWORKS

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ABSTRACT

Queuing systems with limited resources, in which customers require a device and a certain amount of limited resources for the duration of their service, proved their effectiveness in the performance analysis of modern wireless networks. However, the application of the queuing systems leads to complex computations. In this paper, we develop the simulation tool for the limited resources queuing systems and apply it to the analysis of M2M traffic characteristics in a LTE network cell.

I. INTRODUCTION

Queuing systems with limited resources are very promising in the performance analysis of the contemporary wireless networks. The key advantage of them is possibility to capture peculiarities of different radio resources allocation schemes by definition of appropriate cumulative distribution function (CDF) of resource requirements.

All analytical results for probability measures of resource queuing systems were obtained under assumption of Poisson [5,8] or state-dependent Poisson arrivals [6]. However, analytical formulas for probabilistic characteristics are too complex to be used directly due to multiple convolutions of the resource requirements CDF. In [7], we derived the recurrent algorithm for evaluation of stationary measures for the case of discrete resource requirements and proposed the sampling approach for continuous resources. However, the complexity of the calculations is still high and the algorithms are only applicable under assumption of Poisson arrivals. Hence, the development of a tool for simulation of queuing systems with limited resources became a very important task.

In the paper, we describe the developed simulation tool and use it to evaluate performance measures of M2M traffic in a LTE network cell. By the way, we provide comparison of calculations accuracy with the methods, proposed in [7].

The rest of the paper is organized as follows. Section II describes the queuing system with limited resources and provides a short summary of analytical results for it, while section III gives a brief description of the simulation tool. In Sections IV, the developed simulation tool is used for the analysis of LTE cell characteristics, simulation results are presented. Section V concludes the paper.

II. QUEUING SYSTEM WITH LIMITED RESOURCES

We consider a multiserver queueing system with N servers, in which arriving customer occupies not only a server, but also a volume of limited resources. The total volume of resources in the system is R and volumes of customers' resource requirements are independent identically distributed random variables with CDF $F(x)$. Customers arrive according to a Poisson process with intensity λ and the serving times have exponential distribution with rate μ. We assume here that resource requirements are independent of arrival and serving processes.

Let $\xi(t)$ be the number of customers in the system at moment $t>0$ and $\gamma(t)=\left(\gamma_1(t),....,\gamma_{\xi(t)}(t)\right)$ - the vector of occupied resources by each customer. The system behavior is described by the stochastic process $X(t)=\left(\xi(t),\gamma(t)\right)$ over the set of states $S=\left\{(n,r_1,...,r_n):0\le n\le N, r_i\ge 0, \sum_{i=1}^{n} r_i\le R\right\}$. Figure 1 shows the scheme of the queuing system.

Let t_i be the moment of arrival of the i-th customer. If upon arrival of the i-th customer with resource requirements r_i, the system does not have free servers ($\xi(t_i)=N$) or there is not enough unoccupied resources to meet the resource requirements, i.e. $r_i>R-\sum_{j=1}^{\xi(t_i)}\gamma_i(t_i)$,

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then the customer is lost. If $\xi(t_i) < N$ and $r_i \le R - \sum_{j=1}^{\xi(t_i)} \gamma_i(t_i)$, then the customer is accepted and occupies r_i resources. Upon the departure of a customer, it releases the server and all resources that were occupied by it.

In [5], the described system was analyzed and formulas for stationary probabilities were obtained. Stationary probabilities

$$q_0 = \lim_{t\to\infty} P\{\xi(t)=0\}, \tag{1}$$

$$q_n(x) = \lim_{t\to\infty} P\left\{\xi(t)=n, \sum_{i=1}^{n}\gamma_i(t) \le x\right\}, \tag{2}$$

are given by formulas (3) and (4):

$$q_0 = \left(1 + \sum_{n=1}^{N} \frac{\rho^n}{n!} F^{(n)}(R)\right)^{-1}, \tag{3}$$

$$q_n(x) = q_0 \frac{\rho^n}{n!} F^{(n)}(x), 1 \le n \le N, 0 \le x \le R, \tag{4}$$

where $F^{(n)}(x)$ is the n-fold convolution of resource requirements CDF $F(x)$ and $\rho = \lambda / \mu$ is the offered load.

The main characteristics of interest in the model are blocking probability B and the average volume of occupied resources b. In [5], the formulas for the characteristics were derived:

$$B = 1 - q_0 \sum_{n=0}^{N-1} \frac{\rho^n}{n!} F^{(n+1)}(R), \tag{5}$$

$$b = q_0 \sum_{n=1}^{N} b_n \frac{\rho^n}{n!}, \tag{6}$$

where $b_n = \int_0^R x F^{(n)}(dx)$.

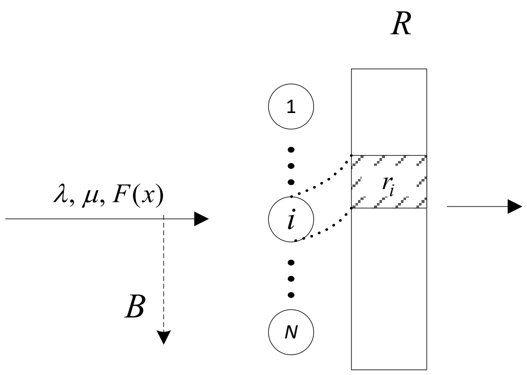

Figure 1. Resource queueing system scheme

The main challenge in evaluating blocking probability and average volume of occupied resources is calculating n-fold convolutions of $F(x)$. For some special types of $F(x)$, its convolutions may be evaluated analytically and then characteristics of interest are calculated easily according to formulas (5) and (6). But in most cases, numerical calculation of convolutions is inevitable. For that reason, we developed the simulation tool for limited resources queuing systems.

III. SIMULATION TOOL DESCRIPTION

In this section, we describe the developed simulation tool. Figure 2 shows block-diagram of the simulation tool.

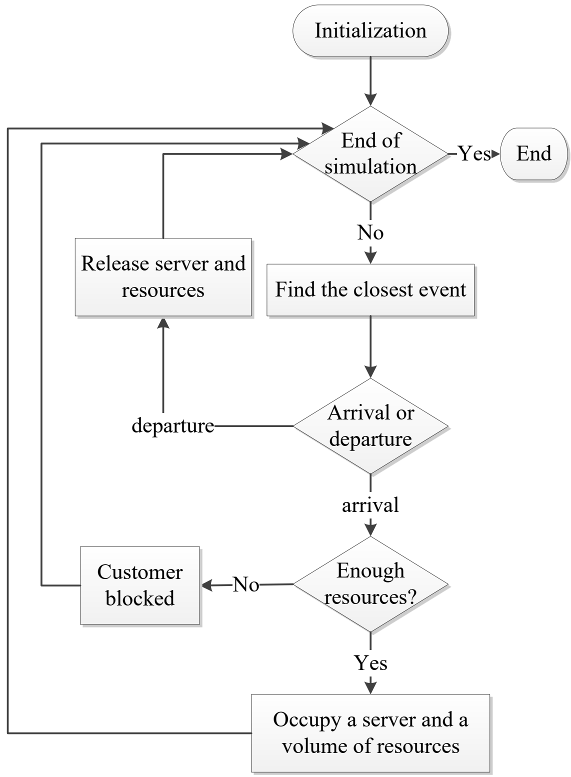

Figure 2. Block-diagram of the simulation tool.

1) Initialization: initial parameters setup. Define two types of events: arrival and departure of customers. Set *current_time*, *total_occupied_resources* and all components of N-dimensional vector *resources* to zero, define next *arrival_time* according to the Poisson distribution with rate λ and set all elements of N-dimensional vector *departure_time* to infinity. Define *total_number_of_customers* in the simulation session.
2) Start simulation cycle. Check for the end of simulation. If not, find the closest event, set *current_time*=*event_time*.
   a. If the closest event is arrival, then go to 3.
   b. If the closest event is departure, then go to 5.
3) Set *resource_requirements* of the customer according to $F(x)$, check whether the customer is accepted or not.
   a. If volume of unoccupied resources is greater or equal to *resource_requirements* and there is a free server in the system, then customer is accepted, go to 4.

b. If volume of unoccupied resources is less than *resource_requirements* or there are no free servers in the system, then the customer is blocked. Set new *arrival_time,* update statistics and go to 2.

4) Define a server to serve the customer, set the corresponding element of *departure_time* vector according to the exponential distribution with rate μ and set corresponding element of *resources* vector to *resource_requirements*. Increase *occupied_resources* by *resource_requirements* and set new *arrival_time*. Update statistics and go to 2.
5) Decrease *total_occupied_resources* by corresponding element of *resources* vector and set then set this element to zero. Moreover, set the corresponding element of *departure_time* to infinity, update statistics and go to 2.

The simulation session continues until the number of arrived customers exceeds *total_number_of_customers*.

IV. SIMULATION RESULTS

In this section, we use the developed simulation tool for the analysis of machine-to-machine (M2M) traffic [4] characteristics in a LTE cell. Table 1 shows radio propagation and load parameters of the base station [1].

Table 1: Numerical example data

Parameter	**Value**
L	100 m
ω	10 MHz
N	1000
$p_{\max}$	0.00398 W
r_0	100 Kbit/s
λ	[5 – 200] 1/s
μ	1 s
N_0	10^{-9} W
G	197.43
κ	5

First three parameters in table 1 define cell characteristics. Here L is the range of the base station, ω is the frequency bandwidth used for M2M traffic and N is the maximum number of active devices. M2M devices are characterized by the maximum transmit power $p_{\max}$, required bitrate for data transmission r_0, the rate of device activation λ and the mean duration of data transmission μ^{-1}. Final block of in table 1 define signal propagation parameters: N_0 is the noise power, G is the propagation constant and κ is the propagation exponent.

Earlier in [7], we derived CDF of resource requirements assuming that Full Power scheduler is used on the base station:

$$F(x)=\begin{cases}0, & x\le 0;\\ \dfrac{1}{L^2}\left(\dfrac{Gp_{\max}}{N_0}\right)^{2/\kappa}\left(e^{\frac{r_0}{x\omega}}-1\right)^{-2/\kappa}, & x\in(0,\varphi];\\ 1, & x>\varphi,\end{cases} \quad (7)$$

where $\phi=\dfrac{r_0}{\omega\ln\left(\dfrac{Gp_{\max}}{N_0L^{\kappa}}+1\right)}$. The corresponding probability density function (PDF) $f(x)$ is given by

$$f(x)=\begin{cases}0, & x\notin(0,\varphi]\\ \dfrac{2r_0}{L^2\omega\kappa}\left(\dfrac{Gp_{\max}}{N_0}\right)^{2/\kappa}\dfrac{e^{\frac{r_0}{x\omega}}}{x^2}\cdot\left(e^{\frac{r_0}{x\omega}}-1\right)^{-\frac{2+\kappa}{\kappa}}, & x\in(0,\varphi].\end{cases} \quad (8)$$

Here volume of resources means share of a time slot that is needed to guarantee the bitrate r_0 [2, 3]. Thus, the total amount of resources in the system is R=1.

For the generation of random numbers with CDF $F(x)$ one needs the inverse function $F^{-1}(x)$:

$$F^{-1}(x)=\frac{\frac{r_0}{\omega}}{\ln\left(1+\frac{Gp_{\max}}{N_0}\left(L^2x\right)^{-\kappa/2}\right)}. \quad (9)$$

The simulation results were compared with calculations from [7], where performance measures of the queueing system were obtained using sampling of the CDF (7) and applying recurrence algorithm for discrete resource requirements (figures 3 and 4).

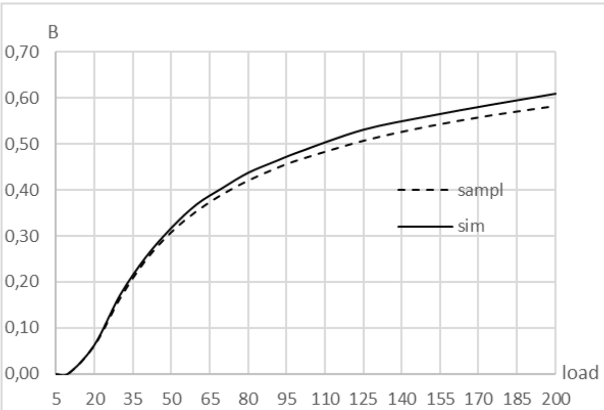

Figure 3. Blocking probability *B*.

As it is seen from figure 4, the blocking probability growth slows down with the increase of the load. The effect can be explained by different resource requirements of M2M sessions. Indeed, with the growth of the load, the system accepts mainly low-requirement sessions and blocks resource-greedy sessions. Both (figure 3 and figure 4) show us that results of samplification and simulations are rather close.

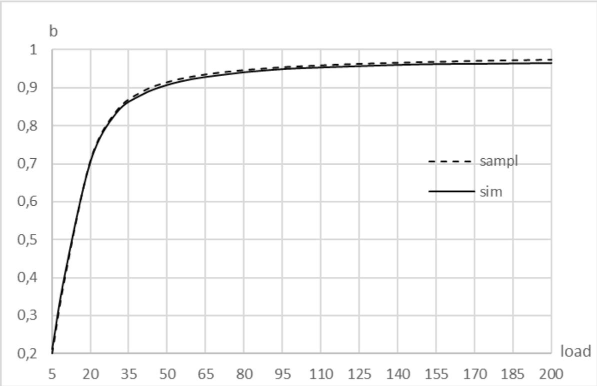

Figure 4. Average volume of occupied resources *b*.

Table 2 shows relative error of the simulations compared to the samplification method for different values of offered load. One can see that the relative error of average volume of occupied resources is nearly 1%, but when it comes to blocking probability the relative error rises to nearly 4%.

Table 2. Relative errors for *B* and *b* for various ρ .

ρ	**Relative error *B* (%)**	**Relative error *b* (%)**
5	0,354	4,641
10	9,294	1,843
20	2,038	0,642
30	4,284	0,742
40	2,613	1,056
50	2,976	0,968
60	4,117	0,860
70	3,431	0,893
80	4,061	0,757
90	3,573	0,687
100	3,686	0,689
125	4,747	0,797
150	4,127	0,776
175	4,139	0,981
200	4,602	1,085

V. CONCLUSION

In the paper, we developed the simulation tool for the queueing systems with limited resources and random resource requirements. The tool allows to evaluate performance measures of modern wireless networks with any custom radio resource scheduler.

In our future work, we plan to improve the condition for the end of simulation, so that the simulations continue until the relative error does not exceed some predefined level.

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