Links throughput evaluation in the telecommunication networks

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When planning the telecommunication networks it is important to determine the link throughput to provide quality of service, to prevent network overloading and to avoid bottlenecks. In this paper, a method for evaluating the link throughput in the modern telecommunications networks with packet switching based on the classical teletraffic system M/M/1/k is proposed. It is shown the dependence of the carried traffic from the queue size at a defined loss probability, and the dependence of the carried traffic from the defined waiting time, normalized to the average service time at a certain probability to wait more than a defined waiting time and a queue size. The presented graphic dependencies allow at defined quality of service, namely the probability of packet loss and admissible delays, to determine the allowable carried traffic of the lines. The determining the link throughput allows for efficient mechanisms operation of the congestion management in the modern telecommunications networks with packet switching.

Оценка на пропускателната способност на линиите в телекомуникационните мрежи (Сеферин Т. Мирчев). *При планиране на телекомуникационните мрежи е важно да се определи пропускателната способност на линиите, за да се предоставят качествени услуги, да не се допуска претоварване в мрежата и да се избягват тесните места. В този доклад е предложен метод за оценка на пропускателната способност на линиите в съвременните телекомуникационни мрежи с пакетна комутация на основата на класическата телетрафична система M/M/1/k. Показана е зависимостта на обслужения трафик от размера на опашката при зададена вероятност за загуби, а също и зависимостта на обслужения трафик от зададено време за чакане, нормирано спрямо средното време за обслужване, при определени вероятност да се чака повече от зададеното време и размер на опашката. Представените графични зависимости дават възможност при зададено качество на обслужване, а именно вероятност за загуба на пакети и допустими закъснения, да се определи допустимия обслужен трафик на линиите. Определянето на пропускателната способност на линиите дава възможност за ефективна работа на механизмите за управление на претоварванията в съвременните телекомуникационни мрежи с пакетна комутация.*

1. Introduction

The random processes in the modern packet-switched telecommunications networks are usually described by single-channel waiting systems. The packet switching itself requires the packets to be stored in memory and then transmitted to the corresponding output. The behavior of the outputs of the switches and the routers is described by single-channel waiting systems with finite queues. The throughput if the outputs, namely the maximum carried traffic at a given quality of service, determines the throughput of the lines connecting the switching nodes in the network. The throughput depends on the capacity of the lines or, in other words, on the bandwidth. In the core networks is usually accepted a Poisson arrival flow and an exponential distribution service time, which simplifies the analysis. This assumption is accepted at the lines throughput evaluation in this article. When planning the telecommunications networks, it is important to determine the throughput of the lines to provide quality of service, to avoid network congestions and bottlenecks.

The purpose of this article is to propose a method for estimating the throughput of the modern packet-switched telecommunication networks based on the classical teletraffic system M/M/1/k.

2. State of the problem in the literature

The teletraffic engineering provides useful tools for modeling random processes in telecommunications networks [1]. Usually, the queuing systems models are widely used in the network planning and in the quality of service evaluation [2]. The queuing systems are used to evaluate service quality parameters such as probability of packet loss, average packet delay, and throughput.

Formulas for the M/G/1/k system are presented in [3]. Their results are compared with the formulas for the M/M/1/k system and with simulation modeling. The characteristics of the M/G/1/k system are evaluated and the applicability of the approach for practical design, optimization and control problems is demonstrated.

A new analytical model of the IEEE 802.11 network with distributed channel access coordinating function based on the single-channel waiting system M/M/1/k is introduced in [4]. The proposed model makes it possible to evaluate the bandwidth, delays and loss of frames.

The characteristics of a finite-capacity femto cell network are evaluated in [5] using the single-channel waiting system M/M/1/k by the probability of packet loss, the average packet delays and the usability.

A wireless fully-connected network is investigated in [6] by load balancing and model nodes via a single-channel waiting system M/M/1. The traffic distribution algorithms for wireless full-area networks are analyzed in [7] using a line model based on the waiting teletraffic system M/D/1.

The nodes of the wireless fully-connected network are modeled in [8] as a combination of two single-channel teletraffic systems M/M/1/k to distinguish between forwarding and local generated traffic. With the developed analytical model is evaluated the throughput and the delays of a clustered FiWi network.

A single-channel continuous-time M/M/1 system is analyzed in [9], in which the server operates at two different speeds. The behavior of a single-channel system determines the behavior of a fluid buffer, which allows with this model to describe the process of shaping of the traffic with two levels in an ATM network.

The relatively complex single-channel system M(N)/G/1/k with state dependent arrival intensity, generally distributed service time and service interruptions is studied in [10].

3. Single channel waiting system M/M/1/k

We consider the classical single-channel waiting system M/M/1/k with a Poisson arrival flow, exponentially distributed service time and limited queue size [1], [11]. It is described by the following intensities of arrival and departure

$$(1)\qquad \begin{array}{lll} \lambda_i = \lambda & by & i = 0,1,2,\dots,k+1 \\ \mu_j = \mu & by & j = 1,2,3,\dots,k+1 \end{array},$$

where: λ is the packets arrival intensity;
μ is the service intensity;
k is the size of the queue.

The state transition diagram of the teletraffic system M/M/1/k is shown in figure 1.

The state probabilities P_j of the investigated system are obtained by the common solution of the birth and death processes

$$(2)\qquad P_j = \frac{A^j(1-A)}{1-A^{k+2}} \quad by \quad j = 0,1,2,\dots,k+1 \;,$$

where A is the offered traffic that is equal to the ratio of the arrival and service intensities.

4. Characteristics of the M/M/1/k system

The carried traffic is equal to the probability that the system is busy

$$(3)\qquad A_o = 1 - P_0 \,.$$

The loss probability by time is equal to the probability that the queue at the system is full

$$(4)\qquad B = P_{k+1} \,.$$

The average number of packets in the system is

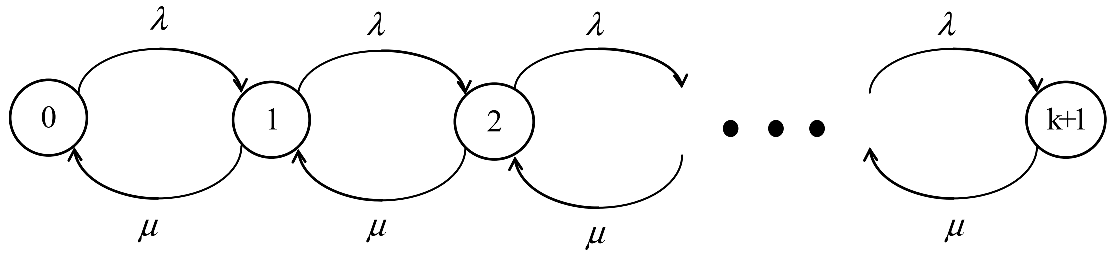

Fig.1. State transition diagram of the M/M/1/k system.

determined by the state probabilities

(5) $$L = \sum_{j=1}^{k+1} j P_j \; .$$

The average waiting time in the system is determined by the Little formula

(6) $$W = L/\lambda \; .$$

The queue size at given loss probability by time and offered traffic can be determined by the following formula obtained from (2)

(7) $$k = \left\lceil \frac{ln\;[B/(1-A-AB)}{ln\;(A)} \right\rceil - 1 \; .$$

The probability of arrival packets to wait is determined by the probability that the system is busy without the probability that the queue is full when the arrival packets are not served

(8) $$P(t_w > 0) = \sum_{j=1}^{k} P_j = 1 - P_0 - P_{k+1} \; .$$

The probability of arrival packets to wait more than a defined time t' in the service discipline of “first come – first served” is determined as follows

(9) $$P(t_w > t') = \sum_{i=1}^{k} P_i \, Q_i(>t') \; .$$

When a packet enters the system and it is in a state from 1 to k, there is a probability that it will wait longer than the defined time. This will happen when the number of the finishing service of the packets in the defined time interval is less than the system state number. Once the service time is exponentially distributed and the server is busy for the defined time interval, the departure process is described by a Poisson distribution. The probability to have j finishing services for the defined time interval t' is

(10) $$Q_j(t') = \frac{(\mu\, t')^j}{j!} e^{-\mu t'} \; .$$

The conditional probability that a packet will wait more than the defined time interval t' when the system is in state i ($1 \le i \le k$) is

(11) $$Q_i(>t') = \sum_{r=0}^{i-n} \frac{(\mu t')^r}{r!} e^{-\mu t'} \; .$$

5. Numerical results

This section presents graphically the numerical results obtained with a computer program. The carried traffic at a given quality of service is calculated using the iterative method of splitting.

The dependence of the carried traffic on the queue size at a given loss probability is shown in figure 2. It is seen that with a queue size of less than 15 packets the throughput is relatively low. In order to have usability above 90%, the queue size needs to be larger than 45 packages. The large queue size leads to longer delays.

The dependence of the carried traffic on the defined waiting time, normalized to the average service time, with a given probability of waiting more than the defined waiting time, queue size k = 100 and service intensity $\mu = 1$ is presented in figure 3. In the modern IP networks, packets with a length of 500, 1000 and 1500 bytes are usually handled. When we know the transmission speed of the line, we can easily calculate the average service time. The admissible delays for the various services will determine the normalized waiting time. By using this normalized waiting time and for the selected low probability of waiting more than this waiting time, the carried traffic can be calculated.

It can be seen from figure 3 that when the line speed and the admissible delay determine the defined waiting time less than 20 times the average service time the throughput is relatively low. In order to have usability above 90%, the defined waiting time must be greater than 70 times the average service time. The large values of the defined waiting time lead to greater throughput and longer delays.

6. Conclusion

The presented method for determining the carried traffic of the lines at the defined admissible loss probability and the low probability of waiting more than a defined waiting time on the basis of the classical queueing system M/M/1/k enables accurate sizing of the telecommunication networks and improvement of the quality of service. The presented graphical dependencies of the carried traffic on the queue size and on the defined waiting time enable at a given quality of service to determine the usability of the lines. The calculation of the lines throughput enables the efficient operation of congestion management mechanisms in modern packet-switched telecommunication networks.

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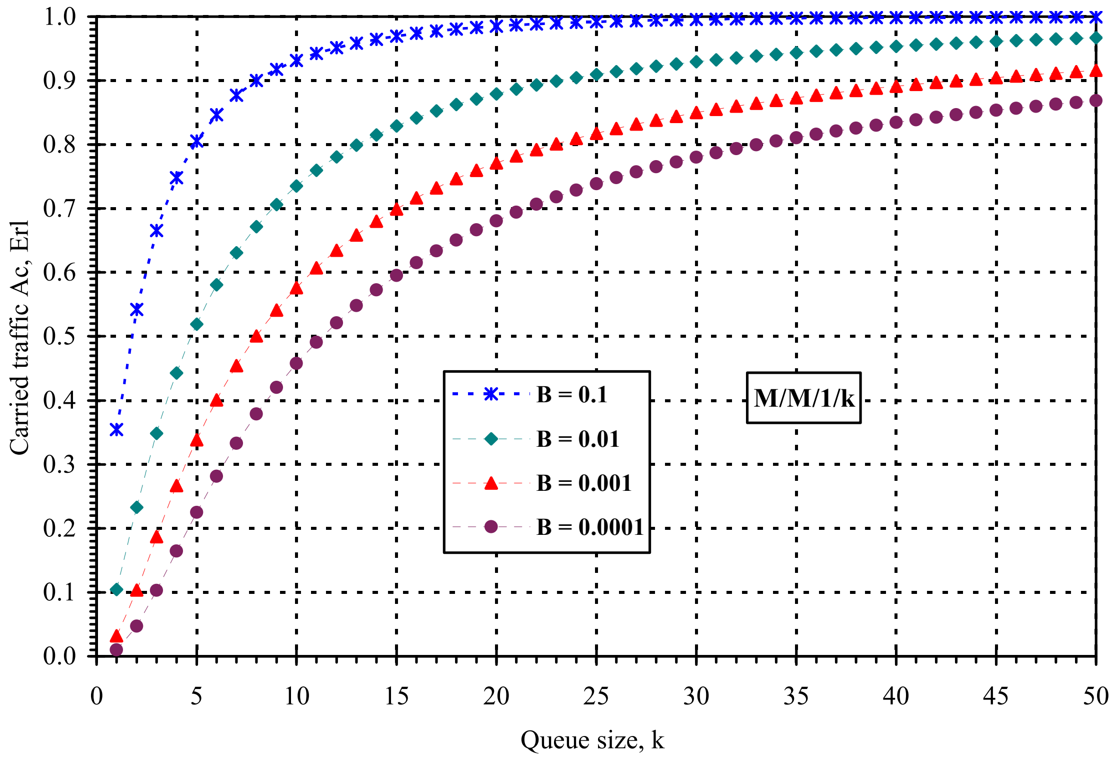

Fig.2. Dependence of he carried traffic A_c on queue size k at different loss probability B

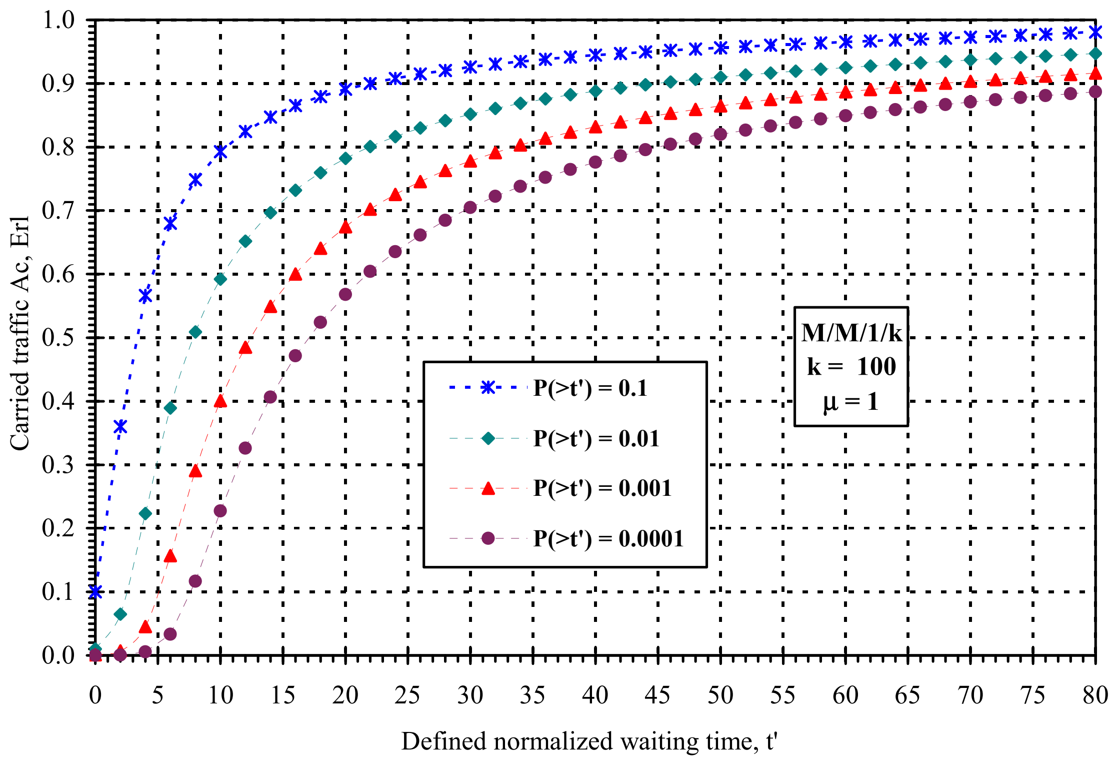

Fig.3. Dependence of the carried traffic A_c on the defined normalized waiting time t' at different probability of waiting more than the defined time P (> t')

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