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CALCULATION OF AVERAGE TIME OF PACKET DELAY IN THE STORAGE BUFFER OF A SINGLE-CHANNEL SYSTEM WITH SELF-SIMILAR TRAFFIC

Anatoliy Lozhkovskyi, Yevgeniy Levenberg
O. S. Popov Odessa national academy of telecommunications, Odessa, Ukraine
aloshk@onat.edu.ua

Abstract: First step for the calculation of service quality characteristics in a single-channel packet communication system is to estimate the Hurst exponent for self-similar traffic, after which, according to the well-known Norros formula, the average number of packets in the system N is calculated. However, such an algorithm does not allow calculating two very important service quality characteristics, such as the average waiting time of packets in the cumulative buffer (not in the system as a whole) and the waiting probability of the service start of the packet. In the paper the new method for approximating the probability distribution function of the system states is proposed, where a simple exponential function with the r/N distribution parameter was used for the approximating function. From this approximating function the new formula for calculating the waiting probability for the service start of the packet in a one-channel system with self-similar traffic is obtained. This method of calculation is based on the phenomenon that packets in self-similar traffic are not smoothly distributed over different time intervals. They are grouped into "blocks" within certain time intervals, but there are hardly any of them within the others. Therefore, for such traffic, in the distribution function of the number of packets in a single-channel system, the probability P_0 of a complete absence of packets in it increases. The results obtained in the paper will be useful for the further development of monitoring subsystems of power comlexes.

Key words: probability of waiting, service quality, Hurst exponent, self-similar traffic**.**

1. Introduction

In packet communication networks, the traffic or the distribution of the number of packets per time unit is well described by a self-similar random process with a self-similar coefficient (the Hurst exponent) of 0.65–0.8 or more [1]. The main reason for the self-similarity of traffic is the integral nature of the network (multiservice). This network is used simultaneously for the transmission of speech, video, and data represented in the form of standard packet. Here, the flow of different applications and services is provided by the same network with unified protocols and control laws.

For packet networks, the mathematical model of self-similar traffic is the most popular, but there is no reliable and recognized methodology for calculating the parameters and service quality characteristics in the mass-servicing systems while servicing such traffic. With the increasing degree of self-similarity of packet traffic, the service quality characteristics in the system significantly deteriorate compared with the maintenance of traffic of similar intensity, but without the effect of self-similarity.

The first step for the calculation of service quality characteristics (QoS) in a single-channel system with an infinite queue for self-similar traffic is to estimate the Hurst exponent, after which, according to the well-known Norros formula [2], the average number of packets in the system is calculated. Other characteristics, such as the average number of packets in the queue of Q, the average packet stay in the system of T, and the average latency of packets in the system of W are then calculated based on their known functional relationships with the calculated mean N [3].

However, such an algorithm does not allow, basing on the established value of the Hurst exponent H, the calculation of such characteristics as the probability of service expectation P_w and the average delay of packets in the accumulation buffer t_q.

The purpose of this work is to establish an approximation function for the distribution of states of a single-channel system with an infinite queue and self-similar traffic and on its basis the formulae for calculating the probability of service expectation of a packet in the cumulative buffer.

2. Complexity of the problem

The evaluation of QoS characteristics in the mass-servicing systems is always performed on the basis of a mathematical description of the system response to the input packet stream. The system response can be defined as the states which, due to the random nature of the flow of packets, are mathematically described by the probabilistic distribution function of the number of occupied channels and points for waiting P_i, where i is the number of packets in the system (in channels and queue). This function coincides with the function of the distribution of the number of packets in the system (serviced and waiting in the queue), since each packet occupies one channel in the system or one point for waiting at the queue [3].

In the case of the simplest Poisson flow model in a mass-servicing system with losses or expectations (queue), the states of the system are described by one of the known Erlang distributions: the first or second Erlang distribution, respectively [3]. Finding the distribution function of the system state for more complex stream models is a very difficult task and, therefore, for the above-mentioned self-similar model of flow, there are no similar solutions.

In packet networks, packet flows (traffic) significantly differ from the Poisson flow model with the exponential function of allocating the time interval between the moments of packet arrival. Here, the packets flow is formed by a set of sources of requests for services provided by the network applications that provide video, data, speech, etc. The sources of requests taking part in the process of creating the flow of packets differ significantly having the different specific intensity of the load. The load intensity of the resulting packet stream at any given time depends on what applications are served by query sources and what is the ratio of their number to different applications. The structure of traffic is also influenced by the technological features of the used service algorithms. For example, if the service is provided by multiple applications or protocols, or the repeated transfer of incorrectly accepted packets, then the moments of packet requests are much correlated. Because of this, the output streams vary considerably and in the resultant traffic, there are long-term dependencies in the intensity of packet arrivals. In this case, traffic is no longer a mere sum of the several number of independent stationery and ordinary streams, such as Poisson flows of telephone networks. In multi-service packet switched networks, traffic is heterogeneous, and streams of different applications require a certain level of service quality. Under these conditions, the flow of all applications provides a single multiservice network with shared protocols and management laws, despite the fact that the sources of each application have different rates of transmission of information or change it during the communication session (maximum and average speed). Due to this, the combined packet stream is characterized by the so-called "burstiness" of traffic with random periodicity and the duration of peaks and silence. For such packet, traffic is characterized by strong unevenness of the intensity of the arrival of packets. Packets are not smoothly dispersed over the different time intervals, but are grouped into "blocks" on some intervals, but there are hardly any of them within the others [4]. Therefore, for such traffic in the function of the distribution of the number of packets in a single-channel system, increasing the probability P_0 of the complete absence of packets in it is shown in Fig. 1.

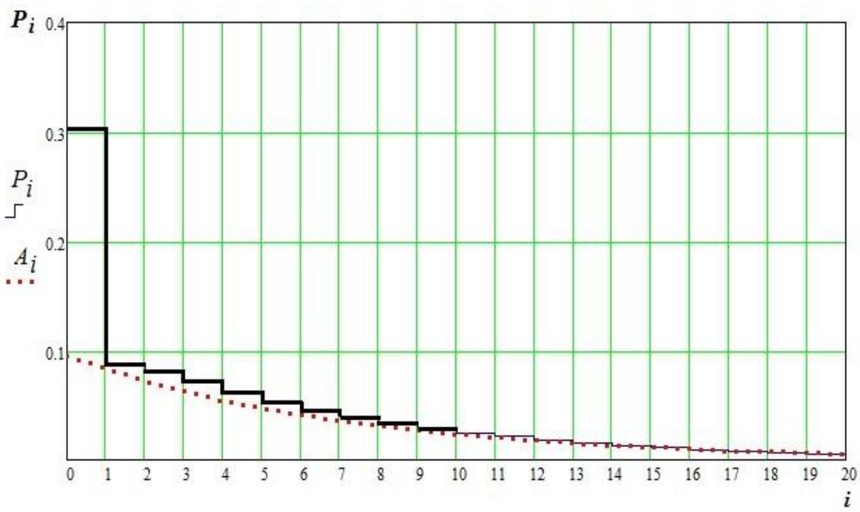

Fig. 1. The distribution function of the system state P_i and its approximation A_i.

The efficiency of servicing such traffic is very low, since in its processing during periods of slump load with probability P_0 system resources are used rather little, and it is necessary to increase the length of the cumulative buffer to prevent the loss of packets at load peaks. Designing the same bandwidth of the system is, as a rule, based on the average traffic intensity, which does not simultaneously ensure its effective use and the given level of QoS.

3. Basic formulas and investigation

For single-channel system with self-similar traffic, infinite queue and a constant processing time (system fBM/D/1/∞), an approximate solution is given in [2], where it is shown that the number of N packets in the system is considered at any time

$$N = \frac{(1-r)^{\frac{H}{H-1}}}{r^{\frac{0.5}{H-1}}}. \quad (1)$$

The Hurst method allows revealing in packet data statistics such properties of flow as clustering, the tendency to follow the direction of the trend (persistence) and the rapid intermittence of successive values of traffic intensity (bursts of intensity), strong aftereffect, strong memory, self-similarity, the presence of periodic and non-periodic cycles (due to the peculiarities of the transmission protocols used) [5]. However, the existing methods for calculating the Hurst exponent are quite laborious, which makes it difficult to use them under conditions of real processor time for processing traffic parameters while identifying its self-similar properties.

The paper [6] offers a simplified method for calculating the self-similarity coefficient of packet network traffic. Its simplification is provided by performing calculations not for all possible values of R/S-statistics (regression), but only for two of them. The error of the calculations does not exceed 2–5 %.

From Fig. 1 it can be seen that the part of the distribution function of the number of packets in the P_i system without the probability P_0 is sufficiently qualitatively consistent with the approximating function A_i from the following expression:

$$A_i = r\frac{r}{N}\exp\left(-\frac{r}{N}i\right), \quad (2)$$

where ρ is the load of the system (utilization factor) equal to $0.3 < r < 1$; N is the average number of packets in the system.

As it can be seen from (2), the approximating function A_i is the result of multiplying the loading of the system r by a certain exponential function with the distribution parameter r/N and, therefore, $\int_0^\infty A_i \neq 1$, that is, all probabilities A_i do not represent the complete group of events.

In the non-Poisson flow, the probability of waiting in a one-channel system according to [3, p. 272] is defined as

$$P_W = \sum_{i=1}^{\infty} P_i' = 1 - P_0',$$

where P_i' is the probability of having i packets in the system only at the moment of receiving new packets. Then, in the distribution function P_i, represented in Fig. 1, each P_i value does not depend on the moment the packet arrives in the system (it does not depend on whether the packet arrives or does not arrive in the system) and, therefore, the probability P_0 is not appropriate for calculating the waiting probability of P_w.

From the point of view of the system state distribution function P_i'', which consists of the probabilities P_i'' of having packets in the system i only when no new packets are received, the "waiting service" event occurs only when there are two or more packets in the system, that is, the waiting probability is equal

$$P_W = 1 - P_0'' - P_1''. \quad (3)$$

The function A_i is not fully a function of the distribution of the number of packets in the system, but only its part, starting with A_1, is close to the part of the P_i function without the probability P_0. The function A_i without A_0 describes approximately the new space of events in the system from one packet to the infinite number of packets. In this new space of events, you can calculate probabilities, and so on, considering them in accordance with the classical definition of probability: “the probability of an event is equal to the ratio of the number of favorable events of these cases to the total number of cases”. Thus, for example, the probability will be determined as follows

$$P_1''' = \frac{A_1}{\sum_{i=0}^{\infty} A_i}. \quad (4)$$

However, the sum of all probabilities A_i in the denominator of expression (4) is obtained from the space of events in which the event “complete absence of packets in the system” with the probability P_0 of P_i distribution is removed, where each P_i value does not depend on whether the packet arrives or does not arrive the system. In other words, the probability A_1 is satisfied by the sum of the probabilities A_i, that is, the probabilities of the space in which the event “absence of packets in the system” is impossible, in other words, from which the packets in the system "always arrive" (at the moment of their receiving or not receiving). Therefore, the likelihood of probability is taken into account. If packets in the system are "always there", then an event consisting in the presence of one packet in the system (the minimum possible number of packets for their constant presence) can only happen when no new packets arrive. Therefore, probability P_1'' in probability P_1''' is already taken into account. Consequently, the probability P_1''' is equal to the sum of probabilities P_0'' and P_1'', that is,

$$P_1''' = P_0'' + P_1''. \quad (5)$$

Thus, according to the expressions (3), (4) and (5), the waiting probability for the service of a packet in a single-channel system with an infinite queue of fBM/D/1/∞ type can be calculated. Through successive transformations, it has been proved that the waiting probability for the service of a packet in a single-channel system with an infinite queue for self-similar traffic can be determined as follows

$$P_W = 1 - \frac{A_1}{\sum_{i=0}^{\infty} A_i}. \quad (6)$$

Taking into account the constant part of the approximating function (2), which is present in the numerator and the denominator of expression (6), the final expression for calculating the probability of waiting is as follows:

$$P_W = 1 - \frac{\exp\left(\frac{r}{N}\right)}{\sum_{i=0}^{\infty} \exp\left(-\frac{r}{N} i\right)}. \quad (7)$$

So, if the average number of packets in the system N is given (or the upper limit of the possible average N obtained by calculating the Hurst exponent according to the Norros formula (1),), the probability of service expectation P_w for the packet can be calculated using the approximation (2) by the formula (6), or directly by the formula (7).

Furthermore, due to the known ratio [2], such characteristics as the average number of packets in the queue Q, the average packet stay in the system T, and the average latency of packets in the system W are calculated:

$$Q = N - r, \qquad T = \frac{N}{r}, \qquad W = T - 1,$$

where T and W are given in the units of average service time.

Only then, the average latency of packets in the cumulative buffer can be calculated by the formula

$$t_q = \frac{W}{P_w}. \quad (8)$$

To evaluate the service quality characteristics of self-similarity traffic, simulation methods can be used, for example [7]. However, the result of this assessment depends on the chosen modeling method. Since self-similar traffic (the time interval between packets) is best described by the Weibull or Pareto distribution, the influence of modeling methods on QoS parameters in conditions of self-similarity traffic is investigated in [8]. In the absence of reliable and accurate methods for assessing the quality of service characteristics in systems with self-similar traffic, a simplified approach to determining the Hurst exponent (the degree of self-similarity of traffic) is unacceptable. If we do not take into account the actual distribution of the time intervals between packets in self-similar traffic and do not apply the exact formulas, the use of the approximate solution (1) known as the Norros formula causes large errors. If, on the basis of the results of statistical measurements of the parameters of real traffic, we have approximated function which is defined (Weibull, Pareto or other), then we obtain such a new formula that the values of the Hurst exponent for the corresponding distributions are unambiguous.

4. Conclusion

The performed simulation confirmed the correctness of this method for calculating the service quality characteristics in a one-channel system with self-similar traffic. At the same time, the difference between simulation and calculation results does not exceed 5 % when the system loads vary in the range of $0.3 < \rho < 1$ (error less than 2 % with $r \geq 0.6$) and the Hurst exponent values change in the range of $0.5 < H < 0.9$.

Authors consider the obtained result as a basis for developing a packet-oriented information system for monitoring the energetic complexes and systems. While monitoring system become more big-data oriented, the networks with high throughput are necessary elements of such a system. Thus, studies in the field of improving service quality in high-speed telecommunication networks might be useful for further improvement and development of monitoring processes in power systems.

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РОЗРАХУНОК СЕРЕДНЬОГО ЧАСУ ЗАТРИМКИ ПАКЕТІВ У НАКОПИЧУВАЛЬНОМУ БУФЕРІ ОДНОКАНАЛЬНОЇ СИСТЕМИ З САМОПОДІБНИМ ТРАФІКОМ

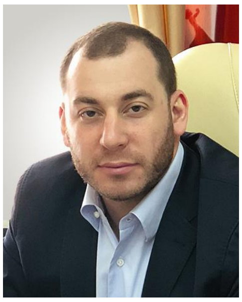
Анатолій Ложковський, Євгеній Левенберг

Для розрахунку характеристик якості обслуговування (QoS) в одноканальній системі мережі пакетного зв'язку спочатку необхідно оцінити показник Херста самоподібності трафіку, після чого, відповідно до відомої формули Норроса, обчислити середню кількість пакетів у системі N, а потім через відомі співвідношення розрахувати інші характеристики QoS. Однак це не дає змоги обчислити дві дуже важливі характеристики якості обслуговування, такі як середній час очікування пакетів у накопичувальному буфері, а не в системі загалом, та імовірність очікування початку обслуговування пакета.

Запропоновано новий метод апроксимації ймовірнісної функції розподілу станів системи. Для апроксимуючої функції використана проста експонентна функція з параметром ρ/N, а на її основі отримано формулу для обчислення ймовірності очікування початку обслуговування пакета в одноканальній системі мережі з самоподібним трафіком. Вона заснована на тому, що пакети в самоподобному трафіку не плавно розподіляються на різних часових інтервалах, а нерівномірно згруповані в "пачки" в одних часових інтервалах і іноді повністю відсутні в деяких інших часових інтервалах. Тому в функції розподілу кількості пакетів у системі суттєво зростає ймовірність P_0 повної відсутності пакетів.

Anatolii Lozhkovskyi – Professor (2011), Doctor of Engineering (2010), Head of the Switching Systems Department (2006). He was recognized as the Honorary Signalman of Ukraine (2008) and awarded with the Excellence in Education of Ukraine (2014).

Laureate of the State Prize of Ukraine in the field of science and technology (2014). Main directions of scientific activity: telecommunication systems and networks, distribution theory of information, teletraffick theory, evaluation of service quality and bandwidth of telecommunication networks, imitative modeling of mass service systems, development of software applications.



Yeugenii Levenberg – graduate student of the O. S. Popov Odessa National Academy of Telecommunications. Master degree in Telecommunication Systems and Networks (2008). Specialist degree in Lawyer, Personnel management. (2011). He has established a company for the construction of engineering communications – "LEV-GROUP", LLC (2006). Areas of research interest: telecommunication systems and networks, linear-cable constructions, queuing systems, evaluation of self-similar traffic service quality.