REMARKS ON PACKET LOSS PROBABILITY FOR THE NETWORK TRAFFIC WITH SELF-SIMILAR BEHAVIOUR

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ABSTRACT

A number of recent empirical and analytical studies of traffic measurements show self-similar nature in actual packet networks. There has been mounting evidence that the performance of queuing models with self-similar inputs is radically different from the performance predicted by traditional traffic models. due to presence of burst traffic leading to a higher delay and packet losses. The present paper presents study of packet loss probability dependence on the number of individual traffic sources.

KEYWORDS

Measurement-Based Admission Control, Performance evaluation, Quality of Service, self-similar traffic.

1. INTRODUCTION

A number of recent empirical and analytical studies of traffic measurements from a variety of working packet networks have convincingly demonstrated that actual network traffic is self-similar or long-range dependent in nature - in sharp contrast to commonly made traffic modelling assumptions. Recently, studies identified some evidences of self-similar behaviour in computer network traffic, as well as its severe implications in network performance [8, 9]. Mainly due to presence of burst traffic in several time-scales leading to a higher end-to-end delay and packet losses.

Starting with the work by Norros [7], there has been mounting evidence that clearly shows that the performance of queuing models with self-similar inputs can be radically different from the performance predicted by traditional traffic models, especially related to Markovian models with short-range dependence. The practical effect of self-similarity is that the buffers needed at switches and multiplexers must be bigger than those predicted by traditional queuing analysis.

Traffic bursts make classical queuing models to fail and raise issues for the necessity of efficient algorithms of admission control determination. The measurement of packet loss probability mainly depends on buffer size and traffic characteristics.

For research of the dependence the Pareto/M/1/K queuing model, described by R. Rodriguez [11], is applied and demonstrated in Chapter 1. The following chapter deals with the simulation environment implemented for the verification of the queuing model presented in the previous chapter. Chapter 2 starts with a commonly used technique for generating self-similar traffic and significant conclusions about the arbitrary number of individual traffic sources impact on the implication of the traffic characteristics were reached. The next section presents the framework and scenarios of the simulation.

The following part shows the empirical results of the study and demonstrates the packet loss probability dependence on individual traffic source number is presented. Section 4 presents the simulation results and comments. Finally, in Chapter 3, implications of the current study and directions for future research are discussed.

2. BUFFER SIZE ESTIMATION

The buffer size plays critical role for the network performance. The adequate size of the buffer maintains Quality of Service (QoS) requirements within limited network capacity for as many users as possible. To get benefits the accurate model for the buffer size calculation should be used. Since classical queuing models do not suit modern packet switched networks the other models have to be used.

Network data reveals heavy-tails in their probability distributions or long-range dependence [1, 3]. Pareto probability distribution function (PDF) has been suggested as a suitable function for such data. The commonly considered measure of self-similarity is so-called Hurst parameter (H) that is clearly related to the shape (α) parameter of a heavy-tailed distribution function. The Hurst parameter for the Pareto PDF that has been recommended in many research works as an option for Internet data description, according to analytical and empirical procedures shows the relation H=(3- α)/2[5]. A value of H = 0.5 indicates the lack of self-similarity that corresponds to Poisson data flows, whereas large values for H (close to 1.0) indicate a large degree of long range dependence in the process.

The lack of closed-form expression for their Laplace transform for most of heavy-tailed distributions forces the development of numerical techniques to analyze queuing systems with self-similar type of traffic. In the present study the size of the buffer was chosen according to R. Rodriguez [11]. In his work the author shows the analytical expression for the derivative of the Laplace transform of the Pareto PDF and uses it with a purpose to calculate the asymptotic packet loss probability.

According to R. Rodriguez [11], the loss probability $P_{K_{LOSS}}$ of the GI/M/1/K theorem by Choi, B. Kim & I.Wee [4] can be written in closed form as following:

$$P_{Loss}^{K} = \left(1 - \frac{\alpha(\alpha-1)}{\rho} M^{\frac{\alpha}{2}-1} e^{M/2}\right) \times \left[\sqrt{M} W_{-\frac{\alpha+1}{2},-\frac{\alpha}{2}}(M) - W_{-\frac{\alpha}{2},\frac{1-\alpha}{2}}(M)\right] \sigma^{K}$$

where $M = \dfrac{(\alpha-1)(1-\sigma)}{\rho}$ and $W_{\eta,\xi}(\phi)$ - Whittaker's function.

It is important to keep in mind that this is an asymptotic result and it may not give feasible solutions for small values of the parameters involved.

The Fig.1 presents the relation between Hurst parameter, buffer size and packet loss probability for different utilization of the queuing system evaluated by R. Rodriguez [11]. He shows that the closed-form mathematical expressions for the performance measures in Pareto/M/1/K queuing system gives appropriate results.

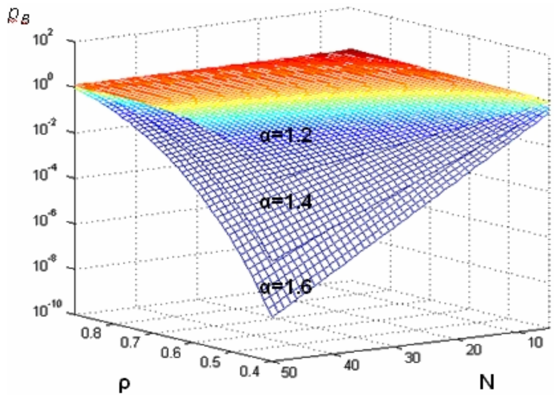

Figure 1. Relation between utilization, buffer size and packet loss probability for Hurst parameter H=0.9(a), 0.75(b), 0.5(c)

It is commonly considered that a linear increase in buffer sizes will produce nearly exponential decreases in packet loss, and that an increase in buffer size will result in a proportional increase in the effective use of transmission capacity. As it can be seen in the Fig.1 (self-similar traffic), these assumptions do not hold. The decrease in packet loss with buffer size is far less than expected, and as it can be seen, the buffer requirements begin to explode at lower levels of utilization for higher degrees of long-range dependence (higher values of H).

3. SIMULATION ENVIRONMENT

3.1 ON-OFF Model

The traditional traffic source models such as Poisson and Exponential PDF which superposition does not exhibit self-similarity must be replaced with more accurate models in order to obtain reliable simulation results [5]. For this reason, usual performance metrics, such as throughput, delay, jitter, packets loss and queue lengths, must be evaluated taking into account these evidences as a support for obtaining coherent results.

In the present research the simulation of the self-similar traffic is based on the ON-OFF model. Originally, it was suggested by Mandelbrot [10]. This method is based on superposition of many independent and identically distributed ON-OFF sources.

In the present paper by the ON-OFF source model, we mean a model where the ON- and OFF-periods strictly alternate. The ON- and OFF-period sequences are independent from each another. The network measurements show the reason to assume that in real traffic the OFF-period is longer then ON-period. ON-period corresponds to active time period. During that time transmitted packets are separated by small time intervals. It is reasonable to assume that packet sizes within a period remain constant. The ON period is termed packet “train”. OFF-period corresponds to silent period, when no packet is transmitted.

The ON-OFF model was chosen for our simulation as it has been shown in the literature that self-similar network traffic can be generated by multiplexing several sources of Pareto-distributed ON- and OFF- periods [1].

The ON-OFF model was implemented using the OPNET simulation software (see next Chapter). Each source sends bursts with random duration distributed by Pareto distribution. In our ON-OFF model, the number of sources is fixed for each scenario.

The traffic generated by sources is independent and identically distributed. In the paper the following approach is used. The total intensity generated by all sources is the constant value through the all scenarios and does not depend on the source number. It means that the traffic intensity of each source is in inverse ratio to the number of sources. While the number of sources increases the intensity of each individual source decreases and vice verse.

The results, gained during the simulation, show that characteristics of the traffic do not depend on the number of sources which are consistent to the results [18, 19]. The results are illustrated in the Fig.2. The next chapter introduces a holistic view of the simulation framework that implements ON-OFF traffic model for the current project.

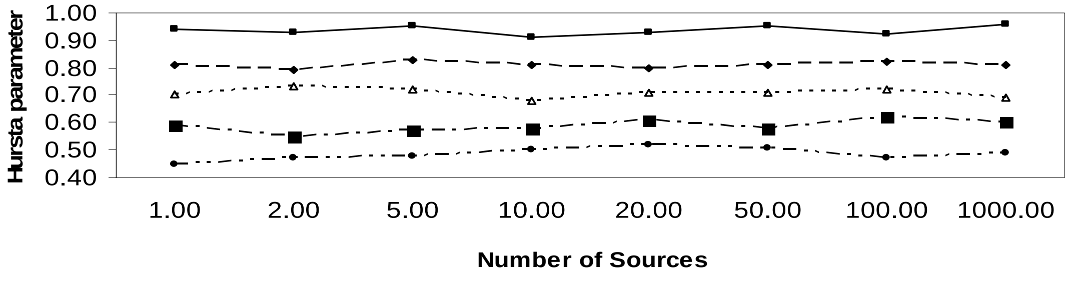

Figure 2. Hurst parameter dependence on number of ON-OFF sources

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3.2 Simulation Framework

The real network traffic is based on the aggregation and superposition of ON-OFF sources, where activity (ON) and inactivity (OFF) periods follow a heavy tailed PDF. This approach could allow an immediate use of widespread network simulation tools, such as the software family from OPNET.

The analysis of self-similarity undertaken in this paper involves the simulation of aggregation of ON-OFF traffic sources, traffic measurement and estimation of the Hurst parameter. The numbers of traffic sources used in different scenarios were 1, 2, 5, 10, 20.

Source average aggregate rate Λ was set to create the 0.8 network utilization. During the activity periods (ON), each source sends data at a rate of Λ/n, where n is the number of sources.

In our ON-OFF model, the number of sources is fixed for each scenario, while each source sends several bursts with random duration (Fig.3).). The destination does not send any reply to these requests. A packet analyzer was connected to the network to record the information.

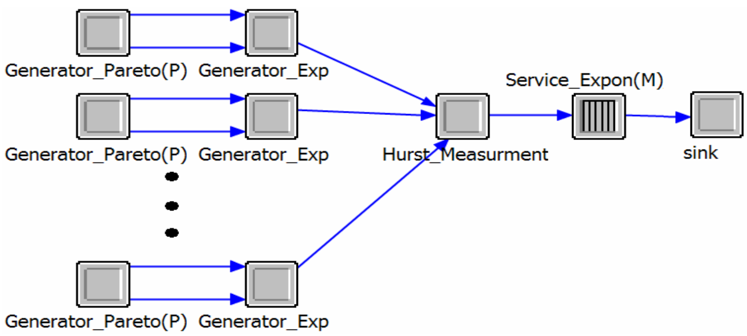

Figure 3. The node model of the ON-OFF traffic generator in OPNET.

3.3 Results

The Fig.3 presents buffer overflow dependence on the number of ON-OFF sources, where each source presents a session while ON period exists. Interesting result can be observed at the figure 3. The simulation shows that the buffer overflow probability decreases while the number of the ON-OFF sources grows. It is necessary to emphasize that the summarized traffic of the sources does not depend on the number of sources. It is necessary to keep in mind, that interarrival rate of each source is in inverse ration to the number of sources. The results of the OPNET simulation were checked against the results of GPSS simulator and they appeared to be very similar. GPSS simulator provided similar results that overflow probability depends of the number of ON-OFF sources.

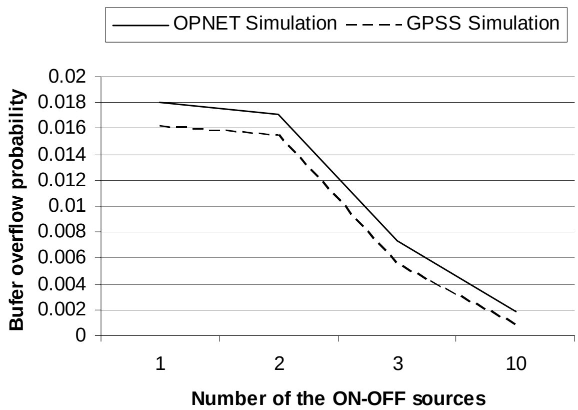

Figure 4. Buffer overflows probability dependence on ON-OFF sources number for OPNET (solid line) and GPSS (dashed line) simulations. The overflow probability correspond to scenario with Hurst equal to 0.75

It is not shown on the figure, but for the same scenario overflow probability starts to increase when the number of the ON-OFF sources goes up from 10-20. The figure presents the buffer overflow probability for the α=1.5 (H=0.75) and the number of the ON-OFF sources are 1; 2; 3; 10.

As it was mentioned in the previous section, the Hurst parameter does not very on ON-OFF sources. It means that during the simulation the Hurst parameter for each number of the source was approximately the same. The phenomenon when the buffer overflow probability decreases while ON-OFF sources increase can be perfectly used in MBAC algorithm to provide better network utilization and to gain better effort.

3.4 Discussion and comments

Taking into consideration the above mentioned arguments about the packet loss probability dependence on ON-OFF source number this section addresses issues regarding the analytical model for that phenomena.

The analysis examined the applicability of a special case of the birth-death process, named Machine Repairman Model, when the birth rate λ_j is of the form (M-j) λ, j= 0,1,...,M, and the death rate, $\mu_j=\mu$, for analytical description of ON-OFF traffic model. This structure can be useful in the modelling of interactive computer systems where an individual terminal user issues a request at the rate λ whenever it is in the “thinking state” that corresponds to packet “train” or ON-interval.

If *j* out of the total of *M* terminals is currently waiting for a response to a pending request (corresponds to OFF-interval), the effective request rate is then (M-j) λ. The request completion rate is denoted by μ. Similarly, when *M* machines share a repair facility, the failure rate of each machine is λ and the repair rate is μ (see Fig. 6.5). The repair-man machine with the finite number of sources and infinite queue length is well described by L. Klienrock (1979). The Machine Repair model approach described by L. Klienrock (1979) is commonly considered traffic model for exponential distributed interarrival packet rate, finite number of sources and infinite queue length.

In our case the queue size has finite length (K) and the interarrival rate of the each source decreases proportionally to the number of the sources (M>K) and therefore the aggregated rate has the constant value and can be altered as follows:

$$\pi_k = \pi_0 \cdot \left[M \cdot \left(\frac{\lambda}{(\mu \cdot M)} \right)^k \cdot \prod_{i=0}^{k-1} (M-i) \right], \text{ where } \pi_0 = \frac{1}{\sum_{k=0}^{K} \left[M \cdot \left(\frac{\lambda}{(\mu \cdot M)} \right)^k \cdot \prod_{i=0}^{k-1} (M-i) \right]}$$

The M corresponds to the number of the sources and λ/M corresponds to the interarrival rate of the each source. From the Fig. 5 it is clearly seen that there exists clear dependence in the buffer overflow probability and the number of the traffic sources. The above mentioned analytical model does not deal with Pareto distributed ON-OFF interarrival rate, nevertheless, we assume that this could be good point for delving into this phenomena.

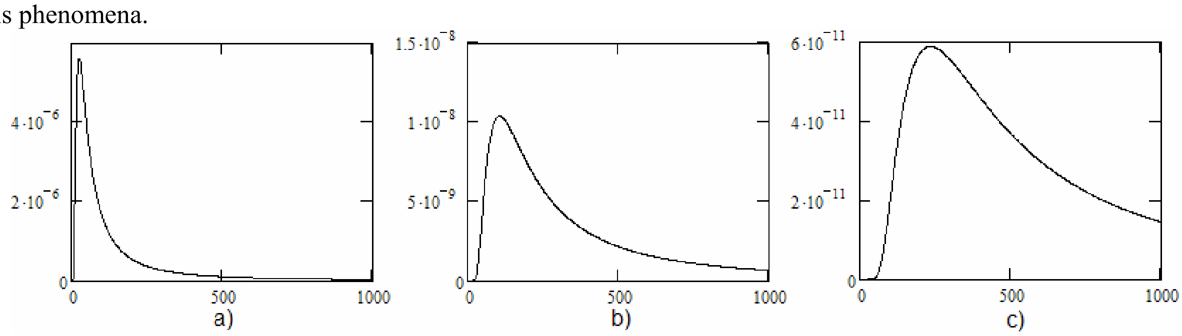

Figure 5. The overflow probability dependence on the source number according to Machine Repairman model for the finite queue size equal 10 (a), 20 (b) and 30 (c) and network utilization 0.7.

4. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

In the paper two main objectives of the ON-OFF traffic model individual source number influence on the traffic and queuing model parameters are presented. The fist finding is traffic parameters invariance to the number of the ON-OFF sources and it has appeared to be in consistency with reports presented by different authors.

The second significant finding is that in the traffic model where the aggregated traffic intensity is the constant implication but interarrival rate of each individual source is inversely proportional to the number of simultaneous sources, the packet loss probability decreases while the number of the sources increases. Implications of this finding can guarantee very high utilization of the MBAC algorithm.

As the future work, we intend to find out analytical relation between utilization, the number of sources and the shape parameter of the Pareto PDF. The mentioned above analytical model together with fast Hurst parameter estimator provide an accurate model for the efficient measurement-based admission control.

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