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STATISTICS AND PROGNOSIS THE PARAMETERS OF HETEROGENEOUS TRAFFIC IN COMPUTER NETWORKS OF CRITICAL APPLICATION

Чанг Шу. Статистика і прогноз різнорідного трафіку в обчислювальних мережах критичного застосування. Розглянуті проблеми толерантності затримки і якість послуги в обчислювальних мережах критичного застосування. Розроблений метод контролю мережних характеристик, заснований на розділеному управлінні і навчанні як уніфікована структура для адаптивних систем реального часу. Розглянуті причини затримки пакетів і методи компенсації затримок за рахунок прогнозу параметрів передачі, завдяки чому зменшується негативний вплив цих затримок. Представлені результати розрахунків прогнозу характеристик трафіку в мережі.

Ключові слова: СИСТЕМА КРИТИЧНОГО ЗАСТОСУВАННЯ, САМОПОДІБНИЙ ТРАФІК, ЗАТРИМКА ПАКЕТІВ, ПРОГНОЗ, МІНІМАЛЬНА СЕРЕДНЬОКВАДРАТИЧНА ПОМИЛКА

Чанг Шу. Статистика и прогноз разнородного трафика в вычислительных сетях критичного применения. Рассмотрены проблемы толерантности задержки и качество услуги в вычислительных сетях критического применения. Разработан метод контроля сетевых характеристик, основанный на разделенном управлении и обучении как унифицированная структура для адаптивных систем реального времени. Рассмотрены причины задержки пакетов и методы компенсации задержек за счет предсказания параметров передачи, благодаря чему уменьшается негативное влияние этих задержек. Представлены результаты расчетов прогноза характеристик трафика в сети.

Ключевые слова: СИСТЕМА КРИТИЧНОГО ПРИМЕНЕНИЯ, САМОПОДОБНЫЙ ТРАФИК, ЗАДЕРЖКА ПАКЕТОВ, МИНИМАЛЬНАЯ СРЕДНЕКВАДРАТИЧЕСКАЯ ОШИБКА, ПРОГНОЗ

Chang Shu. Statistics and prognosis the parameters of heterogeneous traffic in computer networks of critical application. The problems of delay tolerance and quality of service in computer networks of critical application are learned. The method of control of networks based on partitioned estimation and control as unified framework for adaptive real-time systems is developed. Considering of delays of control data and compensating of delays due to prediction of traffic parameters in advance we decrease negative impact of these delays. The results of calculations of improvement of network performance are represented.

Keywords: SYSTEM OF CRITICAL APPLICATION, SELF-SIMILAR TRAFFIC, PACKET DELAYS, LEAST MEAN-SQUARE ERROR, PROGNOSIS

The networks of critical application have such specific features. First of all, the system of critical application is characterized by great spread in values of necessary calculating resources for optimum and extreme cases. Nevertheless, all services must be observed in real time-scale under any conditions of implementation. Then, it is heterogeneous system having network and terminal equipment with large range of technical parameters, application interfaces and protocols, including so called Key Performance Indicators (KPI's). It's clear that capacity, quality of service (QoS), reliability and other characteristics of network in general are limited by corresponding characteristics of the poorest chain link or network node. At last, the requirements to QoS, especially to reliability of data transfer, have to be very high since aviation safety depends from unbreakable work of communications directly.

Besides, the system of critical application as any complex and distributed system is system with delayed response. The sources of delays are fundamental limitations on speed of propagation of signals through any physical media and communication and processing nodes, such as switches, routers etc. We may consider these limitations on the stages of projecting and technical exploitation of networks.

Another serious sources of delays, losses and forced retransmissions of data are overloads and congestions of critical parts of network. The most efficient way of loss control is continuous analysis and optimal control of network functioning including routing and redirection of data flows.

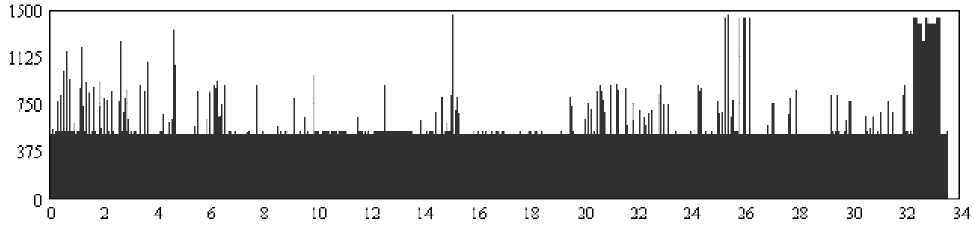
A number of different control mechanisms have been proposed to solve these problems. Algorithms of traffic policing and shaping such as leaky and token buckets are ones of the methods widely used in the network access control field and they can dynamically allocate bandwidth and efficiently minimize packet losses. Additionally, different control strategies were proposed to manage traffic flow into the backbone network. The results showed that the feedback control laws can improve network performance by improving throughput, reducing packet losses, and relaxing congestion. On the other hand, in [1], it was observed that the system performance was highly degraded in the presence of feedback delay (arising from communications). Due to the time delay, what we capture in real time is the lagged or delayed traffic information. Control based on delayed information leads to excessive degradation of network performance. Thus, in practice, its impact cannot be ignored and must be taken into consideration and compensated for [2].

Traffic prediction methods have been widely used in network management. By use of prediction techniques, that is, forecasting the future behavior of the traffic, one can effectively prevent traffic jams, traffic congestion, and network crashes. Inspired by these ideas, we have applied prediction techniques [3,4] to solve the problems encountered in [1].

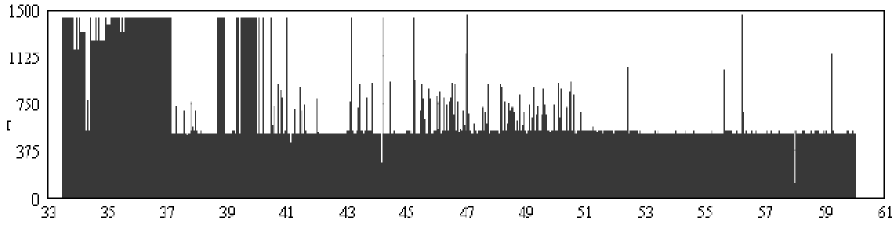
For this purpose, we propose a real-time feedback control mechanism based on the predicted state and traffic. The traffic and state information are predicted for different values of prediction times based on their past history (the traffic history measured online). An accurate prediction for the future traffic and state (short-term prediction) is able to provide better control compensating for time delay. Thus the impact of time delay can be minimized and the system performance improved.

In this work an online predictor based on the principle of the least mean square error (LMSE) is developed. It is one of the simplest methods. It was noted in [5], that LMSE can achieve better accuracy compared to those complex long-memory predictors for online measurements. Without the requirement of complex computation, it can be implemented at a high speed. As a result of traffic prediction, the system performance degradation due to delay is reduced by use of proper control actions. According to our results, it is possible to optimize the system performance and minimize the cost function by implementing the new method.

In order to understand and solve the performance-related problems in computer communication network, it is critical to build a dynamic model of the information flow through the system (Fig.1). Further, the basic statistical properties of measured trace data must be known.



a) first 33 min



б) next 27 min

Fig. 1. General model of network traffic

Traditional characterization of the Internet traffic is based on the Poisson process (which exhibits short-range dependence), Bernoulli process, or more generally doubly stochastic Poisson process (DSPP).

A recent study [5] shows that network traffic has self-similarity characteristics and long-range dependence. Self-similarity means that a certain property of traffic behavior is preserved over space and/or time scales, and long-range dependence is said to exhibit long-term correlations which decay at rates slower than exponential ones. On the other hand, the correlation functions of traditional traffic models decay exponentially or faster. In this paper, a general model is constructed to simulate the incoming traffic illustrated in Fig. 1, which is similar to those in [6].

To simulate a network, we construct a mathematical model comprised of N individual users (traffic streams), served by N corresponding, all of which are coupled to a multiplexor connected to an outgoing link having (bandwidth) capacity C.

Each token bucket implements its algorithm to police the arriving packet. The nonconforming traffic streams are dropped while all the conforming traffic are multiplexed and queued up for entering the multiplexor. As a matter of fact, not all conforming traffic from token buckets will be accepted because of the size limitation of the multiplexor (buffer size Q) and the link capacity (speed) of the accessing node. If the sum of these traffics exceeds the multiplexor size, some part of the conforming traffic maybe dropped. The discarded traffic is defined as the traffic loss at the multiplexor $L(t_k)$.

In general, the traffic loss at the token buckets during the k_{th} time interval is given by

$$L_T(t_k)=\sum_{i=1}^{N} r_i(t_k)=\sum_{i=1}^{N}\left[V_i(t_k)-g_i(t_k)\right],$$

where $V(t_k)$ – packet size of the arriving traffic; $r(t_k)$ – conforming traffic; $g(t_k)$ – non-conforming traffic, while the multiplexor loss during the same time interval is given by

$$L_M(t_k)=\sum_{i=1}^{N} g_i(t_k)-\sum_{i=1}^{N} g_i(t_k)\wedge\left[Q-\left(\left[q(t_k)-C*\tau\right]\vee 0\right)\right]$$

In addition to these losses, it is also important to include a penalty for the waiting time or time spent on the queue before being served. For simplicity we assume that it is unambiguous function of queue length.

Adding all these, we obtain the cost functional. Since the incoming source (or user demand) is a random process, we must compute the average cost as being the expected value of the sum of all the costs described above. This is given by

$$J(u)=E\left\{\sum_{k=0}^{K}\alpha(t_k)L_M(t_k)+\sum_{k=0}^{K}\beta(t_k)L_T(t_k)+\sum_{k=0}^{K}\gamma(t_k)q(t_k)\right\}, \tag{1}$$

where u is the control law which determines the state of the system and hence the individual losses and finally the total cost. The functions α, β, γ represent the weights or relative importance given to each of the three distinct losses.

Since the exact stochastic characterization of our traffic is not available or is unknown, the Monte Carlo method is employed to compute the expected values of the performance measures. For applying the Monte Carlo technique [7], we let N_s denote the number of samples used and let $\Omega=\{w_j, j=1,2,3,\ldots,N_s\}$ denote the elementary events or sample paths with finite cardinality N_s. The objective functional (1) is then given by

$$J(u)\cong\frac{1}{N_s}\sum_{j=1}^{N_s}\left\{\sum_{k=0}^{K}\alpha(t_k)L_M(t_k,\omega_j)+\sum_{k=0}^{K}\beta(t_k)L_T(t_k,\omega_j)+\sum_{k=0}^{K}\gamma(t_k)q(t_k,\omega_j)\right\}.$$

The first term of the expression gives the average weighted loss at the multiplexor, the second gives that for token buckets, and the last one is the penalty assigned to the average waiting time in the multiplexor.

To illustrate the dependence of estimation error on the observation window size W_s and the prediction time T_d, we use the statistical modeling technique to compute the expected value of the (estimation) error given by where w_j denotes the j-th sample path and N_s denotes the number of sample paths used. The inverse of the signal-to-noise ratio (E_{SNR}) is used as another measure to evaluate the quality of prediction results:

$$E_{SNR}=(SNR)^{-1}=\frac{\sum e^2}{\sum\left(V(t_k)\right)^2}=\frac{\left(\left(1/N_s\right)\sum_{j=1}^{N_s}\left(\hat{V}(t_k,w_j)-V(t_k,w_j)\right)\right)^2}{\sum\left(V(t_k)\right)^2}.$$

As model of a self-similar stream the stream of requests was used, generated after the method of FSNDP – fractal-shot-noise-driven Poisson process. For the decision of task of prognosis of the state of network it is suggested to apply the standard method of estimation of parameters after the criterion of minimum of least mean-square error (LMSE). However much this method gives optimum results only for stationary (even in wide sense) processes on the interval of supervision. At the same time the splashes of intensity of a self-similar traffic are violation of stationary. From other side, it is possible to expect that the evaluation of parameters of a self-similar traffic as process with statistical descriptions, which fall slowly, will be more effective, than processes without aftereffect. It is therefore necessary to analyze efficiency of the LMSE methods for the models of traffic with properties of self-similarity. In essence, such method of approximation is some modification of the known method Zade and Ragazzini. The results of calculations of errors of prognosis by the LMSE method are shown on the fig. 2.

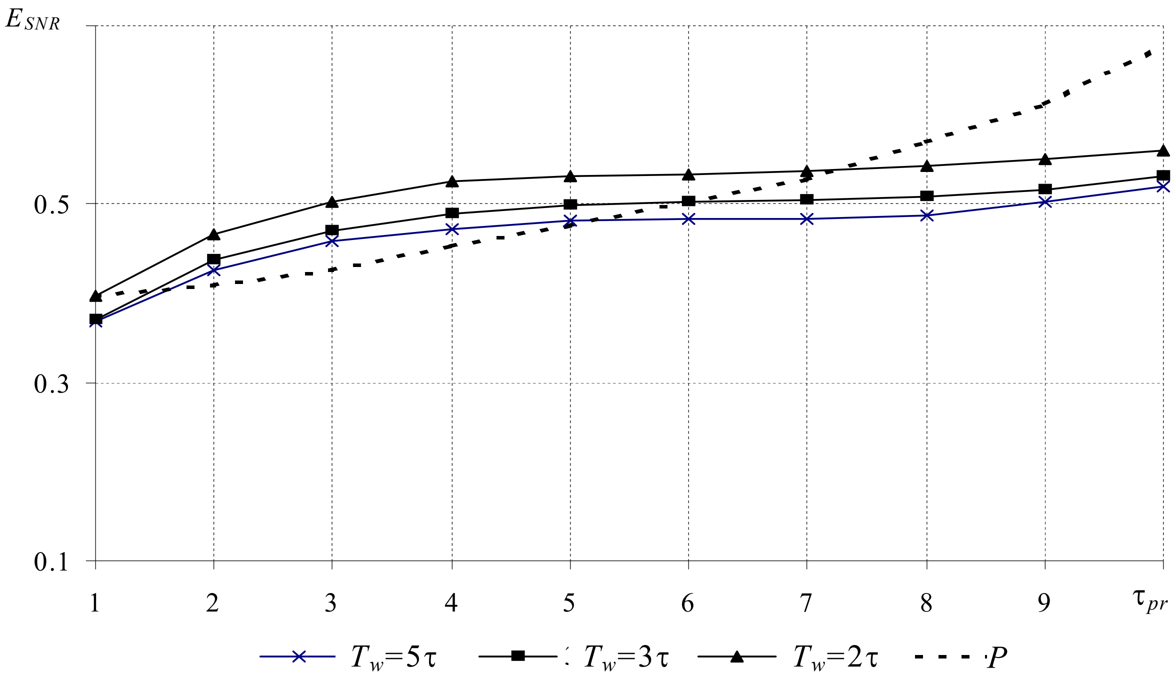


Fig. 2. The dependence of the least mean-square error from the interval of averaging

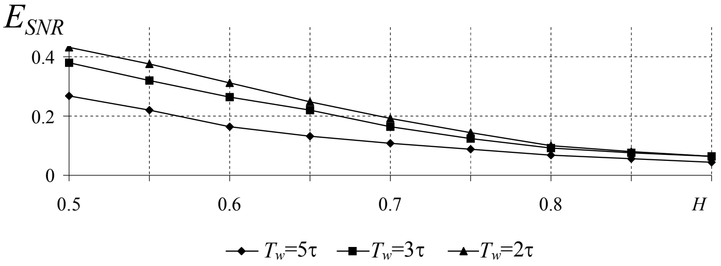


Fig. 3. Prediction errors versus Hurst parameter under constant delay time T_d

For any fixed window size, E_{SNR} increases with the increase of prediction time and appears to reach a plateau. As expected, E_{SNR} is smaller for larger Hurst parameters due to increasing of long-range dependence of parameters of random process. This is further illustrated in Fig. 3.

Conclusion. It is possible to compensate the impact of communication delay causing performance degradation using the method of prediction of traffic variations and expected network overload. The method of LMSE presented in this paper improves the overall system performance and prevents network losses. The numerical simulation results presented have shown the effectiveness of the proposed predictive feedback control law. It was found that processes with larger Hurst parameter have better prediction performance. This result is expectable in considering long-range dependence of self-similar traffic characteristics. The results of this work also lead to a better understanding of the impact of Hurst parameters on network performance.

In summary, this work provides a useful tool for design and optimization of future networks using predictive feedback control law thereby avoiding transfer instability.

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ОЦЕНИВАНИЕ ПРОИЗВОДИТЕЛЬНОСТИ СПЕЦИАЛИЗИРОВАННЫХ БЕСПРОВОДНЫХ СЕТЕЙ ПРИ ПРОИЗВОЛЬНЫХ СТАТИСТИКАХ ДЛИНЫ ПАКЕТОВ ДАННЫХ

Амірханов Е. Д. Оцінювання продуктивності спеціалізованих бездротових мереж при довільних статистиках довжини пакетів даних. Розглянута задача оцінки продуктивності спеціалізованих бездротових мереж, в яких число діючих станцій змінюється по випадковому закону і не може з достатньою достовірністю контролюватися в процесі передачі даних. Для отримання асимптотичних характеристик тривалості передачі запропоновано використовувати інформаційно-ентропійні міри модельних розподілів. Розглянуто вплив ключових і додаткових параметрів ефективності в даних умовах функціонування мережі і дані оцінки взаємної кореляції ключових параметрів ефективності.

Ключові слова: БЕЗДРОТОВА МЕРЕЖА, САМОПОДІБНИЙ ТРАФІК, ІНФОРМАЦІЙНО-ЕНТРОПІЙНА МІРА, ДИФЕРЕНЦІАЛЬНА ЕНТРОПІЯ, ПАРАМЕТРИ ЕФЕКТИВНОСТІ

Амирханов Э. Д. Оценивание производительности специализированных беспроводных сетей при произвольных статистиках длины пакетов данных Рассмотрена задача оценки производительности специализированных беспроводных сетей, в которых число действующих станций изменяется по случайному закону и не может с достаточной достоверностью контролироваться в процессе передачи данных. Для получения асимптотических характеристик длительности передачи предложено использовать информационно-энтропийные меры модельных распределений. Рассмотрено влияние ключевых и дополнительных параметров эффективности в рассматриваемых условиях функционирования сети и даны оценки взаимной корреляции ключевых параметров эффективности.

Ключевые слова: БЕСПРОВОДНАЯ СЕТЬ, САМОПОДОБНЫЙ ТРАФИК, ИНФОРМАЦИОННО-ЭНТРОПИЙНАЯ МЕРА, ДИФФЕРЕНЦИАЛЬНАЯ ЭНТРОПИЯ, ПАРАМЕТРЫ ЭФФЕКТИВНОСТИ

Amirkhanov E.D. Estimation of productivity of the specialized wireless networks at the arbitrary statistics of length of data packets. The problem of estimation of productivity of the specialized wireless networks is considered, in which the number of the operating stations changes on a casual law and cannot with sufficient authenticity be controlled in the process of data communication. For the receipt of asymptotic descriptions of duration