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MODELS AND CHARACTERISTICS OF TCP FLOWS IN STOCHASTIC NETWORK ENVIRONMENT

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Abstract. The modern approach to studying processes and the phenomena is based on use of their mathematical models. Efficiency of such approach essentially depends on the purposes of research among which problems of automatic control and prediction have highest priority. Opportunities of control often limited by parametrical uncertainty of used models, therefore the increasing efforts are received with the methods based on mechanisms of adaptation. For many years Internet, as object which features are shown through specific parameters or characteristics as dynamism, hierarchy and adaptability, draws attention and big interest from researchers and engineers. In the paper TCP processes are considered as specific logical-dynamic objects which reflect important protocol properties including adaptation of network application to changing characteristics and parameters of the network environment. Proposed approach is based on description of statistical dynamics of computer networks with fractal properties with the mathematical apparatus of fractional derivatives.

Keywords: computer network, transport protocols, model, fractional derivatives

Introduction

Attempts of judgment of analytical model to computer network traffic behavior and TCP flows in terms of measurement characteristics were undertaken for a long time. But many open questions in the understanding and implementation of modeling concepts are remains unexplored especially in the case when fluctuation factors have many sources. Network complexity has dynamic and stochastic aspects and stem from the fact that we cannot make independent measurement of system's parameters on network and transport or TCP levels: all such measures are correlated, and this fact reduce efficacy of well-known modeling approaches that describes only static aspects of network complexity behavior. According to recent studies [1,2] TCP flows forms 80-90% of the total traffic volume and passes through the variety of communication media shows both dynamic and stochastic properties. Understanding of relationships between TCP dynamics and characteristics of stochastic network environment is important goal of the current research. Proposed ways based on procedures that separating randomness which describes by statistical invariant measure from dynamics that is computable and representing algorithmically. To evaluate the model [3] we extend parametric state space and offered simple mechanism to modeling fast recovery phase and congestion avoidance algorithm.

We based on analytical methods that stratify three basic essences: deterministic aspects of application level, temporal/special dynamics and stochastic forces that form unpredictable behavior of network environment. Main interest of paper is to identify and evaluate appropriate factors and mechanisms that can be addressed in order to confirm a hypothesis [3,4] that packets loss rate has uniform distribution with sliding borders.

Network environment and model

One of the major components in the success of the Internet is the layered open system interconnection (OSI) architecture. Layering simplifies network design and leads to robust scalable protocols in the internet. But layering suffers from sub-optimality and inflexibility. Layering is sub-optimal because each layer has insufficient information about the network since it does not allow the sharing of information among the layers. Layering is inflexible because the developer of a new application has solely dependence on the functionality of the lower layers. Based on "best effort" strategy Internet evolves in a way that throughput or global performance is maximized. This suggests that some hidden optimization is at work and shapes collective behavior of nodes and complex dynamics of network traffic. To describe observed phenomenon we will uses specific statistical models and concept of self-organizing behavior. For design purposes the statistical description is the least detailed, but the most universal. This approach also restrains that exact measurements of processes are required. Thus the statements about existing available metering framework and assumption about robust statistical feature of measurement processes are not completely adequate to real network environment.

The most part of measurement studies deal with network performance, inter arrival time intervals and packet (or bytes) counts. Their first and second order statistics changes with network load. Noted above property – self-similarity and heavy-tailed distribution have the various natures therefore they are difficult for considering within single model. That is why, for Channel (MAC), Network (IP) and even TCP layers stationary hypothesis can be applied for different interval T. Measurement models should be adequate in relation to their invariant property and hypothesis that all singularities can be simulated within framework of proposed models.

Below simple model of TCP dynamics will be used to find out specific invariant characteristics and investigate robust procedure that can be useful to describe important characteristics of network complexity.

TCP model

Specific contribution to the traffic fluctuations is brought from IP layer and TCP dynamics. We will estimates these fluctuations by means of second order statistics. As show numerous experimental data most adequately these processes in modern computer networks are approximated by Wiener fractal process $B_\varphi(t)$ [5,6]. This process can be received by means of a fractional derivative which looks like $\frac{d^\alpha x}{dt^\alpha} = \xi(t)$, where functions $\xi(t)$ and $x(t)$ belong to sets for which inequalities $\int_0^t |\xi(t)| dt < \infty$ and $\int_0^t |x(t)| dt < \infty$ are carried out, $\xi(t)$ – also the real, continuous function, satisfying the Lipchitz conditions $|\xi_t(x_1) - \xi_t(x_2)| \le A|x_1 - x_2|$, where A – is a constant. In the given job the fractional derivative is used for reception of fractional integral – convolution integral, in which pulse transitive function of a sedate kind. Such kind of a target signal of dynamic system gives to entrance process character of slowly changing dependences possessing scale-invariant properties.

Solving the equation $\frac{d^\alpha x(t)}{dt^\alpha} = \lambda x(t) + \xi(t)$, using the Mittag-Leffler function (M-L): where $E_{\alpha,\gamma}(y) = \sum_{j=0}^{\infty} \frac{y^j}{\Gamma(\alpha j + \gamma)}$; $\alpha > 0, \gamma > 0$, $\Gamma(\cdot)$ – is a gamma function, with $\lambda = 0$ we will receive [5] $x(t) = x(0) E_{\alpha,1}(-\lambda t^\alpha) + \frac{1}{\Gamma(1-\alpha)} \int_0^t \frac{E_{\alpha,\alpha}(-\lambda (t-t')^\alpha)}{(t-t')^{1-\alpha}} \xi(t') dt'$. The second composed in this expression is called as fractional integral and as shown [5], operation of fractional integration is return operation of fractional differentiation. In view of exponential dependence statistical characteristics possess property of self-similarity.

The factor of correlation necessary for forecasting and management by the network traffic $r_{B_\Phi}(k;T)=\frac{1}{2}[(k+1)^{\alpha+1}-2k^{\alpha+1}+(k-1)^{\alpha-1}]$, and at $k>>1$, it is $r_{B_\Phi}(k;T)\approx\frac{1}{2}\alpha(1+\alpha)k^{\alpha-1}$ and as it follows from expression, the correlation factor represents lingering, at $\alpha\to 1$, self-similar (because of sedate function) and scale-invariant (in relation to an interval T) dependence.

As show experimental research, the correlation moments of the second order of RTT-delays of data transmission in TCP protocol possess the same scale-invariant properties.

For increase of accuracy of proposed approach it is necessary to consider a number of the factors connected with uniform distribution of congestion avoidance moments which are generated by network infrastructure itself and forms local behavior of TCP virtual connection at this specific phase. At each discreet time moments "k" TCP segment flow "y" at congestion avoidance phase can be describes by formulas (Fig.1):

$$X_{k+1}=R(X_k,\xi_k)X_k,\quad Y_k=F(X_k),$$

where
$$R(X_k,\xi_k)=\begin{cases}1;\ \xi_k=0,\ X_k=C\\ 1/2;\ \xi_k=1\\ 1/X_k;\ \xi_k=2\\ (X_k+1)/X_k;\ \xi_k=0,\ X_k<C,\end{cases}$$

where $\psi(\xi)$ is indicator function of possible congestion; ξ is stochastic variable with uniform distribution function for each interval.

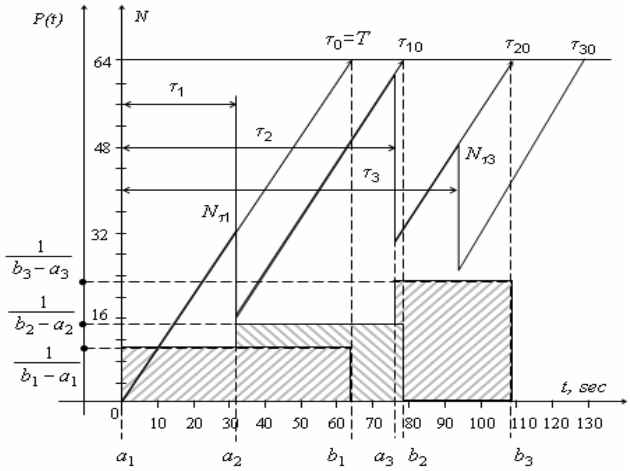

Fig.1. Congestion window "N" behavior and cross-interval uniform distribution P(t) of recovering points, where: $b_1-a_1>b_2-a_2$, $b_2-a_2>b_3-a_3$

Main parameters and characteristics can be expressed by simple formulas:

$$\tau_{10}=T+\frac{\tau_1}{2},\ \tau_{20}=T+\frac{\tau_1}{4}+\frac{\tau_2}{2},\ \tau_{20}=T+\frac{\tau_1}{8}+\frac{\tau_2}{4}+\frac{\tau_3}{2}$$

where τ_1 is variables with uniform distribution $1/T\,(a=0,b=T)$; τ_2 is variables with distribution $1/(\tau_{10}-\tau_1)(a=\tau_1,b=\tau_{10})$; τ_3 is variables with distribution $1/(\tau_{20}-\tau_2)$ $(a=\tau_2,b=\tau_{20})$.

Based on this model the first and the second orders statistical characteristics of packet source window can be expressed by statistical relations:

$$M_1(\tau_{10}) = \int_0^T \frac{\partial\tau_1}{T} \int_{-\infty}^{\infty} \tau\delta(\tau - \tau_{10})\partial\tau\,,\ D(\tau_{10}) = M_2(\tau_{10}) - M_1^2(\tau_{10})\,;$$

$$M_1(\tau_{20}) = \int_0^T \frac{\partial\tau_1}{T} \int_{\tau_1}^{\tau_{10}} \frac{\partial\tau_2}{\tau_{10} - \tau_1} \int_{-\infty}^{\infty} \tau\delta(\tau - \tau_{20})\partial\tau\,,\ D(\tau_{20}) = M_2(\tau_{20}) - M_1^2(\tau_{20})\,;$$

$$M_1(\tau_{30}) = \int_0^T \frac{\partial\tau_1}{T} \int_{\tau_1}^{\tau_{10}} \frac{\partial\tau_2}{\tau_{10} - \tau_1} \int_{\tau_2}^{\tau_{20}} \frac{\partial\tau_3}{\tau_{20} - \tau_2} \int_{-\infty}^{\infty} \tau\delta(\tau - \tau_{30})\partial\tau\,,\ D(\tau_{30}) = M_2(\tau_{30}) - M_1^2(\tau_{30})\,.$$

This points are belongs to the power order function:

$D(t) = K(t - 64)^{1+\alpha}$, where $K = 1{,}17$; $\alpha = 0{,}82$.

Analysis of TCP characteristics is based on complexity aspects regarding to possible metering restriction allow us to consider experimental data that derived from tcpdump process as a chaotic discreet time series. The basic reasons of such local behavior are statistical nature of delays and measurement errors in the router buffers between transmission media and network application layer. Errors in measurement time-series may cause specific artifacts burst in packet counts and deform spectral as well as statistical properties of studied processes.

Conclusion

1. Stochastic feature of the TCP connection is limited by several parameters that can be extracted from measurement data. This fact sheds new light on the nature of adaptive feature of network environment and could lead to more efficient behavior of routers and other network components.
2. It is possible to merge fractal parameters and statistical characteristics of network traffic in common TCP flow model that can be used to predict network behavior and router performance.
3. To achieve a greater accuracy in prediction of network congestion is possible by description of statistical dynamics with fractal properties by fractional derivatives models.

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