The Impact of Self-similar Traffic on Network Delay

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Abstract

The effect of self-similar traffic on the delay of a single queue system is first studied through the use of the measured traffic and models as input process. A model-driven simulation-based method is then proposed for the computation of mean line delay in a network routing design. Both the hybrid-FGN and the FARIMA algorithms have been used to synthesize self-similar sample paths. The comparison results with real-traffic data sets firmly establish the usefulness of our model-driven simulation based method. We have proposed a practical database method that helps the designer to determine the parameters in network design. This approach may likely play an important role in network design and analysis.

Key words

self-similar traffic, FGN, FARIMA, network delay, performance analysis ,simulation

I. INTRODUCTION

One of the most complex and crucial aspects of network design is the choice of an efficient routing algorithm. There are many routing algorithms such as flow-based routing. The key step in many of these algorithms is to calculate the mean line delay using the M/M/1 queueing model [Tan96].

Recently, with the progress in sophisticated traffic measurements, an enormous volume of traffic samples has been collected from working networks and made available to researchers. In some early traffic analysis at Bellcore [Lel94], high resolution traffic measurement showed that, in a sharp contrast to the common Poisson model, measured packet traffic has a self-similar (fractal) characteristic. In particular, the traffic exhibits long-range dependence, e.g., autocorrelations that can span many time scales. During the last several years, numerous researchers worldwide have conducted measurement studies on wide-area networks [Pax94], World Wide Web traffic [Cro96], cell-level ATM traffic [Ger96] and so on. They all reported and confirmed the presence of fractal features in measured network traffic.

The work on self-similarity in network traffic has demonstrated the practical implications for a wide range of traffic management and traffic engineering problems including networking dimensioning, quality of service, overload control, call admission, error monitoring, etc. The success of future network technologies such as ATM and applications such as video on demand may depend on our ability to accurately model traffic flows in the networks and our ability to make performance predictions in the working environment.

This paper will study the impact of self-similar traffic on the calculation of the mean line delay in a network. Both the model-driven and trace-driven simulation-based methods have been utilized. Several models are studied from which we propose a new method for calculating network delay.

II. SELF-SIMILAR TRAFFIC STUDIES

In order to study the impact of self-similarity (or fractal) on network delay, we have carried out some study on the data sets obtained from inside and outside of China. We have one set of measurement data from CERNET (the Chinese Education and Research Network) center, and three sets of measurement data from Bellcore Lab. [Lel94]. The CERNET/ trace was conducted on an Ethernet cable at the CERNET center. The cable carried not only a major portion of the DNS and Web server traffic, but also all traffic to and from the Internet of China. Three traces from Bellcore were conducted
on an Ethernet cable at the Bellcore Morristown Research and Engineering facility. At that time, the Ethernet cable carried not only a major portion of the Lab's traffic, but also all traffic to and from the Internet of Bellcore. These data sets are identified by:

cJun.TL: The one million arrivals of the trace at CERNET on 15 June 1997.

pAug.TL: The one million arrivals of the trace at Bellcore on 29 August 1989.

pOct.TL: The one million arrivals of the trace at Bellcore on 5 October 1989.

OctExt.TL: The one million external arrivals of the trace at Bellcore on 3 October 1989.

Hurst parameter is the most important parameter to catch the self-similar behavior. Variance-time plots, R/S analysis and Periodogram-based method are three methods that are commonly used for the estimation of Hurst parameter. We have estimated the Hurst parameter of the above four actual network traffic sets. The results are shown in Table 1 from which we can see that the Hurst parameters of the four traffic samples are all larger than 0.5. Thus, we can say they are all self-similar.

III. SELF-SIMILAR TRAFFIC MODLES

Self-similarity is an important property of traffic in high-speed networks traffic, which cannot be normally captured by traditional traffic models. The most widely-studied self-similar processes are second-order. These include the FGN (fractional Gaussian noise) and the FARIMA (fractional ARIMA) processes. Associated with the FGN process is the FBM (Fractional Brownian Motion), which is simply the integrated version of FGN.

In the following, we will use the FARIMA models, and in addition, we propose a new hybrid FGN method based on the AFGN (Approximate FGN). In Section 4, the practical aspects of our hybrid-FGN and FARIMA models will be examined by comparing their performance on determining delay using the CERNET and the Bellcore traces.

3.1. The hybrid-FGN Model

The AFGN and RMD algorithms have been used to synthesize self-similar sample paths. The AFGN algorithm [Mand69] is accurate but very inefficient. On the other hand, the RMD algorithm [Lau95] is inaccurate but much faster. Here we propose a new hybrid method based on the AFGN and the RMD. Our experiment shows this method is a faster and more accurate algorithm.

In the hybrid-method, we use the AFGN to generate the end points, and the RMD to produce a subtrace with a level of depth. Let $\{Y_i\}$ be the FBM sample, then the increment process $\{X_i=Y_i-Y_{i-1}\}$ is an FGN sample. Without loss of generality, let the value of the origin Y_0 at time 0 be 0. The following is a description of the algorithm:

(1) Use the AFGN algorithm to generate the increment, say X_1, and obtain the first two end- points of the FBM samples Y0=0 and Y1= X1.

(2) Use the RMD algorithm with a pre-given level of depth, L, and generate the subtrace consisting of the 2L FBM samples $\{Y_i\}$ between time points 0 and 1.

(3) Use the AFGN algorithm again to produce the increment X_2, and obtain the third end-point of the FBM process, i.e., $Y_2= X_1 + X_2$.

(4) Use the RMD algorithm on the end-points Y_1 and Y_2 to generate another substrace consisting of the 2^L FBM samples $\{Y_i\}$ between time points 1 and 2.

(5) Repeat the above steps to generate the 2^L samples of the FBM sample path in each iteration until there are enough samples for the studying of network performance.

The increment process of the above FBM sample is then the desirable FGN sample.

3.2 The FARIMA model

In this model, we assume the process X_k has a Gaussian marginal distribution with a zero mean, a variance v_0, and a fractional differencing parameter given by d=H-1/2. The autocorrelation function can be determined from d, and has an asymptotically hyperbolic shape, i.e.,

$$\rho_k = \frac{d(1+d)\cdots(k-1+d)}{(1-d)(2-d)\cdots(k-d)}$$

The following are the steps of an algorithm for generating the FARIMA(0,d,0) self-similar process [Hos84]:

(1) Choose X_0 from the the Normal distribution N(0, v_0). Set $N_0 = 0$ and $D_0=1$.

(2) For each of k=1,..,n, repeat the following steps

$$N_k = \rho_k - \sum_{j=1}^{k-1} \phi_{k-1,j}\rho_{k-j}$$

$$D_k = D_{k-1} - N_{k-1}^2 / D_{k-1}$$

$$\phi_{kk} = N_k / D_k$$

$$\phi_{kj} = \phi_{k-1,j} - \phi_{kk}\phi_{k-1,k-j}, \quad j=1,\ldots,k-1$$

$$m_k = \sum_{j=1}^{k} \phi_{kj} X_{k-j}$$

$$v_k = (1-\phi_{kk}^2) v_{k-1}$$

Note that n points are generated.

(3) Choose X_k from N(m_k, v_k).

IV. NETWORK DELAY OF SELF-SIMILAR TRAFFFIC

Since the mean network delay is a function of the mean node delays, we shall focus on the effect of self-similar traffic on the mean node delay. We shall use simulations here for our experiments because simulation is a very useful and practical tool for studying network performance. Both trace-driven and model-driven simulations are used to obtain the delay performance. We have made use of the RTSS (Real Time System Simulator) simulation tool [Shu96]. RTSS is an event-driven simulation software developed at Tianjin University with the capability for graphical model building and animation display. The main features of RTSS are more flexible and easier to upgrade. The RTSS model of a system is an open queueing network.

4.1. Experiments on Network Delay Study

In the traditional flow-based routing, the mean line delay can be computed from the M/M/1 queuing model [Tan96]:

$$T = \frac{1/\mu C}{1-\rho}$$

T-- mean delay in second
$1/\mu$ -- mean packet size in bits
C -- capacity in bps
ρ-- utilization factor

To establish our reference for comparison, we have used this M/M/1 model .

Next we consider self-similar arrivals that have an exponentially-distributed service requirement. We shall use the notation of a S/M/1 queue, where S stands for self-similar. Then we compute the node delay by the following steps.

First, we used the measured traffic traces from CERNET (cJun.TL) and Bellcore (pAug.TL, pOct.TL and OctExt.TL) as the arrival processes in our trace-driven simulation to study the delay performance.

Second, we used the FGN model to generate the arrival process in our model-driven simulation to study the delay of network.

Third, we used the FARIMA model to generate the arrival process in our model-driven simulation to study the delay of network.

4.2 Performance Evaluation

We consider the practical aspects of our hybrid-FGN and FARIMA models by comparing them using the CERNET and Bellcore traces. By performance evaluation, we want to show the relationship between the delay and utilization factor based on traditional M/M/1 model, FGN models, FARIMA models and actual traffic.

In our performance evaluation, we use $\mu C = 710$ packets/ sec. The results of the hybrid-FGN model and the FARIMA model are shown in Fig. 1 and Fig. 2 respectively. The performance of an M/M/1 queue is also included for comparison.

Comparing the result of trace-driven simulation of the CERNET and Bellcore traces (four dots) with the calculated mean delay using the formula which is derived from the traditional M/M/1 model of queueing theory, we found that the actual network delay based on self-similar arrival process is larger than the calculated delay based on Poisson arrival. In general, the larger the utilization factor, the larger the difference.

From the performance curves of the FGN and FARIMA models, we found that the larger Hurst parameter, the larger the delay. When compared with the traditional M/M/1 model, we also observe that the FGN and FARIMA models can better approximate the delay performance of the actual traffic from the CERNET and Bellcore traces (shown in four dots). This is especially true when the utilization factor is large, say larger than 0.6. On the other hand, the calculated delay based on FGN and FARIMA arrival processes are still less than the actual network delay based on self-similar arrival process, and the FGN models appear to better match the actual traffic than the FARIMA models.

V. PROPOSAL FOR DETERMINING LINE DELAY

Our results from the performance evaluation in section 4 firmly establish the usefulness of our FGN and FARIMA models in calculating the mean delay for each line in the network. Based on our experience, we propose the following new method for calculating the mean delay. The procedure steps are

(1) Assume a set of μC values and a set of Hurst parameters.
(2) For a given pair of Hurst parameter and μC value, perform the S/M/1 model-driven simulation using the FGN model. Each simulation will obtain a delay performance curve as a function of the utilization factor. This done in two nested loops: one on the Hurst parameter, and the other on the μC value so that we obtain a set of family curves.
(3) Build a database for the delay vs utilization curves for different pairs of μC value and Hurst parameter.
(4) Repeat steps (2) and (3) using the FARIMA model in the simulation.
(5) Based on a given set of utilization factor, μC value, Hurst parameters and a model (FGN or FARIMA), one can determine the mean node and network delay of a design.

Since the constructed databases store the relationship among utilization factor, μC value, Hurst parameter and mean delay, we can use them on a variety of network design strategies. For instance, when one wants to design a network of known delay requirements, one can first search the utilization factor from the database. After selecting the delay and utilization factor, one can obtain the corresponding μC values for network design.

VI. CONCLUSION

Our studies have shown that self-similar input traffic dramatically increases the delay at a single queue system. We have proposed and implemented two algorithms: (1) the FARIMA generation algorithm, and (2) the faster and more accurate hybrid-FGN generation algorithm that is based on the AFGN and RMD algorithms,. Based on the results of the hybrid-FGN and the FARIMA model-driven simulations, we developed a method that can determine the mean delay of network when the traffic has self-similarity. This method will likely play an important role in delay-based routing design due to its capability to predict maximum-delay and delay-jitter performance in the presence of self-similarity in traffic.

VII. ACKNOWLEDGMENTS

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Table 1
Hurst parameter estimation for four data sets

File	number	Hurst parameter		
		Variance -time	R/S	Periodogram -based
cJun.TL	1000000	0.77	0.83	0.84
pAug.TL	1000000	0.82	0.80	0.83
pOct.TL	1000000	0.88	0.80	0.87
OctExt.TL	1000000	0.93	0.88	0.93

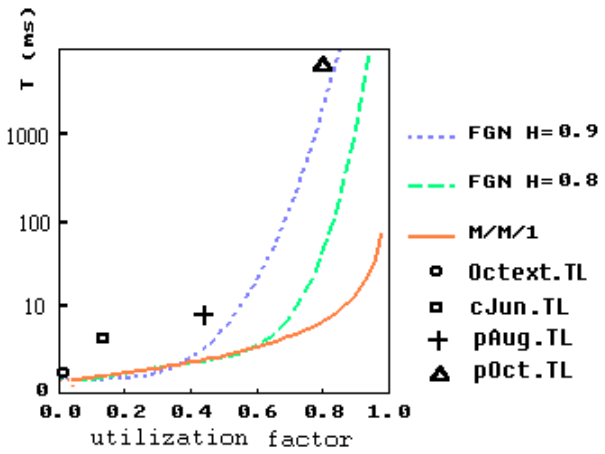

Figure 1: Network delay on FGN models

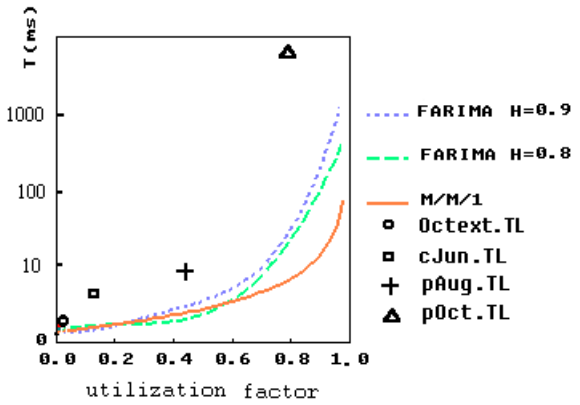

Figure 2: Network delay on FARIMA models