How many traffic sources are enough?

Sireen Malik, Ulrich Killat
Digital Communication Systems
Technical University of Hamburg-Harburg, Germany
E-mail:{s.malik, killat}@ tuhh.de

***Abstract*— A usual way of creating Long Range Dependent (LRD) traffic is by the superposition of on-off sources. The question that how many sources are enough to make a realistic Internet simulation, has not been theoretically explained till yet. It has now become relevant, as the simulation technology is faced with the challenge of simulating high speed networks. As traffic sources consume computing power, it is logical to use as small a number of sources as possible without compromising the quality of the simulations. We first introduce a simple aggregation strategy at the session level, and define its limits by recognizing that the number of active sources follows a certain distribution. By comparing mean packet End-to-End (E2E) delay we show the effectiveness of this technique. Our results show that the average number of active sources has a correlation with mean packet E2E delay.**

I. Introduction

The findings [1,2] in the 1990s that the Internet traffic is Long Range Dependent (LRD) in its nature has not only had a deep impact on the issues of traffic engineering and network dimensioning but also on network simulations. From this perspective it becomes important to generate traffic with LRD character. LRD is attributed mainly to session characteristics, or user behavior. Various methods have been proposed and a summary is presented in [3]. A sophisticated approach is the generation of traffic by superposition of on-off sources [4]. If either, or both, the on- and off-times are heavy-tailed distributed then the resulting traffic is LRD in nature.

The protocol specific mechanisms and congestion control algorithms operating on small time scales give rise to complex structural properties which are different from large time scaling behavior. To complete the total picture, the inclusion of TCP is a first step towards understanding the complex phenomenon of multifractality which was discovered recently and is mainly attributed to the transport protocol [5,6,7].

In [8,9] the authors introduced the HTTP-TCP source which includes a full implementation of the Transmission Control Protocol (TCP) to transport the session level data. It is a closed loop source as it integrates TCP. The HTTP-TCP source encompasses both aspects of the scaling behavior. A typical user is mimicked by an on-off behavior at the session level. During the on-phase TCP transports the heavy-tailed web pages from the server to the client. The superposition of the on-off sources leads to LRD traffic. The inclusion of TCP brings in the small time scale behavior leading to very realistic simulations.

Large capacity networks carry large volumes of traffic. A large number of traffic sources would be required to simulate a high speed network. However, each source puts a demand on the computer resources (CPU and memory). Therefore, the finite available computing resources bound the number of sources that can be simulated. The scalability argument is true for every type of traffic source. However, it is even more serious for the HTTP-TCP source as it involves a client-server pair: both occupy memory space and produce traffic.

To reduce the required number of sources to produce target traffic we use a simple aggregation strategy based on the assumption that the web page arrivals process is poissonian. Since sum of poissonian processes is a poissonian process we simply scale the off-time, or the think-time, to pack a number of users in one source. However, the aggregation at the session level has an impact on the Quality of Service (QoS) parameters such as E2E delay.

It is assumed that the number of active connections follow a binomial distribution. This is a simplifying assumption, however, we believe that it allows the formulation of a good engineering rule based on very simple and tractable formulas.

Our results show that the E2E packet delay depends upon the number of simultaneously active sources. We aim to find the least number of sources for which there is no significant impact on the mean E2E packet delay. The differences are expected as we give up some degree of parallelism existing in the real world.

We also measure Throughput (TP), Co-efficient of Variation (CV) and Hurst parameter (H) [10] to see the impact of aggregation.

In section II we explain the methodology, in the later sections we discuss the simulation setup and then the results.

II. Aggregation at session level

We first briefly discuss the details of HTTP-TCP source. Let ist be the time between the arrivals of consecutive user requests for web pages at the web server. Let $ist = T_{on} + T_{off}$. The T_{on}, on-time, is heavy-tailed distributed because of the heavy-tailed file size distribution. The T_{off}, the off-time (in seconds),

The research reported in this paper falls under the MultiTeraNet (PLANIP) project funded by the Ministry of Education and Research, Germany.

is negative exponentially distributed. On getting a user request the HTTP protocol at the session level fetches the requested web page and passes it to the TCP. Let V be the average file size (in Bytes) which the web server generates at rate r. Let Z be the average number of objects per web page. If F denotes the average web page size (in Bytes) then $F = V * Z$. TCP transports the web page from the web server to the web user. The transmission of an average web page at the session level is done on average in T_{on} time (in seconds). After the download of a web page, the user remains inactive for an average T_{off} time, the user think-time, before making the next request. Each web user cycles through this on and off behavior. Because of its prevalence, HTTP-1.1 is considered at the session layer. It sends the web pages through a persistent connection. This means that a single connection is used to transport all the files in the web page.

Assuming that in an appropriately dimensioned network there are negligible packet losses, in [8,9] the authors came up with the following expression for the throughput of a single traffic source.

$$TP = \frac{F}{N * RTT + T_{off}}, \tag{1}$$

where N is the average number of $RTTs$ required to transport an average web page of size F. Therefore, the source on-time, $T_{on} = N * RTT$. Let M be the total number of sources. Then the aggregate traffic resulting from M sources is given as:

$$TP = M * \frac{F}{N * RTT + T_{off}}. \tag{2}$$

When $T_{off} \gg T_{on}$, one can safely assume that the user request arrival process is poissonian i.e. ist is negative exponentially distributed. Superposition of Poisson processes is a Poisson process. Therefore, one can model the aggregate request arrival process for M identical users by scaling T_{off} time.

Here we define Z, the aggregation level, as the number of sources that will be replaced by one source.

$$Z = \frac{M}{W}, \tag{3}$$

where W is the *reduced* number of sources. The aggregate traffic produced by W sources can be written as,

$$TP = W * \frac{F}{N * RTT + T_{off,w}}, \tag{4}$$

where $T_{off,w}$ is the scaled user think-time (in seconds):

$$T_{off,w} = \frac{T_{off}}{Z}. \tag{5}$$

The mean number of active sources can be calculated. The probability of an on-off source going into an active state when M sources are used, is given by [11]:

$$P_{on,m} = \frac{N * RTT}{N * RTT + T_{off}}. \tag{6}$$

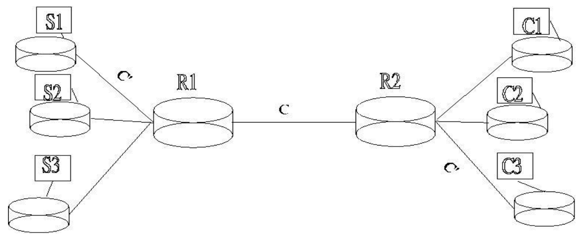

Fig. 1. Simulation setup. Capacities: the core link has C=50Mbps and the edge links $C^{'} = 25Mbps$. Propagation delays: 5msec of the core link and 10msec for the edge links.

TABLE I

TRAFFIC PARAMETERS FOR ALL SIMULATIONS

TP	CV	H
$\approx 35Mbps$	≈ 1.4	≈ 0.7

For simplicity we assume that RTT is equal to the two way propagation delay. Let K be the number of active sources when total M sources are used. For the binomial distribution, the mean number of active sources is given as:

$$E(K) = P_{on} * M. \tag{7}$$

Let $P_{on,w}$ be the probability of an on-off source going into an active state when W sources are used, where

$$P_{on,w} = \frac{N * RTT}{N * RTT + T_{off,w}}. \tag{8}$$

Let Q be the number of active sources when W sources are used, then

$$E(Q) = P_{on,w} * W. \tag{9}$$

Our results showed that under the condition,

$$E(K) = E(Q), \tag{10}$$

the traffic did not show significant differences in TP, CV and H. It was observed that mean E2E packet delay had a strong correlation with mean number of active sources. The results showed that for $W = 2 * E[K]$ that there was no impact on the TP, CV and H, and that the mean E2E packet delay was only off by ≈10%.

III. SIMULATION SETUP

For simulations we use the Ptolemy Simulator extended for network simulations at our department. Fig. 1 demonstrates the simulation setup.

S1, S2 and S3 depict the web servers. C1, C2 and C3 are the clients. HTTP-1.1 was used at the session level, as an example. TCP Reno was used as the transport protocol. Capacities: the core link has C=50Mbps and the edge links $C^{'} = 25Mbps$. Propagation delays: 5msec of the core link and 10msec for the edge links.The total number of sources to be simulated was

TABLE II

LEVEL OF AGGREGATION AND $E[Q]$)

Z	W	$T_{off,m}$	E[Q]
1	2820=M	40=T_{off}	24.46=$E[K]$
2	1440	20	24.77
4	740	10	25.02
8	372	5	24.34
14	198	2.4	25.2
25	114	1.25	24.94
43	66	0.6	24.32
63	45	0.32	23.51
78	36	0.21	22.5
134	21	0.0005	21

divided equally among the three web servers. Buffer size was kept as $1000 Packets$.

For HTTP-TCP settings, we followed [12] which gives the average file size of $10Kbytes$ with shape parameter $\alpha = 1.5$ for the heavy-tailed distribution for which we used the Truncated Power Tail (TPT) distribution [13]. The average number of files per web page was set as 6 from the geometric distribution. Therefore average web page size is $60Kbytes$. User think time as approximately $40seconds$ and negative exponentially distributed. For this average web page size, $N = 7RTT's$ are needed, assuming no loss. Please note one RTT is required for opening the connection. For TCP, $MSS = 1460Bytes$ and $MaxCWND = 65355Bytes$ were set.

For this trial, we chose an aggregate traffic of $35Mbps$ on the core link. This approximately translates to 2820 sources. The TP, CV and H were measured. We then decreased the number of sources and generated the same TP by reducing the off-time. Table I gives the results for the three parameters, for all scenarios. The parameters TP and CV did not change much - showing that they are almost independent of the level of aggregation. However, Hurst parameter showed a decrease from ≈ 0.74 to ≈ 0.66 for high aggregation levels ($Z > 60$). The significance of this decrease is a topic of our future research.

Table II has the parameter settings for each setup. It gives the aggregation level, the number of sources, the off-time and the average number of active sources. The first row of the table indicates the parameter settings based on a typical user-behavior i.e., there is no aggregation. The rows can be read in the following way, for example for $Z = 2$, that half the number of sources would be required to produce the same traffic by reducing the off-time of every source by half.

We now point out to Fig. 2 and Fig. 3. The first figure gives the results of the simulation experiments. The second figure is based on the theoretical values of $E[Q]$. Observe the almost similar shape of both curves which show that mean E2E packet delay and an average number of active sources have a direct relationship. Then, the limiting criteria should be that we should have enough sources to have the same mean E2E packet delay. For the aggregation level up to 24, there is no

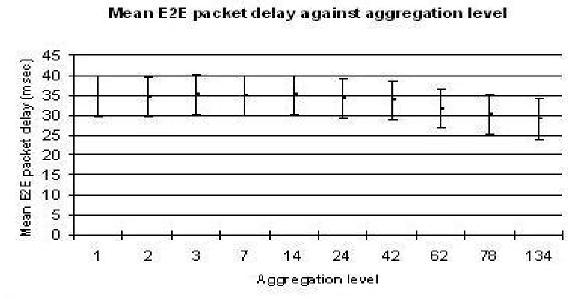

Fig. 2. Mean packet E2E delay comparison for an increasing level of aggregation.

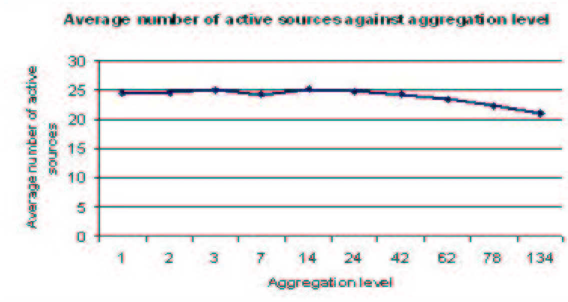

Fig. 3. Average number of active sources comparison for an increasing level of aggregation.

change in the mean E2E delay, and hence produces excellent match. For the aggregation levels between 42-62, the mean delay is only 10% off from the actual delay. For this level, the number of total sources is approximately double the number of active sources.

Engineering rule: Let Y be the given aggregate TP, then using (2) determine M, the total number of sources. Using (6) and (7) calculate $E(K)$, the average number of active sources. Then the required number of sources is $W \geq 2 * E(K)$. For this setting there is no impact on the important traffic parameters such as TP, CV, H and mean E2E packet delay is approximately the same.

IV. CONCLUSION

In this paper we have given an explanation of how many sources are required to make a realistic simulation. It is clear that a large number of sources only increases the complexity, and are not required at all. The 40-60 times reduced number of sources also opens the room for high speed networks' simulations.

REFERENCES

[1] V.Paxon and S. Floyd, "Wide-Area Traffic: The Failure of Poisson Modeling", IEEE/ACM Transactions on Networking, 1995

[2] W. Leland, M.Taqqu, W.Willinger and D. Wilson, "On the Self-Similar Nature of Ethernet Traffic", IEEE/ACM Transactions on Networking, 1995

[3] Helmut Hlavacs, Gabriele Kotsis, Christine Steinkellner, “Traffic Source Modelling”, Technical Report No. TR-99101, Institute of Applied Computer Science and Information Systems, University of Vienna, Austria.

[4] Mark Crovella and A. Bestavros, “Explaining world web web traffic self-similarity”, Technical Report TR-95-015, Computer Science Department, Boston University, Oct 1995.

[5] Ashol Erramilli, Onuttom Narayan, Arnold Nedidhardt, Iraj Saniee, “Performance Analysis of Multi-Scaling in Wide Area TCP/IP Traffic”, IEEE INFOCOM ’00, Tel-Aviv Israel, Mar. 2000

[6] A. Feldmann, A. C. Gilbert, P. Huang, W. Willinger, "Dynamics of IP traffic: A study of the role of variability and the impact of control", ACM/SIGCOMM’99, Boston, MA, 1999.

[7] A. Feldmann, A. Gilbert, W. Willinger, "Data Networks as cascades: Explaining the multifractal nature of Internet WAN traffic", ACM/SIGCOMM’99, Boston, MA, 1998.

[8] K. Below and U. Killat, "Reducing the Complexity of Realistic Large Scale Internet Simulations", IEEE Global Communications Conference (GLOBECOM), San Francisco, USA, 2003

[9] K. Below, U. Killat, "Allocation of HTTP/TCP Sources for Traffic Generation in Large Network Simulations", 2nd Polish-German Teletraffic Symposium (PGTS 2002), Gdansk, Poland, pp. 175–182, September 2002

[10] D. Veitch, P.Abry, “A Wavelet Based Joint Estimator for the Parameters of Long-Range Dependence”, IEEE Trans. Info, April 1999

[11] D.P. Heyman, T.V. Lakshman and A.L. Niedhardt, ”New method for analyzing feedback protocols with applications to engineering web traffic over the Internet”, ACM SIGMETRICS, 1997

[12] Hyoung-Kee Choi and John O. Limb, “A behavioral Model of Web Traffic”, 7^{th} Annual International Conference on Network Protocols, Toronto, Canada, 1999

[13] Lester Lipsky, Michael Greiner, Hans Peter Schwefel, Helmut Gogl, “How to Model Telecommunication (and other) Systems Where “Self-Similar” (Power-Tail) behavior is Observed”, July 16, 1997