ANALYSIS OF THE INFLUENCE OF SELF-SIMILAR TRAFFIC IN THE PERFORMANCE OF REAL TIME APPLICATIONS

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ABSTRACT
In this work we present a network convergence environment and the results of the performance evaluation of real time applications in the presence of self similar traffic with different levels of burstiness. Our primary goal is to prove that the grooming of traffic flows that may result in different burstiness levels, represented by the Hurst parameter, has to be considered in the mapping of traffic flows in FEC (Forwarding Equivalence Class). We show the results of two different experiments and the latency, losses and interarrival time calculus related to a real time application. Also we make our considerations of how the traffic characterization procedure should promote an improvement in the development of traffic engineering procedures.

KEY WORDS
self-similar, MPLS, traffic characterization, converged networks.

1 Introduction

Today exists a well accepted tendency that the future of telecommunications will be guided by the integration of voice and data services in a multi-service network. Many subjects related to this tendency are still open to discussion, such as the convergence process, the performance issues involved, as well as the new services, costs and benefits of such evolution [1].

The integration of different types of traffic in an unique network represents some changes for the traditional approach of traffic analysis. By one side, we have the voice traffic, that has the property that it is relatively homogeneous and predictable in some manner. The performance analysis, the mathematical modeling, the optimization and queuing theory applicable to these processes is well known and accepted by the telecom community. The circuit switched network used for the voice transmission is though well engineered in a teletraffic theory. This theory has been fundamental for the development of the telephone network.

The traffic-performance relation relies on the assumption that telephone calls arrive as a stationary Poisson process.

By the other hand we have the data traffic, which in comparison to voice traffic is much more variable. The nature of several and individual connections, with packets of different sizes with different rates and on different and dynamic paths led to a network with a different approach based on a statistical multiplexing process in behalf of efficiency and robustness. The arrival of new packets may overload the links when they arrive in rates higher than the link capacity. In that case, the packets are buffered, awaiting transmission. When the excess rate remains for a considerable period, congestion happens, the buffers fill up and it results in some packets losses. Normally, to control the congestion, the router detecting this situation sends a packet to the traffic source, announcing the problem. But we have to consider that the larger the end-to-end delay, the longer it will take to inform that the network is congested. Studies have shown that high speed network traffic is more bursty and its variability cannot be predicted in a trivial way, which makes difficult to control the congestion in a packet switched network, such as the Internet [2].

2 Self Similar Traffic

The first works in the area [3] proved that Ethernet traffic has a high degree of burstiness that appears in a wide range of scales and was characterized as a self similar process.

This results show that traffic bursts in data networks occur on many different time scales and that such multiscale burstiness does not fit the world of traffic modeling based on the Poisson approach.

The measure of degree of self similarity in a time series is similar as characterizing the burstiness of the traffic flow. The impact of burstiness in network congestion shows that the congested periods can be extremely long with concentrated losses, that the linear increases in buffer sizes do not result in packet drop rates and that a slight increase in the number of active connections can result in a large increase in the packet loss rate.

2.1 The Converged Network

A fundamental problem of the IP network in comparison to the circuit switched network is the lack of capacity in providing different QoS (Quality of Service) degrees. As an example, the impact of delay and jitter in a voice connection
is much more disturbing than in a ftp (file transfer protocol) connection, so it seems clear that the applications should have different treatments, not only from the service perspective, but also from an economic and marketing view.

In behalf of this evolution, based on an infrastructure convergence, in a logical and physical level, different technologies have been proposed. The physical Internet backbone evolution and the MPLS (Multi-protocol Label Switching) specification as well as the DiffServ (Differentiated Services) are considered nowadays the means for supporting these new paradigms.

One of the most important utilities of the MPLS is the capacity to introduce the process of TE (Traffic Engineering), which aims to implement routing flows that optimize the use of resources to provide high quality services as well as considering other important variables, such as costs and charging. The research interest also extends to the MPLS evolution forward GMPLS (Generalize MPLS), i.e considering also the transport layer in the optimizing process and all the interaction with the actual and well accepted technologies.

In a MPLS network, the use of hop-by-hop computed path paradigm of IP networks is substituted by an explicit routing mechanism. This mechanism permits a particular packet stream to follow a pre-determined path. This path, known as LSP (Label Switch Path), is identified by a label that maps the different nodes of the network that form the path based on the value of a FEC (Forwarding Equivalence Class). The packet is forwarded along the LSP by a switching label process, diminishing the lookup table overhead of IP networks, since instead of a search in the routing table with a high number of rows, in MPLS the table access is direct (by the unique label identifier in that node).

The path determination is a traffic engineering task. The use of shortest path algorithms, as in OSPF (Open Shortest Path First) and IS-IS (Inter System-Inter System) protocols, shows some efficiency but lack of some considerations such as links constraints, QoS (Quality of Service) requirements, load sharing, modifications on links metrics that can affect the total network traffic and abrupt changes on traffic demands. Also, the computation of path results in a NP-complete problem as the number of variables describint the topology increases.

There are several proposals which discuss reactive MPLS traffic engineering. All these proposals investigate reactive MPLS traffic engineering with multipath balancing and present simulation results which are focused on small networks.

Other problem that arises is the mapping of flows in FECs [4] due to the lack of a traffic characterization model that facilitates this issue since currently traffic theory plays a very minor role in Internet. The certain detection of the level of burstiness may help the traffic flows mappings since the bursts of a higher priority traffic flows could obstruct the lower priority flows for long periods of time and also this degree may be used to dynamically define the traffic priorities.

This work intends to verify the impact of performance for real time applications in the presence of a certain degree of self-similarity in an experimental converged network.

In the following section we describe the experimental network implemented at our lab that simulates a converged network and also we present a detailed description of the experiments and simulations developed on different traffic flows with several degrees of self-similarity.

In section 4, we make an analysis of results and focus ideas that arise from this analysis for the traffic characterization procedure in MPLS networks. In section 5, we present our conclusions and future work.

3 The Experimental Work

3.1 The Testbed

The testbed is showed in figure 1. Basically, it is formed by five different networks: a PSTN (Public Switched Telephony Network), an ADSL (Assymetric Digital Subscriber Line) access network, two local area networks (LANs), a wireless LAN and a MPLS/Diffserv core.

The PSTN is formed with two local exchanges, Tropico RA and a S12, both from Alcatel. The ADSL network, two local area networks and a wireless LAN are both interconnected by the MPLS core, so in this way, we concentrate the traffic from different sources in an unique point. The main goal is to have in the MPLS core the forwarding process of different types of traffic, from several applications and with different QoS needs, which simulates in some manner a real multiservice network. The MPLS/DiffServ core has four routers, based on the Linux Operating System Kernel 2.4.21 and an open source MPLS implementation [5].

The routers are four computers Pentium IV 2.1GHz and are interconnected by 10/100 Mbps links. The first router, LSR01 connects three LANs to the core, and the LSR03, via a radio link of 2 Mbps connects the fourth LAN. The routers LSR02 and LSR04 are the forwarding elements of the core. The MPLS core underlies in an Ethernet network and uses the OSPF protocol for routes advertising.
This platform has been fully tested with several experiments [5], which showed that the MPLS platform has less losses than the IP environment. Surprisingly, these tests also showed that the latency of the MPLS platform is higher but appeared to have lower losses for identical traffic flows comparing to the IP platform.

3.2 The Experiments

It is known that in the case of bursty traffic, the aggregation of different flows results in a higher degree of burstiness, i.e. a higher H value. Using this fact, we propose the evaluation of a CBR application, in terms of latency and packet losses in a MPLS core in three different scenarios.

First Scenario Evaluation of the performance of a CBR application with 14 multiplexed sources, with a resulting H between 0.5 and 0.55 (low burstiness) with an average data rate between 1.1Mbps and 1.2Mbps, routed in an unique LSP in the MPLS core.

Second Scenario Evaluation of the performance of a CBR application with 10 multiplexed sources, with a resulting H of 0.8, and an average data rate between 1.1Mbps and 1.2Mbps routed in an unique LSP in the MPLS core.

Third Scenario In a simulation environment, shown in figure 2, we evaluate the influence of the channel load as well as the variance coefficient in the measures of latency and jitter. The gray line in figure 2 shows the path of the CBR traffic to be analyzed.

Figure 2: Simulation environment

For scenario 1 and 2 we used a synthetic self similar traffic generator which works with a number of independent sources and targets, with alternate states “on” and “off” with a heavy tail distribution, in this case a stable Pareto distribution. The same number of servers and clients are used in both scenarios to simulate the applications to produce the self similar traffic. Observe that the heavy tail property points for the distribution how much data it will send, but it does not say how the source will in fact send the data. The CBR application in this two scenarios is a 512kbps synthetic flow with packets size of 256 bytes.

For the third scenario, we generated traffic traces with com 8 different values of the Hurst parameter, varying from de 0.5 to 0.85, all with the same variance coefficient. For each simulation we used four traffic flows: F1 (n0 to n5), F2 (n0 to n6), F3 (n8 to n9) and F4 (n0 to n7) The flows F1, F2 e F3 have the same H parameter in each simulation. The F4 flow is the one CBR traffic type to be evaluated.

Fourth Scenario. For this simulation we used traffic flows with six different variance a coefficients, varying from 50 to 300, all with the same Hurst parameter of 0.7 and with the same channel load ρ. For each value of a, we made a simulation and collected the measures. The network of figure 2 was used.

We used two methods for the verification of self similarity. The first method is the variance time plot and the second method is verified in [6] which appeared to be fast and reliable.

The first method uses the relation between the variance of the aggregated process $X^{(m)}$ and the block size $m$ is given by (1), where $a$ is some finite positive constant and $0<\beta<1$. Applying the log function in both sides of (1), a β estimate results by calculating $\log(var(X^{(m)}))$ corresponding for various $m$ values, plotting the result against $\log(m)$ and then least square fitting a straight line through the resulting points. The estimated $\beta$ is related to H by $H=1-\beta/2$.

$$\log(var(X^{(m)})) = am^\beta, \text{ as } m \to \infty$$  \hspace{1cm} (1)

The second method considers that a second order stationary process is said to be exactly second order self similar as defined in (2), and considering that $X_t$ is a fractional Gaussian noise, the estimated H parameter of the process is defined in (3) This method has confidence intervals that are contained in the wavelet method for H calculus, and also is much faster. This results in shorter time series sets which and a better performance, making it possible the on-line calculus for traffic flows.

$$\rho(k)=\frac{1}{2}(\|K+1^{2H}\|^{2H}+\|K-1^{2H}\|^{2H})$$  \hspace{1cm} (2)

$$H = \frac{1}{2}[1+\log_2(1+\rho(1))]$$  \hspace{1cm} (3)

In both cases we collected 50,000 packets to analyze the self similarity which is equivalent in our network configuration for a period of 5.3 minutes of traffic trace.

3.3 The Results

First Scenario In this scenario we intend to analyze the behavior of the CBR traffic in presence of a traffic with a low degree of self similarity.

Since the traffic generator is based on a Pareto distribution, the parameters given to the serie generation process intended to produce a low self similarity of the traffic. All the traffic sources were from LAN1 (see figure 1) and sent traffic to LAN2 in several ports. The traffic trace of the intended self similar traffic is collected in LSR01.

First, in figure 3, we show the bandwidth utilization with an average data rate of 1.1 Mbps. In this figure appears clearly that indeed the traffic has several bursts, examining figure 3 we can verify that the behavior of the flows do not characterize a self similar traffic, since the autocorreletion function of the flows, does not have an acceptable aproximation for the autocorreletion function expected, plotted in dashes in figure 4. This can be verified by the calculus of the H parameter for the flow in 0.1 sec time scale, which is 0.54, using the two methods mentioned in the precedent section of this work.
Second Scenario  As mentioned earlier, the second scenario intends to observe the changes in the results of a CBR traffic in the presence of a traffic with a higher self similarity degree.

Once again, the traffic sources reside in LAN1 (Figure 1) and the traffic traces of the intended self similar traffic are collected in the LAN2.

In figure 5 we show the bandwidth utilization of the 10 traffic flows with an average data rate of 1.1 Mbps.

In figure 6, in solid line, appears the autocorrelation function of the aggregated flows and in dashes the theoretical function expected. In this figure we observe that both functions have a similar behavior which is also sustained by the H of 0.8 calculated for the scale of 0.1 seconds. A very little variation was observed in the value of the H parameter in different time scales which is the time invariance behavior expected for the self similar traffic.

Since in this second scenario, the parameter H has a higher value, the expectations were that the packet losses will increase. Previous results in other works [3] show that packet traffic spikes that cause the losses depend on the long range dependence characteristic.

Comparison of scenario 1 and 2 In table 1 we show a comparison of the results of the two scenarios. We can verify that in the first scenario the mean latency and the mean packet losses are higher than in the first scenario. In the case of the latency, the first scenario shows twice the mean latency of the second scenario. In the case of the packet losses, the first scenario shows five times more losses than the second scenario.

The results of the previous experiments confirm that a higher degree of self similar traffic in a MPLS network produces higher packet losses. Also, examining figure 5 and figure 10, we can see that in the case of the self similar traffic, the packet losses appear to be concentrated in certain intervals, which may result in a poor performance in the case of a CBR application, such as VoIP.

Third Scenario. For the simulation we show in table 2 the measures for a channel load $\rho=0.7$. On figure 7 appear the curves of mean delays for different channel loads. Clearly it appears that for higher channel load, the delay has higher proportional grows.
### Table 1: Comparative Results

<table>
<thead>
<tr>
<th>$H$</th>
<th>Mean Latency</th>
<th>Mean Packet Losses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.80</td>
<td>0.029</td>
<td>3.6</td>
</tr>
<tr>
<td>0.54</td>
<td>0.013</td>
<td>0.7</td>
</tr>
</tbody>
</table>

### Table 2: Delay, Jitter and Losses

<table>
<thead>
<tr>
<th>$H$</th>
<th>$\rho = 0.7$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Delay (seg)</td>
</tr>
<tr>
<td>0.50</td>
<td>0.244</td>
</tr>
<tr>
<td>0.55</td>
<td>0.248</td>
</tr>
<tr>
<td>0.60</td>
<td>0.269</td>
</tr>
<tr>
<td>0.65</td>
<td>0.343</td>
</tr>
<tr>
<td>0.70</td>
<td>0.411</td>
</tr>
<tr>
<td>0.75</td>
<td>0.499</td>
</tr>
<tr>
<td>0.80</td>
<td>0.791</td>
</tr>
<tr>
<td>0.85</td>
<td>1.117</td>
</tr>
</tbody>
</table>

![Figure 7: Measures for different channel loads](image)

### Table 3: Comparative Results

<table>
<thead>
<tr>
<th>Variance coefficient ($\alpha$)</th>
<th>Mean Delay</th>
<th>Jitter</th>
<th>Packet Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.370</td>
<td>0.048</td>
<td>2</td>
</tr>
<tr>
<td>0.1</td>
<td>0.626</td>
<td>0.069</td>
<td>14</td>
</tr>
<tr>
<td>0.15</td>
<td>0.842</td>
<td>0.089</td>
<td>28</td>
</tr>
<tr>
<td>0.2</td>
<td>1.226</td>
<td>0.129</td>
<td>89</td>
</tr>
<tr>
<td>0.25</td>
<td>1.418</td>
<td>0.144</td>
<td>80</td>
</tr>
<tr>
<td>0.3</td>
<td>1.518</td>
<td>0.169</td>
<td>115</td>
</tr>
</tbody>
</table>

**Fourth Scenario.** For the simulation we show in table 3 the measures for a channel load $\rho=0.7$. On figure 8 and 9 appear the curves of delay, jitter and packet losses respectively, where it clearly appears that for higher variance coefficients the values of these measures increase.

### 4 The Traffic Characterization for MPLS Networks

The traffic engineering process has three main steps: measure, model and control. In the first step, the network topology and the traffic demands are identified. In the second step, the modeling step evaluates the weights in the different links and produces an optimal setting for the different traffic flows, and finally, the last step consists in make the changes necessary to maintain the network operation. Having a timely and accurate view of the current state of the network helps the task of selecting good link weights.

The traffic measures of volume of traffic between each pair of routers may come from the past experience or from a view of the traffic demands using measurement techniques. The offered traffic may be calculated based on observations of the aggregate load on links inside the network.

The traffic engineering process needs an effective way to predict the flow of traffic through the network based on the routing configuration, but also, we argue that it needs to know the kind of traffic that should transit, a more precisely characterization, where the view of traffic as a self similar process, considering the $H$ parameter and the variance coefficient, as well as the channel load, appear as the important elements for this characterization.

Currently, there is a difficult to map traffic flows in specific FECs[4]. This difficult arises from the lack of proven models that can characterize the traffic flows and identify an appropriate FEC, without human intervention. Using a Diffserv implementation, we can choose the type of service of a certain application, and use this type of service and its requirements to induce the mapping of flows in a certain FEC. We argue that there exists the necessity to use a more precise method to identify the traffic characteristics, and though use these informations to make a more efficient traffic mapping in routing paths, considering the QoS requirements also.

So, the TE process should consider the QoS metrics of the traffic as a self similar process, and in this case the metrics used can used the approach of the work of [8], which uses the fBm (Fractional Brownian Motion) envelope process of a traffic trace. In (4) and (5) appears the definition of the traffic as a fBm process and the fBm envelope process, where $A(t)$ is a cumulative second order self similar process and $\hat{A}(t)$ is the envelope process, where the $k$ parameter indicates the probability that $A(t)$ will overpass $\hat{A}(t)$, on time $t$. $Z(t)$ is a normalized fBm process.

\[
A(t)=at+\sigma Z(t). 
\]  
\[
\hat{A}(t) = at + k \sqrt{\sigma^2 t} = at + k\sigma^H. 
\]

With Eq. 4 and 5, an expression for end-to-end delay and packet losses can be induced and used for the calculus of QoS metrics in critical applications. Considering the above, we can think of a TE procedure in the following manner: given a network with represented by a graph $G(V,E)$, where $V$ are the nodes and the pair belonging to $E$ represent the
LSPs between different elements of $V$, our proposal, in a general view, has the following steps:

1. For each $v_i \in V$, in $n$ time intervals, produce an entry in a traffic matrix for H control, if $v_i$ is an edge router of the MPLS core.
2. Calculate the envelope process of the traffic trace.
3. Estimate the QoS of the routing path and compare its value with established thresholds.
4. For each element that is over the threshold do the following:
   - For the pair $(v_i, y_j) \in E$ find the pair $(v'_i, y'_j) \in E$ and evaluate the aggregated traffic flow QoS metrics of the different flows and remap the flows in the better paths for these requirements, if there exists available bandwidth.
   - Go to step 1.

**5 Conclusions and future work**

As we have seen in the experiments presented in this work, the degree of self similarity has an important influence in the performance of multimedia applications, especially in the case of packet losses which tend to concentrate in certain time intervals. In this work, we presented an experimental testbed for converged networks and validated the expected results for self-similar traffic. Also the influence of channel load and variance coefficients was investigated through different simulation experiments.

Considering the problem of traffic engineering in MPLS networks, the TE task should consider the traffic characterization as a self-similar process for an accurate traffic mapping of FECs, for certain QoS metrics. We proposed an algorithm that with heuristic methods could improve the QoS metrics in a MPLS network.

Future experiments should evaluate the performance of the proposed algorithm in simulation environments and in the experimental testbed shown in this work.

**References**


