A Traffic Characterization Procedure for Multimedia Applications in Converged Networks

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Abstract

This work presents a traffic characterization procedure for Traffic Engineering (TE) in converged networks. An analytical model, focused in a self-similar aggregated traffic characterization is proposed, which considers QoS restrictions for delay metrics. The model, together with evolutionary techniques, is used for the optimization of the link capacity assignment task in network planning with multi-service applications. The results show that the traffic characterization model is reliable as a part of the optimization of costs in converged networks.

1. Introduction

The rapid growth of services and applications driven by the IP protocol trend to the packet switched network as the natural choice for the future of telecommunications. Moreover, the migration of all services to IP (Internet Protocol), require guaranteeing QoS (Quality of Service) specially for real time applications which results in the need to provide fast provisioning and scalability in order to offer multi-service capabilities [1].

Nowadays, MPLS (Multiprotocol Label Switching Protocol) appears as a solution to implement traffic engineering (TE) mechanisms, which will allow a major integration between the different planes of the layers in the network reference model [2].

The MPLS has several elements. It works with labels, LSPs (Label Switched Paths) and switching elements, the LSRs (Label Switching Routers) [3]. For each LSP exists a group of FECs (Forward Equivalence Classes) that describes the traffic requirements and consequently, defines the LSPs for packets.

In a MPLS network, the use of the 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 predetermined path. This path, the LSP, is identified by a label that maps packets into different nodes of the network that form the path. The packet is then 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 big number of rows, in the MPLS, the table access is direct (by the unique label identifier in that node). Thus, as in traditional circuit switching networks, the explicit routing in MPLS forwards the packet in a predetermined path, established with antecedence to the packet sending task.

The TE procedure should optimize the network resources for different traffic fluctuations. This task should be performed considering the different network layers and technologies, the different classes of services and their QoS needs. In converged networks, a common operation is the traffic aggregation of different applications, which is a basic networking activity that merges separate traffic streams at network nodes. The nature of this traffic, appears to have a self-similar nature [4].

In the recent years, the self-similar nature of Internet traffic has been demonstrated with high quality measures [5,6]. The impact of this kind of traffic in QoS measures has been already analyzed. Also observations in the electronic domain and in the optical packet switching networks have confirmed that the performance of optical network is seriously degraded because of the self-similarity of the traffic [7].

The challenge for the telecommunications companies is to extend the integration of the upper layers of the network reference model, nowadays in intense migration to MPLS, with the synchronous digital hierarchy (SDH) and wavelength division multiplexing (WDM) in order to facilitate the traffic engineering (TE) capabilities of the network.

In this work we present a framework that treats the QoS measures in an IP/MPLS scenario for self-similar traffic, and use this characterization for optimization of
links capacities assignment. In Section 2 we define the traffic characterization procedure for converged networks. In Section 3, an explanation about the procedure to optimize links capabilities is shown as well as its iteration with the proposed traffic model. In Section 4, the accuracy of the optimization method with a set of experimental results is shown, which appeared to achieve accurate QoS values for different traffic aggregations and network topologies. In Section 5 we present the conclusions and future work regarding this research.

2. Traffic Characterization for Converged Networks

The integration of different types of traffic in a unique network represents some changes in the traditional approach of traffic analysis. By one side, we have the voice traffic that is relatively homogeneous and predictable in some manner. Many concurrent voice connections can be multiplexed in fixed time slots and the arrival of new calls depends on a well known link capacity available.

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 the 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. The works of Gerla and Kleinrock [8] extended the applications of the queue theory with the M/M/1 model to packet networks. In this model, the assumptions are that the BER (Bit Error Rate) is zero and the Poisson traffic exhibits short range dependence. Based on the Kleinrock’s theorem, the independence of arrivals on each node is preserved. In this way, the method treats network elements as M/M/1 queues and from these models, expressions for delay in packet networks have been derived. This methodology has been the basis for other proposed methods [9].

The telephony legacy had a great influence on data network research and limited the attempts to validate the modeling assumptions against real traffic measurements. Works in the area [5,10] proved that Internet traffic burstiness appears in a wide range of scales and can be characterized as a self similar process. This results show that traffic bursts in data networks occur in many different time scales and that such multiscale burstiness does not fit the world of traffic modeling based on the Poisson approach and the M/M/1 models mentioned earlier.

The implications of these discoveries induce the elaboration of new models with enough formality that would permit an application in the network planning task, nowadays for converged networks with multi-service applications.

2.1. Self Similar Traffic

Self-similarity is associated with fractal geometry. The network traffic in terms of packets per second or bytes per second can be considered a stochastic time series. Let \( Y(t) \) be a stochastic process for \( t \in \mathbb{R} \). \( Y(t) \) is a self-similar process with Hurst parameter \( \frac{1}{2} \times H \times 1 \), denoted by \( H-ss \), if \( Y(t) = a^{-H}Y(at) \) for \( a > 0, t \times 0 \), where the equality refers to a probabilistic sense, i.e, \( Y(t) \) is a scaled version of \( Y(at) \), after the normalization by \( a^{-H} \), having the same distribution[11].

The \( H \) parameter is known as the Hurst parameter of self-similarity. Lower values of \( H \) to 0.5 typify the Poisson traffic and values closer to 1, correspond to a higher degree of long range dependence, which has great implications in terms of performance.

Consider the time discrete stochastic process \( X(t) \), which represents the traffic volume in packets, bytes or bits, in the time slot \( t \in \mathbb{N} \). A new process from \( X(t) \) can be defined, for the formulation of the scale invariant property, expressed in (1).

\[
X^m(t) = \frac{1}{m}(X(t)_{n=m+1} + X(t)_{n=m+2} + \ldots + X(t)_{n=m}) \quad (1)
\]

for \( m = 1, 2, 3, \ldots \) where \( X^m(t) \) is the aggregated process, obtained by the division of the original time series in blocks of size \( m \). The new time series is a replica of the original series, \( m \) times reduced. As the original time series, \( X^m(t) \) is also a stochastic process in the wide sense. If the original process \( X(t) \) is self-similar, \( X^m(t) \) will have the same autocorrelation coefficient as \( X(t) \), expressed by the relation \( \rho^m(k) = \rho(k) \).

To describe the long range dependence property, consider that the process \( X(t) \) has a Hurst parameter \( \frac{1}{2} \times H \times 1 \). This process is exactly second order self similar if the autocorrelation coefficient is expressed by (2), with \( m \times 1 \).

\[
\rho(k) = \rho^m(k) = \frac{1}{2}[k + 1]^{2H} - 2[k]^{2H} + [k - 1]^{2H} \quad (2)
\]

Generally, in the process with short range dependence the covariance function decays very fast, accordingly to an exponential function, but in the self similar process with long range dependence, the covariance function decays slowly, with a hyperbolic behavior. This difference has a huge implication in terms of performance metrics in a packet switched network.

Nowadays, is generally accepted that network traffic exhibits the features of long-range dependence and
self-similarity. This approach was one of the major changes in the last decade regarding the network area.

The parameter $H$, which measures the degree of self-similarity can be calculated over a traffic trace using several methods [11]. Also, it is known that in the case of bursty traffic, the aggregation of different flows preserves the degree of burstiness [12].

Currently, there is a difficult to evaluate the QoS parameters of a traffic flow with self-similarity. This arises from the lack of proven models that can characterize the traffic flows with this characteristic. Regarding the MPLS technology, an accurate traffic characterization could improve the definition of a FEC associated to certain flows, a current open topic for research in the TE area [2].

A valid TE process for converged networks relies on accurate QoS metrics. Then, this task needs a traffic model that is capable to capture the real nature of the different traffic flows and their aggregations.

In this work, we consider that the treatment of traffic as self-similar produces more accurate QoS metrics in comparison with the ones obtained with the traditional models, mainly based in Poisson traffic.

The traffic characterization of self-similarity as a self-similar stochastic process, defined by $A(t)= t^H$, where $t$ is a random variable with normal distribution, zero mean, variance=1 and $H$ is the Hurst parameter. Then, $A(t)$ is a random variable, with normal distribution and zero mean. The $A(t)$ variance derives from the incremental process $[A(t)-A(s)]$, expressed in (3) and (4).

$$\text{var}[A(t)]=\text{var}[\beta t^H]=\text{var}[\beta t]^{2H}=t^{2H}$$  \hspace{1cm} (3)

$$\text{var}([A(t)-A(s)])=E[(A(t)-A(s))^2]=(t-s)^{2H}$$  \hspace{1cm} (4)

The $A(t)$ process may represent the number of bits that arrived in the time interval $(0,t)$, where $A(t)=a+ Z(t)$, with $Z(t)$ is a normalized fBm, with mean $a$, variance $\sigma^2$ and $H \in \{1/2, 1\}$. For a fBm process $A(t)$, with mean $a$ and variance $\sigma^2$, the envelope process $\hat{A}(t)$ is given by (5).

$$\hat{A}(t)=at + k\sigma^\sqrt{t}$$  \hspace{1cm} (5)

The $k$ parameter determines the probability that $A(t)$ will surpass $\hat{A}(t)$, in the time slot $t$. If $A(t)$ is a fBm process, the expression for $k$ may be approximated by a residual Gauss distribution and may be expressed as in (6). An extension of the definition in (5) is made in [14], where the envelope $A_{\beta}(t)$, for $H>0.5$ is defined as in (7).

$$k = \sqrt{-2\ln\epsilon}$$  \hspace{1cm} (6)

$$\hat{A}_{\beta}(t) = at + k\sigma^H$$  \hspace{1cm} (7)

As an example of the envelope process, we illustrate its calculation in Fig. 1, for the real Internet traffic series available in [15]. The variance and $H$ parameters were extracted from the real time series and in 5000 time slots of 0.01 seconds, the envelope process was plotted, for $\epsilon=0.001$. The figure shows that the process achieves a good approximation of the aggregated traffic series.

An expression for the maximum buffer size on each node is showed in (8). This expression uses the maximum time scale, calculated from (7), the main proposal of the work developed in [16]. The authors demonstrate that the time scale represents the moment in which the buffers gets full and may be used for maximum delays calculations.

The above equations were used in the previous mentioned works for QoS approximations in ATM networks. In our particular work, we will study their suitability for the MPLS case, with some proper adjustments, as shown in the next section.

$$q_{\text{max}} = (c-a)^{\frac{H}{1-H}}(k\sigma)^{\frac{1}{1-H}}H^{\frac{1}{1-H}}(1-H)$$  \hspace{1cm} (8)

2.2. The Hybrid Traffic Model

In a MPLS network, each node is an element of a LSP, which can be considered as a virtual circuit in the network. We also know that the delay is an additive metric, so, the total delay of a circuit is the sum of the individual delays on each node.

Using (8), we can obtain an expression for the total delay in a LSP, with a certain probability, as has been already shown in [17]. So, the expression shown in (8), divided by the channel capacity should inform an upper limit for the delay of a flow on each node as part of a certain LSP.

In our work, we adjust the expression in (8) to consider the load in the link. We consider the influence of the channel load together with the $H$ value in the delay calculus. To quantify their influence, some experiments in a hypothetical scenario, shown in Fig. 2, were made. In this scenario we evaluate the channel load as well as the $H$ parameter and the measures of latency, jitter and packet losses.

For this experiment, traffic traces were generated with 8 different values of the Hurst parameter, varying from 0.5 to 0.85, all with the same variance coefficient. For each simulation four traffic flows were used and were mapped on hypothetical paths (see Fig. 2): F1 (n0 to n5), F2 (n0 to n6), F3 (n8 to n9) and F4 (n0 to n7).

The flows F1, F2 and F3 have the same $H$ parameter in each simulation. The F4 flow is a CBR traffic, which appears in the green line in Fig. 2.
The simulation results for the CBR traffic are shown in Table 1, for a channel load =0.7. On Fig. 3 appear the curves of mean delays for different channel loads.

The results indicate that for higher channel load, the delay has higher proportional grows. These results induce that the channel load is of valuable consideration for the traffic characterization as well as the statistical components of the flows.

In Fig. 4 appears that for channel loads lower than 0.3, the M/M/1 model has a fine approximation for the simulated value, with a certain trend to underestimate.

For the case of the pure self-similar model, the estimated delays values for channel loads between 0.3 and 0.6 establish maximum values that trend to oversize the network capacities sizes.

![Figure 1. Envelope Process and Real Time Series](image1)

![Figure 2. Simulation environment](image2)

**Figure 3. Measures for different channel loads**

With this analysis, our proposal is to use a hybrid traffic model, with the following restrictions:

a) the maximum channel load admissible is 70%;

b) for channel loads lower than 30%, the model for the delay calculus is the M/M/1, which corresponds to the Kleinrock equations for data networks [8];

c) for channel loads between 30% and 70%, the pure self-similar model shown in (8), adapted for the delay in a virtual path is used.

So, our proposed model, shown in (9), has two different windows: for channel load lower than 0.3 the M/M/1 model is applied and for loads equal or higher than 0.3 the model based on self-similar traffic is applied, where $T$ is the delay in a node. The variables $c$ and $a$ are the capacity of the channel and the mean rate respectively. The channel load is $\rho$, with $\rho<0.7$.

$$T = \begin{cases} \frac{((c-a)^{H} - a^{H}) (k\sigma)^{1-H} H^{H} (1-H)}{c} & \rho \geq 0.3 \\ \text{Model M/M/1} & \rho < 0.3 \end{cases}$$  \hspace{1cm} (9)
The novelty of this approach is to obtain a closer to reality value of delay for multimedia traffic network, which should promote a more accurate calculus of network capacities. This would promote an improvement in the network operation costs, since the network planning procedure will consider delay values that are not oversized.

3. The Optimization Procedure

The problem formulation for capacity assignment in a network is shown in Table 2.

As can be seen in Table 2, the optimization variable is the cost, which is related to the network capacities and to the restrictions shown in line 4. This problem formulation has been treated in several works [8,18] and in this particular case, the routing politics are considered as given, which is a simplification of the routing optimization problem.

In the routing optimization problem, the link capacities as well as the routing paths should be found, considering a minimal cost and a set of restrictions. The routing politics are fundamental for network performance in terms of QoS metrics and costs, but for this particular case we want to show the potentiality of the hybrid traffic model for optimization purposes, so the formulation of Table 2 will be used.

There are several optimization methods for the problem as shown in Table 2 [19]. Recently, in the network area and other application fields, the genetic algorithms (GA) appear as a useful tool for these purposes.

Table 2. Problem Formulation

<table>
<thead>
<tr>
<th>Given</th>
<th>A topology</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A traffic matrix R</td>
</tr>
<tr>
<td></td>
<td>The routing politics</td>
</tr>
<tr>
<td>Minimize</td>
<td>A cost function</td>
</tr>
<tr>
<td>With the</td>
<td>$C=(C_r, C_p, \ldots, C_j), \ b=$number of</td>
</tr>
<tr>
<td>variables</td>
<td>nodes in a LSP</td>
</tr>
<tr>
<td>Restrictions</td>
<td>1) $f \cdot C$: the aggregated flows have a</td>
</tr>
<tr>
<td></td>
<td>total bandwidth coger than the capacity</td>
</tr>
<tr>
<td></td>
<td>2) a QoS value, for this case a maximum delay</td>
</tr>
<tr>
<td></td>
<td>parameter</td>
</tr>
</tbody>
</table>

The fundamental idea of the GAs reside in the nature dynamics of reproduction and survival of species, where in normal conditions, the more capable individuals are the ones that have the higher chances to survive. So, for a particular problem, the GA dynamics can choose the individuals that represent the suboptimal solution set for a certain optimization parameter. For the dynamics to work correctly, the problem formulation and restrictions should represent, in the most accurate way, the nature of the problem to be solved.

The GA procedure initially creates a first generation, in a random way. The first generation is evaluated, through a specific function related to the problem to be solved. In this evaluation, each individual in the generation may be represented by a string of values and receives a fitness value. Next, a new generation is produced, through the application of a reproduction operator, and the cross procedures selects pairs of strings that appear, according to the fitness value, the more reliable to produce other individuals. With a probability operator, mutation is applied in this new born individuals and the evaluation procedure gets in place again. The process continues to take place until certain stop criteria, which in our case, through different experiments was chosen based on the number of generations.

For our particular problem, as formulated in Table 2, the process of reproduction, cross and mutation consider the hybrid traffic model proposed in (9). The optimization goal is a cost function and the restrictions are the ones that appear in line 4. Our individuals are a set of strings that represent the set $C_i$, which are used to evaluate the restrictions in a certain topology, as well as the optimization function.

The cost function used for this procedure is shown in (10), where $p_{ij}$ is the cost of the capacity unit of the link $(i,j)$, where $i$ and $j$ are the source and destination nodes. The function appears to be generic enough to any kind of physical medium. Naturally, depending on the network characteristics, different cost functions may be implemented and tested.

$$\text{Cost} = \sum_{i,j} p_{ij} C_{ij}$$ (10)
4. The Experiments

To evaluate the procedures shown in section 2 and 3, two different network scenarios were composed. The first scenario is shown in Fig. 5. As can be seen, this scenario represents a small network, in which each one of the flows ingress the MPLS core through routers R1 and R2 and finish in R3 and R4.

![Figure 5. Scenario 1: MPLS core with 4 nodes and four aggregated traffic flows.](image)

On the right side of Fig. 5 appears the routing table for each flow. Each one of the flows represents the aggregation of different flows that are subsequently aggregated in the different nodes of the core.

The second scenario is shown in Fig. 6. This represents a bigger network, with 12 nodes and 10 different aggregated flows.

The traffic flows considered for both scenarios have the following characteristics:
- are described by the variables \((H,a,v)\), where \(H\) is the Hurst parameter, \(0 < H < 0.95\), \(a\) is the mean and \(v\) is the variance coefficient.

Since the different flows suffer aggregations in the nodes of the MPLS core, a procedure to calculate the aggregated \(H\) and variance value, in order to compute the envelope process, is necessary. We must consider that the flows have different \(H\) values, varying from 0.5 to 0.95, in which the 0.5 represents a typical Poisson traffic. For this experiments, we apply the concepts shown in the work of [12], which use expressions (11) and (12) for the calculation of the aggregated \(H_g\) and the aggregated variance coefficient.

\[
H_g = H(0) = \frac{\sum H_s \sigma_s}{\sum \sigma_s} \quad (11)
\]

\[
\sigma_g = \sigma(0) = \sum \sigma_s \quad (12)
\]

- the flows aggregations preserve the degree of self-similarity, a result already observed in several experiments.

The above suppositions are coherent with the fact that the traffic in converged networks is the superposition of several flows of independent sources with different characteristics.

![Figure 6. Scenario 2: MPLS core with 12 nodes and 10 aggregated traffic flows.](image)

For the first scenario, the F1, F2 and F3 flows are self-similar with \(H=0.8\), \(a=8000\) bps and \(v=1250\). The F4 flow is a CBR flow with \(a=1000\) bps. Two optimizations were made, where the first uses M/M/1 model, and the second uses the proposed hybrid traffic model. The capacities obtained for each model are compared with simulations made in the NS – Network Simulator [20]. The comparative results are shown in Table 3 and 4.

The results in Table 3 show that the optimization procedure with the M/M/1 model does not capture the real nature of traffic, since the delays obtained in simulations are higher than the ones expected with the obtained capacities. By the other hand, the results in Table 4 show that the optimization with the hybrid model produces a maximum delay for the flows, in some cases, tending to oversize the network capacities.

<table>
<thead>
<tr>
<th>Flow</th>
<th>Analytical Delay</th>
<th>Simulation Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>0.06</td>
<td>0.17</td>
</tr>
<tr>
<td>F2</td>
<td>0.08</td>
<td>0.20</td>
</tr>
<tr>
<td>F3</td>
<td>0.03</td>
<td>0.07</td>
</tr>
<tr>
<td>F4</td>
<td>0.14</td>
<td>0.29</td>
</tr>
</tbody>
</table>
Table 4. Results hybrid model for scenario 1

<table>
<thead>
<tr>
<th>Flow</th>
<th>Analytical Delay</th>
<th>Simulation Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>0.09</td>
<td>0.05</td>
</tr>
<tr>
<td>F2</td>
<td>0.10</td>
<td>0.05</td>
</tr>
<tr>
<td>F3</td>
<td>0.05</td>
<td>0.02</td>
</tr>
<tr>
<td>F4</td>
<td>0.14</td>
<td>0.09</td>
</tr>
</tbody>
</table>

In Table 5, a comparison of delay metrics is shown in the hypothetical network of Fig. 6. The flows identifiers are in column 1. The simulations were made also in NS. The F3, F5, F7 and F9 are CBR (Constant Bit Rate) flows with $a=1000$ kbps and the others are self similar flows with $H=0.8$, $a=1250$ and $a=8000$ kbps. For this problem, 3 different networks were projected and optimized based on M/M/1, self-similar and the proposed hybrid model. The third column shows the delays calculated with the hybrid model (the analytical results of the other models are not shown). Columns 4-6 show the simulations with the capacities established through calculations with each of the above mentioned analytical models, restricted to the value of column 2 which contains the maximum delay admissible for each flow.

As can be seen, the simulations in the network calculated with each model, were not able to accomplish the maximum delay restrictions for certain flows (F2 and F4 for M/M/1 and self-similar, F8 for M/M/1, F9 for self-similar), which will result in a undersized network.

For the hybrid model, in all the cases the simulation resulted in a value that was very close to the analytical calculus, and for all the flows the maximum delays were accomplished. This confirms the better accuracy of the hybrid model proposed in this work.

In Table 6, for the second scenario, the capacities obtained with the three different traffic models are shown. For the M/M/1 model, the capacities are underestimated in the cases where the traffic aggregations have values of $H>0.5$ and higher channel loads. For the pure self-similar model, the capacities are very sub estimated and over estimated for light and heavy channel loads respectively.

For the hybrid model proposed in this work, the capacities are the most accurate to comply with the delay limits established and the simulation results, shown before through the calculations in Table 5. The simulations with the capacities of column 1 and 3 of Table 6 reported QoS values higher than the required limits, and even packet losses for F2, F4 and F8.

Table 5. Delay calculus of network simulations with different networks and the hybrid model.

<table>
<thead>
<tr>
<th>F</th>
<th>Max Delay</th>
<th>Hybrid Model</th>
<th>M/M/1 Model</th>
<th>Self-similar</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>0.050</td>
<td>0.020</td>
<td>0.020</td>
<td>0.040</td>
</tr>
<tr>
<td>F2</td>
<td>0.150</td>
<td>0.070</td>
<td>0.068</td>
<td>0.210</td>
</tr>
<tr>
<td>F3</td>
<td>0.050</td>
<td>0.020</td>
<td>0.030</td>
<td>0.050</td>
</tr>
<tr>
<td>F4</td>
<td>0.200</td>
<td>0.070</td>
<td>0.066</td>
<td>0.210</td>
</tr>
<tr>
<td>F5</td>
<td>0.050</td>
<td>0.040</td>
<td>0.043</td>
<td>0.070</td>
</tr>
<tr>
<td>F6</td>
<td>0.080</td>
<td>0.040</td>
<td>0.027</td>
<td>0.060</td>
</tr>
<tr>
<td>F7</td>
<td>0.180</td>
<td>0.110</td>
<td>0.104</td>
<td>0.230</td>
</tr>
<tr>
<td>F8</td>
<td>0.090</td>
<td>0.070</td>
<td>0.046</td>
<td>0.160</td>
</tr>
<tr>
<td>F9</td>
<td>0.060</td>
<td>0.040</td>
<td>0.048</td>
<td>0.050</td>
</tr>
<tr>
<td>F10</td>
<td>0.100</td>
<td>0.030</td>
<td>0.026</td>
<td>0.040</td>
</tr>
</tbody>
</table>

Table 6. Optimized capacities (in kbits) of three different traffic models.

<table>
<thead>
<tr>
<th>Link</th>
<th>M/M/1</th>
<th>Hybrid model</th>
<th>Self-similar</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1,2</td>
<td>42.2</td>
<td>72.5</td>
<td>33.9</td>
</tr>
<tr>
<td>C1,4</td>
<td>68.6</td>
<td>73.3</td>
<td>103.0</td>
</tr>
<tr>
<td>C2,3</td>
<td>27.7</td>
<td>39.1</td>
<td>23.7</td>
</tr>
<tr>
<td>C2,4</td>
<td>83.0</td>
<td>22.3</td>
<td>24.4</td>
</tr>
<tr>
<td>C2,10</td>
<td>29.5</td>
<td>63.3</td>
<td>44.1</td>
</tr>
<tr>
<td>C3,7</td>
<td>82.3</td>
<td>121.0</td>
<td>37.3</td>
</tr>
<tr>
<td>C4,10</td>
<td>31.0</td>
<td>73.5</td>
<td>42.4</td>
</tr>
<tr>
<td>C5,10</td>
<td>17.1</td>
<td>24.9</td>
<td>22.2</td>
</tr>
<tr>
<td>C6,11</td>
<td>51.8</td>
<td>149.0</td>
<td>23.4</td>
</tr>
<tr>
<td>C7,4</td>
<td>34.0</td>
<td>52.1</td>
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<td>C7,6</td>
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<td>55.3</td>
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<td>28.5</td>
<td>60.3</td>
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So, the above results show that the optimization method together with the hybrid traffic model proposed in this work, improves the capacity planning procedure in a converged network with different traffic aggregations. The method can be extended to introduce other metrics, such as packet losses.

5. Conclusions and Future Work

In this paper, we proposed a hybrid traffic model for the treatment of aggregated traffic in converged networks. The proposed model aims the calculation of accurate delay metrics for different flows aggregations, considering the self-similar nature of traffic and the load on each link that forms the LSP path in a MPLS core.

Then, the hybrid traffic model is used to optimize the network capacities of two hypothetical IP/MPLS
cores. The optimization uses a heuristic with genetic algorithms and the hybrid traffic model is used to calculate the QoS restrictions on the different topologies for the aggregated traffic flows. The link capacities are optimized based on a linear cost function that can be extended to consider a variety of physical mediums.

The simulation results show better accuracy for the proposed model than the M/M/1 model and the pure self-similar model and could be the primary element of a TE procedure that will promote network stability and resource optimization.

The future work of this research will extend the hybrid traffic model to consider packet losses and evaluate its accuracy to map flows in FECs accordingly to QoS requirements using evolutionary techniques, as part of a TE task in converged networks.

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7. References