A Scalable Approach for Steady State Traffic Modeling in High-Speed Backbone Networks

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***Abstract*— This work proposes a high modular and scalable framework to effectively represent the average behavior of high-speed backbone networks, which usually deliver large volumes of highly aggregated traffic. The proposed framework combines together suitable TCP and network layers' models to effectively represent both the steady-state backbone network behavior and the performance level perceived by users. In Our approach is composed by three different analytical models working at different aggregation and logical levels, which interact to compute the most relevant performance indexes. The global computational effort is so low that it can be effectively used inside iterative optimization procedures for high speed networks.**

Keywords- TCP modeling, backbone traffic.

I. INTRODUCTION

During the last years, TCP modeling has received a great attention by the Scientific Community, which has produced a large number of models (e.g., among others [1], [2], [3] and [4]) to evaluate the most important features of this protocol. Although these models already cover a wide range of network problems, we found useful to develop a new framework, able to study network performance with a nimble mathematical representation.

The proposed framework can provide a significant contribution for developing new simple software tools, aimed at finding fundamental performance traffic indexes in high-speed backbone networks. In order to represent high-speed backbone network environments, where links carry large volumes of highly aggregated traffic, we generally need advanced and complex analytical models, able to guarantee suitable scalability and the accuracy levels.

Starting from this scenario, our base idea is to propose an original framework to "divide and conquer" the complexity of the overall analytical representation. In this sense, the proposal allows to model steady state network performance at different aggregation and logical layers with a very modular approach.

Thus, our framework simply combines together suitable TCP and network layers' models to effectively represent both the steady-state backbone network behavior and the performance level perceived by users.

The framework is substantially composed by three different sub-models that work at different logical and aggregation levels: the Stationary sub-Model (SsM), the Network sub-Model (NsM) and the Single TCP Connection sub-Model (STCM). The resulting global procedure is characterized by such a low computational complexity to be effectively used inside iterative optimization procedures [3].

II. THE PROPOSED FRAMEWORK

We utilized the three sub-models previously introduced to represent traffic behavior at different aggregation and logical levels. In particular, we defined as "*aggregated flow*" the set of traffic flows/connections crossing the network between the same pair of end points.This flow definition allows grouping all the connections characterized by the same network path.

With the aim of estimating the average throughputs and transfer times experienced by all the TCP connections feeding a certain aggregated flow, we need of a suitable STCM. Since SCTMs generally require RTT and end-to-end packet loss probability values as input parameters, we developed a new method (the NsM) to rapidly compute both these parameters.

In detail, we chose to use (and to improve with few refinements) the one proposed in [11]. In particular, Sikdar at al. proposed an interesting approach for modeling a single TCP New Reno connection in a fairly detailed way.

Fig. 1 shows an overall overview of the proposed framework, and underlines how the NsM sub-model works as a glue layer between the SsM and the SCTM: starting from the link utilizations obtained with the SsM, it estimates the local loss probabilities and the average waiting times, independently at each network link buffer by using a $M^x/D/1/N$ queue model with persistent call renewal.

In detail, the SsM works at the maximum level of traffic aggregation, and aims at describing the aggregated behavior of TCP connections at steady-point, by considering them as fluid flows that take up a certain bandwidth portion on all the crossed links. The SsM has been studied and proposed to obtain the average link bandwidth utilizations in a very fast way: starting from very few data about the traffic matrix, the SsM obtains the average link utilizations and the aggregated flows' throughput. It is based on both the max-min rule [6] and the fluid approximation, and it is realized as a simple "one-shot" algorithmic procedure. This procedure derives from the idea of assuming a fair equilibrium of flow rates, as proposed in [4].

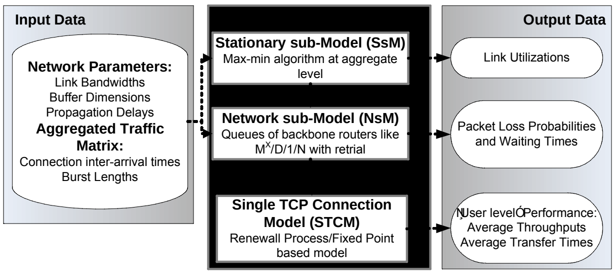

Fig. 1. Overall scheme of the proposed model.

Regarding the NsM, we decided to represent the egress buffers of network routers with independent $M^x/D/1/N$ queues [7] with persistent call renewal [10] (to take into account TCP loss packet retransmissions). Similar approaches can be found in [8]. This original approach helps us to maintain a low complexity level, while keeping a good level of accuracy. Let us now introduce the following notations for a generic network buffer: N, buffer size; ρ, traffic utilization; *MSS*, average packet size; p_n, probability of having n packets in the buffer; λ, the mean arrival rate of packet batches; $\{\beta_j, j=1,2,..\}$, the discrete distribution of batch sizes, supposed to be exponential; β, the average batch size; μ, the packet service rate. Deriving the $M^x/D/1/N$ model from the more general $M^x/G/1$, we obtain the generating function:

$$P(z)=\frac{(1-z)(1-\rho)\left(1-\lambda\alpha(z)\{1-G(z)\}\right)}{1-z-\lambda\left(1-\frac{1}{\mu}\right)\{1-G(z)\}\int_0^\infty e^{-\lambda(1-G(z))t}dt} \qquad (1)$$

Where, $G(z)$ is defined as in the following:

$$G(z)=\sum_{j=1}^{\infty}\frac{e^{-j}}{\sum_{i=1}^{\infty}e^{-i}}z^j \qquad (9)$$

We obtain the average values of packet lossing probability for the finite queue model through the following approximation:

$$p_{loss}=1-\sum_{n=0}^{N}p_n \quad \text{where} \quad p_n=\frac{1}{n!}\left.\frac{d^nP(z)}{dz^n}\right|_{z=0} \qquad (12)$$

While for the average waiting time, we apply the Little's law:

$$t_{wait}=\frac{1}{\lambda}\cdot\left.\frac{dP(z)}{dz}\right|_{z=1} \qquad (13)$$

In order to introduce the persistent call renewal, we include the $M^x/D/1/N$ model into a framework that binds the final offered traffic (with packet retransmissions) to the traffic handled as a function of the drop probability.

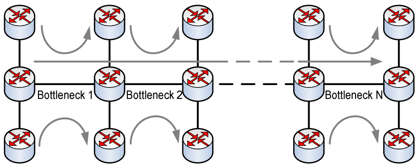

Fig. 13. The generic parking-lot network topology used in the second test session.

III. NUMERICAL RESULTS

The reported tests have been realized by using the "worst-case" network topologies in Figs. 13. For all the three sub-models, we used the NS2 as term of comparison. All the parameters measured with NS2 have been obtained with a confidence interval of 95%.

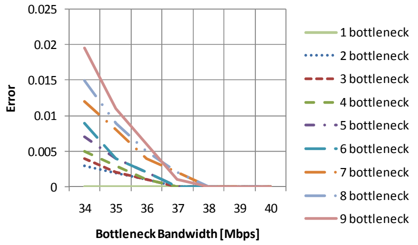

Fig. 14. Normalized Error of SsM versus NS2 and according both different bandwidth values of link 1 and network topologies.

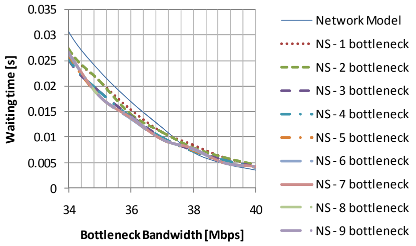

Fig. 15. Average waiting times, for the NsM and NS2, of the buffer associated to the first bottleneck link.

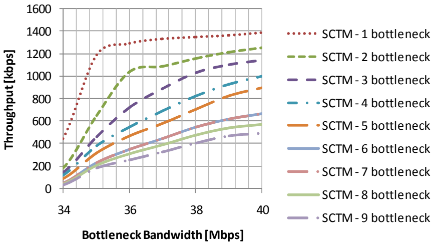

Fig. 17. Average connection throughput estimated with the SCTM.

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