Chapter 9
Providing Quality of Service to Computer Networks through Traffic Modeling: Improving the Estimation of Bandwidth and Data Loss Probability

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ABSTRACT
In this chapter, the authors examine two important network traffic issues: estimation of effective bandwidth and data loss probability in communication networks. They focus on estimation approaches based on network traffic modeling. Initially, they review some concepts related to network traffic modeling such as monofractal and multifractal properties. Further, they address the issue of estimating the effective bandwidth for network traffic flows. Besides effective bandwidth, the knowledge of the loss probability explicitly allows us to guarantee some QoS parameters required by the traffic flows, for example, by discarding flows with intolerable byte loss rate. In this sense, the authors present an overview of loss probability estimation methods including an approach that considers multifractal characteristics of network traffic. That is, given the model parameters, the data loss probability for network traffic can be directly computed. They conclude that both the multifractal based effective bandwidth and loss probability estimation methods can be powerful tools for really providing QoS to network flows.

INTRODUCTION
The seminal paper published by Leland et al. triggered a new direction on traffic modeling research, by unveiling the fractal nature of network traffic processes (Leland, Taqqu, Willinger, Wilson, & Bellcore, 1994). These authors experimentally demonstrated that the LAN Ethernet traffic collected in Bellcore Morristown Research and Engineering Center exhibits self-similar properties and burstiness in a wide range of time scales.
After that, many research papers have shown that such self-similar behavior, unable to be faithfully represented through most classic Markovian stochastic models, is not restricted solely to the Ethernet LAN environment (Willinger, Taqqu, & Erramilli, 1996), and in fact, strongly impacts on the network performance (Park & Willinger, 2000). Among many different fractal modeling approaches, the fractional Brownian motion (fBm) or its incremental process, called fractional Gaussian noise (fGn), has become popular for modern traffic modeling because of its simplicity. However, such a self-similar traffic model is capable of capturing the traffic correlation property only over large time scales.

A more sophisticated description of network traffic behavior based on multifractal analysis was introduced by Lévy Véhel et al. (J. Lévy Véhel & R. H. Riedi, 1997), and latter by Feldmann et al. (Feldmann, Gilbert, Willinger, & Kurtz, 1998). The multifractal analysis generalizes the self-similar behavior observed in the network traffic in a natural way.

Self-similar processes, or more generically speaking, monofractal processes are characterized by a single time-invariant parameter, the Hurst parameter (Garrett & Willinger, 1994). Contrary to monofractal processes, multifractal processes allow such characteristics to vary in time, therefore, increasing the flexibility in describing irregular phenomena that arise in real signals.

Statistical models derived from multifractal processes are capable of representing the actual network traffic behavior in a more complete and accurate manner. Although the research carried out on multifractals is not quite recent, few multifractal models in fact have been developed up to now. Among them, we cite the following: the Multifractal Wavelet Model (MWM) proposed by Riedi et al (Riedi, Crouse, Ribeiro, & Baraniuk, 1999), the Variable Variance Gaussian Multiplier Model (VVGMM) proposed by Krishna et al (Krishna P, Gadre, & Desai, 2003), and the multifractional Brownian model (mBm) in (Peltier & Lévy Véhel, 1995). The definition of the mBm process generalizes the fractional Brownian motion, a monofractal process with a constant exponent $H$ (global scaling parameter) to the case where $H$ is no longer a constant, but a time-varying function (Peltier & Lévy Véhel, 1995).

The explanations for the origins of monofractal and multifractal characteristics of network traffic processes have physical interpretations. The self-similarity observed in Web traffic can be related to the underlying heavy tailed distribution of file sizes (Crovella & Bestavros, 1997). Some researches about the probability distributions of ON and OFF times lead to the conclusion that ON times are heavier tailed than OFF times and are hence more significant in determining Web traffic self-similarity. The flow of packets over fine time scales is shaped mainly by protocols and end-to-end congestion control schemes (e.g., TCP/IP) that regulate the complex interactions between different flows on a network. This small-scale behavior of traffic can be modeled by a multiplicative cascade that is a multifractal model. According to this theory, the effects of some network mechanisms and protocols at different time scales causes this multiplicative behavior (Feldmann, Gilbert, & Willinger, 1998).

In this chapter, we discuss about estimation of effective bandwidth and data loss probability considering different network traffic modeling approaches. We focus on works involving self-similar and multifractal concepts, presenting some recent developments on these issues. We also briefly point out the importance and influence of such traffic modeling concepts to algorithms and tools developed to provide QoS guarantees to network traffic flows. Furthermore, we present results of traffic modeling, effective bandwidth and loss probability estimation considering real Ethernet and Internet traffic traces. Concerning the underlying network, we assume a simplified model. That is, we consider a single server queue model for the verification of the proposed effective bandwidth and loss probability estimation ap-
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