Providing Deterministic Guarantees For Bursty Traffic
(Extended Abstract)

Hui Zhang and Domenico Ferrari
`hzhang,ferrari@tenet.ICSI.Berkeley.EDU`
The Tenet Group
Computer Science Division
University of California at Berkeley
and
International Computer Science Institute

1 Introduction

High speed networking has introduced opportunities for new applications such as video conferencing, scientific visualization and medical imaging. These applications have stringent performance requirements in terms of throughput, delay, delay jitter and loss rate. The best-effort service provided by the current packet-switching networks is not adequate. Services that support performance guarantees are needed.

To provide guaranteed service, resources have to be reserved within the network. One important consideration about any resource reservation scheme is whether it can achieve a high utilization of the network. In general, resource reservation schemes works well for smooth traffic. However, many clients requiring performance guarantees have bursty sources, for example, compressed video. If reservation is based on the peak rate of each connection, new requests will be rejected when the sum of the peak rates of all the connections reaches link speed. In this case, the network will be under-utilized by guaranteed service traffic when the peak-average rate ratio is high.

Therefore, it is important to derive solutions that can provide performance guarantees even when the sum of the peak rates of all the connections is greater than link speed, and to understand the relationship between the server utilization and traffic burstiness. In this paper, we discuss these issues within the framework of the Tenet real-time channel scheme, to be summarized in the sequel.

The reminder of the paper is organized as follows. Section 2 briefly reviews the real-time channel scheme and shows the limitations of the admission control tests for the deterministic service in the current form. Section 3 presents the analysis which provides delay bounds for the First-Come-First-Served (FCFS) discipline in both cases when the sum of the peak rates of all the connections is either larger or smaller than 1. Section 4 gives numerical examples to illustrate the results in Section 3. Section 5 discusses the implications of the results. Section 6 concludes the paper with a summary of the results.

2 Background

In this section, we give a brief overview of the current version of the Tenet resource management algorithms [3].

The Tenet algorithms are based on a communication abstraction called a *real-time channel* [4]. A real-time channel is a network channel associated with traffic and performance parameters. The parameters are provided by the clients to specify their traffic characteristics and performance requirements. The traffic specification consists of parameters $(Xmin, Xave, I, Smax)$, where $Xmin$ is the minimum packet inter-arrival time, $Xave$ is the worst-case average packet inter-arrival time over an an averaging interval, I is the averaging interval, and $Smax$ is the maximum packet size. In such a specification, it is easy to see that $Xave/Xmin$ is the peak-average-rate-ratio, which is an indicator of the traffic burstiness. It should be also noticed that I also affects the traffic burstiness. For the given values of $Xmin$ and $Xave$, I determines how long the source can continuously send packets at the peak rate in the worst case. The larger $Xave/Xmin$ and I, the burstier the traffic. Tenet algorithms provide both deterministic and statistical guarantees. For the purpose of this paper, we only consider deterministic guarantees. For a channel with deterministic delay bound $\overline{D}$, the network guarantees that the delays of all the packets on that channel will be less than $\overline{D}$ as long as the channel does not violate its traffic specification.

A channel needs to be *established* before data can be transferred. This channel establishment is achieved in the following manner: a real-time client specifies its traffic characteristics and end-to-end performance requirements to the network; the network determines the most suitable route for a channel with these traffic characteristics and performance requirements; it then translates the end-to-end parameters into local parameters at each node, and attempts to reserve resources at these nodes accordingly. This is done in a distributed manner during a round-trip communication.

In order to provide performance guarantees, two levels of controls are needed: at the channel level, channel admission control algorithms reserve resources for each of the channels and limit the maximum utilization of the network by real-time traffic; at the packet level, the service discipline at each of the switches determines the multiplexing policy and allocates resources to different channels according to the reservations.

As shown in [2, 10], many service disciplines can be used to provide real-time service. However, different service disciplines require different admission control algorithms. In [4], conditions are given for a variation of the Earliest-Due-Date discipline. Three tests need be satisfied before a new channel request can be accepted. The three tests are: (a) *deterministic test*, which limits the peak utilization of the server to be less than 1; (b) *delay bound or schedulability test*, which avoids the case of scheduling saturation; and (c) *buffer test*, which ensures enough buffer space is available. For the purpose of the discussion in this paper, we will focus on the deterministic test, which requires

$$\sum_{j=1}^{n} \frac{1}{Xmin_j} \times \frac{Smax_j}{l} < 1 \tag{1}$$

where l is the link speed [1] and n is the number of channels traversing the link.

Although, the tests guarantee that deterministic delay bounds can be provided, they are rather restrictive in the sense the peak utilization of the link by real-time traffic is limited to be less than 1. If the peak-average-rate-ratio is high, the average link utilization by real-time traffic will be low.

3 Delay Analysis

In this section, we show that deterministic delay bounds can be obtained even when the peak utilization of the link is greater than 1 (the average utilization of the link has to be less than 1). We show that the result holds even for simple discipline like FCFS. We use the techniques developed by [1] to obtain delay bounds for an FCFS server. We use the discrete traffic model $(Xmin, Xave, I, Smax)$ rather than the fluid model in [1]. A discrete model has the advantage that it better characterizes multimedia sources than fluid approximations.

Figure 1(a) illustrates some of the concepts used in the analysis. The horizontal axis is the time. The upper curve in the figure is the sum of the bits that have arrived. Each arrival of a packet causes a jump in this curve. The lower curve is the number of bits that have been transmitted. The difference between the two curves is the *backlog* function. A work-conserving server always transmits packets at a constant rate when there is a backlog. The points where the arrival curve and the service curve meet, or where the backlog is zero, divide the time axis into *busy periods* and *idle periods*.

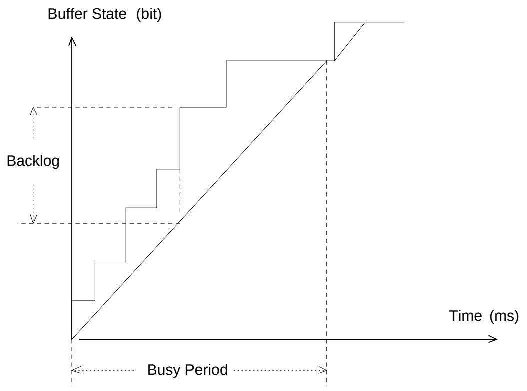
One important observation is that the maximum length of a busy period is an upper bound on delay for any work-conserving discipline. Also, the longest backlog divided by link speed is an upper bound on delay for an FCFS server.

Central to the analysis is the concept of *traffic constraint function* b(.). $b_j(u)$ is defined to be the maximum number of bits that can arrive on connection j during *any* interval of length u. For a traffic source that obeys the model $(Xmin_j, Xave_j, I_j, Smax_j)$, it is easy to show that

$$b_j(u) = (min(\lceil \frac{u\ mod\ I_j}{Xmin_j} \rceil, \lceil \frac{I_j}{Xave_j} \rceil) + \lceil \frac{u}{I_j} \rceil \times \lceil \frac{I_j}{Xave_j} \rceil) \times Smax \tag{2}$$

---

[1] We consider a network with non-blocking switches, where queueing happens at the output link of each switch. The processing time of each packet is thus equal to the transmission time, and is bounded by $\frac{Smax_j}{l}$



Concepts: Delay, Backlog and Busy Period
(a)