SIMULATION OF PACKET DATA NETWORKS USING OPNET

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Abstract

In this paper we describe the use of the OPNET simulation tool for modeling and analysis of packet data networks. We simulate two types of high-performance networks: Fiber Distributed Data Interface and Asynchronous Transfer Mode. We examine the performance of the FDDI protocol by varying network parameters in two network configurations. We also model a simple ATM network and measure its performance under various ATM service categories. Finally, we develop an OPNET process model for *leaky bucket* congestion control algorithm. We examine its performance and its effect on the traffic patterns (loss and burst size) in an ATM network.

1. Introduction

Fiber Distributed Data Interface (FDDI) and Asynchronous Transfer Mode (ATM) are two well-known technologies used in today's high-performance packet data networks. FDDI network is an older and well-established technology used in Local Area Networks (LAN's). ATM is an emerging technology used as a backbone support in high-speed networks. We use OPNET to simulate networks employing these two technologies. Our simulation scenarios include client-server and source-destination networks with various protocol parameters and service categories. We also simulate a policing mechanism for ATM networks.

In Section 2, we first describe simulation scenarios of the FDDI protocol and two distinct network topologies. We describe simulations of an ATM network with emphasis on the performance comparison of various ATM service categories in Section 3. The implementation of a *leaky bucket* congestion control algorithm as an OPNET process model is presented in Section 4. We use the model to examine the performance of the leaky bucket and dual leaky bucket policing mechanisms, and to study their effect on traffic patterns (loss and burst size) in ATM.

2. FDDI Networks

In this section we simulate the performance of the FDDI protocol. We consider network throughput, link utilizations, and end-to-end delay by varying network parameters in two network configurations.

FDDI is a networking technology that supports 100 Mbps transmission rate, for up to 500 communicating stations configured in a ring or a hub topology. FDDI was developed and standardized by the American National Standards Institute (ANSI) X3T9.5 committee in 1987 [1]. It uses fiber optic cables, up to 200 km in length (single ring), in a LAN environment. In a dual-ring topology, maximum distance is 100 km. FDDI supports three types of devices: single-attachment stations, dual-attachment stations, and concentrators. Because OPNET does not support dual-attachment stations, we used scenarios with single-attachment stations connected in a hub topology with FDDI concentrators.

FDDI uses a timed-token access protocol that is similar to Token Ring access protocol (IEEE 802.5). Timed-token mechanism of FDDI is suitable for both asynchronous and synchronous transmissions. Voice and real-time traffic use synchronous transmission mode, while other applications use asynchronous mode.

FDDI model is available in the OPNET model library. Users can select the following model parameters: the number of stations attached to the ring, application traffic generation rate (load), the synchronous bandwidth allocation at each station, the mix of asynchronous and synchronous traffic generated at each station, the requested value of the Target Token Rotation Time (TTRT) by each station, station latency, and the propagation delay separating stations on the ring (hop propagation delay) [2]. The performance of an FDDI network, such as throughput, link utilization, and delay, depends on the choice of these parameters.

We simulate two distinct FDDI network configurations shown in Figs. 1 and 3. In the first configuration we

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consider the end-to-end delay variation with the load, while in the second we consider the throughput. In our simulation scenarios, we vary the model attributes and we monitor their influence on other performance parameters.

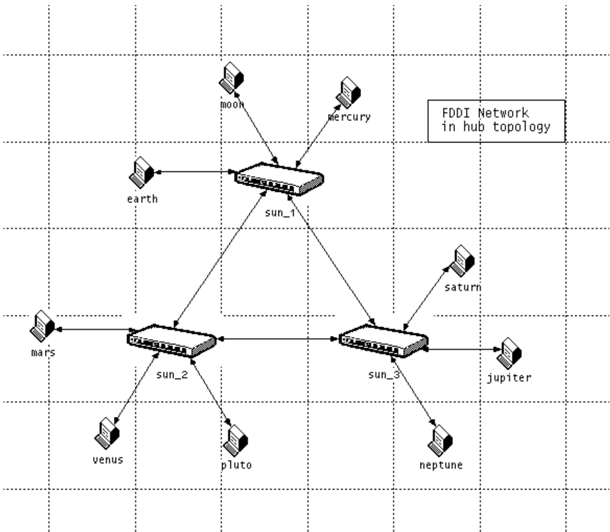


Figure 1. FDDI hub configuration. The network consists of three concentrators (FDDI hubs) and nine stations. The concentrators are connected with FDDI duplex links in a dual-ring topology. The stations are attached to the ring via concentrators, creating a hub topology.

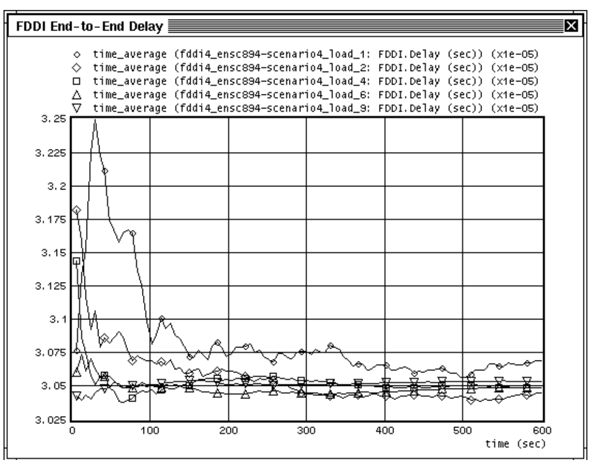


Figure 2. FDDI end-to-end delay (sec) plots, with traffic load as a parameter. Load, mean number of frames sent by the source, according to an exponential distribution, was varied from 1 to 100 packets per second.

The time-average FDDI end-to-end delay in the network is shown in Fig. 2. We can observe that, as expected, as network load increases, end-to-end delay in the network decreases. We can also observe that the delay appears to be leveling off with time, which indicates that the network is stable.

We now consider the second network configuration. Our goal is to estimate the performance of FDDI network for one custom application - file transfer protocol (FTP). The server's processing speed is 20,000 bytes/sec. Average file size is set to 15,000 bytes, with 10 file transfers per hour.

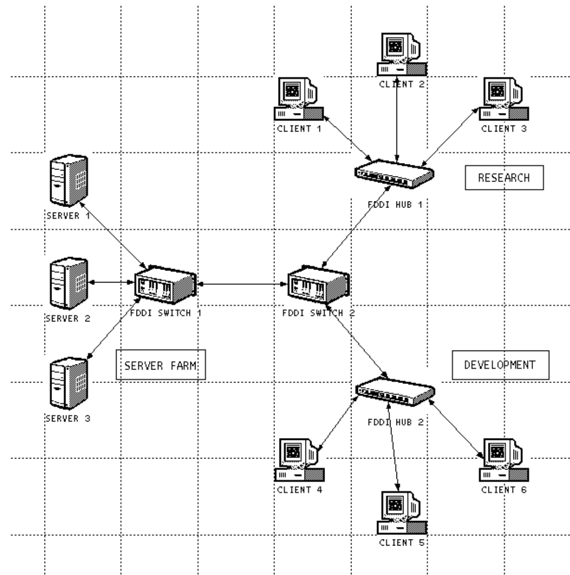


Figure 3. FDDI client-server configuration. This network topology is suitable for applications such as FTP. Clients are connected to the network via FDDI hubs. Hubs and servers at different locations are connected via two FDDI switches.

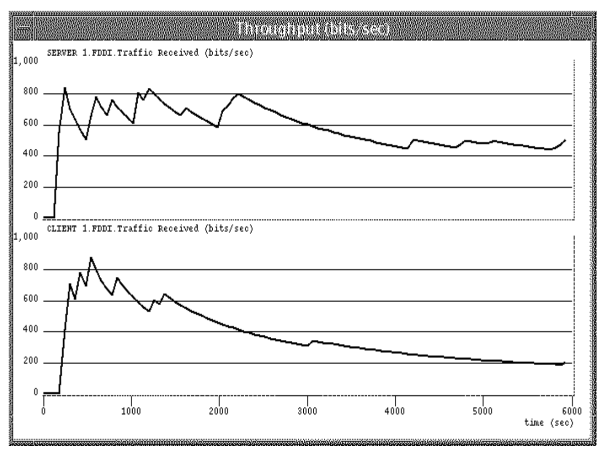


Figure 4. Throughput (bits/sec) plots of Server 1 (top) and Client 1 (bottom).

From Fig. 4 we can observe that the server's throughput, once stabilized, is twice as large as the client's throughput. This is expected because the number of servers is smaller than the number of served clients in the network. The leveling of the throughput with time also indicates a stable network.

3. ATM service categories

In this section we describe simulations of a simple client-server ATM network, shown in Fig. 5. The network consists of five ATM clients (each requesting a different service category), two ATM packet switches, and one ATM server.

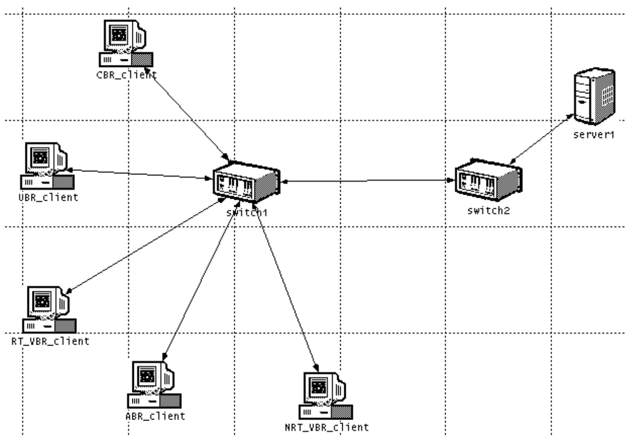


Figure 5. ATM client-server network consisting of two switches, an ATM server, and five clients requesting five distinct ATM service categories.

Applications in an ATM network require different quality of service (QoS) and, therefore, different traffic categories. For example, a voice application such as a telephone conversation requires a small transfer delay not noticeable to the users. However, transfer delay is not that important for quality video applications with unidirectional video transfers. In such applications, the delay jitter (variation in delay) is an important QoS parameter and should be kept small. The errors and losses in a voice application or in a video broadcast might not be very noticeable or important. Nevertheless for applications such as data transfers, accuracy is critical. An ATM network has to be able to achieve the required performance for each of the described applications. That is the reason that five different service categories are supported in ATM technology: constant bit rate (CBR), available bit rate (ABR), real time variable bit rate (RT_VBR), non-real-time variable bit rate (NTR_VBR), and unspecified bit rate (UBR) [3].

It is usually difficult to compare and rank the performance of these five service categories. Each service category has its own advantages and disadvantages. CBR and RT_VBR traffic are mostly deployed for real time applications, such as voice and video, which put tight constraints on delay and delay jitter. CBR is, however, more reliable. It guarantees that, once the connection is set up, the source can emit cells for any period of time, at any rate lower than or equal to the peak cell rate (PCR), while upholding the QoS commitments.

An ATM client-server network with CBR and ABR clients is available in the OPNET library. In order to observe the performance of all the service categories, we have added three more clients. Each client sends request packets of 1 byte to the server. The request generation rate is identical for all clients. The connections from the clients will only be admitted if all the intermediate nodes in the network can support the requested bandwidth and QoS. Once a call is admitted, it is routed through the switches to the server. The server processes the requests and sends to the clients response packets of 500 bytes. Traffic patterns received by each client are shown in Fig. 6. As it can be seen, the traffic has a constant bit rate for the CBR client, and is of a more bursty nature for the remaining clients.

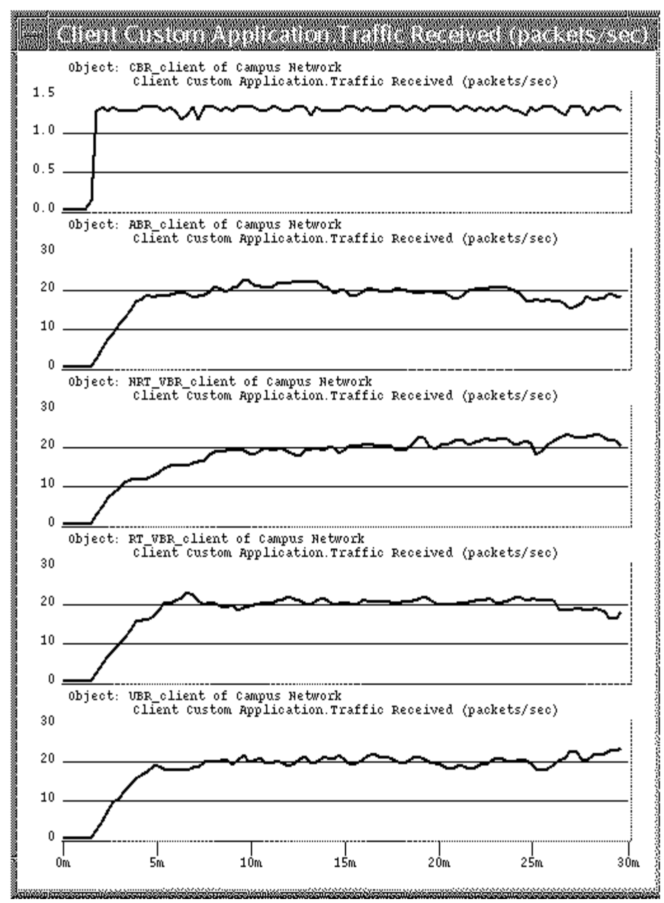


Figure 6. Traffic received (packets/sec) by CBR, ABR, NRT_VBR, RT_VBR, and UBR clients (top to bottom) from the server in the network shown in Fig. 5.

The response time for each of the clients in our network is shown in Fig. 7. Response time is the time elapsed between sending a request to the server and receiving a response. As it can be seen from Fig. 7, the response time is the smallest for the CBR source. This implies that CBR delivers the best QoS among the five service categories we have simulated. The delay and delay jitter for our simulation scenario are shown in Figs. 8 and 9, respectively. Again, it can be seen that the CBR client has the best quality of service because it has the smallest delay and delay jitter (almost zero). As expected, the RT_VBR client has the second best delay jitter.

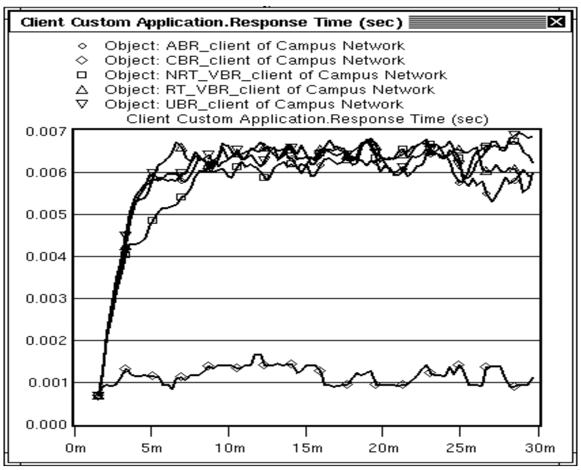


Figure 7. Response time (sec) for each client of Fig. 5. This is the elapsed time between sending a request packet to the server and receiving a response from it.

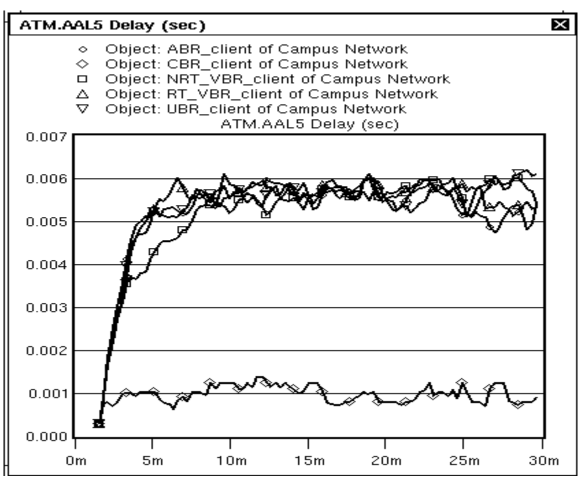


Figure 8. The propagation delay (sec) of packets from each client to the server shown in Fig. 5.

4. ATM congestion control mechanism

In this section we present the OPNET implementation of the leaky bucket congestion control algorithm. In ATM networks, channels do not have fixed bandwidths. Thus, users can cause congestion in the network by exceeding their negotiated bandwidth. Prohibiting users from doing so (policing) is important, because if excessive data enters the public ATM network without being controlled, the network may be overloaded and may encounter an unexpected high cell loss. This cell loss affects not only the violating connections, but also the other connections in the network. This degrades the network functionality. A policing mechanism called leaky bucket [4, 5] was proposed to remedy this situation for connections with CBR traffic. A variation called dual leaky bucket (two concatenated leaky buckets) is used for policing connections with VBR traffic.

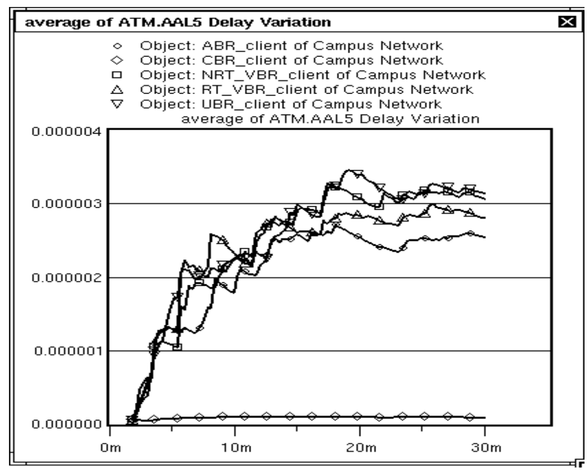


Figure 9. Average delay jitter for different clients of the network shown in Fig. 5.

4.1 Leaky bucket process model

The leaky bucket mechanism limits the difference between the negotiated mean cell rate (MCR) parameter and the actual cell rate of a traffic source. It can be viewed as a bucket, placed immediately after each source. Each cell generated by the traffic source carries a token and attempts to place it in the bucket. If the bucket is empty, the token is placed and the cell is sent to the network. If the bucket is full, the cell is discarded. The bucket gets emptied at a constant rate equal to the negotiated MCR parameter of the source. The size of the bucket is equal to an upper bound of the burst length, and it determines the maximum number of cells that can be sent consecutively into the network. We have implemented the leaky bucket by creating a counter in the OPNET process model. This counter gets incremented each time a cell is generated by the source. It gets decremented with a rate equal to the source's MCR.

Our leaky bucket process model is shown in Fig. 10. It contains five states. Starting from *initial* state, the process can either reach *arrival* state when a packet arrives, or *idle* state where it remains until the next cell arrives. From *arrival* state, the process reaches either *serve* or *drop* state, depending on whether the bucket is full or empty, respectively.

Users can change the following parameters in the leaky bucket process model:

- leaking rate (equal to the negotiated cell rate)
- bucket size (the upper bound on the burst size).

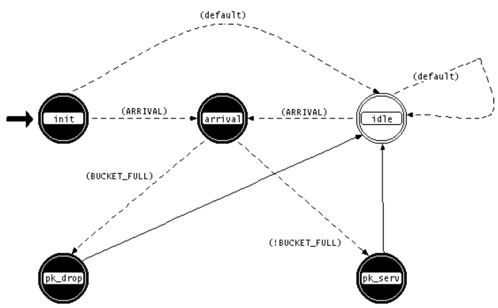


Figure 10. State transition diagram of the leaky bucket process model.

Single leaky bucket is used to police CBR traffic. Since MCR is the only parameter negotiated with the network for this type of traffic, single leaky bucket is designed to monitor the MCR parameter.

We implement a dual leaky bucket mechanism by concatenating two leaky bucket process models. This mechanism may be used to police VBR sources. In VBR traffic, both MCR and PCR traffic parameters need to be policed [5]. The first and the second bucket's leaking rates are set to the PCR and MCR of the source, respectively. Cells are discarded when one of the two leaky buckets has reached its threshold value.

The leaky bucket OPNET process model, named "leaky bucket", has been deposited into the OPNET Contributed Model Depot [6]. This process model is then used to create *single* and *dual* leaky bucket node models.

4.2 ATM network model

In order to illustrate the functionality of leaky bucket mechanisms, we model a small ATM network shown in Fig. 11. Sources 1 and 2 have negotiated CBR and VBR traffic, respectively. However, the sources are not conforming to their negotiated traffic contract and the actual traffic they send has a higher rate than their contract. Therefore, leaky buckets are used to police these sources. The negotiated MCR and PCR of the sources, as well as the bucket size and the leaking rate of the leaky buckets are shown in Table 1.

Source-1 is policed by a single leaky bucket mechanism with leaking rate equal to the negotiated MCR. We choose the bucket size by taking into account that the size should be selected as small as possible in order to limit the full-rate bursts allowed into the network. Nevertheless, we keep the size reasonably large, because a very small bucket size causes cells from conforming sources to be discarded.

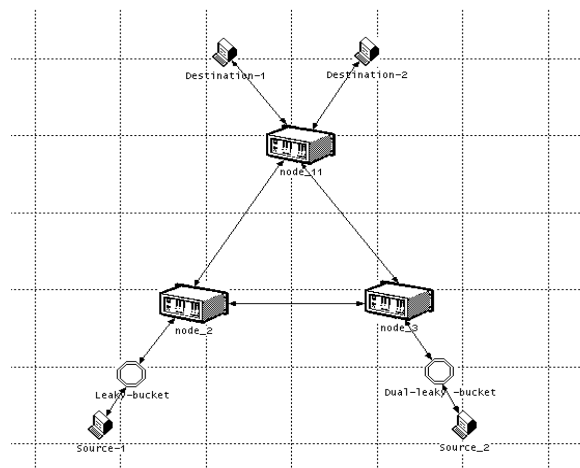


Figure 11. ATM network model. The model consists of a CBR and a VBR ATM source, three ATM switches, and two destinations. A leaky bucket process model is used for each source.

A dual leaky bucket is used to police Source-2. The leaking rate of the first leaky bucket is equal to the negotiated PCR of the VBR traffic source. Its bucket size is chosen according to both PCR and delay jitter parameters of the connection. The leaking rate of the second bucket is equal to the MCR negotiated by the source. Its bucket size is the maximum burst accepted by the network.

		Source-1	Source-2
Traffic type		CBR	VBR
Negotiated MCR		2	1
Negotiated PCR		-	2
Leaky bucket 1	leaking rate	2	2
	bucket size	30	60
Leaky bucket 2	leaking rate	-	1
	bucket size	-	40

Table 1. Traffic rate and leaky bucket parameters set in the network of Fig. 11.

4.3 Simulation results

We are interested in the performance of the leaky bucket mechanism when used to police misbehaving sources. During simulation, we collect the number of packets that are discarded by leaky bucket and observe the burst size allowed into the network. The burst size is equal to the number of free spaces in the bucket at each instance. It can be calculated by subtracting the number of bucket spaces occupied by tokens from the bucket size.

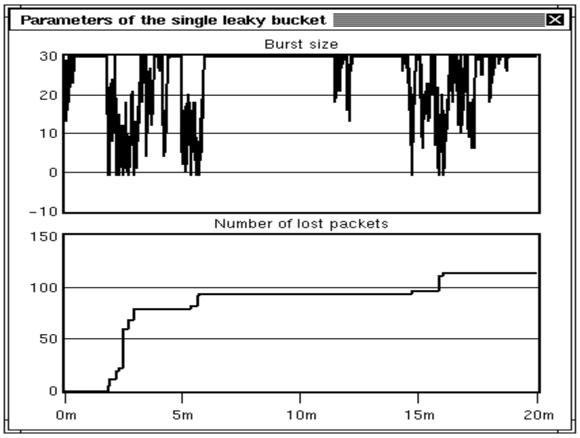
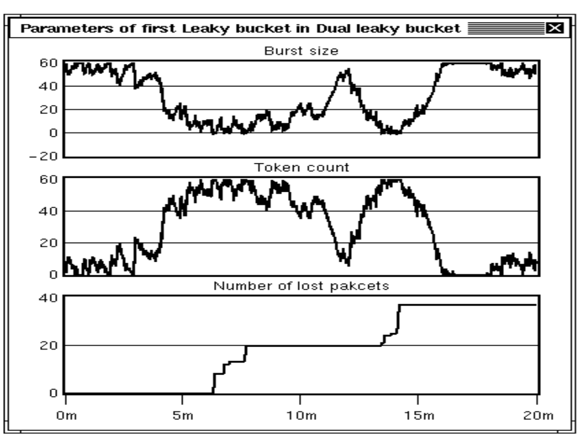
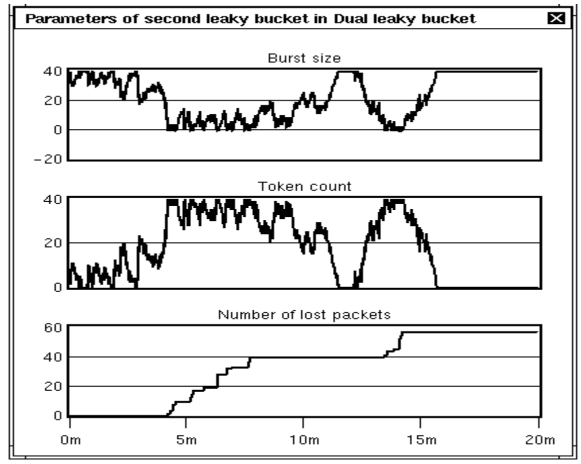


Figure 12. Single leaky bucket: Burst size (cells) allowed into the network (top). Number of lost cells (bottom).

Fig. 12 (top) shows that the size of the burst entering the network is limited by the bucket size (30 cells). The number of lost cells from Source-1, after it has been policed, is shown in Fig. 12 (bottom). This number is a function of the leaking rate (MCR) and the bucket size. Fig. 13 illustrates the performance of the dual leaky bucket. The number of lost cells is a function of the leaking rates: PCR for the first and MCR for the second bucket.



(a)



(b)

Figure 13. Dual leaky bucket: The burst size (top), the number of tokens in the bucket (middle), and the number of lost cells (bottom) for the first (a) and second (b) leaky bucket.

5. Conclusions

In this paper we focused on simulating two commonly used packet data network technologies: FDDI and ATM. We simulated two FDDI and two ATM network scenarios. Our major contribution is modeling the leaky bucket congestion control mechanism for ATM networks. The model is available from the OPNET Contributed Model Depot.

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