Modeling And Simulation Of ATM Networks

Zhonghui Yao and David C. Blight
TRLabs
10-75 Scurfield Blvd.
Winnipeg, Manitoba R3Y 1P6
Department of Electrical and Computer Engineering
The University of Manitoba
Winnipeg, Manitoba R3T 5V6
E_mail: [zyao|blight]@ee.umanitoba.ca
Phone: (204) 488-5619
Fax: (204) 488-1564

Abstract: B-ISDN can support various communication services because it uses ATM as the basis and ATM is a high-bandwidth, low-delay, cell switching and multiplexing technology. OPNET is a CAD tool which is specialized in communication protocols and networks. This paper presents our recent work of developing ATM network models with OPNET.

Key words: ATM, OPNET, layered protocol, modeling, simulation, analysis.

I. Introduction

Due to the increased number of networks in existence and their greater complexity, designing new systems and improving the performance of existing ones has become more difficult and time consuming, therefore, it is more important to use modeling and simulation tools to deal with this complexity. OPNET (Optimized Network Engineering Tools) is a comprehensive engineering system, capable of simulating large communication networks with detailed protocol modeling and performance analysis. It provides an opportunity to examine the higher level and more complex behavior of ATM (Asynchronous Transfer Mode) networks. In this paper, OPNET has been used to design and simulate an ATM network model. The model is constructed with a number of ATM switches and Ethernet LANs. Each Ethernet LAN has a number of TCP/IP based workstations connected by bus. The paper is organized into three sections: Section I gives an introduction to OPNET and the communication network architecture; Section II deals with modeling, simulation and analysis with OPNET; and Section III presents a summary and future work.

OPNET: OPNET is a sophisticated workstation-based environment for the modeling and performance-evaluation of communication systems, protocols and networks. OPNET features include: graphical specification of models; a dynamic, event-scheduled Simulation Kernel; integrated data analysis tools; and hierarchical, object-based modeling [1]. OPNET consists of eight tools (or editors) which provide a graphical interface to the model users. Each tool focuses on particular aspects of the modeling task and allowing the model developer to perform some set of related OPNET functions within a window that is contained in the overall OPNET graphical environment. In addition, the script language can also be used to run compilation, simulation, debugging and so on. OPNET tools plus the Animation Tool fall into three major categories that correspond to the three phases of the model development and use. Figure 1 illustrates these three phases.

![Figure 1. The cycle of model development.](image_url)

The model specification is the task of developing a representation of the system that is to be modeled. OPNET supports the concept of model reuse so that most models are based on lower level models developed beforehand and stored in model libraries. Models are based on the basic concepts and primitive building blocks. The goal of most modeling is to obtain measures of a system’s performance or to make observations concerning a system’s behavior. OPNET supports these activities by creating an executable model of the system. This allows accurate estimation of true system performance and realistic observations of true system behavior to be obtained by executing one or more simulations of the model. The desired data can be collected via a number of mechanisms. The third phase of most OPNET-based modeling effort is the examination of data collected during simulation. In addition to numerical output, OPNET
can provide a visual analysis of a network model’s behavior. Animation is a dynamic graphical representation of selected events that occurred during a simulation.

**ATM and B-ISDN:** ATM is a network architecture, it makes use of common-channel signaling with all control signals traveling on the same dedicated virtual channel, and allows multiple logical connections to exist on a single physical circuit. ATM networks transmit information using fixed-size cells which consist of a 5-byte header and a 48-byte data field. B-ISDN (Broadband-Integrated Services Digital Network) is a layered protocol reference model specified by ITU-T. It is based on the principles of the OSI reference model, but does not comply with the OSI principles in a number of ways. Unlike the OSI reference model, the B-ISDN ATM reference model is defined as being three-dimensional [2][4][5]. It consists of three planes and four layers as shown in Figure 2.

![Figure 2](image)

**Figure 2. The B-ISDN ATM reference model.**

The user plane deals with data transport, flow control, error correction and other user functions. The control plane is concerned with connection management. The layer and plane management functions relate to resource management and inter layer coordination. The ATM operations reside in the ATM layer and the ATM adaptation layer (AAL). The AAL layer is responsible for supporting the different applications in the upper layers. At the sending machine, it segments the user traffic into 48-byte service data units (SDUs) and passes them to the ATM layer. At the receiving machine, it accepts 48-byte SDUs from the ATM layer and reassembles them into the original user traffic syntax. The ATM layer is responsible for processing the cell header, flow control operations between machines and processing the various fields in the cell header. The upper layer contains the user applications and other upper layer protocols. The physical layer can be implemented with a number of interfaces and protocols. SONET (Synchronous Optical NETwork) is one of such protocols which provides synchronous Time Division Multiplexing (TDM) as well as operation, administration and maintenance (OAM) functions.

**TCP/IP reference model:** The TCP/IP (Transmission Control Protocol/Internet Protocol) reference model as illustrated in Figure 3 is used in Internet to connect multiple networks together in a seamless way [2][5].

![Figure 3](image)

**Figure 3. OSI and TCP/IP.**

IP is defined in the internet layer. IP functions include fragmentations, reassembly and routing. IP is not designed to support reliability mechanisms such as error recovery and flow control. It passes those jobs to the next higher layer, the transport layer which is designed to allow peer entities on the source and destination hosts to carry on a conversation. TCP is defined in this layer and is a widely used connection-oriented transport layer protocol that provides reliable packet delivery over an unreliable network. TCP performs connection establishment/termination, retransmission, re-sequencing and flow control functions and it is typically used with the IP network layer protocol.

**Ethernet LAN:** Ethernet is a LAN (Local Area Network) technology. The operation of the Ethernet LAN is managed by the Medium Access Control (MAC) protocol which is based on Carrier Sense Multiple Access with Collision Detection (CSMA/CD) protocol and has been standardized by IEEE under the name 802.3 [2]. The CSMA/CD protocol is designed to provide fair access to the shared communication channel so that all stations connected to LAN get a chance to use the network [6]. The Ethernet MAC layer accepts data packets from a higher layer protocol, such as IP, and attempts to transmit them at appropriate time to other stations on the bus. Because the higher layer protocols can forward data at any time and the bus is a broadcast medium, there is a possibility that several stations attempt to transmit simultaneously. Therefore, collisions are unavoidable events on an Ethernet.
A gateway in Internet is a machine that performs relaying functions between networks [2]. It is designed to remain transparent to the end-user applications. The gateway does not care what type of network is attached to it and is capable to support any type of applications because the end-user application does not reside in the gateway and the gateway considers the application message as nothing more than a transparent Protocol Data Unit (PDU). The principal purpose of the gateway is to receive a message that contains adequate addressing information and route the message to its final destination or to the next gateway.

II. Modeling and simulation

Designed model: Figure 4 to Figure 7 are OPNET models of the designed network. Figure 4 represents the model on the network level. The topology of this model reflects an actual ATM network. The network model consists of eleven ATM switches and nineteen sub-networks. Assuming that all sub-networks are Ethernet LANs. The maximum data rate of sub-networks is either 15Mbps or 2Mbps. Two types of physical links, T3 (45Mbps) and OC-3 (155Mbps) are considered.

Figure 4. Network (top level).

Figure 5 represents a sub-network model which is an Ethernet LAN. Ethernet LANs are implemented with a gateway and a number of TCP/IP workstations which are connected by bus. The gateway acts as an interface between Ethernet and an ATM network to support TCP/IP applications over ATM. In addition to N60 which includes ten workstations as shown in Figure 5, N110 consists of seven workstations and all other LANs have two workstations attached.

Figure 5. Ethernet LAN (N60).

Figure 6 and Figure 7 represent the node level models. An ATM switch is implemented with four processor nodes and a number of point-to-point receiving/transmitting nodes. Four processor nodes together act as the ATM layer and perform the ATM layer functions.

Figure 6. (a) ATM switch, (b) Ethernet workstation.

Figure 7. Gateway.
Layered protocol concept: Communication networks usually use layered protocols to decompose a complex system into several manageable parts called layers. Each layer has a well-defined interface to the adjacent layers. A layer offers a specific set of services to its higher layer. And at the same time, it receives services provided by its lower layer [3][4][5]. OPNET implements network components based on the layered protocol concept. Figure 5 illustrates the relationship between each node according to the layered protocol concept. For instance, the gateway, as an interface, is implemented with layers corresponding to both Ethernet workstation and ATM switch.

Experiment description: After model specification, an executable model for simulation can be created. In this paper, following issues are considered with respect to the model simulation and analysis: collecting global and local statistics, observing the network performance in terms of different links (T3 and OC-3) and LANs with different data rate (2Mbps and 15Mbps).

Two experiments have been done. Table 1 describes the experiments briefly. In both experiments, the duration of each simulation is defined as 20 second. Packets specified to be transferred after the 20th second are ignored since they do not influence the simulation results in 0-20 second simulation period.

The packet size for TELNET is specified as uniform distributed in range [100, 1000]. The packet size for FTP is specified in two environment files. The queue capacity of the IP module in the gateway node is specified as either the default value (infinity) or 32,000 bits and 1,000 packets for the bit and packet capacity, respectively.

In Experiment I, W1 of N5x (x=0,..., 9) and N10y (y=0,..., 6) are specified to communicate with W1 of N60 and N110; while Wx of N60 and Wy of N110 communicate with N5x and N10y, respectively. The starting and end time for transferring packets are defined in two environment files. The starting times are specified from 0 to 10 second for 2Mbps LANs and from 11 to 18 second for 15Mbps LANs. This results that different types of LANs are active at different time periods.

In Experiment II, in addition to the specification in Experiment I, N60 and N110 are defined to transmit packets at 0 and 11 second, respectively. Therefore, at 0 and 11 second, the packets being transferred are (11 and 8 times) more then them in Experiment I. This different setting will lead to the different simulation results. This will be seen in the next part of this section.

Global statistics: In OPNET, statistics are classified as global and local statistics. The difference between them is that for local statistics, the data source for the statistic output vector is a particular module; whereas for global statistics, all the modules in the particular layer contribute to the same output vector [2]. The global statistics consist of the end-to-end delay and cell delay variance (CDV) on AAL and ATM layers. End-to-end delay on AAL layer is computed as the difference between the
time the AAL PDU is created at the source AAL, and the time it is reassembled at the destination AAL, which is shown in (Eq-1). Delay variance is the variance in end-to-end delay. These delay statistics are collected both globally and locally in a process model.

$$\text{ete}_{\text{delay}}_{\text{AAL}} = t_{\text{cAAL}} - t_{\text{sAAL}} \quad \text{(Eq-1)}$$

where $t_{\text{cAAL}}$ is the current simulation time; $t_{\text{sAAL}}$ is the time when the PDU is created at the source AAL. $\text{ete}_{\text{delay}}_{\text{AAL}}$ in (Eq-1) is updated whenever the corresponding process model is executed. End-to-end delay on ATM layer is computed as the difference between the time ATM cells are sent from the source ATM layer module, and the time they arrive at the destination ATM layer module. CDV is the variance of these end-to-end delay. ATM layer statistics are different from them in AAL layer since ATM and AAL layers perform different functions. The global statistics obtained from experiments are shown in Figure 9 and Figure 10.

In Figure 9 and Figure 10, with the increase of the packet size at a certain time instance (here, 0 and 11 second), the end-to-end delay on AAL layer is increasing and the increase appears at defined time instances (i.e., 0 and 11 second). The cell delay variance on AAL layer in experiment I is smoother and smaller than it in experiment II. But the maximum value of the end-to-end delay on ATM layer is actually decreasing and the CDV on ATM layer in experiment II is smoother and smaller. This because the end-to-end delay on AAL layer blocks the packets so that the packets being transferred over ATM layer are actually not as many as them over AAL layer. The shapes of the end-to-end delay and the cell delay variance on AAL and ATM layer in either experiment are different because they perform different layer functions. Also, the end-to-end delay on 2Mbps LANs (0 second) is greater than it on 15Mbps LANs (11 second). This makes sense since the maximum data rate of 15Mbps LANs (15Mbps) is higher than it of 2Mbps LANs (2Mbps) and the number of 15Mbps LANs (8) is smaller than it of 2Mbps LANs (11).

**Local statistics about different links:** Creating a probe model in terms of T3 and OC-3, the utilization, bit-throughput and delay over T3 and OC-3 can be obtained as shown in Figure 11. The numbers on Figure 11 are approximate maximum values. For instance, the approximate maximum bit-throughput of T3 is $1.75 \times 10^8$ and it is $2.4 \times 10^8$ of OC-3. In Figure 11, the utilization of OC-3 is lower than it of T3, the bit-throughput over OC-3 is higher than it over T3 and the delay on OC-3 is lower than it on T3 because the maximum date rate of OC-3 (155Mbps) is greater than it of T3 (45Mbps).

**Local statistics about different data rate:** Statistics in terms of LANs with different data rate are also obtained. Figure 12 shows the collected statistics in terms of infinity queue capacity. The delay of 15Mbps LANs (0.01) is smaller than it of 2Mbps LANs (0.15) since the maximum rate of 15Mbps LANs is greater than it of
2Mbps LANs. And there is no overflow occurred in both cases because the queue capacity is infinity.

In Figure 13 and Figure 14, the IP queue capacity is specified as 32,000 bits. It can be seen that the overflows show up. For example, in Figure 12, the bit-size (the packet size measured in bit) can reach up to 580,000 bits, while in Figure 13 the bit-size can not exceed 32,000 bits, otherwise the overflow occurs because of the limited queue capacity. Comparing Figure 12 with Figure 13, the delay on 2Mbps LANs decreases from 0.15 to 0.009, because the bit-size decreases which is about 580,000 in the first case (Figure 12) and 32,000 in the second case (Figure 13). Comparing Figure 12 with Figure 14, delays on 15Mbps LANs are similar, because the bit-size are similar in both cases.

III. Summary and future work

This paper presents an ATM network model designed and simulated with OPNET. The model consists of eleven ATM switches and nineteen Ethernet LANs. Ethernet LANs are implemented by a gateway and a number of TCP/IP based workstations. Based on the modeling experience, OPNET has been found to have a lot of advantages. Three phases in terms of modeling, simulation and analysis in OPNET provide a clear idea of the model development, this idea is very useful to OPNET users. Process models are basic building blocks. OPNET provides a wide variety of standard models which can be used directly or after a little modifying to construct desired network models. The layered protocol model is the key point, it makes modeling much more efficient and easier.

According to the work that has been done in this paper, follows could be considered as future work: at the first phase of the model development: considering some different topologies; attaching different types of sub-networks to ATM switches; increasing the number of switches, enlarging the network model; designing some non-standard node and process models to meet the requirements when modeling a large network with hybrid sub-networks. At the second and third phases: modifying corresponding process models in order to collect more statistics in terms of traffic management; repeating simulation with different parameters and different type of traffic sources; increasing the simulation time.

References