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**Design and Simulation of Global
Intelligent Medical Networks**

by

Lin Wang Leung

**A dissertation submitted to the Graduate Faculty in Computer
Science in partial fulfillment of the requirements for the degree of
Doctor of Philosophy, The City University of New York**

2005

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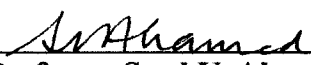
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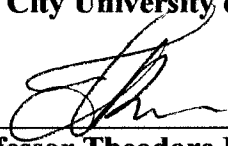
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This manuscript has been read and accepted for the Graduate Faculty in Computer Science in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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Abstract

Design and Simulation of Global Intelligent Medical Networks

By

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This dissertation investigates the increasingly important subject of using current Medical Networks as a means of communicating medical information. The IN (Intelligent Networks) and AIN (Advanced Intelligent Networks) services can be realized through the use of IM_ATM (Intelligent Medical Asynchronous Transfer Mode) switch architecture. Medical procedures will be implemented by using the medical codes. ATM cells are modified to accommodate the following information: specially tailored security code, patient ID, five digits of CPT (Current

Procedure Terminology) medical codes and other customized information. One bit from the PT (Payload Type) Field of the header block that has been reserved for future use is utilized to distinguish the request information from the customers.

Five Network models: 5-node regional networks, 9-node regional networks, Single National WAN cloud, three International WAN Clouds, and five Global WAN clouds are designed and created for testing and analyzing both traditional and new IM_ATM networks. Each of 128kbps, 256kbps, and 512kbps bandwidths are assigned with three traffic intensities (60%, 75%, and 90%). 1000B and 500B (or 800B and 400B) message sources are chosen for the traditional and 46B for the IM_ATM networks.

Simulation is an important tool for modeling a network to determine its performance characteristics. After carefully evaluate these two simulation software, COMNET III is chosen to model both the traditional and IM_ATM networks. The statistics of Message Count, Message Delay (packets created, packets delivered, and packets dropped), Message + Response; Message Delay in MS (milliseconds), and Channel/Link Utilization (%) are collected. These measures are used for

testing and cross-comparing of both the traditional and new IM_ATM networks. The limitations of the traditional networks and merits of the new IM_ATM architecture are discussed and analyzed. Suggestions are also made for future research topics.

Acknowledgements

I am deeply indebted to my mentor Professor Ahamed for the initiation and completion of this dissertation. Professor Ahamed's mentorship and inspiration has been the guiding light throughout the process of my research and writing. My gratitude also goes to Professor Brown, who has been equivalent to my guardian during my stay in the Graduate Center, with his wise counsel and gentle supervision, and also Professor Anshel who has broadened the horizon of my knowledge of cryptography and computer security through his lectures; he too should be credited for infusing my joint publications with Joe Wei. Words just cannot express thanks enough to Professor Mike Kress, for his invaluable advice, insight, as well as his generosity in time spent on my behalf, and not least to Dr. Lawrence for lending his expertise in the subject matter. All of them have had a significant role in enriching my dissertation. Without any of the aforementioned, I would never have reached the stage that I am at today. I must also express sincere appreciation to my dear friend, Dr. Chigurupati Rani, for her companionship in my otherwise lonely intellectual journey. To many of my dear friends and colleagues, names too numerous to be mentioned separately here, I offer thanks from the bottom of my heart, for all of your friendly encouragement. Last but

not least, I will never forget the support of my family; their ever-ready sacrifices endured throughout these long years of my pursuit of the Ph.D. degree have made me understand the true value of a devoted family.

Design and Simulation of Global

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Chapter 1

1. INTRODUCTION

This dissertation is devoted to the increasingly important subject of current Medical Networks. As a means of communication for medical information, Medical Networks, the existing Intelligent Networks (IN) and Advanced Intelligent Networks (AIN) are studied. Through the use of IN, and AIN methodologies, I designed an intelligent ATM switch architecture, and then applied this to the various medical networks which I created.

My research examines how telehealth and telemedicine are structured and investigates some of the infrastructure and technologies of the world's most modern networks, such as Integrated System Digital Networks (ISDN), Synchronous Optical Networks (SONET), and Asynchronous Transfer Mode (ATM). In addition, I explore how IN and AIN services can be realized through the modern ATM technologies; and what should be done to bring modernized telehealth and telemedicine systems to fruition through the merger of AIN services and ATM technology; and how these two are fully

capable of meeting current and future support of multimedia services, tailored for the need of modern society.

In chapter two, *Switching Networks*, I introduce the historical development of the Electronic Switching System, 1ESS, the first software-driven Stored program controlled (SPC) Central Office; the modified 1A ESS which provided the growth and increasing number of specific services demanded from 1ESS. The micro-programmed control of the processor was also introduced to the switching system in the 3ESS, with faster logic and automatic code conversion. The next major development in toll switching systems was the 4ESS, which was capable of handling an estimated half a million calls per hour, with a trunk capacity of over 100,000 calls per hour. Recently, the existing 4ESS switch, is capable of interfacing with the Switching System No. 7 (SS7) and DS3 via its' common network interfaces. Interfacing with the 5ESS-2000 platforms permit enhanced processing capabilities, as they existed in the IN environments and servicing capabilities with Operation, Administration, Maintenance, and Provision (OAM & P). Current Modern-ESS techniques are also presented in the chapter. All circuit, message and packet switching techniques, and the common characteristics of frame and cell relay are described briefly in this chapter.

In chapter three, *Transmission Media*, both conducted and radiated media are introduced. In conducted media, I describe the different applications and transmission characteristics of twisted pair, coaxial cables and optical fibers. In radiated media, the

application and transmission characteristics of terrestrial microwave, satellite microwave and radio wave transmission media environment are described.

In chapter four, *Evolution of Telecommunication Networks*, I present the Standards and Evolution of Telecommunication Networks. The Open System Interconnection (OSI) model was developed by the International Standards Organization (ISO). The basic objective of the OSI reference model is to standardize the rules of interaction among interconnected systems; this will allow computers globally to communicate. The OSI model has seven layers, which include: Physical, Data Link, Network, Transport, Session, Presentation, and Application; each named to correspond to one of the seven defined subtasks. Each layer contains a logically grouped subset of the functions required for controlling network communications. The modern networks – ISDN, SONET, and ATM are discussed. Functioning as highly multiplexed and time-shared systems, SONET and ATM technologies also provide additional applications, by employing their components of high reliability and integrity. They are highly effective, inexpensive, and the loss of payload is rare.

In chapter Five, *Intelligent Networks*, I give an introduction of the modern High speed networks and their applications. Furthermore, I describe the development of the Intelligent Network 1 (IN/1), and its four building blocks: (1) Service Switching Point (SSP); (2) Service Control Point (SCP); (3) Service Management System (SMS); and (4) Signal Transfer Point (STP). The services provided by the IN/1: 800 Number Services, Alternate Billing Services (ABS), and Private Virtual Network (PVN) services are

introduced. New elements, Service Control Logic (SCL), Service Logic Programs (SLP), and Intelligent Peripheral (IP) and their services for the IN/1+ are also described. The configuration of Intelligent Network 2 (IN/2) provides some new features: Vendor Feature Nodes (VFN) functionality and Service Creation Environment (SCE), which make the network more adaptable, because additional elements can be added for newer services via IP. The four planes and six capabilities sets of Intelligent Network Conceptual Model (INCM) and Global Intelligent Networks are also described here. The Platform 0 and Platform 1 services for the existing AIN, which provide many services for the modern networks, are also included. In this chapter, I examine the details of ATM's architecture, protocol, cell format, and switching techniques. I also explore the AAL layer and the manner in which ATM cells are packaged for network transmission.

In Chapter six, *Medical Informatics*, the definition and historical development of telehealth and telemedicine are detailed. Additionally, the needs and rapidly growing interest in telemedicine services in developing countries are presented. The use and application of telemedicine in radiology and dermatology and other medical platforms are explained. Standard medical codes of classification systems; International Clinical 9th Edition Clinical Modification (ICD-9-CM) and International Clinical 10th Edition Clinical Modification (ICD-10-CM) Diagnosis Codes, ICD9-CM and ICD-10-CM Procedure, Drug, and Current Procedure Terminology (CPT) Codes are all described in detail in this chapter. Finally, medical rules used to convert medical data such as symptoms; analysis results and physician's observation in medical diagnosis and treatment into medical information are described.

In Chapter Seven, *Intelligent Medical Networks*, I discuss the need to extend access in achieving better health care quality outcomes, and cost efficiencies in providing health services. I also explain the need to extend access to larger populations and health care information to more customers. I introduce Intelligent Medical Networks to the existing AIN. An explanation as to the need for Intelligent Medical Networks, and how this is achieved by enhancing the Application Layer from the OSI Model is also included; as is the subject of using current Medical Networks as a means of communicating medical information. How the IN and AIN services can be realized through the use of Intelligent Medical ATM (IM_ATM) switch architecture is explained. Medical procedures can be implemented by using the medical codes and ATM cells are modified to accommodate the following information: specially tailored security code, patient ID (social security number), five digits CPT codes, and other customized information. The social security number and other sensitive patient data will be protected by using modern encryption methods for use within the patient record. One bit from the Payload Type (PT) field of the header block that has been reserved for future use is utilized to distinguish the request information from the customers.

In chapter eight, *Simulation and Simulation Tools*, I explore and investigate popular simulation tools; OPNET and COMNET III are considered. OPNET, originally developed by Massachusetts Institute of Technology (MIT), was introduced in 1987 as the first commercial network simulator. It offers a highly graphical interface that facilitates object-oriented modeling of hierarchical network models. A standard

distribution of OPNET contains models of standardized communication technologies; such as Ethernet and FDDI. The OPNET Network Model, OPNET Network Editor, OPNET Node Editor, OPNET Processor Editor, OPNET Probe Editor, OPNET Simulator Editor, and OPNET Analysis Tool are all defined. The COMNET III model supports a building-block approach whereby the blocks are "objects". This model utilizes a library of objects that closely models objects within real networks. COMNET III is also a performance analysis tool for computer and communication networks. Based on a description of a network, control algorithms and workload, COMNET III simulates the operation of the network and provides measures of network performance. Network descriptions are created graphically through a highly intuitive user interface that speeds model formulation and experimentation. The elements of COMNET III; nodes, links, arcs, simulation environment, simulation topology, simulation methodology are presented in this chapter.

Three categories described within link Utilization are: (1) Channel Utilization, (2) Utilization by Application, and (3) Utilization by Protocol. Frames Delivered, Frames Resent/Error, Transmission Delay and Link Utilization are defined within the Channel Utilization. The number of packets delivered per second, number of bytes delivered by the link, number of kilobits delivered by the link, and percent utilization of the link are all defined. The utilization by Protocol provides a breakdown of the link usage by protocols. Within the Wide Area Network (WAN) Model, there are three categories in the WAN cloud: (1) Frame Delay by VCs, (2) Frame Count by VCs, and (3) Access Link Statistics at Entry and Exit. Frame Delay and Burst Size are described within the Frame Delay by

VCs. The Frame Count by VCs provides the throughput measure for each virtual circuit, these numbers are further divided between normal and discarded eligible frames. Data/Statistics for each access link in a WAN cloud, Entry/Exit of Access Link, Frames Accepted, Frames Dropped, Buffer, and Utilization percentage are all included in the Access Link Statistics. There are three categories in sources: (1) Message Delay; (2) Message Delivered; and (3) Packet Delay. Message delay is the time between the first packet of the message on the originating node, and the time that the originating node is notified that the message has been assembled by the destination. Message delivery data shown on the delay before the message were reassembled by the destination; that is the time between creating the first packet of the message on the originating node and the time of receiving the last packet on the destination node. The Packet Delay data are a summary of the number of packets created, delivered, and dropped for each message and a response source. In a telecommunication network, the number and the size of messages arriving at a node may vary with time, resulting in a different distribution potential at varying times.

In chapter nine, *Simulation and Simulation Results*, the study was divided into five different models; two regional, one national, one International and one Global networks. Two sets of simulations were performed; the traditional and IM_ATM calculations, the traditional ones were tested with the message sizes of 100, 200, 400, and 800 bytes the IM_ATM with 46 bytes. Each of the message size was examined with 128kbps, 256kbps, and 512kbps bandwidths, and each bandwidth consists of three

different traffic intensities; 60%, 75%, and 90%. The following five models were created and analyzed for the simulation results:

Regional Networks:

There are two regional networks; 1) Five-node Regional Networks, there are five nodes altogether in each network, one source each node, each source is sending information to every other respective destination. 2) Nine-node Regional Networks, there are nine nodes altogether in each network, one source for each node, each source is only sending information to pre-determined destinations.

National Networks:

A single WAN Cloud with 5 nodes and 20 Virtual Circuits (VC's), each source is sending a message to every other respective destination.

International Networks:

Three WAN clouds, two levels, Globe WAN Cloud connects to two other WAN Clouds; Europe (EU) and North America (NA) WANs, and each of these consists of five nodes. Each source is sending messages to every other respective destination.

Global Networks:

Three level Five WAN clouds with Global WAN Cloud is connected to four International WAN Clouds; Baltic Nations (BA), East Asia (EA), Europe (EU), and North America (NA) WANs, and each of the four International WAN Clouds is in turn, connected to other Regional Networks.

In chapter ten, *Conclusion*, I summarize the testing, comparing, and cross-comparison of both the traditional and newly developed IM_ATM networks. The limitations of the traditional networks and merits of the new IM_ATM architectures are analyzed and reported. Additionally, future research ideas and proposals are also discussed.

Chapter 2

2. SWITCHING NETWORKS

For transmission of data beyond a local area, communication is typically achieved by transmitting data from source to destination through a network of intermediate switching nodes; this switched network design is sometimes used to implement LANs and WANs as well. The switching nodes are not concerned with the content of the data; rather their purpose is to provide a switching facility that will move the data from node to node until they reach their destinations. The end devices that which to communicate may be referred to as stations, these stations may be computers, terminals, telephones, or other communicating devices, and each station attaches to a node. The nodes are connected to one another in some topology by transmission links, and the collection of nodes together with their links is referred to as a communication network. Data entering the network from a station are routed to the destination by being switched from node to node.

- Some nodes connect only to other nodes. Their sole task is the internal switching of data. Other nodes have one or more stations attached as well; in addition to their

switching functions such nodes accept data from and deliver data to the attached stations.

- Node-node links are usually multiplexed, using either FDM (frequency division multiplexing), TDM (time division multiplexing), WDM (wave length division multiplexing) or DWDM (dense wave length division multiplexing).
- Usually, the network is not fully connected; that is, there is not a direct link between every possible pair of nodes. However, it is always desirable to have more than one possible path through the network for each pair of stations.

Since 1980s, computer networks have been growing explosively and computer communication has become an essential part of our daily life. Networking is used in business, government, health industry, libraries, and educational sector. Computer networking is a complex subject. Many switching technologies exist, and each technology has features that distinguish it from the others.

2.1. Electronic Switching Systems

The electronic switching systems (ESSs) play a very important role in the communication systems, they control the flow of information through the network in a complex form.

2.1.1. 1ESS-4ESS

The first software-driven stored program controlled (SPC) Central Office (CO) is introduced as the No.1 ESS switches in 1965. The hardware in this CO is not all software controlled. Numerous subsystems (such as, line-scanner, signal distributor, and central pulse distributor) are combined into a basic hardware unit to interface with the line and trunk circuits and perform local functions. They are monitored by their own program control. This switch is primarily electromechanical in nature. Because of software considerations, the No.1 ESS switch-based Central Office is designed specifically to handle the communication functions in real time with the dependability in (about two hours downtime) and life span of 940 years typical Central Offices. The centralized control for the first No. 1 ESS is driven by one group of programs with about 100,000 words. With the growth and number of specific services demanded from the No. 1 ESS, the program size increased to 250,000 words of code. The program word for the No. 1 ESS is 44 bits. The program store size is 131,000 words and each generic CO could have as many as 12 program stores for handling as many as 65,000 lines in parallel. The cycle time is 5.5 microseconds.

In 1970s the No. 1A ESS is capable of serving up to 128,000 lines and 32,000 trunks with a total capacity of 10,000 erlangs. This number translated to 36 million call seconds per hour, since each erlang is equivalent to 3,600 call seconds per hour. During

the late 1960s and early 1970s other switching systems, No. 2 ESS, No. 2B ESS and No. 3 ESS are also introduced, but the impact of these switches is not as dramatic since the systems addressed the growth and speed aspects of switching systems. The micro-programmed control of the processor is introduced to the switching system in the No. 3A ESS with faster logic and automatic code conversion.

The next major step is the toll switching system, 4ESS, and this machine is a logical extension of the No. 1 ESS to reduce the fixed costs and running expenses, and to provide flexibility with the changing socioeconomic dynamics of the early 1970s. The more the processing capabilities for toll, the more sophisticated toll network resource and channel allocation are, and the PCM (pulse code modulation) transmission and switching capabilities are also included in the 4ESS. The first 4ESS is capable of handling about half a million calls per hour with a trunk capacity of over 100,000 calls per hour. This switch provided a benchmark for the capacity and reliability of trunk switching systems. To a degree, the 4ESS switch initiated the impact of computerized control onto toll switching- what computers had initiated in the data processing field years ago. The recent 4ESS switch completes up to 800,000 calls per hour as the call attempts reach about 1,200,000 during peak calling periods. More recently, the existing 4ESS switch is capable of interfacing with the SS7 via its common network interface and the ISDN implementation with CCITT (now ITU) Q.931 standards. In a more current design the 4ESS switch can also interface with DS3 carrier systems initially and then with the SONET-based transmission facilities.

2.1.2. 5ESS

In 1982, with the introduction of 5ESS, the first single-module local switch, and then with the introduction of the multi-module 5ESS started another major trend in Central Office capabilities. This machine offers many distinct features:

- It is a single system that can serve all the applications: operator, local, toll and international.
- It provides for digital switching between numerous subscriber loop carrier systems and inter-exchange carrier circuits, and facilitates the transition to ISDN.
- It has a modular approach in the hardware and software design, which permits adding and interfacing with the older generation switching systems.
- Its hardware modularity permits gradual growth as the network and service demands increase.
- Digital in devices, it is more reliable comparable to most computer systems. Extra error correction stages and parallel functionality of the CPUs permit quick and dependable retract ability of any call processing steps.
- The computer orientation of the switch design permits local and centralized maintenance by running diagnostics in any module, combined modules, extended subsystems, or global systems. The OA&M functions become much simpler.
- The 5ESS encoded in a higher-level language (the C language), allows CO capabilities to be added and deleted easily. The system is portable and modular, and it can be customized to a particular CO need. Digital services, such as ISDN and intelligent network (IN) services can accommodated by altering the flow

control within the call-processing environment; such network can include the detection of the trigger condition, data base lookup in a NID (network information data base) or invoking an IP, or exercising a SLP.

2.1.3. 5ESS-2000 and Modern ESS

The 5ESS-2000 switches in the American environment, contends with both the ISDN and IN functionality. In addition, this newer 5ESS platform permits enhanced processing capabilities, as they exist in the IN environments, and servicing capabilities with simpler OAM&P. It can handle up to 200,000 lines, newer remote-switching modules with line capacities of 20,000 lines, and wireless services, etc. The interfacing with the 5ESS-2000 permits it to perform as a totally software-driven versatile switch.

The switching module (SM-2000) of this machine permits interfacing with the fiber optic networks using the synchronous digital hierarchy (SDH) with OC-1 and OC-12 carrier capabilities. The 5ESS-2000 platforms make the provisioning of digital services of ISDN quite easy and manageable. Vendors are integrating the optical rate OC-1 through OC-48 with conventional ISDN and broadband ISDN switching systems.

The basic service required of communication networks is the transfer of data (voice, image, and video) from source to destination. The communication network is designed to transfer variable-length blocks of information up to some specified maximum size through switching nodes. Data entering the network from a source are routed to the

destination by being switched from node to node. The nodes are connected to one another by transmission links. Different switching techniques are used for data transmission in communication networks: Circuit Switching; Message Switching; and Packet Switching. Using queuing theory Kleinrock's work elegantly demonstrated the effectiveness of the packet-switching approach for bursty traffic sources. Two approaches evolved from packet switching techniques, namely Frame Relay and Cell Relay from ATM. These technologies differ in the way the nodes switch information from one link to another on the way from source to destination.

2.2. Switching Techniques

From the point of view of the average telephone engineer, the phone system is divided into two principal parts: outside plant (the local loops and trunks, since they are physically outside the switching offices) and inside the plant (the switches), which are inside the switching offices.

Three different switching techniques are used nowadays: circuit switching, message switching, and packet switching. Introduction to each one of them are given below.

2.2.1. Circuit Switching

Communication via circuit switching implies that there is a dedicated communication path between two stations. A physical connection is established between two nodes, see Figure 2.1 [61]. Channel capacity is dedicated for the duration of a connection, even if no data are being transferred. Switching and transmission resources within the network are reserved for the exclusive use of the circuit for the duration of the connection. There are five stages for the data transfer to take place through a switched channel: (a) an idle channel is identified and tagged; (b) a connection is established; (c) the data is transferred; (d) the channel is released; and (e) once again, the channel resumes idle status.

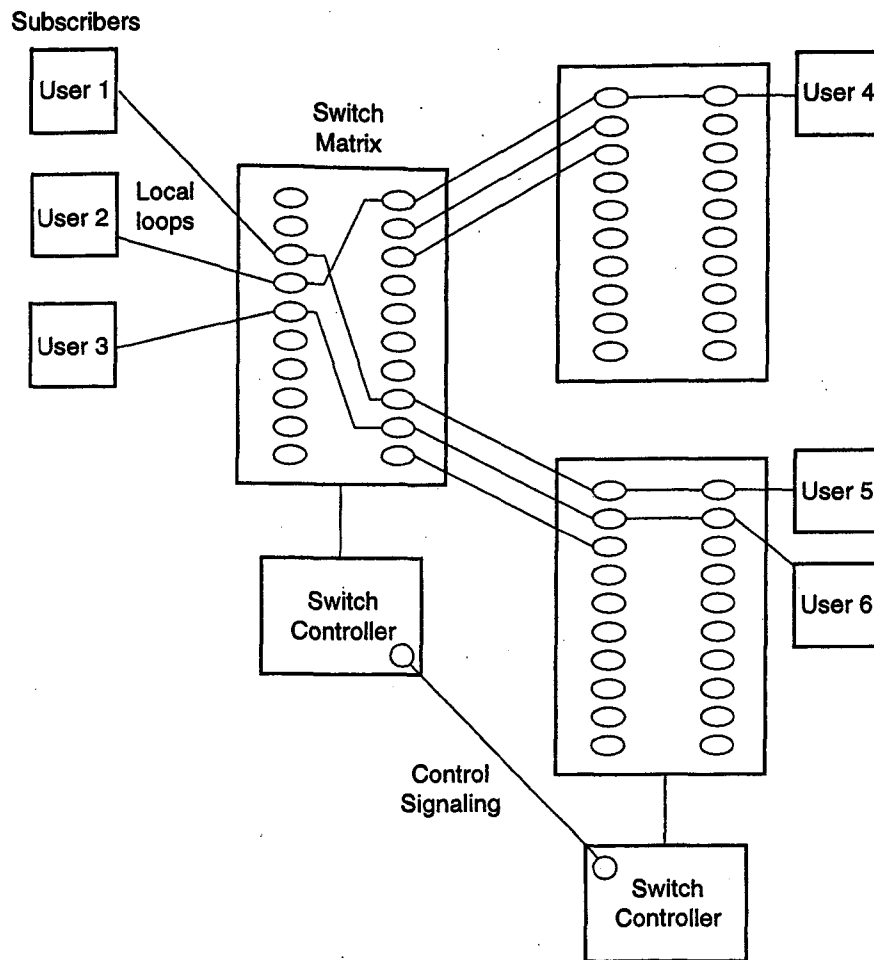


Figure 2.1: Circuit Switching

This sequence of stages closely parallels the well-established network steps in a typical voice call that follows the five network functions: call setup, alert, connect, disconnect, and release. Circuit-switched networks are analogous to the voice telephone system, and such connections are termed virtual circuits. Virtual circuit establishes a single route for data between the nodes that does not vary for the life of the connection, hence, they are connection-oriented.

Circuit switching was developed to handle voice traffic. But it can also be used for data traffic. Circuit switching can be rather inefficient. The best-known example of a circuit-switching network is the public telephone network. The telephone networks are connection-oriented because they require the setting up of a connection before the actual transfer of information can take place; this is an important property of circuit switching. IBM's SNA (Systems Network Architecture) is another example of a circuit-switched network [61].

Circuit-switching technology has been driven by those applications that handle voice traffic. One of the requirements for voice traffic is that there must be virtually no transmission delay and no variation of delays. A constant signal transmission rate must be maintained, because transmission and reception occur at the same signal rate. These requirements are necessary to allow normal human conversation. Circuit switching is preferred for its simplicity, constant-delay capacity, and constant-link capacity. One of its key strengths is that it is transparent. Once a circuit is established, it appears as a direct connection to the two attached stations no special networking logic is needed at the station.

In the context of ISDN (Integrated Services Digital Network), the information necessary to accomplish these steps is incorporated in the ITU-T (International Telecommunications Union-Telecommunications Standardization Sector); formerly known as CCITT (International Telegraph and Telephone Consultative Committee),

Q.931 protocol at the network layer used over the D (Delta) channel to set up the B (Bearer) channel.

2.2.2. Message Switching

When message switching is used, no physical path is established in advance between sender and receiver. A message of information is first received in its entirety with sender and receiver addresses and identification, stored in the first switching office (i.e., router) and then forwarded later, one hop at a time. The message path and its orientation, circuit (connection-oriented) or packet (connectionless-oriented), can be chosen by the agent receiving the message. An operator makes a routing decision based on destination address information. The operator then stores the message until the communication line becomes available to forward the message to the next appropriate station. This process is repeated until the message arrives at the destination station. A network using this technique is called store-and-forward network shown in Figure 2.2 [58].

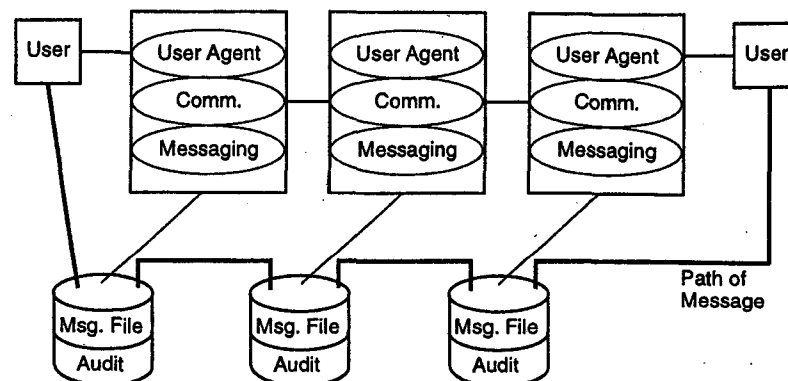


Figure 2.2: Message Switching

The best-known example of a message-switching network is the first electromechanical telecommunication systems used for telegrams. With message switching, there is no limit on message size. So the routers must have enough disk space to buffer long blocks. A single block may tie up a router-router line for minutes, rendering message switching useless for interactive traffic. To get around these problems, packet switching network was developed.

2.2.3. Packet Switching

When packet switching is used, the exact physical path is not established in advance between sender and receiver. In this connectionless-oriented data transfer, all data to be transmitted is first assembled into one or more packets by the source data terminal equipment (DTE), see Figure 2.3 [61]. The packet size are variable, there is an upper limit on packet size so that the packets can be buffered in router main memory instead of on disk. If a source has a longer message to send, the message is broken up into a series of packets. Both the source and destination network addresses are included in the header in these packets. The packets are then passed bit by bit from the source DTE to its local packet switching exchange (PSE). Each PSE contains a routing directory specifying the outgoing links to be used for each network address.

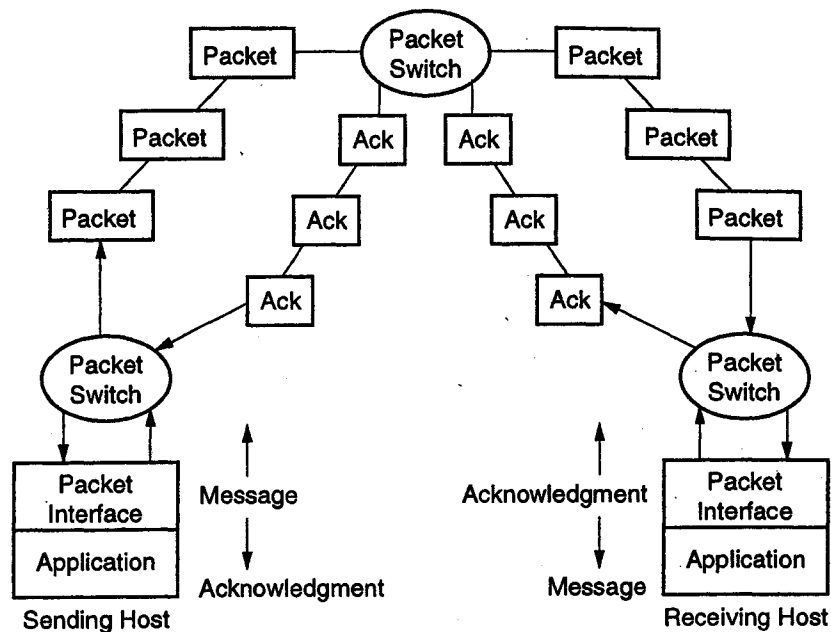


Figure 2.3: Packet Switching

The PSE forwards the packet on the appropriate link at the maximum available bit rate. At the destination PSE, determined by the destination address within the packet, the packet is finally passed the destination DTE. The destination DTE sends an acknowledgement back to the source DTE when a packet is received error free.

Circuit switching and packet switching differ in many respects. The main difference is that circuit switching statically reserves the required bandwidth in advance—any unused bandwidth on an allocated circuit is just wasted. Packet switching acquires and releases the required bandwidth as needed and it may be utilized by other packets from unrelated sources going to unrelated destinations, because circuits are never

dedicated. Another major difference is that circuit switching is completely transparent; the carrier does not determine the basic parameters. Packet switching is not transparent; the carrier determines the basic parameters.

ITU-T (formerly CCITT) has specified the widely accepted X.25, X.75, X.28, and X.29 protocol at the network layer. Ethernet standards dominate the packet-switching usage for LANs, and X.25 for WANs. The best-known examples of a packet-switching networks are E-mail and Internet. The availability of the packet-switched networks can get extremely widespread with FDDI (Fiber Distributed Data Interface). SONET and ATM technologies provide additional applications. Both ATM and TCP/IP networks are based on packet switching. However, ATM is connection-oriented, whereas IP is connectionless. The packet-switching networks are controlled for their flow and for any possible errors. Being highly multiplexed and time-shared, they are highly efficient and very inexpensive.

2.2.4. Frame Relay

Frame Relay originally was designed for used across ISDN interfaces. Today, it is used over a variety of other network interfaces as well. Frame Relay is a high-performance WAN protocol that operates at the physical and data link layers of the OSI reference model.

Frame Relay is also an example of packet-switched technology. Variable-length packets are used for more efficient and flexible data transfers. These packets are switched between the various segments in the network until the destination is reached. Statistical multiplexing techniques control network access in a packet-switched network. This technique accommodates more flexibility. Frame Relay often is described as a streamlined version of X.25, frame relay typically operates over WAM facilities that offer more reliable connection services and a higher degree of reliability than the facilities available during the late 1970s and early 1980s that served as the common platforms for X.25 WANs.

Frame relay is defined by the ITU-T recommendation I.122 as an adaptation of the ISDN interface for the purpose of providing frame relay services. It is a connection-oriented data transport service for public switched networks (PSN).

Initial proposals for the standardization of Frame Relay were presented to the CCITT in 1984 and did not experience significant deploying during the late 1980s because of lack of interoperability and complete standardization. Internationally, Frame Relay was standardized by the ITU-T. In the United States, Frame Relay is an ANSI standard, in the private domain, where it serves to optimize dedicated high-speed links (1.544Mbps), and also in the public domain where numerous operators offer a permanent virtual link service from 56 kbps to 1.544 Mbps [4]. Frame relay service, first offered commercially in 1993, has become one of today's most popular public telecommunications services. The primary application of frame relay is to interface high-

speed LANs to WANs, while other applications include image transfer and remote mainframe access.

Frame relay provides connection-oriented data link layer communication. This means that a defined communication exists between each pair of devices and that these connections are associated with a connection identifier. This service is implemented by using a Frame Relay virtual circuit, which is a logical connection created between two data terminal equipment devices across a Frame Relay Packet-switched network.

The frame format of frame relay is shown in Figure 2.4 [61]. The 2-octet header contains address information (DLCI, EA) for routing, congestion-control information (F/BECN, DE) for notification and enforcement, and the C/R bit whose usage is application-specific. The frame check sequence (FCS) is a 16-bit CRC for error detection: erroneous frames are discarded and are not retransmitted by the network. The standard specifies the use of permanent virtual circuits for connections.

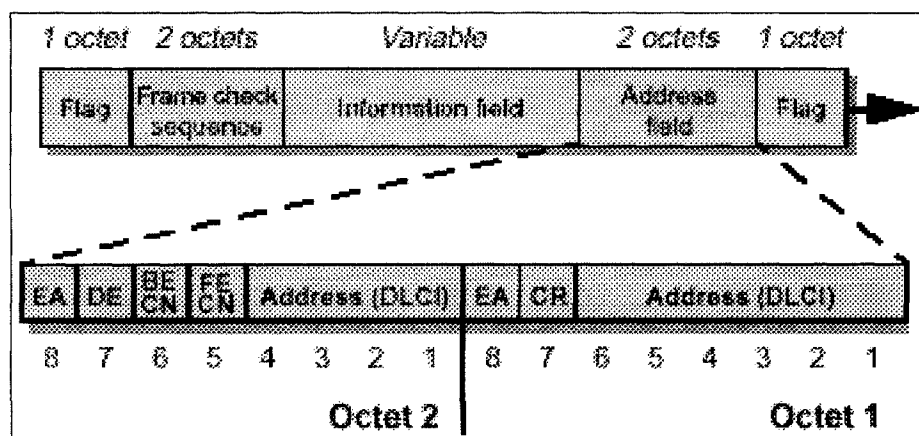


Figure 2.4: Frame Format of Frame Relay

DLCI = Data link connection identifier (12-bit);

F/BE CN = Forward/backward explicit congestion notification;

C/R = Command/response; **DE** = Discard eligibility;

EA = Extended address; **EA=0** indicates that the next byte is also an address byte;

EA = 1 indicates the last address byte.

2.2.5. Cell Relay

Cell relay is operated using two technologies which have common characteristics: the ATM (Asynchronous Transfer Mode), chosen by CCITT (ITU-T) for the information transfer mode of broadband ISDN (BISDN); and the DQDB (Distributed Queue Dual Bus) technology. DQDB (Australian) is a standard defined by IEEE 802.6 committee for the construction of metropolitan networks [4]. Cell relay is a packet switching technology that operates at the physical and data link layers of the OSI model. It uses a small, fixed-length cell. These small cells can carry any type of information such as data, voice, and video at tremendously high speeds. A more detailed description of Cell Relay switching technique is given in chapter four.

Chapter 3

3. TRANSMISSION MEDIA

The successful transmission of data depends principally on two factors: the quality of the signal being transmitted and the characteristics of the transmission medium. Transmission medium is the physical path between transmitter and receiver in a data transmission system. The transmission of data between computers and terminals can take place along several different media paths. The characteristics and quality of a data transmission are determined by both the characteristics of the medium and the characteristics of the signal. Various media can be used for the actual transmission, but in many instances, the data communication user has no option in choosing a medium. Each medium has its own niche in terms of bandwidth, delay, cost, and ease of installation and maintenance. Transmission media may be classified as conducted or radiated [61]. Conducted transmission medium is point-to-point source to destination. In the case of the guided medium, the medium itself is more important in determining the limitations of transmission. The waves are guided along a physical path, such as twisted pair, coaxial cable, and optical fiber. For radiated media, the bandwidth of the signal

produced by the transmitting antenna is more important in determining than the medium in determining transmission characteristics. The radiated media provide a means for transmitting electromagnetic waves, but do not guide them, such as radio, terrestrial microwave, and satellite microwave [61]; this form of transmission is usually referred to as wireless transmission. The media most commonly used today, as well as their transmission characteristics will be described here.

The spectrum or frequency band of the signal produced by the transmitting antenna is more important than the medium in determining transmission characteristics. We describe the media most commonly used today, as well as their transmission characteristics in this chapter.

3.1 Conducted Media

Three types of conducted media are discussed in this section: twisted pair wire, coaxial cable, and fiber-optic cable. As the name conducted media implies, these media are visible and are part of the physical portion of the network.

3.1.1. Twisted Wire Pair

Physical Description

A twisted pair consists of two insulated copper wires arranged in a regular spiral pattern. A wire pair acts as a single communication link. Typically, a number of these pairs are bundled together into a cable of wrapping then in a tough protective sheath. Over the longer distances, cables may contain hundreds of pairs. The twisting tends to decrease the crosstalk interference between adjacent pairs in a cable. Neighboring pairs in a bundle typically have somewhat different twist lengths to reduce the crosstalk interference. On long-distance links, the twist length typically varies from 5 to 15 cm. The wires in a pair have thicknesses of from 0.4 to 0.9 mm.

Applications

By far the most common transmission medium for both analog and digital signals is twisted pair. It is the most commonly used medium in the telephone network and is the workhorse for communication within buildings. In the telephone system, individual residential telephone sets are connected to the local telephone exchange, "central office or "end office," by twisted-pair wire. These are referred to as subscriber loops. Within an office building, telephone service is provided by means of a private branch exchange (PBX) system or to a Centrex facility at the end office. These twisted pair installations were designed to support voice traffic using analog signaling. However, by means of a modem, these facilities can handle digital data traffic at a good data rates.

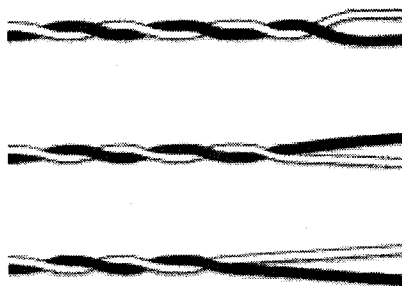


Figure 3.1: Twisted-Pair Cable

Transmission Characteristics

Twisted pair may be used for analog and digital transmissions. For analog signals, amplifiers are required about every 5 to 6 kilometers. For digital signals, repeaters are required every 2 to 3 kilometers. Compared to other commonly used guided transmission media, twisted pair is limited in distance, bandwidth, and data rate. The attenuation for twisted pair is a very strong function of frequency. Other impairments are also severe for twisted pair. The medium is quite susceptible to interference and noise. Impulse noise also easily intrudes into twisted pair. Several measures are taken to reduce impairments. Shielding the wire with metallic braid or sheathing reduces interference. For point-to-point analog signaling, a bandwidth of up to about 1 MHz is possible. This accommodates a number of voice channels. For long-distance digital signaling, data rates of up to a few Mbps are possible; for very short distances, data rates of up to multi-Gpbs have been achieved in commercially available products.

3.1.2. Coaxial Cable

Physical Description

Coaxial cable, like twisted pair, consists of two conductors, but is constructed differently to permit it to operate over a wider range of frequencies. It consists of a hollow outer cylindrical conductor that surrounds a single inner wire conductor. The inner conductor is held in place by either regularly spaced insulating rings or a solid dielectric material. The outer conductor is covered with a jacket or shield. A single coaxial cable has a diameter of from 1 to 2.5 cm. Because of its shielded, concentric construction, coaxial cable is much less susceptible to interference and crosstalk than the twisted pair. Coaxial cable can be used over longer distances and support more stations on a shared line than twisted pair.

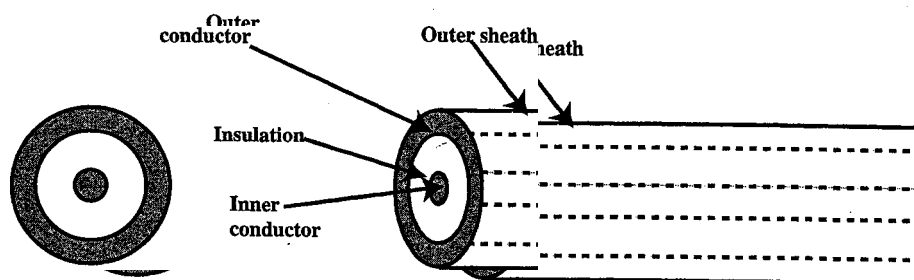


Figure 3.2: Coaxial Cable

Applications

Coaxial cable is also commonly used transmission medium, the widest use of coaxial cable are as follows:

- Television distribution
- Long-distance telephone transmission
- Short-run computer system links
- Local area networks

Coaxial cable is spreading rapidly as a means of distributing TV signals to individual homes—cable TV. From its modest beginnings as community Antenna Television (CATV), designed to provide service to remote areas. A cable TV system can carry hundreds of TV channels at ranges up to a few tens of kilometers. Coaxial cable has traditionally been an important part of the long-distance telephone network, and today, it faces increasing competition from optical fiber, terrestrial microwave, and satellites. Using frequency-division multiplexing, a coaxial cable can carry over 10,000 voice channels simultaneously. Coaxial cable is also commonly used for short-range connections between devices. Using digital signaling, coaxial cable can be used to provide high-speed I/O channels on computer systems.

Transmission Characteristics

Coaxial cable is used to transmit both analog and digital signals. As can be seen from Figure 3.2, coaxial cable has frequency characteristics that are superior to those of twisted pair, and can hence be used effectively at higher frequencies and data rates. Because of its shielded, concentric construction, coaxial cable is much less susceptible to interference and cross-talk than twisted pair. The principal constraints on performance are attenuation, thermal noise, and intermodulation noise. The latter is present only when

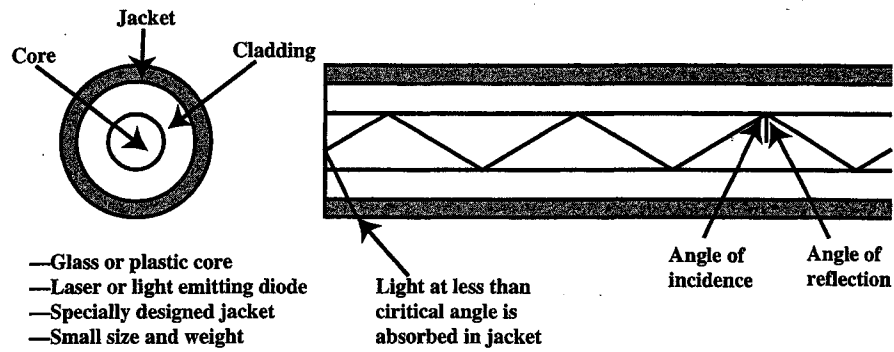
several channels are frequency bands are in use on the cable. For long-distance transmission of analog signals, amplifiers are needed every few kilometers, with closer spacing required if higher frequencies are used. The usable spectrum for analog signaling extends to about 500 MHz. For digital signaling, repeaters are needed every kilometer or so, with closer spacing needed for higher data rates.

3.1.3. Optical Fiber

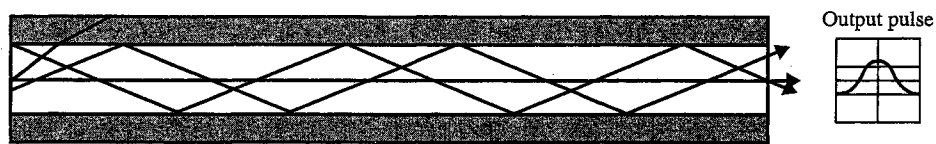
Physical Description

An optical fiber is a thin, flexible medium capable of guiding an optical ray. Various glasses and plastics can be used to make optical fibers. The lowest losses have been obtained using fibers of ultrapure fused silica. Ultrapure fiber is difficult to manufacture; high-loss multicomponent glass fibers are more economical and still provide good performance. Plastic fiber is even less costly and can be used for short-haul links, for which moderately high losses are acceptable. An optical fiber cable has a cylindrical shape and consists of three concentric sections: consists of three concentric sections: the core, the cladding, and the jacket (Figure 3.3). The core is the inner most section and consists of one or more very thin strands, or fibers made of glass or plastic; the core has a diameter in the range of 8 to 100 μm . Each fiber is surrounded by its own cladding, a glass or plastic coating that has optical properties different from those of the core. The interface between the core and cladding acts as a reflector to confine light that would otherwise escape the core. The outermost layer is the jacket made of plastic and

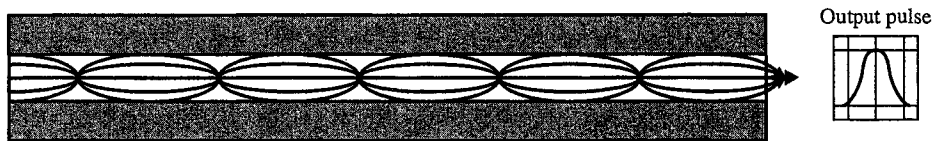
other material layered to protect against moisture, abrasion, crushing, and other environmental dangers. The information itself is transmitted through the core in the form a fluctuating beam of light.



(a) Optical Fiber



(b) Step-index multimode



(c) Graded-index multimode



(d) Single Mode

Figure 3.3: Optical Fiber and Optical Fiber Transmission Modes

Applications

Long-haul fiber transmission is becoming very common in the telephone network. Long-haul routes average about 1500 km in length and offer high capacity (20,000 to 60,000 voice channels). Metropolitan trunk circuits have an average length of 12 km and may have more than 100,000 voice channels in a trunk group. Most facilities are installed in underground conduits and are repeaterless, joining telephone exchanges in a metropolitan or city area. Rural exchange trunks have circuit lengths ranging from 40 to 160 km and link towns and villages. In the United States, they often connect the exchanges of different telephone companies. Subscriber loop circuits are fibers that run directly from the central exchange to a subscriber. These facilities are beginning to displace twisted pair and coaxial cable links. The continuing improvements in performance and decline in prices have made it an important application for LANs. Standards have been developed and products introduced for optical fiber networks that have a total capacity of 100 Mbps to 1 Gbps and can support thousands of stations in a large office building or a complex of buildings [61].

The advantages of optical fiber over twisted pair and coaxial cable become more compelling as the demand for all types of information (voice, data, image, video) increases.

Transmission Characteristics

Optical fiber transmits a signal-encoded beam of light by means of total internal reflection. Total internal reflection can occur in any transparent medium that has a higher

index of refraction than the surrounding materials. The optical fiber acts as a waveguide for frequencies in the range of about 10^{14} to 10^{15} Hz; this covers portion of the infrared and visible spectra. There are three different types of transmissions (Figure 3.3):

- **Step-index Multimode:** Light from a source enters the core. Rays at shallow angles are reflected and propagated along the fiber; other rays are absorbed by the surrounding material. This type of fiber is best suited for transmission over very short distances.
- **Graded-index Multimode:** The higher refractive index at the center makes the light rays moving down the axis advance more slowly than those near the cladding. Rather than zig-zagging off the cladding, light in the core curves helically because of the graded index, reducing its travel distance. The shortened path and higher speed allows light at the periphery to arrive at a receiver at about the same time as the straight rays in the core axis. Graded-index fibers are used in LANs.
- **Single-mode:** When fiber core radius is reduced, fewer angles will reflect. By reducing the radius of the core to the order of a wavelength, only a single angle or mode can pass: the axial ray. This single-mode propagation provides superior performance. Because there is a single transmission path with single-mode transmission, the distortion found in multimode cannot occur. Single-mode is typically used for long-distance applications, including telephone and cable television.

Two different types of light source are used in fiber optic system: the light-emitting diode (LED) and the injection laser diode (LD). Both are semiconductor devices

that emit a beam of light when a voltage is applied. The LED is less costly, operates over a greater temperature range, and has a longer operation life. The LD, which operates on the laser principle, is more efficient and can sustain greater data rates.

There is a relationship among the wavelength employed, the type of transmission, and the achievable data rate. Both single mode and multimode can support several different wavelengths of light and can employ laser and LED light sources. When multiple beams of light at different frequencies are transmitted on the same fiber, the true potential of optical fiber is fully exploited. This is a form of frequency-division multiplexing (FDM), but is commonly called wavelength-division multiplexing (WDM). With WDM, the light is streaming through the fiber. Since the bandwidth of a single fiber is about 25,000 GHz, many channels can be multiplexed together over long-haul routes.

3.2 Radiated Media

For unguided media, transmission and reception are achieved by means of an antenna. For transmission, the antenna radiates electromagnetic energy into the medium (usually free air), and for reception, the antenna picks up electromagnetic waves from the surrounding medium. There are basically two types of transmission: directional and omnidirectional. For directional transmission, the transmitting antenna puts out a focused electromagnetic beam; the transmitting and receiving antennas must be there carefully aligned. In the omnidirectional case, the transmitted signal spread out in all directions

and can be received by many antennas. In general, the higher the frequency of a signal, the more it is possible to focus it into a directional beam.

3.2.1. Terrestrial Microwave

Physical Description

Terrestrial microwave links are widely used to provide communication links when it is impractical or too expensive to install physical transmission media, for example across a river or a swamp or desert. The most common type of microwave antenna is the parabolic “dish”. A typical size is about three meters in diameter. The antenna is fixed rigidly and focuses a narrow beam to achieve line-of-sight transmission to the receiving antenna. Microwave antennas are usually located at substantial heights above ground level to extend the range between antennas and to be able to transmit over intervening obstacles.

Applications

The primary use for terrestrial microwave systems is in long haul telecommunication services, as an alternative to coaxial cable or optical fiber. The microwave facility requires far fewer amplifiers or repeaters than coaxial cable over the same distance. But, it requires line-of-sight transmission. Microwave is commonly used for both voice and television transmission. It is also used for short point-to-point links between buildings. This can be used for closed-circuit TV or as a data link between LANs.

Transmission Characteristics

Common frequencies used for transmission are in the range 2 to 40 GHz. The higher the frequency used, the higher the potential bandwidth and therefore the higher the potential data rate. Attenuation is the main source of loss. In the case of twisted pair and coaxial cable, loss varies logarithmically with distance. Attenuation increases with rainfall - the effects of rainfall become especially noticeable above 10 GHz. Interference is another source of impairment, with the growing popularity of microwave, transmission areas overlap and interference is always a danger. Thus the assignment of frequency bands is strictly regulated. The higher microwave frequencies are less useful for longer distances because of increased attenuation but are quite adequate for shorter distances.

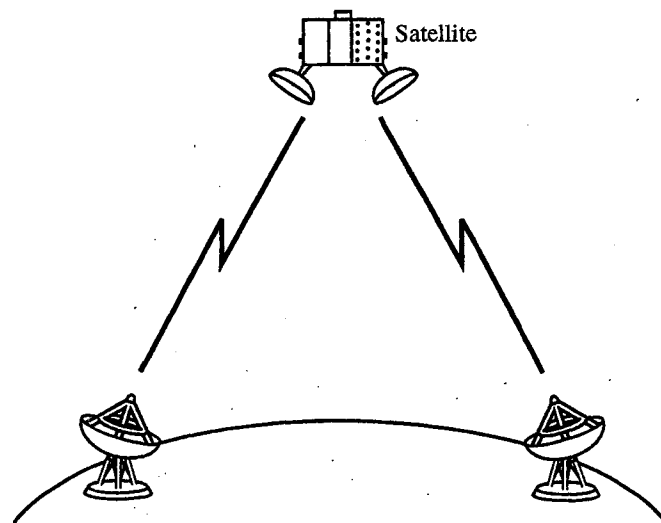
3.2.2. Satellite Microwave

Physical Description

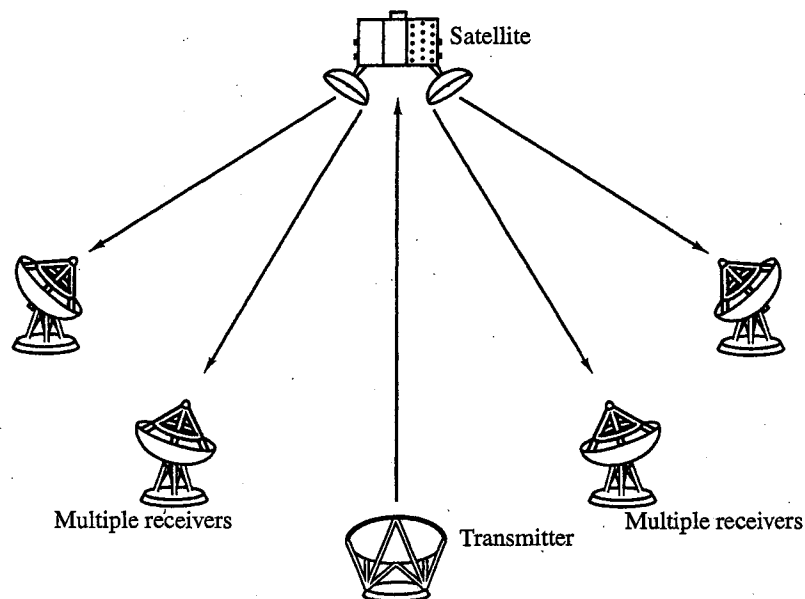
A communication satellite is a microwave relay station. It is used to link two or more ground-based microwave transmitter/receivers, known as earth stations. The satellite receives transmissions on one frequency band (uplink), amplifies or repeats the signals, and transmits it on another frequency (downlink). A single orbiting satellite will operate on a number of frequency bands called transponder channels, or simply transponders.

Figure 3.4 depicts in a general way two common configurations for satellite communication. In the first, the satellite is being used to provide a point-to-point link

between two distant ground-based antennas. In the second, the satellite provides a communications between one ground-based transmitter and a number of ground-based receivers. For a communication satellite to function effectively, it is generally required that it remain stationary with respect to its position over the earth. Traditional geostationary earth orbit satellites (GEOS) are placed in an orbit approximately 22,300 miles above the earth's surface at the equator. The rotation of the satellite is then synchronized to that of the earth, so the satellite appears stationary with respect to the earth. Two satellites using the same frequency band, if close enough together, will interfere with each other. To avoid this, current standards require a 4° spacing (angular displacement as measured from the earth) in the 4/6 GHz band and a 3° spacing at 12/14GHz. Thus the number of possible satellites is quite limited.



(a) Point-to-point link via satellite microwave



(b) Broadcast link via satellite microwave

Figure 3.4: Satellites Communications Configurations

Applications

The communication satellite is a technological revolution as important as fiber optics. Among the most important applications for satellites are the following:

- television distribution
- long-distance telephone transmission
- private business networks

Because of their broadcast nature, satellites are well suited to television distribution and are being used extensively in the United States and throughout the world for this purpose. Satellite transmission is also used for point-to-point trunks between telephone exchange offices in public telephone networks. It is the optimum medium for high-usage international trunks and is competitive with terrestrial systems for many long-distance international links.

There are a number of business data applications for satellite. The satellite provider can divide the total capacity into a number of channels and lease these channels to individual business users. A recent development is the very small aperture terminal (VSAT) system, which provides a low-cost alternative. A number of subscriber stations are equipped with low-cost VSAT antennas. These stations share a satellite transmission capacity for transmission to a hub station. The hub station can exchange messages with each of the subscribers and can relay messages between subscribers.

Transmission Characteristics

The optimum frequency range for satellite transmission is in the range 1 to 10 GHz. Below 1 GHz, there is significant noise from natural sources, including galactic, solar, and atmospheric noise, and human-made interference from various electronic

devices. Above 10 GHz, the signal is severely attenuated by atmospheric absorption and precipitation. Most satellites providing point-to-point service today use a frequency bandwidth in the range 5.925 to 6.425 GHz for transmission from earth satellite (uplink) and a bandwidth in the range 4.7 to 4.2 GHz for transmission from satellite to earth (downlink). The combination is referred to as the 4/6 GHz band. Note that the uplink and downlink frequencies differ.

Several properties of satellite communication should be noted. First, because of the long distances involved, there is a propagation delay of about a quarter second from transmission from one earth station to reception by another earth station. This delay is noticeable in ordinary telephone conversations. It also introduces problems in the area of error control and flow control. Second, satellite microwave is inherently a broadcast facility. Many stations can transmit to the satellite, and a transmission from a satellite can be received by many stations.

3.2.3. Broadcast Radio

Physical Description

The principle difference between broadcast radio and microwaves is that the former is omnidirectional (travel in all directions) and the latter is directional. Thus broadcast radio does not require dish-shaped antennas, and the antennas need not be rigidly mounted to a precise alignment.

Applications

Radio is a general term used to encompass radio and microwave is that the former is omnidirectional, the waves are easy to generate, can travel long distance, and can penetrate buildings easily. Radio is a general term used to encompass frequencies in the range of 3kHz to 300 GHz. We are using the informal term broadcast radio to cover the VHF and Part of the UHF band: 30 MHz to 1GHz. This range covers FM radio and UHF and VHF television. This range is also used for a number of data networking applications.

Transmission Characteristics

The range 30MHz to 1 GHz is an effective one for broadcast communications. Unlike the case for lower-frequency electromagnetic waves, the ionosphere is transparent to radio waves above 3 MHz. Thus, transmission is limited to the line of sight band distant transmitters will not interfere with each other due to reflection from atmosphere. Unlike the higher frequencies of the microwave region, broadcast radio waves are less sensitive to attenuation from rainfall. A prime source of impairment for broadcast radio waves is multipath interference. Reflection from land, water, and natural or human-made objects can create multiple paths between antennas. This effect is frequently evident when TV reception displays multiple images as an airplane passes by.

3.2.4. Infrared and Millimeter Waves

Unguided infrared and millimeter waves are widely used for short-range communication. The remote-control televisions, VCRs, and stereos all use infrared communication. They are relative directional, cheap and easy to build but have major drawback: they do not pass through solid objects. In general as we go from long-wave radio toward visible light, the waves behave more and more like light and less and less like radio. Infrared communication is achieved using transmitter/receiver (transceivers) that modulate noncoherent infrared light. Transceivers must be within the line of sight of each other either directly or via reflection from a light-colored surface such as the ceiling of a room. One important difference between infrared and microwave transmission is that the former does not penetrate walls. Thus the securing and interference problems encountered in microwave systems are not present. Furthermore, there is no frequency allocation issue with infrared, because no licensing is required.

Chapter 4

4. STANDARDS AND EVOLUTION OF TELECOM-NETWORKS

Computer networks have been growing explosively and computer communication has become an essential part of our daily life. Networking is used in business, government, health industry, library, and educational sector. Computer networking is a complex subject. Many technologies exist, and each technology has features that distinguish it from the others.

In the early days of packet switching, the various communications software suites that were available could not communicate with each other. To standardize the communications protocols, and also facilitate their development, the International Organization for Standardization proposed a model known as the Open Systems Interconnection.

4.1. OSI Reference Model

The Open Systems Interconnection model (OSI model) was developed by the International Standards Organization (ISO), it sets the guidelines for developing standards to enable the interconnection of dissimilar computing devices.

The basic objective of the OSI reference model is to standardize the rules of interaction among interconnected systems. It is not the intent of OSI to standardize the internal operation of a system. A system is considered to be one or more autonomous computer(s) with the associated software, and users that are capable of performing information processing and/or transfer. The purpose of the OSI reference model is to allow any computer anywhere in the world to communicate with any other, as long as both obey the OSI standards.

4.1.1. OSI and Communication Systems

There are many ways to describe and analyze data communication networks. All networks provide the same basic functions to transfer a message from sender to receiver, but each network can use different network hardware and software to provide these functions. All of these hardware and software products must work together to successfully transfer a message.

One way to accomplish this is to break the entire set of communication functions into a series of layers, each of which can be separately defined. In this way, vendors can develop software and hardware to provide the functions of each layer separately. The software or hardware can work in any manner and can be easily updated and improved, as long as the interface between that layer and the ones around it remains unchanged. Each piece of hardware and software can then work together in the overall network.

There are many different ways in which the layers in a network can be designed. One of the most important network models is the OSI Reference Model. OSI model helped change the face of network computing. Before the OSI model developed, most commercial networks used by business were built using proprietary nonstandardized technologies developed by one vendor. The OSI subcommittee, whose task was to develop a framework of standards for computer-to-computer communications. In 1984, this effort produced the seven-layer OSI model. The OSI model is the most talked about and most referred to network model. Although each of the seven layers in the OSI model is separate and distinct, the layers are often so closely coupled in practice that decisions in one layer impose certain requirements on other layers around them.

The OSI model helps in understanding the design of packet-switched network architectures. One of the most important advantages of OSI model is the ability to truncate the communication process at any OSI layer at any node, and then resume the communication process at any other node at any other time, up or down the model.

4.1.2. OSI Layers

The ITU-T publishes its OSI model specifications in the X.200 – X.299 Recommendations. The model is organized into seven layers. Each layer contains several to many protocols that are invoked based on the specific needs of the user. However, a protocol entity in a layer need not be invoked and the model provide the means for two users to negotiate the specific protocols needed for a session that takes place between them. Each layer is responsible for performing specific functions to support the end-user application. One should not think of a layer as monolithic code; rather each layer is divided into smaller operational entities, and these entities are invoked by the end user to obtain the services defined in the model.

The seven layers, each named to correspond to one of the seven defined subtasks. Each layer of the OSI model contains a logically grouped subset of the functions required for controlling network communications. The purpose and the general functions of each layer are described below:

Physical Layer: The Physical layer transmits bits to and receives bits from the communication medium. The function of this layer is to activate, maintain, and deactivate the physical connections. This layer also describes the mechanical characteristics of the network as well as the rules by which bits are transmitted. Information units at this layer are called bits.

Data Link Layer: The Data Link layer receives zeros and ones (bits) from the Physical layer and organizes them into logical groups called frames. The Data Link layer includes the rules that control the network access protocols - when a station can transmit, what to do when a node fails, and how to check for errors. Information units at this layer are called frames.

Network Layer: The Network layer routes messages through complex networks. This layer is responsible for establishing, maintaining and terminating network connections in a switched environment of the end systems. Among other functions, standards define how routing and relaying are handled. The upper layers are unaware of the configuration of the network and of the way routers forward messages between the source and destination. This layer adds a header containing the network address of the destination. Information units at this layer are called packets.

Transport Layer: Controls the end-to-end information exchange with the required degree of reliability. The Transport layer ensures reliable data delivery between processes. This layer is responsible for ensuring that data units are transmitted without error, in sequence, and without loss or duplication. This layer is responsible for taking message strings and breaking them up into smaller units that the Network layer can handle. The Transport layer then controls the flow of data, provides for error recovery, reorders the message units, and provides acknowledgment between the two end points of the connection.

Session Layer: Binds and unbinds various users and their applications into a logical units for dispatch and recovery to and from the network during a session. The Session layer manages dialog between two computers by establishing, synchronizing, and terminating communications. This layer also provides establishing communication as half or full duplex.

Presentation Layer: Interprets the information exchanged between the Application Layer and the network. The Presentation layer is concerned with the syntax rules utilized when communicating between two computers. This layer performs a variety of data translations to provide a common interface for user applications. This layer provides reformatting, data compression, and data Encryption functions.

Application Layer: Assures the user that the service provided is consistent with the type of application, provides a uniform interface between end-user applications and the network. This layer provides three functions: (1) Establishing privacy mechanism, (2) Authenticating the intended communication partners, and (3) Determining if adequate resources are presented.

4.2. Modern Networks-New Technology, Digitization and Globalization

The primary problem with present telecommunication networks is that separate networks and separate interfaces are required for every application. Both voice and data circuits can have either a digital or an analog interface, but the interface and terminating equipment are far from uniform. Analog networks are slow and inefficient to handle data, and low-speed data networks are ineffective for voice transmission.

For more than a century, primary international telecommunication infrastructure has been the public circuit-switched telephone system. This system was designed for analog voice transmission and is inadequate for modern communication needs. Anticipating considerable user demand for an end-to-end digital service, the world's telephone companies and PTTs got together in 1984 under the auspices of ITU-T (formerly CCITT) and agreed to build a new, fully digital, circuit-switched, called ISDN, has as its primary goal the integration of voice and nonvoice services.

4.2.1. ISDN (Integrated Services Digital Networks)

The reason for the ISDN architecture is to allow the telecommunication systems to evolve without worrying about interface to other systems. ISDN is only concerned with the interface to a customer or a switching system, not with how the system operates.

It uses the basic architecture of the OSI with enhancements to support out-of-band common-channel signaling.

Hence, ISDN was proposed to provide connectivity over a single digital communications pipeline while opening the network to a range of services that are impractical with the amalgam of networks. ISDN is a digital service provider to its customers. The ISDN architecture was approved in 1984 by CCITT (International Telegraph and Telephone Consultative Committee), now called ITU-T (International Telecommunications Union-Telecommunications Standardization Sector).

ISDN is limited to the ITU standardized signaling information on the D (delta) Channel. ISDN operates on four commonly used channels. The four basic channels in the United States are: (1) B (bearer) channel (64 kbps): Information bearing channel that provides a transparent digital path between one access point of the network and another (user-to-user information transfer). (2) D (delta) channel (16 or 64 kbps): Supporting channel that carries out-of-band signaling information-bearing B channels. The D channel standards are: 16 kbps for BRISDN; and 64 kbps for PRISDN. (3) H0 (384 kbps): user-to-user information transfer, and (4) H1 (1.536 Mbps): user-to-user information transfer.

The ISDN will offers flexibility to users can initiate and terminate services from their own terminals. ISDN is an attempt to diversify the bearer services offered by the telephone network. The different services are provided by different networks (rather than

in one single network) accessed through a common ISDN switch. Diversity is limited because these services are built on top of the traditional 64 kbps channels, which constrains the bit stream rates that can be supported.

4.2.1.1. ISDN Building Blocks, Objectives and Services

The ISDN approach is to provide an end-user with full support through the OSI seven layers although ISDN confined itself in defining the operation at layers 1, 2, 3 of this model. The building blocks of the ISDN consist of: (1) bearer services (2) Channels (3) Interfaces (4) Message sets. The ISDN objectives are: (1) To provide end-end connectivity (2) To gain the economies of digital transmission, switching, and signaling (3) To provide users with direct control over their telecommunications services (5) To provide a universal network interface for voice and data.

ISDN divided into two types of services: the bearer services (LAN interconnections, and high-speed data communications), responsible for providing for the lower three layers of the seven-layer standard; and the teleservices (e.g. telephone, Teletex, Videotex message handling), responsible for providing support through all seven layers of the model and generally making use of the underling lower-layer capability of the bearer services. All of these services demand high-speed transmission and switching within the network.

4.2.1.2. ISDN Rates

There are three different rates described in the physical layers: The BRISDN (Basic Rate ISDN) should be viewed as a replacement for POTS for home or small business use. There are two 64kbps B channels for data transmission and one 16 kbps D channel for signaling (144 kbps), also called basic rate access. The B1 Channel is the number one B channel of BRISDN service that is used to carry 64 kbps PCM voice data for telephone service. The B2 Channel is the number two B channel of BRISDN service that is used to carry 64 kbps packet-switched data.

The PRISDN (Primary Rate ISDN) interface is intended for use at the T reference point for businesses with a PBX (Private Branch Exchange). In North America and Japan, there are twenty-three 64kbps B channels for data transmission and one 16 kbps D channel for signaling (1.544 Mbps.) In Europe, PRISDN is defined as thirty B channels for data transmission and one 64 kbps for D channel signaling (2.048 Mbps.) Both the Basic and Primary Rates ISDN are depicted in Figure 4.1 [4].

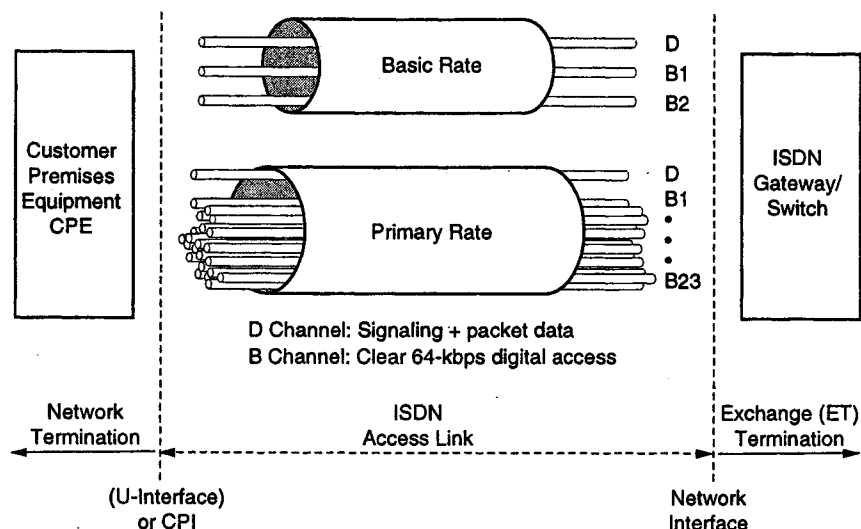


Figure 4.1: ISDN Access from Customer to an ISDN Gateway/Switch
The Primary Rate in Europe is 2.048 Mbps or E1 with 30 Bearer or B Channels and one Delta or D channel.

High-bit-rate services such as image and video services cannot be provided on 64 kbps ISDN. The advances in optical fiber, computing switches and other technologies such as digital signal processing (DSP) and video encoding techniques have stimulated a significant and rapid increase in the demand for new communication services and made B-ISDN (Broadband ISDN) possible. It is the increasing demand for these high-bit-rate services that primarily triggered the evolution of B-ISDN. The availability of high-grade fiber for transmission and the profusion of the rather inexpensive ATM switches are the major driving forces behind broadband digital networks. B-ISDN is based on fiber optic technology. B-ISDN provides a wide range of bandwidth between 155.52 Mbps and 622.08 Mbps.

4.2.1.3. Data Link Layer Frame (LAPD)

The ISDN provides a data link protocol is LAPD, which is a subset of HDLC. The protocol is independent of a transmission bit rate, and it requires a full duplex, a bit transparent, synchronous channel. The Q.931 message is carried within the LAPD frame in the information field. LAPD ensures that the Q.931 messages are transmitted across the link, after which the frame fields are stripped, and the message is presented to the network layer. The principal function of the link layer is to deliver the Q.931 message error-free, despite the error-prone nature of the communications link. The ISDN has served the industry well with its specifications of LAPD and Q.931 message protocol. LAPD has been one of the foundation technologies for frame relay as well as link access procedure for modems.

4.2.2. SONET (Synchronous Optical Network)

SONET (Synchronous Optical Network) is an optical transmission interface originally proposed by BellCore and standardized by ANSI. A compatible version, referred to as Synchronous Digital Hierarchy (SDH), has been published by ITU-T in Recommendation G707 is intended to provide a specification for taking advantage of the high speed digital transmission capability of optical fiber. SONET's high speed and its frame structure permit it to support a very flexible set of bearer services [4]. In addition

to providing higher speeds, SONET offers bandwidth-on-demand capabilities through SONET-based multiplexing technology.

SONET OC optical carrier level standards were developed to carry U.S., Canadian, Korean, Taiwanese and Honk Kong time division multiplexed 1.544 Mbps DS-1 (T-1) and 44 Mbps DS-3 (T-3) streams of voice and data from multiple customers and vendors. They operate at various synchronous transport signals (STSs) levels. SDH, or synchronous digital hierarchy, essentially is the European version of synchronous optical speeds. SDH signals are carried at Synchronous Transfer Mode (STM) speeds. Europe's time division hierarchy is based on E1 and E3 signals. Traffic that is carried between cities in Europe or in undersea cables is often referred to as being carried at STM-1 or STM-16 rates. SONET provides end-to-end fixed-rate channels at speeds that are multiples of 51.84Mbps. The transport of ATM cells over SONET is the basis of B-ISDN network. Its flexible frame structure accommodates both asynchronous traffic such as ATM and synchronous transfer mode (STM) traffic such as voice.

SONET has four functions (layers):

- The photonic layer converts electrical signals to optical signals and vice versa. The SONET equipment converts the electrical signals to light signals suitable for fiber optic cabling. At the receiving end of the transmission, it converts optical signals back to electrical signals.

- The section layer monitors the condition of the transmission between the SONET equipment and optical amplifiers.
- The line layer synchronizes and multiplexes multiple streams into one stream of traffic. It also provides monitoring and administration of SONET multiplexers.
- The path layer assembles and disassembles voice and data carried on SONET into frames. Frames are arrangement of bits that carry user information as well as bits for monitoring and maintaining the line.

4.2.2.1. SONET Frame

Synchronous Transport Signal has nine rows and ninety columns; a single row consists of a header of 3 octets and payload of 87 octets. The 87 octets of payload per row in each of the time rows are known as the synchronous payload envelope and at a bit rate of 51.84 Mbps. At this rate, the time duration of the frame is exactly 125 μ s (OC-1 rate).

SONET specification defines a hierarchy of standardized digital data rates. The lowest level referred as STS-1 (Synchronous Transport Signal level 1) or OC-1 (Optical Carrier level 1) is 51.84 Mbps. This rate can be used to carry a single DS-3 signal or a group of lower-rate signals. The standards for fiber optic digital hierarchy range from the OC-1 rate of 51.84 Mbps to the OC-768 rate of 39.81 Gbps shown in Table 4.1, higher rates can also be achieved.

Optical Level	Electrical Level	Line Rate (Mbps)	Payload Rate (Mbps)	Overhead Rate (Mbps)	SDH Equivalent
OC-1	STS-1	51.840	50.112	1.728	-
OC-3	STS-3	155.520	150.336	5.184	STM-1
OC-12	STS-12	622.080	601.344	20.736	STM-4
OC-48	STS-48	2488.320	2405.376	82.944	STM-16
OC-192	STS-192	9953.280	9621.504	331.776	STM-64
OC-768	STS-768	39813.120	38486.016	1327.104	STM-256

Table 4.1: SONET Digital Hierarchy (SDH)

4.2.2.2. SONET Deployment

SONET services are currently available within many major metropolitan areas. Accessing such services requires the local carrier to bring the fiber-based ring directly to a corporate location and to assign dedicated bandwidth to each SONET customer. Because of the limited geographic scope of most SONET services, it is most appropriate for those organizations with very high bandwidth needs (OC-1 to OC-278) between multiple locations within the limited SONET service area.

Add-drop multiplexers sometimes referred to as broadband bandwidth managers of cross-connect switches, are the customary type of hardware used to access SONET services. Such devices are often capable of adding several T-1 or T-3 digital signals together and converting those combined signals into a single optical SONET signal,

usually OC-3 or higher. In some cases, ATM switches are equipped with SONET interfaces for direct access to either a local SONET ring or commercial SONET services.

4.2.2.3. SONET Dual Ring

Unidirectional path-switched rings in which all users share transmission capacity around the ring rather than using dedicated segments, UPSRs are most commonly used in access networks and adhere to Bellcore standard. UPSRs provide duplicate, geographically diverse paths for each service, thereby protecting against cable cuts and node failures. The system automatically switches to the protection signal if there is a problem with primary data signal.

Bidirectional line-switched ring (BLSR), in which each user's traffic is specifically rerouted in the case of a fiber failure. BLSR architecture employ two fiber rings with bi-directional traffic flow with each ring's capacity divided equally (by STS) between working and protection bandwidth. BLSR provides survivability in the even of electronic, node, or cable failure by automatically routing traffic away from faults in as little as 50 milliseconds. BLSRs are most commonly used for internodes, or carrier backbone networks, and adhere to Bellcore standard.

4.2.2.4. Wavelength Division Multiplexing

SONET network capacity can be increased substantially with the introduction of wavelength division multiplexing. By transmitting more than one wavelength (color) of light simultaneously on a given single-mode fiber, multiple optical signals and the embedded data contained therein can be transmitted simultaneously. Wavelengths are between 50 and 100 GHz apart. When eight or more distinct wavelengths are simultaneously transmitted, the term DWDM (Dense wavelength division multiplexing) is often used. WDM should theoretically be able to produce transmission capacity on a single fiber in the Terabit per second range. Individual DWDM wavelength is referred to as lambdas and has a transmission capacity of 39.81Gbps each. Sixty-four lambdas per fiber can be transmitted with current technology while hundreds of lambdas per fiber are possible in the future.

SONET is a service-independent transport function that can carry the services of the B-ISDN (broadband ISDN) or HDTV as easily as it can carry the circuit-switched traffic of today such as DS-1, and DS-3. It has extensive performance monitoring and fault location capabilities; this network survivability is due to SONET's redundant or dual-ring physical architecture.

4.2.3. ATM (Asynchronous Transfer Mode)

Jon Turner (at Washington University) is to some the "parent" of ATM as it has become deployed in the enterprise and ISP markets. This is in contrast to the "heavy

iron" central office switches which started development first. The subsequent marketing splash of this and the products of other companies gave inertia to the enterprise and LAN ATM switch market. Others focus on the question of who constructed the first *practical* ATM demonstration. Some suggest that J.-P. Coudreuse is one of the technical managers of the CNET "Prelude" project in the early '80s. "Prelude" was apparently the first project that practically demonstrated the feasibility of service integration with cell switching. Others focus on the earliest researcher for cell-based ATM like technology. Sandy Fraser has been mentioned to be the earliest. He had worked with J.-P. Coudreuse in the early 1980s began ATM research in the early 70's. Fraser has presented an excellent summary of the early Bell Labs work on Asynchronous Time Division Multiplexing, easily recognized as cell-based ATM. One product based on this work is the Datakit Virtual Circuit Switch, commercially introduced in December 1983 and still in use by various organizations formerly known as the Bell System.

Asynchronous Transfer Mode (ATM) is the widely accepted standardized cell relay transmission service. The key difference between cell relay and frame relay is that, unlike the variable length frame relay frames, all cells in ATM networks are of a fixed length, 53 octets, the ATM cell format is depicted in Figure 4.2.

The service is connection-oriented, with data transferred over a virtual circuit (VC). The data stream from source to destination follows the same path. The data is transferred in 53-byte packets called cells. Cells from different VCs that occupy the same channel or link are statistically multiplexed. ATM switches may treat the cell

streams in different VC connections unequally over the same channel in order to provide different qualities of service.

ATM offers high-speed data transport capabilities. Since the ATM cells “ride” within the SONET frame, they inherit all properties of SONET. The speed of transport is derived from optical rates, optical speeds and low switching times (because of the simplicity/elegance in the SONET header information). ATM layers are depicted in Figure 4.2 [5].

Asynchronous Transfer Mode (ATM) was designed for use to carry both voice and data traffic. The basis for ATM is high-speed digital bearer which is divided into fixed length cells, and ATM is sometimes called Cell Relay. Packet and circuit switched networks are suitable for message and constant bit rate traffic, respectively. ATM networks combine the good features of both types of networks, making them suitable for variable bit rate (VBR) traffic. ATM networks can provide bearer services with a specified quality of service to meet the needs of all traffic types.

ATM networks support both real-time applications such as video connections and telephone services and non-real-time applications such as e-mail and file transfers. ATM also supports B-ISDNs. ATM is cheaper than telephone networks.

4.2.3.1. ATM Protocol Model

Because of the constant-length cells, cell relay switches can perform much faster than frame relay switches by depending on constant cell length, because more instructions for processing can be included in firmware and hardware. The constant-sized cells also lead to a predictable and dependable processing rate and forwarding or delivery rate. The lack of predictable maximum delivery delay was a key weakness in frame relay.

Two interfaces are defined for ATM: (1) **UNI (user-network interface)** multiplexes customer equipment interface with an ATM network, which carries information between the user and the ATM network. (2) **NNI (network-network interface)**, is a cell standard ATM network switches interface with one another, which carries information between ATM switches. Figure 4.2 depicts the ATN UNI protocol model than conceptually illustrates how input of data, voice, or video can all be processed and transmitted as homogeneous ATM cells, whereas Figure 4.4 [4] relates the layers of the ATM model to the layers of the OSI model.

4.2.3.2. ATM PRM (Protocol Reference Model)

ATM layered protocol architecture is described below:

Physical Layer (PL): PL is responsible for the adaptation of the transmission requirements of ATM cells and the physical media PL has two sublayers: (1) **Physical**

Medium (PM): performs bit timing and physical media adaptation; and (2)

Transmission Convergence (TC): performs cell rate decoupling – rate adaptation of the traffic and the transmission media (through insertion/removal of idle cells; calculations of HEC in either directions of transmission; cell delineation through HEC, which corresponds to the determination of the cell boundary based on the correct HEC, transmission frame adaptation, which is the adaptation of the incoming frame from the higher layers to the specifics of the transmission media.

ATM Layer (AL): AL performs the functions corresponding to the remaining fields of the cell header, as well as the generation/extraction of the cell header itself, in the respective directions of cell transmission. In the case of UNI, AL performs the GFC functions.

ATM Adaptation Layer (AAL): There are six types of AALs

There are six types of AALs (AAL0 – AAL5) for the ATM network transport. They all consist of a lower segmentation and reassembly (SAR) and an upper convergence sublayer (CS), SAR is responsible for creating ATM cells in the outward direction (transmission from the source towards the network) from the messages that are generated by the end—user or the higher-layer applications. CS is responsible for providing service-specific functions such as error correction/detection, clock and timing recovery/transmission, handling of timing jitter and inter-cell timing variations, sequence numbering for recovery of lost/miss-routed cells, and indication of the beginning/continuation/end of user information.

ATM offers high-speed data transport capabilities. Since the ATM cells “ride” within the SONET frame, they inherit all properties of SONET. The speed of transport is derived from optical rates, optical speeds and low switching times because of the simplicity/elegance in the SONET header information.

ATM standards are applicable within LAN/MAN/WANs and to private LANs, campus networks, or any other data networks. These networks can be connected to public, regional or national ATM networks. They can also serve the needs of BRISDN by functioning via connected-oriented ATM switches.

AAL0: Does not require CS and SAR sublayer functions.

AAL1: Applicable for services that require a timing relationship between source and destination. It is used for constant bit rate (CBR) and is connection-oriented.

AAL2: Provides timing relationship, like AAL1, between source and destination. Applicable to variable bit rate (VBR) services and is connection-oriented.

AAL3: Used when the timing relation between source and destination is not required. VBR is desired and service can use connection-oriented sessions. Supports two modes of services: message and streaming modes.

AAL4: This one is for services that do not require a timing relation between source and destination, for VBR, and for connectionless services.

AAL5: AAL5 intended to be used for signaling, data applications, and future applications on the ATM network. It provides VBR services with not timing relation between source and destination. AAL5 does not provide multiplexing capability.

4.2.3.3. Flow Control in ATM Networks

ATM networks are expected to support multimedia services, which require diverse source bandwidth, ranging from a few kbps to several hundreds of Mbps, as in HDTV. Multimedia services may require different quality of service (QoS); for example, real-time voice traffic requires low delay. In many data application a bit error rate higher than 10^{-8} may be unacceptable. Thus, high throughput and error control are required. Real-time video communications require error-free transmission and minimal delay.

ATM networks are supported by very high-speed transmission systems, such as SONET. The propagation delay in ATM networks is much larger than transmission time of a cell. For example, the transmission of a cell on a link with a capacity of 150 Mbps or 600 Mbps is about (0.7 or 2.8) microseconds. Suppose that the physical distance between two ATM is 1000 kilometers. Then the round-trip delay is about 10 milliseconds. During the round-trip delay, almost 3500 (or 14,400) cells can be in transmission between two ATM nodes. The processing of the cell at the ATM switch should be comparable to its transmission time. In these situations, software-based switches are slow, while dedicated hardware switches can be very expensive. Therefore, control protocols in an ATM network are required to be fast, simple, flexible and integrated. Traditional flow control schemes used in packet-switched or circuit-switched networks are not suitable.

User inputs of data, video, or voice must be processed into fixed-length ATM cells before they can be forwarded and delivered by ATM switches. The processing is done on the **AAL** or **ATM adaptation layer**. Depending on the type of input a different type of adaptation process may be used, and different types of delivery requirements or priorities can be assigned within the ATM network. After emerging from the ATM adaptation layer, all cells are in an identical format as illustrated and explained in Figure 4.2.

4.2.3.4. ATM Cell

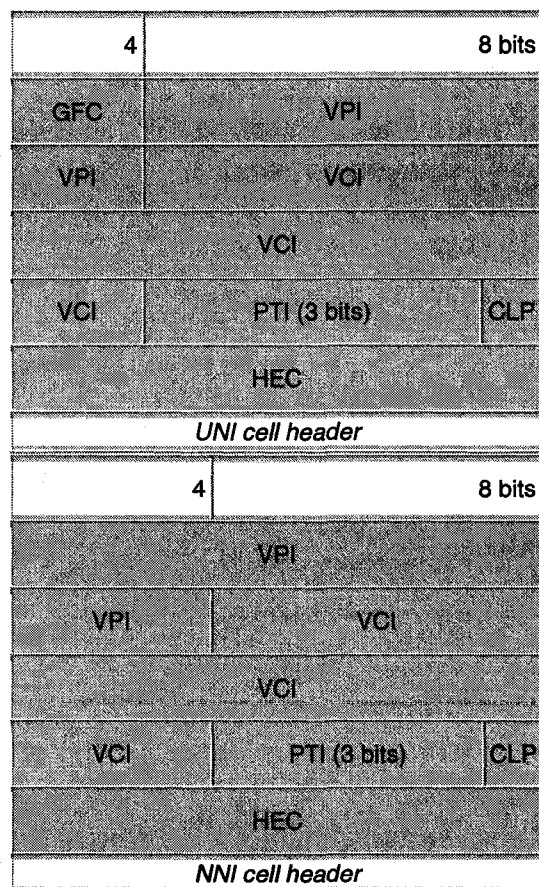


Figure 4.2: ATM Cell Format, Header (5 bytes) and Payload (48 bytes)

GFC (Generic Flow Control): Prescribes a standard method of terminal-network flow control that is fair, robust, and realizable as an option by the ATM device manufacturers.

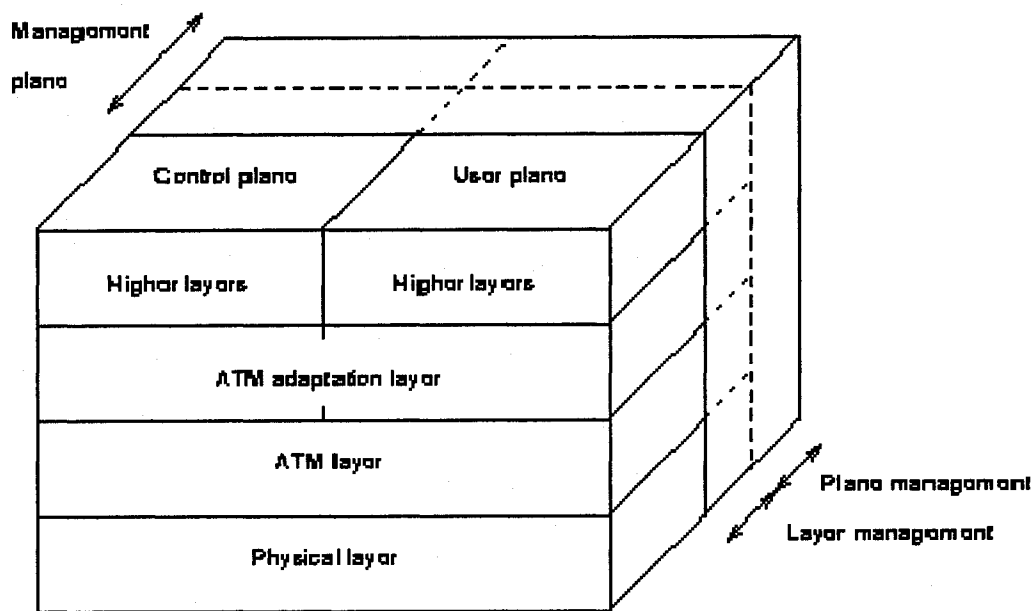
VPI (Virtual Path Identification) and VCI (Virtual Channel Identification): provide numbering identification of the Virtual Paths and Virtual Circuits.

PLT (Payload Type Identification): identifies the types of traffic carried in the ATM cell.

CLP (Cell Loss Priority): assigns high/low priority to the cell (by the network or customer equipment) so that in case of congestion and other problems in the network, cell discarding may be exercised.

HEC (Header Error Check): error correction/detection field that applies to the four bytes of cell header only. Error correction/detection on the remaining user data may be provided by the ATM Adaptation Layer.

Broadband ISDN protocol reference model is based on the ATM reference model



ATM asynchronous transfer mode

Figure 4.3: Overview of the ATM Reference Model for B-ISDN Applications
ATM – Asynchronous Transfer Model; B-ISDN – Broadband ISDN; UNI – User Network Interface

ATM standards are applicable within LANs, MANs, and WANs to private LANs, campus networks, or any other data networks. These networks can be connected to public, regional or national ATM networks. They can also serve the needs of BRISDN by functioning via connected-oriented ATM switches.

4.2.3.5. ATM and SONET

SDH/SONET frames are universal transport containers for all types of digitized data, including data streams such as cell-based ATM, IP ("Packet over SONET"), Frame Relay, and leased line, as well as the entire range of digital and analog telephony. Today,

SDH or SONET is used by major telecom service providers to implement high-speed backbones in WAM.

The transportation of ATM cells over SDH networks specified in ITU-T Recommendation G.707. ATM transport over SONET is specified in ANSI T1.105. SONET is the North American equivalent of SDH, and the two can be considered identical in most respects for equivalent interface rates. The ATM cell stream is encapsulated with byte alignment in or concatenated VC-x containers (SONET in synchronous payload envelopes, or SPE). Because the SPE is not an integer multiple of 53 bytes, a cell can also be split across two SPEs. Before the ATM cells are inserted in the SPEs for transport, the user data field of the cell is scrambled in order to facilitate delineation of the individual cells at the receiving station. If the ATM data rate is too high for the available bandwidth, the cells are discarded, beginning with low-priority cells. The resulting bit rate of the ATM cell stream is synchronous with that of the SPE's, ATM cell mapping to the SDH STM-1 transport module, illustrated in Figure 4.4, is essentially identical with cell mapping to a SONET STS-3c transport system. Similarly, ATM mapping to a SONET STS-12c transport system is identical with mapping to the SDH STM-4c transport module.

When ATM was chosen as the transfer mechanism for the ITU-T's B-ISDN project SDH/SONET frames became transmission vehicle of choice for ATM cell streams. From the perspective of the ITU-T ATM and SONET from the foundation for broadband B-ISDN, the implementation of these technologies provide for greatly

enhanced OAM capabilities from the SONET perspective and greatly reduced the responsibility for traffic integrity by the networks from the ATM perspective. By employing SONET/ATM components of high reliability and integrity the loss of payload is rare, and those rare instances (errors) can be corrected in a more efficient way at the user endpoint.

Transmission of ATM cells over data lines as a plain bit stream, using neither PDH nor SDH/SONET framing, is called a cell-based physical layer. Interface specifications exist for the cell-based physical layer at 622 Mbps, 155 Mbps and 51.84 Mbps. ITU-T recommendation I432 also defines the cell-based physical layer with throughput rates 155Mbps and 644Mbps. The data is transmitted in a continuous stream of ordinary ATM user cells, OAM cells, and idle cells.

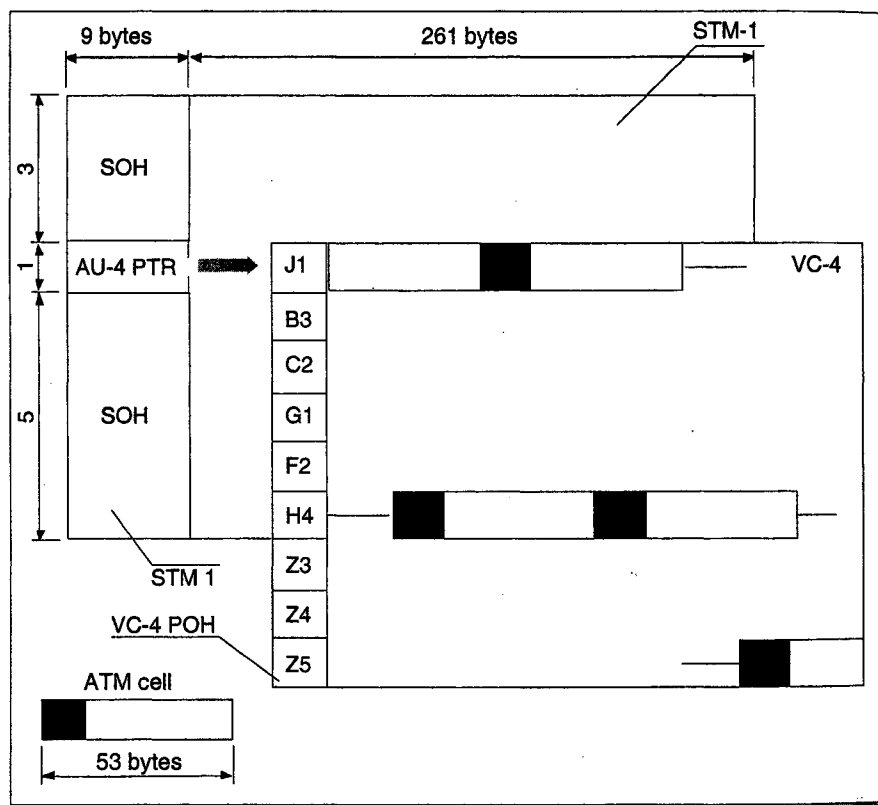


Figure 4.4: Transportation of ATM cells in the STM-1 transport module.

ATM cells are carried through a SONET transport platform of ANSI/T1S1 standards in North American standard synchronous transmission network technology, for optical signal transmission terminates from OC-1 (51.4Mbps) to OC-192 (9.95Gbps), with up to OC-768 (39.81Gbps) available today. The functions of the SONET layer in the B-ISDN reference model is to carry ATM cells at high speed and provide very fast protection switching capability to ATM cells whenever needed.

4.2.3.6. ATM Layers and OSI Model

ATM layers do not map directly with the OSI layers. The operations of the ATM layers typically found in layer one, Data Link Layer and one, Physical layer

of the OSI. The DLL of ATM has two distinct layers: ATM Adaptation Layer and the ATM layer. The Physical Layer is divided into two distinct sublayers: the transmission convergence sublayer (TCS) and the physical medium sublayer (PMS). The relationship of the user connection to the AAL and ATM layers is shown in Figure 4.5 [4].

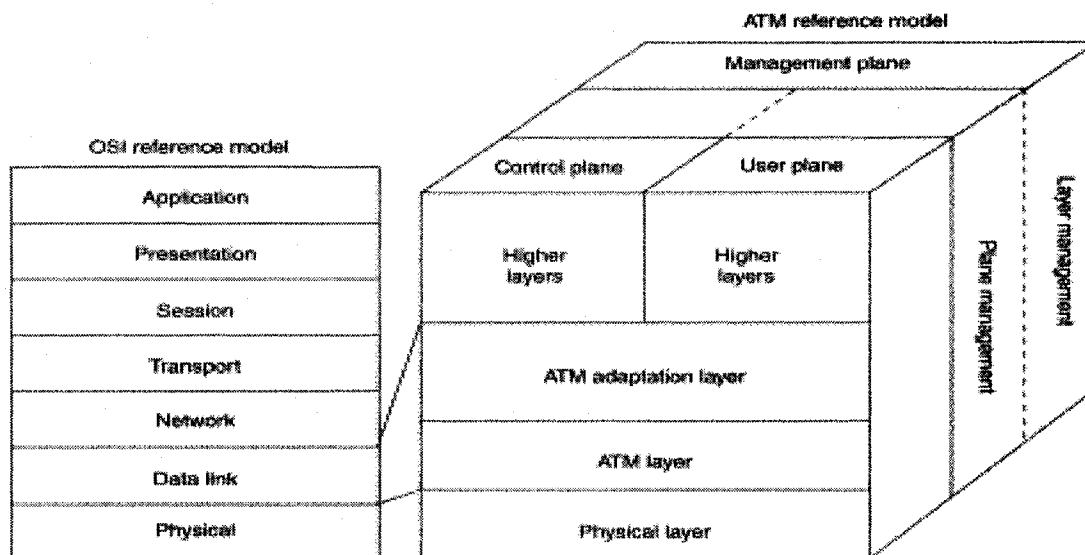


Figure 4.5: ATM Layers within the Data Link and the Physical Layers of the OSI Reference Model

4.2.3.7. ATM and IP traffic

ATM can carry traffic of various speeds. ATM can scale from low-speed to high-speeds use for video and multimedia applications. ATM is installed mainly in carrier

networks. Many new carriers have built networks capable of transmitting traffic from many sources including ISP Internet traffic, CLEC voice traffic and Gigabit Ethernet traffic. Some ATM switches also carry IP traffic. Some of them have the capability to read IP routing information in packets. The switch puts IP packets into cells and reassembles the cells back into packets at the end of the transmission. This is referred to as mapping IP onto ATM.

Chapter 5

5. INTELLIGENT NETWORKS

Intelligent networks (INs) carry and communicate information with distinct algorithmic adaptation. Adaptability occurs at a level or global level. Local adaptability is administered by the programs resident at the nodes within the network. Global adaptability is administered by the coherent functioning of the node to process requests from another node and, thus accomplishes global and extraneous functions.

Numerous distinct networks can and generally do coexist within the IN. These subnetworks operate coherently and cooperatively in the intelligent functioning of the overall network.. In fact, the predictable and accurate response from the entire network is also a dominant requirement for it's acceptance in the user community. The endpoints refer to the access point to and from which information may flow in any standard form (voice, digitized voice, multimedia, or encoded data bearing any type of information). The context of hardware, intelligence resides in the design, architecture, and algorithmic performance of the integrated circuit (IC) chips. The hierarchical interconnection that

permits the ICs to function as network components also contributes to hardware intelligence. In the context of software, intelligence is coded as programs, utilities, or modules. It resides in the active memories of computers through microcode. Thus, the basic computers that control, monitor, and process the information become an integral part of intelligent networks. The flow of the information takes place over appropriate channels within the network. Information also flows within a diversity of participating networks. Channels are assigned dynamically, switched, and reallocated to carry the information from node to node, customer to customer, or workstation to workstation.

There are three major milestones in this evolutionary path: first, the concept of stored program control (SPC) was introduced in 1965 for local switching in the United States. Second, the concept of Channel Interoffice Signaling System 6 (CCISS6) was introduced and implemented during 1976. Third, the concept of service independence was introduced during 1984.

The requirements of classified as an IN are: (1) The databases in SCP (Service Control Point); (2) CCS7 (Common Channel Signaling 7) network; and (3) Some service independence by having numerous databases in SCP.

Basic computer systems, which control, monitor, and process the information become an integral part of intelligent networks. Various long-distance carriers in the United States have been designed different INs with different functions.

AT&T: The service capabilities of the IN were conceived and implemented by **AT&T**. The **Universal Information Services Network (UISN)** was proposed in 1989, it provided three major services: 911 (Public Emergency) Service, Virtual Private Network (VPN) and Automatic Calling Card. **AIN's** (Advanced Intelligent Network) Platform 0 and Platform 1 Services are also part of the **AT&T's** effort.

Bellcore: Services of **IN/1** in 1987, **IN/1+** in early 1990s, and **IN/2** in 1990s are all provided by **Bellcore**.

MCI: **Vnet** from **MCI** has two DAPs (data access points). The function of DAPs is similar to STP. DAPs are controlled by NCS (network control system). The function is similar to SCP & SMS.

Sprint: **VPN (Virtual Private Network)** of **Sprint** uses two STPs and several database control points (DCPs). The STPs are managed by a DCP management system.

Service Networks such as **ABS** (Alternate Billing Service), **ERS** (Emergency Response Service), **PVN** (Private Virtual Network), **AWC** (Area Wide Centrex), and **PPV** (Pay Per View) are also existed in the United States.

The development of INs has also taken place in several other countries, for example, Green Number Service (GNS) in Europe. Since 1987, Freephone Service (800 calls), prevalent in British Telecom, has been available as GNS.

5.1. Intelligent Networks/1 (IN/1)

Bellcore introduced the first generation IN/1 (see Figure 5.1 [4]). The building blocks of IN/1 are: (1) SSP (Service Switching Point); (2) SCP (Service Control Point); (3) SMS (Service Management System); and (4) STP (Signal Transfer Point).

IN/1 contains numerous SSPs and STPs within the Common Channel Signaling 7 (CCS7) network, but only one SCP and SMS (duplicated for disaster recovery). The services provided by IN/1 are: (1) 800 number service; (2) Alternate Billing Service (ABS); and (3) Private Virtual Network (PVN) Service.

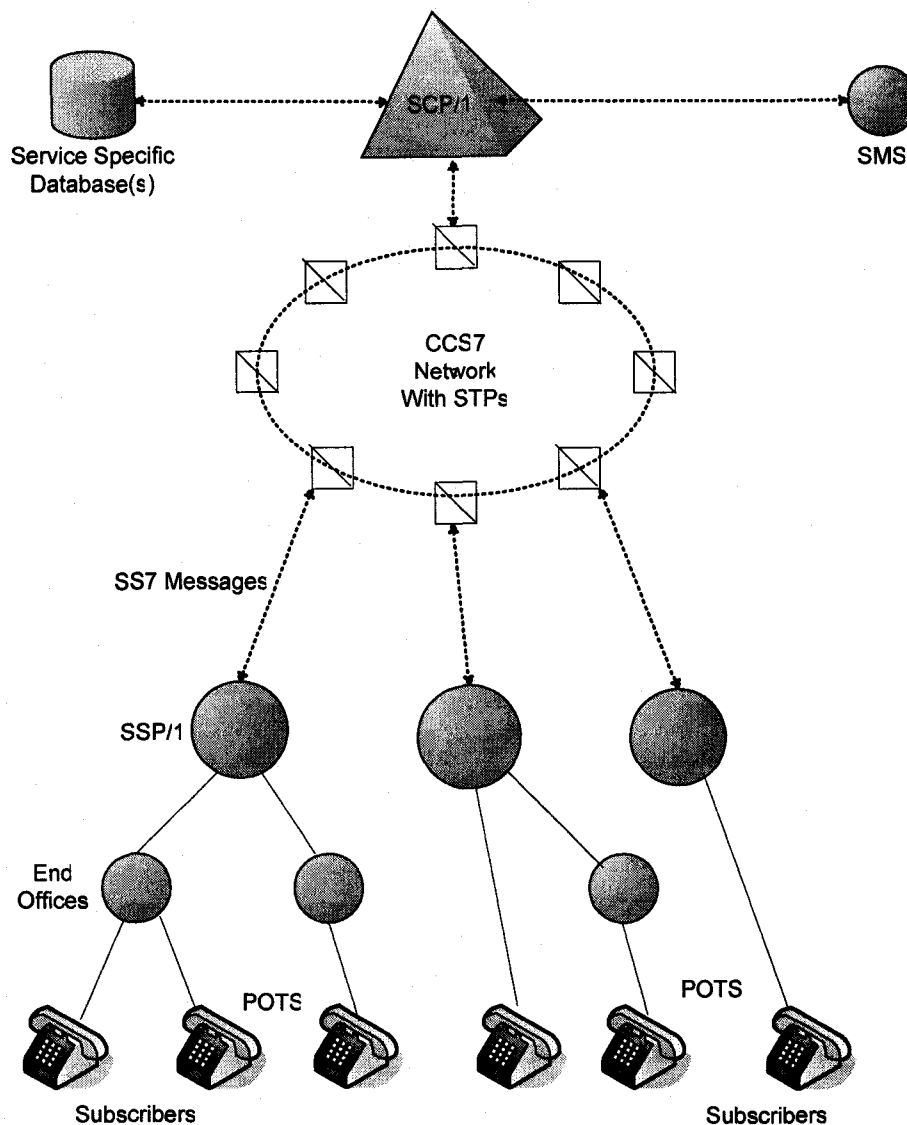


Figure 5.1: Bellcore Architecture of IN/1 (1987)

SCP = service control point; SMS = service management system; STP = signal transfer point; SSP = service switching point; POTS = plain old telephone service.

5.1.1. Service Switching Points (SSP)

SSPs are physical or logical entities, generally located at or near the switching systems that contain call processing software. There are two aspects of the SSP; (a) the physical switch that performs the switching function, and (b) the logical software modules that reside within the switch forcing the execution of the SSP functions. The switching systems contain call processing software which monitors all steps required to complete any call through the network. Each SSP reacts to specific trigger conditions from the customers, it then transmits queries to SCP through STP. The queries to the SCP are passed via the interoffice signaling system (SS7) and are made into information packets via CCS7 network, which consist of highly dependable packet switches. When the SCP responds to the query from the SSP, the SSP instructs the switching system to complete the call upon receiving the response. The switching system executes the call-processing software to complete the process.

5.1.2. Service Control Points (SCP)

A physical or virtual node, SCP contains the active database of customer records. Three databases reside the SCP: (a) 800 number database; (b) ABS database; and (c) PVN database. The database is actively queried by SSP within the network to seek and obtain information for service completion. The effective management and utilization of this database is crucial.

SCP is made up of hardware and software components. It consists: (1) an highly dependable mass storage system makes up the data base storage. (2) a bank of parallel processors with their own dedicated memory blocks serves to access the bulk storage within the SCP, and also communicates with the input/output devices in the data base. (3) a series of front-end processors preprocess the queries received via the SS7 network, with a well defined protocol. (4) a series of BX.25 front-end processors complete the major hardware components. These processors receive service management information from the SMS and provide the interface for maintenance, security, and operations of the SCP. SCP functions include the validation of the caller to call, the address translation of the called party (look-up database, if necessary) and identification of the carrier authorized to carry the call.

5.1.3. Service Management System (SMS)

It is an off-line support facility used to enter customer data into the SCP's database within IN/1 environment. SMS is used to enter the call-processing software into the SCP, it also performs the administrative work for SCP. It communicates with SCP through interface cards that process the BX.25 protocol used for communication between SMS and SCP. The SMS also need a series of front-end processor to link with the dual buses, which provide data paths between the SCP's other front-end processors and the SCP's bank of CPUs. In the IN/1 framework, three sets of software have emerged for the

IN/1, they are: the SMS/800 for 800 services, the data base administration system(DBAS) for the alternate billing service, and the SMS/PVN for private virtual network.

5.1.4. Signal Transfer Point (STP)

Signaling Transfer Points (STP) are distributed within the CCS network and they are extremely reliable packet switches for the transportation of signaling information between SSPs, SCPs, and other STPs. There are four main functions of the STP: (1) error-free message routing, (2) protocol processing, (3) address translation, and (4) message routing data base look up. The STPs contain the translation information necessary to forward the data base queries from the SSPs to the appropriate SCPs.

The CCS7 standard approved by ITU in 1984 used a layered approach to specify the communication protocol, the STPs contain the translation information necessary to forward the data base queries from the SSPs to the appropriate service control points. The exchange of the signaling of information also follows the OSI model. The SS7 network architecture in the United States has undergone considerable enhancement during the 1980s. In divestiture of the Bell System, resulting numerous local exchange carriers have increased the number of STPs dramatically.

5.2. Intelligent Networks/1+ (IN/1+)

The Regional Bell Operating Companies (RBOC), in conjunction with the research done at Bell Communications Research (Bellcore), proposed the IN/1+ concepts and its architecture in order to facilitate the gradual merging of the Ins in the switching and transmission environment with the introduction of newer digital services associated with ISDN and ISDN-like services in the public arena.. The phased introduction of IN/1+ was developed during the early 1990s shown in Figure 5.2 [4]. The transition from IN/1 to IN/1+ is twofold: (1) the transplantation of significant intelligence in the telecommunication networks; and (2) the introduction of newer digital ISDN services.

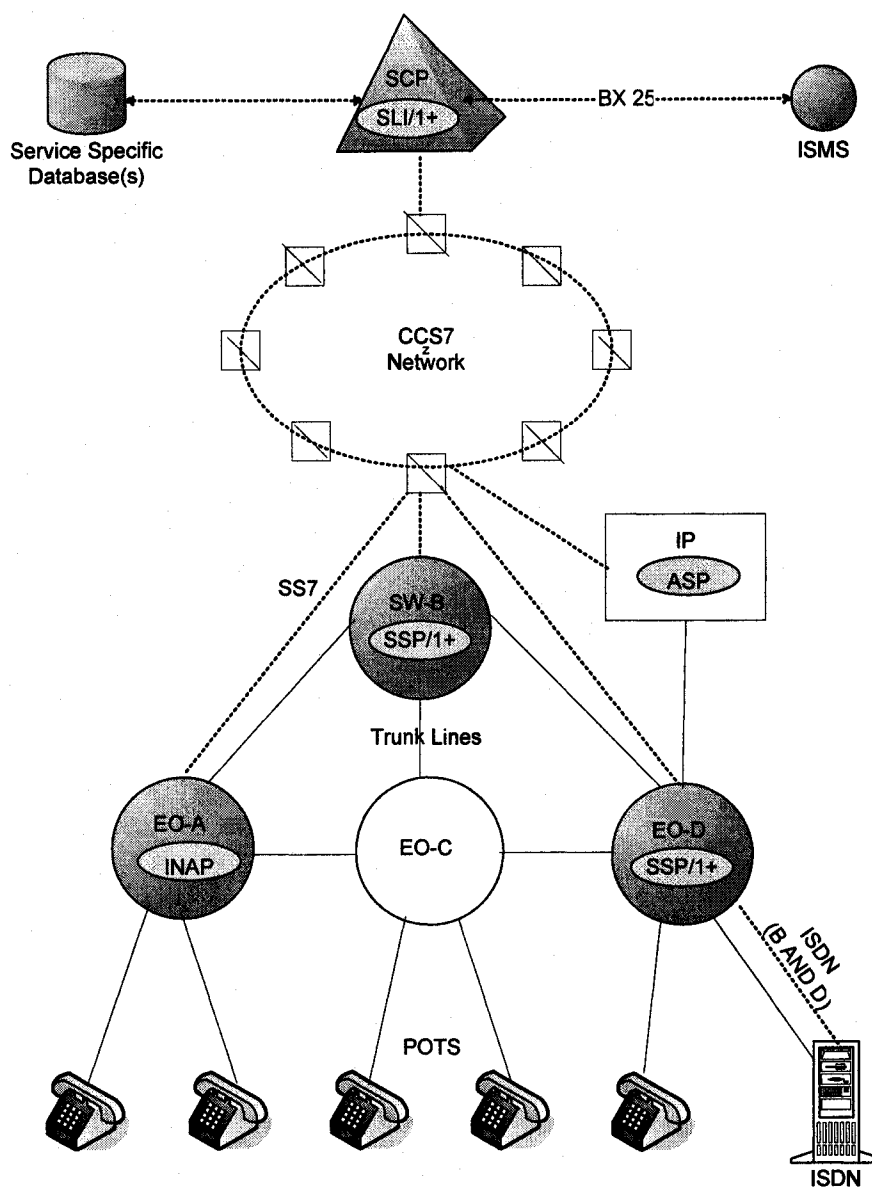


Figure 5.2: Network Architecture of IN/1+

For IN/1, IN/1+ Routine Voice and Voice-Related Services and for ISDN. The IN/1+ services are limited to SSP/1+ lines. Numerous databases are individually accessed depending upon the type of IN/1+ service invoked.

SCP = service control point; SLI/1+ = service logic interpreter/1+; LIDB = line information database; CCS7 = Common Channel Signaling 7; IP = intelligent peripheral; ASP = adjunct service point; SW = switch; SSP/1+ = service switching point/1+; ISDN = integrated services digital network; SS7 = Signaling System 7.

5.2.1. SCP/1+ (Service Control Point)

The SCP/1+ in IN/1+ is also a physical unit that contains Service Control Logic. The SCP/1+ has four basic units: (1) the physical SCP node; (2) an efficient service logic interpreter (SLI/1+); (3) service logic programs (SLPs); and (4) the IN/1+ data. The SLPs are driven by SLI/1+ to accomplish IN/1+ services.

The service logic interpreter (SLI) fir UN/1+ functions as an applications module executing numerous service logic programs (SLPs) simultaneously to perform IN/1+ services. New services should be introduced in the network by executing new SLPs, which are encoded and debugged outside of the SCP/1+ environment. The PVN support of the IN/1 is expected to be feasible in the SLI environment of the IN/1+.

5.2.2. IP (Intelligent Peripheral)

The intelligent peripheral (IP) for IN/1+ is a stand-alone, network compatible element, which can be connected to a switching system. Every IP contains an adjunct service-point (ASP) which responds to the network requests to use the resources. The IP communicates with the switch by way of its voice/data lines. The communication with STPs takes place via SS7 network. The IP is accessed by both customer and operating-company personnel.

5.2.3. SSP/1+ (Service Switching Point)

The SSP/1+ which hosts the service logic interpreter (SLC+), responds to the input, and the SLC/1+ makes contact with the IP by way of the intermediate STP/1+. The SSP/1+ module is the software program contained in the SSP switch. The software module filters out any call that does not require IN/1+ functions. The subset of SS7 that deals with the transactions capabilities applications part (TCAP) is used in the ASP-to-SCP communication via the signal transfer point in the network. The ASP module has control links to the switching fabric of the IP and to the numerous resources within the IP.

5.2.4. INAP (IN Access Point)

The Intelligent network access point (INAP) switch is a physical element which permits the triggers in the IN/1+ service requests and forwards calls to an SSP/1+ switch. If SSP/1+ facility is not available in an Central Office, the INAP logical module can be added in order to process the requests of the users. Two specific versions of INAP exist in the United States, one dealing with SS& and the other dealing with multifrequency inband signaling.

5.2.5. ISMS (Integrated Service Management Point)

The service independence architecture of IN/1+ stresses the operation system. ISMS facilitates the control by both the customer and the operating companies over many IN/1+ services. The five major functions of ISMS are as follows:

- ISMS receives/transmits data from/to the centralized administration and coordination (CA&O) pertaining to the independent networks of the participating service providers.
- ISMS exchanges updates of pertinent SCP, SSP and IP control information between the service providers so that the IN/1+ functions are transparent to the users.
- ISMS responds to the control information of its local service administration (SA) facility for updates and changes in the service environment.
- ISMS dispatches the SCP and updates it with information received from other ISMSs, CA&O facilities, and its local SA.
- ISMS dispatches the SSP and IP updates to the local service switching point and intelligent peripherals. This activity needs considerable management.

The IN/1 services are based upon programmable collection of functional components (FCs). IN/1 is a subset of IN/1+. New services offered by IN/1+ are IN/1 services plus 900, 911 and additional services provided by IPs.

5.3. Intelligent Networks/2

IN/2 contains more hardware and software components to enable flexible services. IN/1+ is a transition phase from IN/1 to IN/2. The difference between IN/1+ and IN/2 is not very significant. The physical/logical building blocks of IN/2 and their associations are depicted in Figure 5.3 [4].

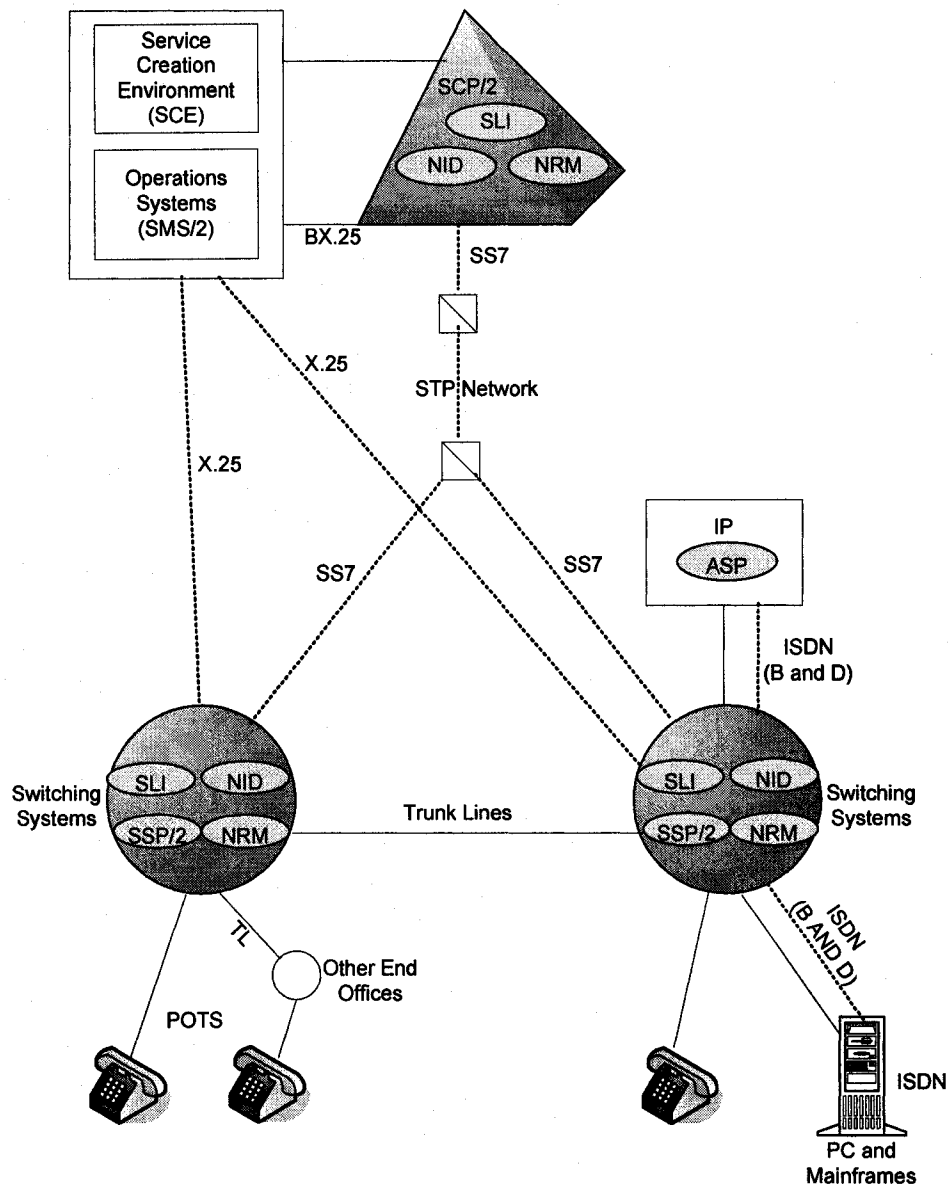


Figure 5.3: A Complete Set of Architecture of IN/2

SLI: Service Logic Interpreter; NIDB: Network Information Database; NRM: Network Resource Manager; SSP/2: Service Switching Point/2; ASP: Adjunct Service Processor; SCE: Service Creation Environment; SCP: Service Control Point; SS: Switching System; SMS/2: Service Management System/2.

From the above figure you can see that the architecture of IN/2 is very adaptable, additional elements can be added for newer services. This configuration provides some VFN functionality via the IP interconnected to the SSP/2 and the STP, thus reaching the SCP/2. The SCE (Service Creation Environment) is also a new feature of IN/2. It

provides the staff of SMS/2 with service logic programs (SLPs) to SLIs. The SLPs are an integral part of the SLIs. The service programs can easily be modified or altered to customize any service. Customizing the service is as simple as altering the program structure of the individually written service programs that are presented to the SLIs for interpretation and execution of the network instructions.

IN/2 offers business community the IN/2 and ISDN services via the same facilities. The IN/2 services are introduced via VFN, IP or UCI (Universal Customer Interface), UCI is under the jurisdiction of SMS/2. VFN is associated with a switch system for new vendor provided services. The memory administration system may or may not be necessary, depending upon the type of switch systems that is serving as the SSP/2. The final version of IN/2 (Figure 5.3 [4]) includes all logical and physical elements.

The following three essential functions provide services to IN/2:

- **Service Definition.** New services must be defined, and this is done by the service logic programmers. The SLPs is written to define the network actions specific to a particular service. The SLPs are a collection of functional components (FCs).
- **Service Interpretation.** SLI Interpret SLPs.

- **Service Logic Program Execution.** SLP must be executed to provide the new service. SSP/2 dispatches a query to SLI, queries come from SSP/2, IP or VFN. SLI interprets and executes the SLP for the requested service.

5.3.1. New Features of IN/2

VFN (Vendor Feature Node):

VFN allows outside vendor services to work in conjunction with IN/2. VFN provide services that the network may not provide due to regulatory or government constraints. For example, stock market reviews, propaganda material and telephone advertising services can be offered by outside service vendors.

The major attraction of IN/2 is the creation of new service much faster than the IN/1 type of network. The network users take advantage of the hardware facilities and software expertise through SCE to create a new service. For example, opinion-polling, gather public response for a major event, video shopping services can be created instantly.

Operations Systems (SMS/2 and SCE):

The SMS/2 handles the customer record administration, coordination and control of the network databases. The SCE provides the software environment to introduce customer-controlled capabilities and/or vendor services through the network facilities.

Coordination between the database and the network facilities is necessary to avoid conditions leading to possible “deadlock” situations.

NIDB (Network Information Database):

NIDB contains the customer-access and network connection information. The databases may be cross-queried by other modules in IN/2.

NRM (Node Resource Manager):

NRM locates and identifies the address of network resources that are required to continue call processing. NRM also provides the SLI with information required to establish a connection to a module in IN/2.

5.4. INCM and Global Intelligent Networks

Intelligent Networks have been born in other countries to provide services similar to the INs in the United States. For example, the British Telecom IN, Digital Derived Services Network (DDSN), Telefonica IN Spain, etc.

The INCM (Intelligent Networks Conceptual Model) of ITU-T has four planes for the construction of the global intelligent network, as shown in Figure 5.5 [4]:

- **The Service Plane**
- **The Global Functional Plane**
- **The Distributed Service Plane**

- **The Physical Plane**

Numerous IN capabilities are referred to as capabilities sets (CSs). Requirements for one or more of the six essential groups of functions within most INs and AINs (Advanced Intelligent Networks) are: (a) Service Creation; (b) Service Management; (c) Service Interaction; (d) Network Management; (e) Service Processing; and (f) Network Internetworking.

5.5. Advanced Intelligent Networks (AIN)

Universal information services provided by (UISN) evolved into an integral part of the AIN services and introduced in the United States in the year of 1992-98. AIN has six basic components, already commissioned into service, see Figure 5.4. They are:

5.5.1. SSP (Service Switch Points)

Hardware Aspects:

The hardware architecture of the SSP must accomplish two categorically different tasks: first, the conventional “computer-like” functions of the switch. The localized CPU controller is logically switched to interpret the op-code of the computer (within the switch). It is essential to thoroughly overhaul the control unit of the CPU functions consistent with the new op-codes for the AIN. Second, the actual logical AIN channel

switching commands (logical network channel switching functions), it is necessary to control the switching fabric. One methodology is to provide a secondary switching computer for this function, thus creating a hierarchical flow of control. This specialized computer may assume the status of a processor or an entire slave computer receiving the AIN channel switching commands. In the AIN switch, at least three distinct pathways are essential: The first pathway addresses the control signal associated with the AIN operation and functions (for example, perform a CLASS service, like identify caller). The second pathway controls the flow of data generated to actually operate the AIN (such as SS7 signals and SLI commands). The third pathway forces the hardware to perform logical channel switching (for example, completing a call on any given B or D customer channel).

Software Aspects:

The fifth and sixth generations of languages are expected to force the new SSP functionality to be more powerful and flexible. SSP functions will integrate database functions in the network language.

5.5.2. SCP (Service Control Points)

SCP contains the application programs that provide AIN services. The Service Logic Interpreter (SLI) is a resident in SCP. SCP can respond to messages from a switch and invoke the application programs.

5.5.3. STP (Service Transfer Points)

STP controls the linkages to SSP, SCP and IP (Intelligent Peripherals) through SS7 network. The advanced signaling interfaces provide the signal flow. Most switching systems have access to this network via the SS7 protocol. The communication between SSPs and their corresponding STPs is highly standardized. Similarly, the communication among the STPs is standardized. This architecture permits Local Exchange Carriers (LECs) to control the new service creation process from the AIN platforms.

5.5.4. IP (Intelligent Peripherals)

IPs are installed to perform voice and data services in the public domain. Communication with the IP may occur over the SS7 network, the trunks/lines of COs (Central Office) or even ISDN line for a distant IP.

Voice services:

- Storage and retrieval of messages
- recognition of voice and its synthesis
- code conversion between the various coding techniques (example, adaptive delta pulse code modulation (ADPCM))
- pulse code modulation (PCM)
- toll quality, μ -law /A-law companding (Two different systems used to encode voice or audio signals which involve compression of the sampled signal according to a fixed formula.)

Data services:

- protocol conversion for narrow and wideband
- data-rate conversion
- video format (NTSC- National Television System Committee), high-definition television (HDTV), still picture etc.

5.5.5. SMS (Service Management Points)

The function of SMS is intricately tied with the functions of the SCP. SMS is an off-line support facility used to enter customer data into the SCP's databases and the call-processing software into SCP. SMS communicates with the SCP through interface cards that process the BX.25 protocol used for communication between SMS and SCP.

5.5.6. AP (Adjunct Processors)

Adjuncts contain service logic and local customer data and have very localized capabilities in the SCP. Adjuncts support intensive services for centrex-type local transactions. Adjuncts are built into the AIN architecture with high-speed data or signaling links.

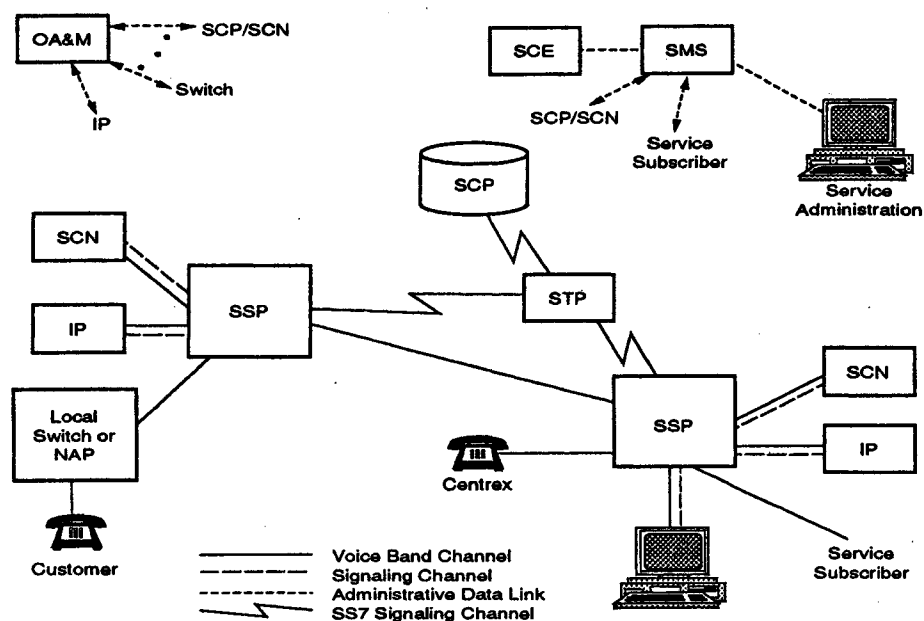


Figure 5.4: A Feasible Architecture of the Intelligent Network for using the AIN Concept
 OA&M=operations administration and maintenance; SCP=service control point;
 SCN=service circuit node; IP=intelligent peripheral; SCE=service creation environment;
 SMS=service management system; SSP=service switching point; STP=signal transfer point;
 NAP=network access point; ISDN=integrated services digital network

Two platforms exist for AIN services: Platform 0 and Platform 1.

1. Platform 0 Services: 800-type network services in the international market; PVN (Private Virtual Networks) services; 700 number (follow me, connect to the called party); calling number-based (call forwarding services); and other specialized, customized local area services.

AIN Platform 0 and its earlier version (the Advanced 800 Network) are compatible with the LECs (local exchange carrier) in the United States and with some European network owners (British Telecom, Spain's Telefonica, and Italy's Societa Italiana per l'Esercizio – SIP).

2. Platform 1 Services: Such as business and mobile wireless customers, network automatic-call distribution, CLASS (customized local area special services) can be enhanced via this platform to call forwarding on busy, customized call waiting, customized audio support and instant feature activation. Other new services such as medical, financial, etc. will be included. The emergency call forwarding service already exists.

ISDN services are also provided by AIN. When all the capabilities of ISDN unfold, the eventual users are likely to be subscribers to multimedia services, video-on-demand, and other futuristic intelligent networks. ISDN is an important network because it provides integrated service facilities for POTS (Plain Old Telephone Service),

facsimiles, PC connections (local, long distance, and global via bearer and packet-switched channels), and local area networks (LAN) services.

The emerging information networking services demand a large bandwidth from telecommunication networks for large volumes of data to be exchanged within a very short interval. Transport technologies to meet these broadband communications need SONET and ATM.

5.6. The Intelligent Networks Applications

The technological capabilities of the INs have been rapidly increasing. Information technologies bring new productivity to business, government organization, health, environment, and education.

5.6.1. Integrated Medical Systems (IMS)

Medical Systems can also benefit from INs; communication of diagnostic information is a high priority in applications of the intelligent network for medical applications. Administration is also a major application where emergency communications, diagnostic dialogs and billings can be coordinate medical evacuation.

In the integrated medical system (IMS), the processing being proposed is based on the methodology fundamental to any problem solving. First, the necessary data is collected in order to identify the problem. Once the problem is identified, a partial hypothesis or a "hunch" (intuitive pattern recognition) is made. Additional search is made based on the partial hypothesis. The existing knowledge banks are queried to categorize the problem, when the confidence level reaches a predefined level. More searches are conducted to gain additional confirmation or denial of the partial hypothesis. The eventual solution to the problem accrues after several searches.

The methodology for processing the IMS functions is to partition the procedural steps in modular, microscopic or macroscopic forms. Logical relations between these steps permit their programming. The IMS turns the problem over to a group of on-line physicians, in case of any uncertainty.

5.6.2. Processor Environment in IMS

The architecture of the CPU of any moderate speed computer is modified with enhanced memory. The enhanced memory will hold executable programs for the micro-procedures for a patient in a hospital, medical center or the country in which the procedure is going to be performed. All the sub-procedures must be assembled based upon the knowledge bases that use AI. For this reason, the software programs of IMS are quite different from that of the traditional computer systems. The assembly level procedural instructions will be tailored to fit the medical facility. Hence, it must be

facilities-dependant assemblers. This type of adaptation is routinely made for computer systems at installation time. It is also done for the switching systems when any software controlled switch for any telecommunication systems is installed.

The dependability concern is handled by dual processors and elaborates error checking. Any unexpected findings are referred to the physician team on duty. Results of procedures will be entered into a patient data base. Opinions and subjective comments will be entered onto a voice-activated message retrieval system. Pictures, X ray, and CAT scans will be entered onto a visual data base of the computer system, making the IMS a truly multimedia system.

5.6.3. Medical Computer Architecture

The medical computer architecture must focus on specific experience and knowledge. Typical data processing functions are not involved.

Medical Processor Unit (MPU) – The medical processor unit does not process data. It only generates a sequence of subprocedures for current or standard medical procedures consistent with the patient history, physician's expert system, and capability of medical facilities available in that particular environment.

The typical function of the MPU is based on knowledge of the patient and experience of the medical team in a general categorical sense and with reference to that

particular patient. For this reason the expert and knowledge-systems based programs is proposed. The micrograms in the MPU will function in three independent ways initially. First, any approved expert system data base is referred for current concepts and breakthroughs. Second, the practice of the particular physician and medical facility is referred to be consistent with the knowledge level of the physician and earlier physicians with this particular patient are referred. All the necessary checks and verifications are made before administering any procedure to a patient in view of the patient history.

The output of this MPU is a series of instructions, which is based upon opinion of the current experts, approved by a team of physician, and verified for processing and expectation by dual, independent processors. The output of the processor is a series of subprocedures that will be dispatched to the actual medical facilities after appropriate allocation existing medical resources to the patient's subprocedures.

Subprocedure Instructions – Three such categories are knowledge-based inferential instructions, search instructions, and administrative or local housekeeping instructions: (1) The knowledge structure of the cause-effect relation is queried and predictable effect is being sought; the preconditions for a given state are being investigated. (2) The search is being initiated. Two groups emerge. The first group deals with search in the knowledge domain, and the second group deals with search in the data domain. (3) The administrative functions of the local medical facility may be activated. The category of instruction is localized to the environment of the medical facilities, the personnel, the support staff, and the type of services. The input/output bus

for the other two type of instruction to avoid any possible contamination of information to and from the established knowledge bases.

Speed and Capacity of the MPU – The speed of the MPU is not crucial, except when the physicians prefer a real-time look up of how the MPU would handle a certain situation.

5.6.4. Architectural Considerations

Two different approaches to a knowledge-bank systems are possible: (1) Processor-Based, Local-Knowledge-Bank System; the processor and knowledge banks are in close proximity, such that bus lines can be extended from processors to these knowledge banks, thus, reducing the seek time in these massive information stores. (2) Distributed-Knowledge-Bank System: Many MPUs and knowledge banks are linked via a high-speed network. Isolated packets of information arrive at the knowledge banks from numerous IMSs. Every procedure is executed via an individual packet command.

5.6.5. Input/Output Consideration

Input and output of IMSs are often highly variable. Attempting to streamline the human and verbal communication appears futile. It is proposed that all the input to the IMS be via a laser-encoded, credit-card-sized, medical identification for routine cases. A short data structure of vital statistics, chronic conditions, allergies, blood type, genetic predisposition, and so on must be encoded on this card with a forward pointer to where all the patient history stored. The input processors can be located like credit card centers tied to the IMS. The output from the IMS can also have significant variations. Ranging from no action to immediate hospitalization or surgery, the IMS reaches all medical service facilities, such as drug dispensing machines, physical therapy centers, blood banks, and nursing homes. One of the possible ways of handling the outputs of the IMS is via specialized nodes created on the network. For example, if the architecture is equipped via a node for physical therapy, all requests for this service would go through this node.

5.6.6. Implementation Considerations

At the first level IMS may be fabricated by a network of general purpose computers with one knowledge machine (KM) acting as the execution unit of the knowledge-based subprocedural instructions. At the most fundamental level of software, standard packages (such as MYCIN or INTERN) may be used in the KM. A special hardware, functioning as a data base machine holds at least a subset of the medical knowledge for a subspecialty. The housekeeping functions are also handled by one general purpose computer hardware unit, with a special software for resource allocation,

billing, and patient record keeping. For specialized software deployment strategy will become essential for optimal performance. To this extent, the design of the IMS is similar to the design and deployment of any other large-scale, special-purpose computer system that has a dominant component of knowledge-processing and data base capability. National and network access is provided by the new communication protocol; embedded in any intelligent network (IN).

Coordinating these medical subprocedures with the expertise of the medical staff and the use, and availability, of medical facilities in the hospital or the medical center, becomes the crucial step in deploying the IMS in practice. Vendors may be added or deleted from the IMS to offer the most optimal and economical service.

This approach supports the hierarchical organization of medical information, its real-time access and associative searches, AI techniques, and specialized operating systems. With the cooperative role played by the interdisciplinary team of systems designers, IMSs can be as useful to the health industry as airplanes are to the transportation industry.

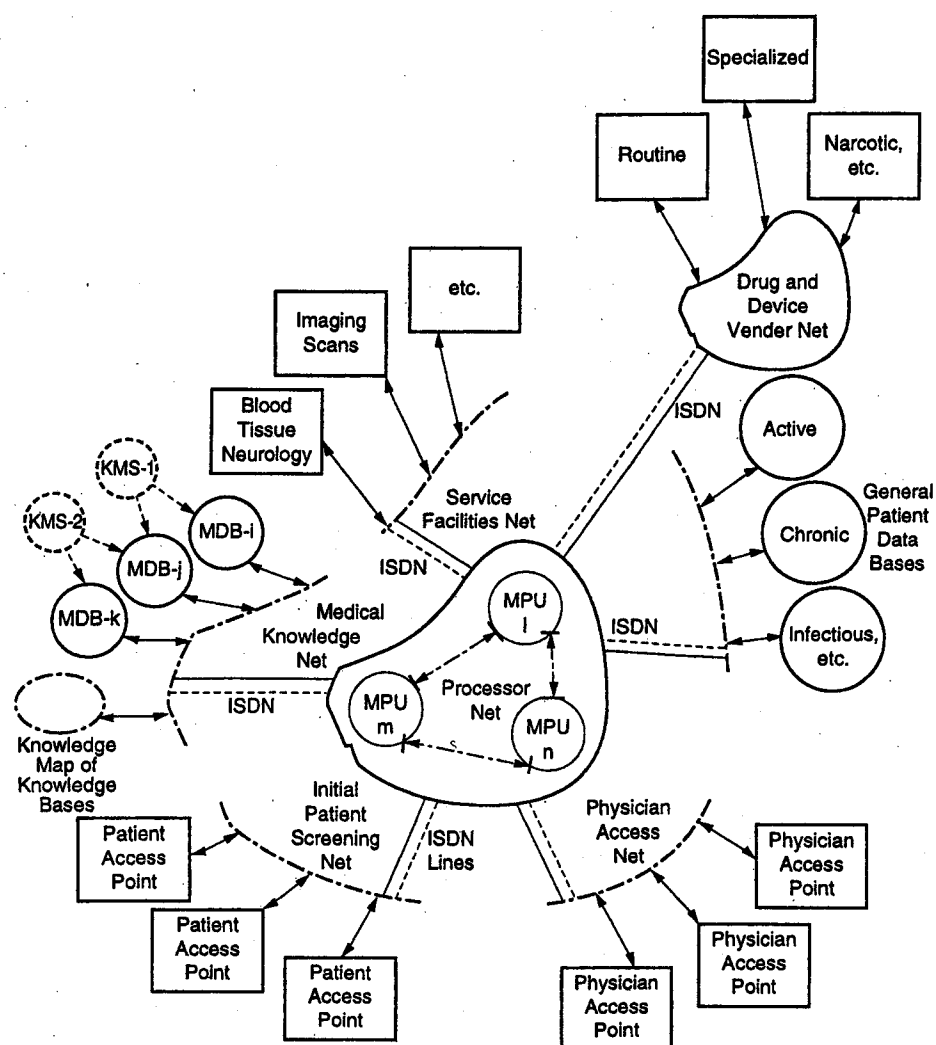


Figure 5.5: Architecture of a Network-Based Intelligent Medical System

KMS=knowledge machine(s); MPU=medical processor unit; MDB=medical data base; A batch of MPUs share the overall task of running the medical facilities of any regional area. Existing hospitals and medical centers may be networked to use their facilities optimally and economically. The resource allocation for the most expensive facilities is done by the operating system driving the processor net. Knowledge processing is also done by the processor net, thus sharing its own resources.

Chapter 6

6. MEDICAL INFORMATICS

Medical informatics is located at the intersection of information technology and the different disciplines of medicine and health care. It has both distinctly applied features and fundamental characteristics. Just as medicine it is multidisciplinary, so is medical informatics.

The domain of medical informatics is determined by the intersection of the terms “medicine” and “informatics”. The first term indicates the area of research, the second one its methodology. Medical informatics has both applied and theoretical aspects; models are developed both in applications and theoretical activities. As in all science, in medical informatics research we strive for the collection of generally applicable knowledge, so that we may use it within a particular domain: health care. In summary: In medical informatics we develop and assess methods and systems for the acquisition, processing, and interpretation of patient data with the help of knowledge that is obtained in scientific research.

In medical informatics, we deal with the entire domain of medicine and health care, from computer-based patient records to image processing and from primary care practices to hospitals and regions of health care. Some areas of the field are relatively fundamental; others have an applied character. The challenge in developing methods and systems in medical informatics is that once the systems have been made operational for one medical specialty, they can also be transferred to some other specialty. Computers and computer networks are the vehicles used to realize these goals.

6.1. Telehealth and Telemedicine

Telemedicine generally refers to the use of telecommunications and medical technologies to provide any or all of the following forms of information exchange, i.e., data, audio and/or visual communication between physician and patient or between physician and health care professional in geographically separate location and to facilitate the exchange of information for medical, health care, research and/or educational and training purposes. Such exchanges can be on-line or off-line.

6.1.1. History of Telemedicine and Telehealth

The initial idea behind telemedicine was, and still is, to overcome time and distance barriers. From inception, the focus has been on physical diagnosis and

prognosis. Physical diagnosis usually requires visual information; hence one needs a device that would enable the physician to “see” the patient. NASA developed a medical support system, which included diagnosis and treatment of in-flight medical emergencies as well as the development of complete medical delivery systems.

However, NASA was not the only one to experiment with the integration of telecommunication systems in the practice of medicine. During the late 1960s and early 1970s, others were also experimenting with telemedicine. The first telemedicine system in which there was a regular interaction between physicians and patients was installed in Boston in 1967. A radiologist who worked at the Massachusetts General Hospital (MGH) setup a diagnostic “center” in the medical station of Logan airport. Physicians passing through were invited to bring X-ray and patient data to a room on the passenger concourse. The X-rays were illuminated by an ordinary light box, scanned by a black and white television camera and the images transferred to a video monitor in the MGH’s radiology department. The physician could discuss the case with MGH radiologists via an ordinary telephone line. The first interactive video link was established between the Nebraska Psychiatric Institute in Omaha and the Norfolk State Hospital, 112 miles away. These two experiments demonstrated that it was possible to undertake remote diagnosis through interactive television and that the transmission of medical data could be accomplished successfully with out any significant loss of information in terms of its quality and detail.

The interest in telemedicine has continued to grow. Today, telecommunication networks are being developed to transmit information about patients to doctors and information from doctors to patients, faster than ever before, and eventually from any location. These same networks can be used to provide access to on-line patient records and medical libraries, to facilitate communications among medical specialists around the country, and to make available standardized medical information and insurance data more readily. Telemedicine technology is advancing and will continue to do so. Although much of the more sophisticated technologies such as virtual reality are still expensive, but the cost of some technologies is dropping, so that telemedicine should become more affordable to more people, regions and countries than ever before.

For countries with limited medical expertise and resources, telecommunication has the potential to provide a solution to some of above mentioned problems. Telemedicine services have the potential to improve both the quality of and access to health care regardless of geography. This enables the medical and health care expertise to be accessed by under-served locations. Health care professional can be more efficient. Telemedicine offers solutions for emergency medical assistance, long distance consultation, administration and logistics, supervision and quality assurance and education and training for health-care professionals and providers. Telemedicine can help in meeting the particular requirements of radiology, pathology, dermatology, traumatology and the many other medical specialties.

Especially, the developing countries have inadequate health care and medical services. Developing countries suffer from a shortage of doctors and other health care professionals. The inadequate and backward infrastructures of telecommunication, plus poor road and transport, make it even more difficult to provide health care in remote and rural areas and to transport patients properly. Where clinics and hospitals exist, they are often ill equipped, and especially, outside urban areas most of them beyond the reach of normal communications.

Developing countries face various problems in the provision of medical service and health care, including funds, expertise, resources, which relate to the lack of facilities and systems. In the developing countries, there has been a rapidly growing interest in telemedicine and telehealth as a means to ease the pressure of health care on national budgets. Some of the technologies and experiences of the developed countries of North America, Europe, Japan and Australia have considerable experience in telemedicine and telehealth could help developing countries in their desire to provide especially, primary health care.

Telemedicine mainly concerns two different aspects related respectively to telecommunication infrastructures and health care organizations. The impact of telemedicine on health care structures can be significant. The telemedicine needs to be implemented carefully and managed well. In this respect, telemedicine can be seen as a tool to reorganize or to build up new health care structures, and the success of telemedicine services will depend heavily on which technologies and services are used,

on how appropriate they are to particular countries, recognizing that the situation may differ from country to country.

6.1.2. Teleradiology

As one of the most used clinical aspects of telemedicine, teleradiology has become more advanced in the past few years. Basically, teleradiology attempts to transfer CT scans, MRI's, and/or X-rays from one location to another. These locations may include from one hospital to another, one imaging center to a hospital, and an imaging center or hospital to a physician's home. The process of sending the information from one location to another includes acquiring the images digitally, transferring the images over the computer, and eventually displaying them on video monitors. This process is called filmless teleradiology and is being implemented in many hospitals. Another option is the use of Digital Imaging. In this process, high-speed communication lines are used to transmit clearer pictures. These images can then be magnified, reduced, enhanced, and have black-white reversal in order to facilitate interpretation.

6.1.3. Telepathology

The first telepathological system was developed in the 1960's at the Massachusetts General Hospital. However, it was not explored and used until the late

1990's. Telepathology is basically the viewing of pathological specimens on monitor and is successful in alleviating the maldistribution of pathology throughout the United States.

There are two main types of telepathology. The first one is called Dynamic Imaging (DI) Telepathology, which is also known as "Real Time Video Imaging." During DI telepathology a microscope is used along with a personal computer to send images. This method is very beneficial because it is almost as the same as the usual technique of pathological examinations. The second type of telepathology is the Static Imaging (SI) Telepathology. In this form, pathologists select images, store them on a computer, and upload the image to other pathologists.

In today's health care system, there are many uses of telepathology. One is to, "provide urgent services at sites either without a pathologist or with a pathologist requiring back-up." Secondly, telepathology can, "Provide immediate access to subspecialty pathology consultants."

For example, if a primary care physician in a rural area needs a pathologist to diagnose a disease, and the nearest pathologist is over hours away, telemedicine can be an excellent alternative. Thirdly, and probably the one most often used, is to "generate second opinions." Often times, physicians are not sure if their diagnosis is correct and in order to confirm their decision, they can contact another telepathologist via telemedicine. Obviously, telepathology has become an important aspect of telemedicine in the past few years and it will even be more so in the years to come.

6.1.4. Teledermatology

Teledermatology is the use of telemedicine for dermatological consultations. This is very important because of the fact that twenty percent of general practitioners are unable to diagnose twenty of the most common dermatological diseases. During a teledermatological consultation, a dermatologist will evaluate clinical and laboratory data, make a diagnosis, and prescribe therapy for patients located at a distance. Ultimately, the goal is to provide care to dermatology patients in underserved areas, improve the quality of care, and decrease the cost of care.

The major advantage to using this type of technology is the fact that the consulting physician can ask the patient and referring physician any questions that may be essential to making a diagnosis and carrying out treatment. Both technologies use two very useful instruments, a dermatoscope and microscope.

Developing countries are inevitably short of high-level hospital infrastructures. The geographical distribution of existing hospitals and health services is far from ideal; usually they are limited to urban centers at county or district level. Referral hospitals with competent medical specialists, and using state of the art medical technology, such as scanners and other sophisticated diagnostic equipment are non-existent, or whether they do exist are best confined to a single metropolis.

There is a growing recognition in many countries of the importance of placing greater priority on the provision of primary health care as a way of minimizing the cost of direct medical care. The World Health Organization principles of primary health care are based on accessibility, continuity and comprehensiveness and are an important foundation on which to build. The approach should be both top-down and bottom-up. A strategic view of the service as a whole is necessary to determine the development of the telemetric framework and infrastructure required to support the overall goals of the services.

6.2. Classification Systems – Medical Codes

Classification is the grouping together of similar items. In a classification of diseases and operations, similar diseases and operations are grouped together. Code numbers are also assigned in classification systems to represent the grouping. A common example of a classification of diagnoses and procedures is the International Classification of Diseases, Ninth Revision, and Clinical Modification (ICD-9-CM).

During the late 1940s and into the 1960s, hospitals began to use the International Classification of Diseases (ICD). This system was derived from the Bertillon classification adopted in 1891 that classified causes of death. About every ten years, the World Health Organization revises ICD for use throughout the world. This international version does not completely meet the needs in the United States because of its emphasis

on more acute, infective processes seen in underdeveloped countries rather than the chronic diseases, such as arteriosclerosis and hypertension. For that reason the ICD-9, the modified of WHO revision is used in the United States for coding death certificate and ICD-9-CM is a clinical modification of WHO's ICD, 9th revision namely, to serve as useful tool in the area of classification of morbidity data for indexing of medical records, medical care review, ambulatory and other medical care programs, as well as for basic health statistics. A newer procedure coding system ICD-10 also developed in 1992.

Currently, ICD-9-CM is used to code diagnoses for all types of patients and procedures for hospital inpatients. The National Center for Health Statistics is responsible for change in the disease classification and the Health Care Financing Administration is responsible for changes in procedure classification.

6.2.1. ICD-9-CM Diagnosis Codes

The ICD-9-CM classification has three digit diagnostic codes with 1 or 2-digit optional sub-codes. All possible 999 codes are utilized within the system, and are broken down by 17 categories.

6.2.2. ICD-9-CM Procedure Codes

Two supplementary classifications for medical procedures are included in ICD-9-CM:

- A V-supplementary classification of procedures, each procedure may be identified by a two-position code with 2- position sub-codes.
- An E-supplementary classification of external causes of injury and poisoning (E800 through E999).

6.2.3. Drug Codes

The format of National Drug Code (NDC) is 5-digit code, 3-digit sub-Code and 2-digit dosage/packaging-size code; the full identification number for the drug code is 10-digit long. The NDC is updated and distributed by HHS in collaboration with drug manufacturers for the following:

- Drugs
- Biologicals

6.2.4. CPT Codes

The combination of Health Care Financing Administration Common Procedure Coding System (HCPCS) as updated and distributed by HHS; and Current Procedure Terminology (CPT) as updated and distributed by AMA for physician and other health related services, these services include, but not limited to, the following:

- Physician Services
- Physiological & Occupational Therapy Services
- Radiological Services
- Clinical Laboratory Tests
- Other Medical Diagnostic procedures
- Hearing and Vision Services
- Transportation Services including ambulance

CPT is a system listing and coding of procedures and services performance by physicians. Each procedure is identified by five-digit code.

Inclusion of a description and its associated specific five-digit identifying code number in CPT is generally based upon the procedure being consistent with contemporary medical practice being performed by physicians in clinical practice in multiple locations.

In addition to the coding rules included in CPT, the HCFA has developed documentation guidelines for the CPT evaluation and management (E & M) codes. The Evaluation and Management section (99201-99499) are used to report nonprocedural physician services performed in the office, emergency department, hospital patient, and other settings.

The CPT 2005 contains 8568 codes and descriptors. The AMA through its Department of CPT Editorial Research and Development provide staff support to the process of adding modifying and deleting the CPT codes.

The HCPCS as updated and distributed by HCFA, HHS for all other substances, equipment, supplies or other items used in health care services, these items include, but not limited to, the following:

- Medical Supplies
- Orthopedic & Prosthetic Devices
- Durable Medical Equipment

The ICD-9-CM Diagnosis Codes, ICD-9-CM Procedure Codes and NDC Drug Codes, were adopted by the insurance companies, hospitals and physicians, these codes and all other objects (their subdivision) in the system associated with these codes.

6.3. Medical Knowledge Base

Medical knowledge base consists of: (1) medical data, (2) medical information, and (3) medical rules.

6.3.1. Medical Data

Medical Data is comprised of Patient's Personal data (ID, Name Age, Address, etc.) and patient's physical data (weight, height, etc.).

6.3.2. Medical Information

Medical Information is comprised of Medical Diagnosis and Medical Treatment. Medical Diagnosis is made based on patient's symptoms and the results of analysis. Medical Treatment is a generalization of Medical Procedure and Drug. The Procedure has such attributes as Procedure codes and Equipment. Medical procedure may be further subdivided into Therapeutically Physical Therapy, Surgery and Rehabilitation Procedure, and each of these procedures may be subdivided further into relevant subclasses.

6.3.3. Medical Rules

Medical rules are descriptions of processes to convert medical data, such as symptoms, analysis results and physician's observation into medical diagnosis and treatment.

The proposed research for my dissertation will base on the medical knowledge base system described as above and utilizes the Intelligent ATM to develop an intelligent medical network system for the health care application.

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Chapter 7

7. INTELLIGENT MEDICAL NETWORKS

The real scenario of a patient experience is one in which, on arriving at the physician's office, hospital, or another health care setting, the patient is quickly identified as someone who has been seen before. The patient's previous laboratory tests and imaging results are reviewed. Test results combined with other clinical data already collected into the system and are reviewed in minutes. If necessary, the data are transferred through a network to a specialist for immediate feedback. The referring specialist views the information simultaneously while conferring by phone. New treatment is documented and automatically added to the central repository, from which the patient as well as other care providers can retrieve information in the future. Special reminders and flags that alert the physician about special conditions that need to be investigated, such as abnormal laboratory results and new reports on patient's allergies, are automatically presented when the patient's care information is retrieved.

In this chapter, I present my research work: IM_ATM (Intelligent ATM Medical Network).

7.1. Intelligent Medical ATM (IM_ATM) Networks

The standard for ATM (Asynchronous Transfer Mode) networks was developed with the goal of designing a single networking technology that would transport real time audio and video as well as text, e-mail, and image files. ATM communications will enable the universal networking of health science and other libraries locally, statewide, nationally and globally. ATM technology provides the bandwidth on demand and offers the advantage of being able to automatically adapt network bandwidth to match that required by the telemetrically applications. The wide range of informational resources could be accessed on demand from locations throughout the health care industry. Many healthcare companies that need a backbone for sending the above applications have already adopted ATM.

ATM is a high-speed, low-delay multiplexing and fast switching technology network, while the cells resemble conventional packets, the 53-byte fixed length cell simplifies the protocol, so transmission can take place on hardware, rather than a software basis. ATM switches have been designed with simplicity and speed in mind. The approach taken is very soft and modular which gives a flexible approach to cell switching with a minimum of special hardware.

ATM Networks, though sophisticated, are not intelligent at the current state. ATM has no direct bearing on IN (Intelligent Network, SSP, STP, SCP, IP, or FN) functions. My research work introduces Intelligent Medical Networks to the existing

AIN (Advanced Intelligent Networks). IM_ATM switch, yet to be developed can be modified from the existing standard ATM routers/switches which will replace the switch in the AIN architecture for services (Figure 5.4 [4]). I apply the intelligent IM_ATM switch architecture to many different medical networks which I design and create for the study. One of the two bits from the header of the ATM cell which reserved for future use is utilized to differentiate whether the request is for the Intelligent Medical Network or not, see Figure 7.1.

The first two octets from payload are reserved for future intelligent services, and the following information will also be included in the payload: 5-digit Current Procedure Terminology (CPT) codes described in Chapter six are used to define various medical procedures. Patient ID is the patient's social security number will be protected by using modern encryption methods, such as Triple Data Encryption Standard (3DES) or Advanced Encryption Standard (AES) for use within the patient record. Optical fiber can be used for the transmission medium of the IM_ATM networks.

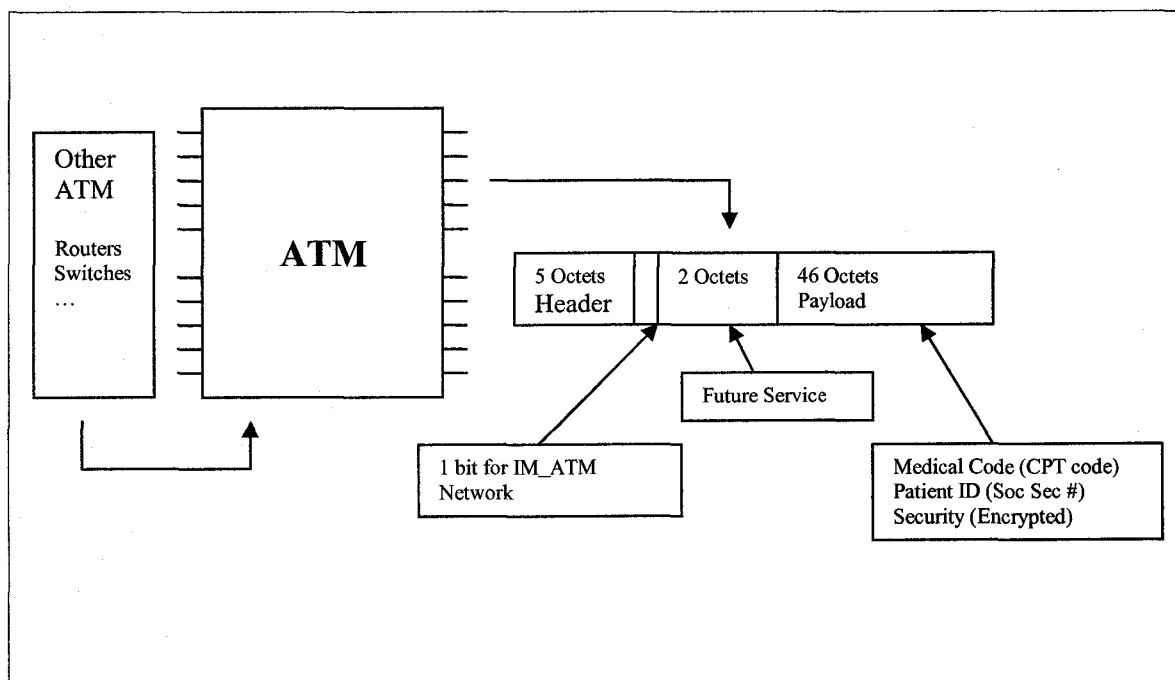


Figure 7.1: Architecture of IM_ATM (Intelligent Medical ATM) Networks

7.2. Methodology

The following distinct models are designed and created for the experiment: (1) **5-Node Regional Networks**; (2) **9-Node Regional Networks**; (3) **Single WAN Clouds with 5 Nodes and 20VCs (Virtual Circuits) National Networks**; (4) **Three WAN Clouds International Networks**; and (5) **Five WAN Clouds Global Networks**.

Regional Networks -- 5-Nodes and 9-Nodes Regional Networks

There are Physician, Patient, Insurance, Hospital, and Laboratory in 5-Node (Figure 5.5) networks and Physician, Patient, Insurance, Imaging, Insurance, Consultant, Hospital, Pharmacy, and Laboratory in 9-Node network model (Figure 5.5). Every node sends messages to every other node for each percentage of the bandwidth. In these models, only 800B and 400B message sizes are chosen for representing of the traditional networks and 46B for the IM_ATM and Experimental IM_ATM networks. Simulation data for Packets Created, Packets Delivered, and Packets Dropped are collected. The total and average number of Packets Created, Packets Delivered, and Packets Dropped, ratio of Packets Dropped/Created and Packets Dropped/Delivered, Average Packets Delay (milliseconds) and Average Percentage of Link and Channel Utilization are calculated.

National Networks – 5 Nodes and 20 Virtual Circuits

The Global Networks contain four international networks: NA (North America), BA (Baltic Nations), EU (Europe), and EA (East Asia), and each international network consists four WANs (cities), and each of them consists many regional networks. For examination of the national networks, I created a single WAN cloud network for each of them. NA (North America) is selected for illustration. The five nodes (cities) are Boston, New York, Washington, Chicago, and Seattle. There are ten message sources and ten destinations for the WAN cloud, namely, Boston-New York, Boston-Washington, Boston-Chicago, Boston-Seattle, New York-Washington, New York-Chicago, New York-Seattle, Washington-Chicago, Washington-Seattle, and Washington-Seattle. There are twenty VCs (virtual circuits) altogether when each node sends messages to every other destination.

International Networks – Three WAN Clouds

There are two-tier WAN Clouds in this model, the first level GLOBE WAN cloud connects other two second level international WANs, namely, NA (North America), and EU (Europe), and each second level node connected to a third level node represented a major city in the each region, each international WAN has five destination nodes here, every node is sending messages to every destination in this model. The cities are Boston, New York, Chicago, Washington, and Seattle in NA and London, Paris, Frankfurt, Brussel, and Milano in EU (Europe). The simulations are performed for 400B and 800B messages. Only a few samples are chosen for the presentations.

Global Networks –Five WAN Clouds

There are three level WAN Clouds in this model. The first level GLOBE WAN in the center connects other four second level International WANs, namely, NA (North America), BA (Baltic Nations), EU (Europe), and EA (East Asia). And each second level WAN node in turn is connected to a third level node which represents a major city in each region. Every node is sending messages to every destination node in this model. The major cities are Boston, New York, Chicago, Washington, and Seattle in NA, Tallinn, Kaunas, Riga, and Vilnius in BA, London, Paris, Frankfurt, Brussel, and Milano in EU (Europe), Beijing Tokyo, Singapore, and HK in EA.

Message size of 100B, 200B, 400B, 500B, and 1000B are examined for the traditional networks and 46B for the IM_ATM. 1.544Mbps is selected as link rate.

128kbps, 256kbps, and 512kbps bandwidths are chosen for calculations of the network traffic. All the simulations are performed for 60%, 75% and 90% link capacities.

Chapter 8

8. SIMULATION AND SIMULATION TOOLS

8.1. Simulation Environment

Hardware: PC: Machine Model, IBM 229213UXPS

Processor Type: Pentium(R) IV CPU, 1.50 GHz 1500

Memory: 512 MB

Hard Drive: 18535 MB Capacity

Software: **Operating System:** MS Windows XP, Version 5.1.

Simulation Software: COMNET IIITM, CACI Products Company, University Edition, Release 2.1.

8.2. Simulation Tools

Two simulation tools are explored. OPNET and COMNET III programs are for simulation of the network's detailed operation and performance.

8.3. OPNET

OPNET was originally developed in MIT and was introduced in 1987 as the first commercial network simulator. It offers a highly graphical interface that facilitates object-oriented modeling of hierarchical network models.

A standard distribution of OPNET contains models of most standard communication technologies like Ethernet, FDDI, ATM, etc.

- **OPNET Network Model:** OPNET Network Models define the position and interconnection of communicating entities, or nodes. Each node is described by a block structured data flow, or OPNET Node Model, which typically depicts the interrelation of processes, protocols, and subsystems. OPNET Network Models may represent LAN's, MAN's, WAN's, on-board vehicular networks, or any combination thereof. Sub-network objects can be used to structure an unlimited topology hierarchy within any Network Model.

- **OPNET Network Editor:** OPNET Network Editor graphically captures the physical topology of a communication network. Networks consist of node and link objects, which are graphically assembled and parameterized via pop-up dialog boxes. To create node objects, users select node types from a library of example and user-defined models.
- **OPNET Node Editor:** The OPNET Node Editor graphically captures node architectures, which are diagrams of data flow between modules typically representing hardware and software subsystems. Module types include processors, queues, and traffic generators, receivers, and transmitters. Processors are general modules that provide complete flexibility in protocol and algorithm specification. The functionality of processors and queues objects is defined using OPNET Process Models.
- **OPNET Processor Editor:** The OPNET Processor Editor uses a state-transition diagram approach to support specification of any type of protocol, resource, application, algorithm, or queuing policy. States and transitions graphically define the progression of a process in response to simulated events. Once a set of OPNET Network, Node, and Process Models are fully defined, users can run simulation studies based via the OPNET Animation Viewer, and plot statistical performance measurements based on simulation studies of the OPNET Analysis Tool.

- **OPNET Processor Editor:** A probe represents a request by the user to collect a particular piece of data within a simulation. Standard and user-specified probes can be inserted at any point in a model to collect statistics. Simulation output collected by probes can be displayed graphically, viewed numerically, or exported to other software packages.
- **OPNET Processor Editor:** The simulation Editor provides a convenient environment for configuring and running a simulation or a group of simulations. Simulation sets are defined by selecting the network model to be executed and then specifying values for input parameters such as seed, duration, and output file names for probed data.
- **OPNET Analysis Tool:** The OPNET Analysis Tool provides a graphical environment that allows users to view and manipulate data collected during simulation runs. Standard and user-specified probes can be inserted at any point in a model to collect statistics. Simulation output collected by probes can be displayed graphically viewed numerically, or exported to other software packages.

8.3.1. COMNET III

COMNET III is a graphical package used to model, analyze and predict the performance characteristics of computing and communication networks. COMNET III can be used to model both Wide Area Networks and Local Area Networks. COMNET III models may contain both types of facilities in one integrated model. It can also provide detailed modeling of network node logic. A node's computers, their I/O subsystems, their databases and the applications which run on the computers can all be modeled. COMNET III is also a performance analysis tool for computer and communication networks. Based on a description of a network, its control algorithms and workload, it simulates the operation of the network and provides measures of network performance. Network descriptions are created graphically through a highly intuitive interface that speeds model formulation and experimentation.

COMNET III is designed to accommodate a variety of network topologies and routing algorithms:

- LAN, WAN and Internetworking systems
- Circuit, message, and packet switching networks
- Connection-oriented and connectionless traffic
- Static, adaptive and user-defined algorithms

COMNET III is used to simulate the network's detailed operation producing dynamic animation and reports depicting network performance. It also predict end-to-end delays, throughput, and utilization of link, buffers and processors reproducing random, bursty

traffic patterns to view peaks and valleys of traffic and not just snapshots and average. It pinpoints sources of delays and bottlenecks.

COMNET III could be used to simulate the intelligent ATM network because of its capability to simulate both the packet-switched and circuit-switched traffic on the same platform. Hence, COMNET III is chosen for study the experiments of my work.

The topology of a network is defined by three basic components: (a) nodes to represent hardware (computers or switches), (b) links that carry traffic between nodes, and (c) arcs to associate nodes to links. In addition to the basic nodes and links, we have Subnet and Transit Net for modeling independent routing domains and hierarchical topology, and the WAN Cloud for modeling wide-area-network services.

8.2.2.1. Nodes

COMNET III has three basic node types: (1) Processing Node, (2) Computer Group Node, and (3) Network Device Node. A Processing Node is used for the modeling of end systems such as computers, printers, facsimile machines, or any general piece of network hardware. A processing node acts as the origin of destination for message traffic, runs applications, and/or acts as a switching point within a network. A processing node contains an internal processor. The processor is used for processing of application and traffic sources that may run on that node. Computer Group Nodes model computers. They can generate or receive traffic like processing nodes. Computer groups are

restricted to modeling end systems because they can only be sources or sinks for traffic. Network Device Nodes model hardware used for routing traffic, including routers, hubs, and switches. The network device node is similar to processing node in that it can source or sink traffic and run applications that utilize the internal processor and internal storage. However, it adds a model for any internal bus structure for moving traffic between input and output ports.

All three types of node, can be sources of traffic and resources for workload, they can accept sources of traffic and applications. To model application, these nodes include a command repertoire as well as parameter.

8.2.2.2. Links

There are two classes of link models available in COMNET III: (1) Point-To-Point links represent a channel between only two nodes. These links model communication channels between any two nodes. Typically, these connections are dedicated lines such as a serial line or a dedicated line connection, between routers in wide-area or multihop networks. WAN Cloud model provides access links to the WAN service by using a variation of point-to-point link available inside the cloud; and (2) Multiaccess links model various protocols for sharing a single medium with multiple nodes.

WAN Clouds are used to model WAN services such as frame relay, cell relay, and packet switching. A WAN Cloud has an internal topology consisting of Access Links and Virtual Circuits (VCs). Virtual Circuits are abstract models of sets of switches and links and connect to Access Links only. Access Links are special case of a Point-To-Point link that works with the WAN Cloud.

8.2.2.3. Arcs

Two types of arcs are available in COMNET III: **(1) Diagonal Arc and (2) Horizontal/Vertical Arc**. The arcs show which nodes use links and they model the node's port connection to the link. In the backbone and subnet topologies, the arcs connecting the links to nodes represent the connections at the nodes that interface to the link media. The arcs are editable to set parameters for the port such as delay, input and output buffers and for the link.

8.3. Simulation Topology

Star Topology is chosen for modeling all the following networks; 5-Node Regional Networks, 9-Node Regional Networks, Single WAN Cloud with 5 Nodes and 20 Virtual Circuits, Three International WAN Clouds, and 5 Global WAN Clouds.

8.4. Simulation Methodology

For the purpose of study, 128kbps, 256kbps, and 512kbps bandwidths are further divided into three percentage of capacities; 60%, 75%, and 90% for all types of networks: Regional, National, International, and Global networks.

8.4.1. Link Utilization

There are three categories included in the links: (1) Channel Utilization, (2) Utilization by Application, and (3) Utilization by Protocol.

(1) Channel Utilization

The channel utilization provides the breakdown of the utilization rates for links used to carry connectionless and VC messages. It presents the number of link layer frames delivered and resent due to error, and transmission delays and link utilization.

(2) Utilization by Application

The utilization by application provides a breakdown of link usage by application for connectionless and virtual circuit messages. In this category the number of packets delivered, packets/second, bytes delivered, kilobits/second delivered, the percentage of

bytes in the category and the link utilization percentage produced by packets, are observed.

(3) Utilization by Protocol

The utilization by protocol report provides a breakdown of link usage by protocol. The statistics in this category are identical to those in Utilization by Application.

8.4.2. Wide Area Networks Modeling

WAN Cloud is available in COMNET III for modeling WAN services in terms of Access Links and Virtual Circuits (VCs). WAN Clouds are used to model frame relay, cell relay, and packet switching services. WAN Cloud behaves similarly to the link objects in that it delivers frames and models the delay of these frames across the network. The cloud's internal structure is defined using Access Links and VCs. VCs are abstract models of sets of switches and links and connect to Access Links only. The Access Link is a special case of a Point-To-Point link that works with the WAN Cloud. They provide the point-of-presence to the WAN cloud. Outside the WAN Cloud (backbone) the connection between a processing node and the WAN Cloud is through an Access Point. An Access Point represents an Access Link in the cloud. We have three types in WAN clouds: (1) Frame Delay by VC, the frame delays by VC presents data for the frame delay and burst size for each VC in a WAN cloud. The frame delay data are for all the frames that the WAN cloud successfully delivers, (2) Frame Counts by VC, The frame count by VC provides the throughput measure for each virtual circuit both in terms of the

number of frames that the virtual circuit accepted or dropped and the number of kilobits accepted or dropped, and (3) Access Link Statistics, The access link statistics are data/statistics for each access link in a WAN cloud. Each access link has two rows: the first is for the entry (source) link and the second is for exit (destination) link. No buffer is modeled for the entry link.

8.4.3. Message and Response Sources Delay

We have three categories in sources: (1) Message Delay; (2) Messages Delivered; and (3) Packet Delay.

(1) Message Delay

Message delay is the time between creating the first packet of the message on the originating node and the time that the originating node is notified that the message has been assembled by the destination. For each destination, the number of messages has been completely assembled at the destination. Messages are broken into packets at the source node according to the transport protocol characteristics and then each packet is sent to the destination.

(2) Messages Delivered

The Message Delivery data show on the delay before the message is reassembled by the destination; that is the time between creating the first packet of the message on the

originating node and the time of receiving the last packet on the destination node. The message may still be worked on by the source after the message is delivered because of retransmissions, waiting for acknowledgements, or for modeling the close-sequence of the connection, but these values are not factored into the message delivered delay.

(3) Packet Delay

The Packet Delay data are a summary of the number of packets created, delivered, resent, or dropped for each message and response source. It also provides the average and maximum packet delay. Packet Delay is the time between creating a packet on the originating node and the time of receiving the packet at the destination node.

Chapter 9

9. SIMULATION AND SIMULATION RESULTS

In this chapter, both the traditional frame-relay and my newly developed cell-relay IM_ATM (Intelligent Medical ATM) networks are created for testing, compared, and analyzed for their limitations and merits. For each type of the aforementioned networks, I design, and create five different network models for the study. They are: 1) Five-Node Regional Networks, 2) Nine-Node Regional Networks, 3) Single WAN-Cloud National Networks, with five nodes and 20 Virtual Circuits, 4) Three WAN-Cloud International Networks, each with four nodes, and 5) Five WAN-Cloud Global Networks, each with 4 nodes.

For the experiments, bandwidth of 128kbps, 256kbps, and 512kbps are selected; link speed of 1.544Mbps with capacity of 60%, 75%, and 90% are used; different message size (100B, 200B, 400B, and 800B) for the traditional and 46B for the IM_ATM are chosen for the test.

The simulation results are compared, analyzed, and presented for both traditional and newly developed IM_ATM networks.

Poisson distribution is chosen for the IAT (Inter Arrival Time), the IAT is determined by using bandwidth and the message size; there are 5 seconds warm up length and 240 seconds replication length for all the simulations.

For ease of analysis and cross comparison, spread sheets and graphs are presented for all statistics of Received Message Counts, Frames Delivered, Frames Dropped, Channel Utilization and Packets Created, Delivered, Dropped, and Packets Delays, and Access Link Stats for the applications. Because of huge volumes of the data gathered from the result of the simulations, some of the simulation runs are presented from sections 9.1 to 9.4.

9.1. Regional Networks

Two models are designed and created for the regional networks, namely: five-node and nine-node regional networks. Only the results of 400 and 800 bytes message sizes for the traditional and 46 bytes for IM_ATM and Experimental IM_ATM networks are chosen for presentations.

9.1.1. Regional Networks – Five-Node

There are five nodes in this model which representing the Physician, Patient, Insurance, Hospital, and Laboratory networks. There are five nodes in each network, one source each node, each source is sending information to every other respective destination.

Simulation data are collected for Packets Created, Packets Delivered, and Packets Dropped. Total number of Packets Created, Packets Delivered, and Packets Dropped, ratio of Packets Dropped/Created and ratio of Packets Dropped/Delivered, Average Packets Delay (milliseconds) and Average Maximum Packets Delay (milliseconds) are gathered. The statistic results are shown from Tables 9.1 to 9.15 and graphs are depicted from Figures 9.1 to 9.22.

Analysis: Packets Created, Delivered, Dropped, Dropped/Created, and Dropped/Delivered

Bandwidth – 128kbps, 256kbps and 512kbps, Message Size - 800B

The average number of packets created is 735, 1218, and 2056, packets delivered is 681, 872, and 1030, and packets dropped is 54, 346, and 1026 for 60%, 75% and 90% capacities, respectively. The ratio of packets dropped/created is 7.38%, 28.40%, and 49.91%, and packets dropped/delivered is 7.97%, 39.66%, and 99.64% for the same capacities of 128kbps.

The average number of packets created for 256kbps and 512kbps is equal to that of 128kbps. The reason for this is that the same message size and constant IAT, the number of packets created remain constant even though the bandwidth increased to 512kbps. However, the number of packets delivered increased to 694, 950, and 1219, and packets dropped to 41, 268, and 837 for 60%, 75% and 90% capacities, respectively. Packets Delivered increase by 1.91% at 60% capacity, 8.94% at 75% and 18.35% at 90%, the packets dropped decreased by 24.07%, 22.54%, and 18.42%, The ratio of packets dropped/created is 5.61%, 22.03%, and 40.71%, and packets dropped/delivered 5.95%, 28.25%, and 68.65% decrease from the 128kbps because of the higher availability of the network bandwidth. These statistics are given from Tables 9.1 to 9.4 and graphs are depicted in Figures 9.1 to 9.5.

Bandwidth – 128kbps, 256kbps and 512kbps, Message Size - 400B

The average number of packets created is 1497, 2412, and 3949, delivered 1341, 1745, and 2070 and dropped 156, 667 and 1878 for 60%, 75% and 90% capacities,

respectively. The ratio of packets dropped/created is 10.42%, 27.66%, and 47.57%, and packets dropped/delivered is 11.63%, 38.24%, and 90.73% for the same capacities of 128kbps.

The average number of packets created for 256 and 512kbps is also equal to that of 128kbps. The reason for this is that the same message size and IAT, the number of packets created remain constant even though the bandwidth increased to 256kbps and 512kbps. However, the number of packets delivered is 1371, 1881, and 2435, and packets dropped 126, 531, and 1514 for 60%, 75% and 90% capacities, respectively. Packets Delivered increased by 2.24% at 60% capacity, 7.80% at 75% and 17.63% at 90%, the packets dropped decreased by 23.81%, 25.61%, and 24.04%, The ratio of packets dropped/created is 8.42%, 22.02%, and 38.34%, and packets dropped/delivered is 9.20%, 28.24%, and 62.18% decrease from the 128kbps because of the higher availability of the network bandwidth. These statistics are given from Tables 9.3 and 9.4 and graphs are depicted in Figures 9.6 and 9.10.

Regional Networks	Message + Response Sources: Packet Delay								
Bandwidth:128kbps	5 Nodes, Warm Up: 5/s, Replication: 240/s								
Message Sizes: 800B	Packets Created			Packets Delivered			Packets Dropped		
Origin/Destination	60%	75%	90%	60%	75%	90%	60%	75%	90%
Physician Src									
Lab	800	1199	2103	746	876	1052	54	323	1051
Hospital	754	1155	2041	701	857	1003	53	298	1038
Patient	724	1235	2090	685	881	987	39	354	1103
Insurance	760	1303	2074	701	961	1050	59	342	1024
Lab Src									
Physician	670	1186	1747	620	841	964	50	345	783
Hospital	666	1301	1830	628	946	997	38	355	833
Patient	742	1226	1869	683	880	1032	59	346	837
Insurance	686	1241	1861	635	892	982	51	349	879
Hospital Src									
Physician	760	1437	2273	695	936	1111	65	501	1162
Lab	796	1365	2272	716	935	1081	80	430	1191
Patient	799	1325	2249	736	843	1089	63	482	1160
Insurance	795	1340	2252	735	905	1070	60	435	1182
Patient Src									
Physician	738	1048	2066	691	833	985	47	215	1081
Lab	688	1042	2102	644	717	1054	44	325	1048
Hospital	691	1072	2056	646	863	1019	45	209	1037
Insurance	688	1020	2006	627	793	999	61	227	1007
Average:	735	1218	2056	681	872	1030	54	346	1026
	Dropped/Created			Dropped/Delivered					
Ratio:	7.38%	28.40%	49.91%	7.97%	39.66%	99.64%			

Table 9.1: Regional Networks (5 Nodes) - Packets Created, Delivered, Dropped, Dropped/Created, and Dropped/Delivered for 800B Message

Regional Networks	Message + Response Sources: Packet Delay (Cont'd)								
Bandwidth: 256kbps	5 Nodes, Warm Up: 5/s, Replication: 240/s								
Message Sizes: 800B	Packets Created			Packets Delivered			Packets Dropped		
Origin/Destination	60%	75%	90%	60%	75%	90%	60%	75%	90%
Physician Src									
Lab	800	1199	2103	762	949	1234	38	250	869
Hospital	754	1155	2041	722	908	1184	32	247	857
Patient	724	1235	2090	695	966	1161	29	269	929
Insurance	760	1303	2074	721	1047	1225	39	256	849
Lab Src									
Physician	670	1186	1747	633	911	1132	37	275	615
Hospital	666	1301	1830	642	1014	1186	24	287	644
Patient	742	1226	1869	708	941	1203	34	285	666
Insurance	686	1241	1861	647	963	1114	39	278	747
Hospital Src									
Physician	760	1437	2273	707	1020	1326	53	417	947
Lab	796	1365	2272	729	1024	1319	67	341	953
Patient	799	1325	2249	745	917	1309	54	408	940
Insurance	795	1340	2252	747	1000	1285	48	340	967
Patient Src									
Physician	738	1048	2066	697	887	1193	41	161	873
Lab	688	1042	2102	647	883	1227	41	159	875
Hospital	691	1072	2056	656	912	1212	35	160	844
Insurance	688	1020	2006	639	859	1192	49	161	814
Average:	735	1218	2056	694	950	1219	41	268	837
	Dropped/Created			Dropped/Delivered					
Ratio:	5.61%	22.03%	40.71%	5.95%	28.25%	68.65%			

Regional Networks	Message + Response Sources: Packet Delay								
Message Sizes: 800B	5 Nodes, Warm Up: 5/s, Replication: 240/s								
Average Packet Delay	Packets Created			Packets Delivered			Packets Dropped		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	735	1218	2056	681	872	1030	54	346	1026
256kbps	735	1218	2056	694	950	1219	41	268	837
512kbps	735	1218	2056	694	950	1219	41	268	837
	Dropped/Created			Dropped/Delivered					
128kbps	7.38%	28.40%	49.91%	7.97%	39.66%	99.64%			
256kbps	5.61%	22.03%	40.71%	5.95%	28.25%	68.65%			
512kbps	5.61%	22.03%	40.71%	5.95%	28.25%	68.65%			

Table 9.2: Regional Networks (5 Nodes) - Average Packets Created, Delivered, Dropped, Dropped/Created, and dropped/Delivered for 800B

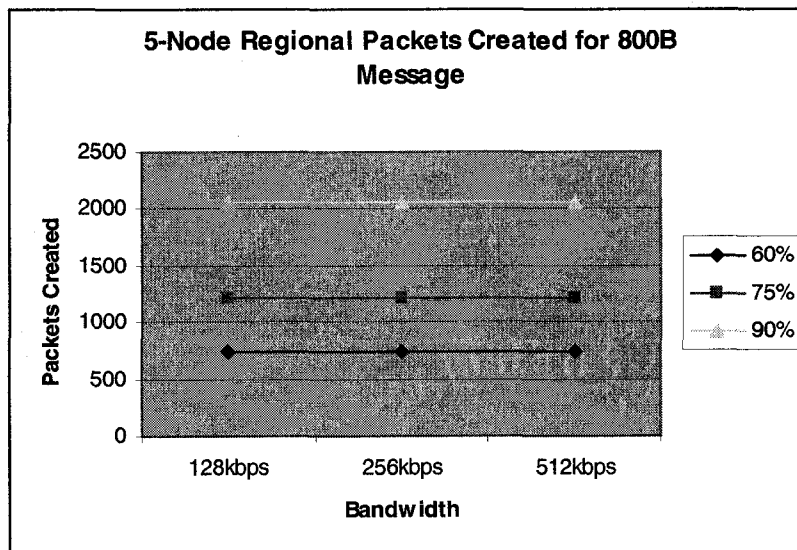


Figure 9.1: Regional Networks (5 Nodes) - Average Packets Created for 800B Message

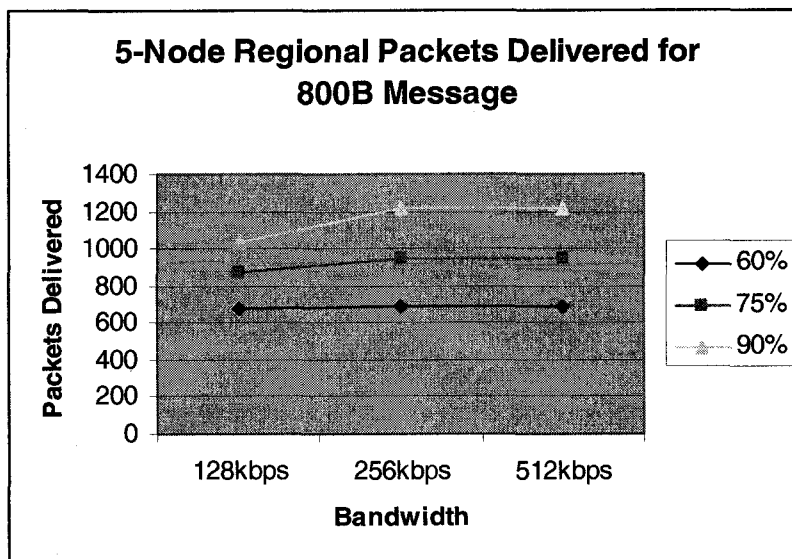


Figure 9.2: Regional Networks (5 Nodes) - Average Packets Delivered for 800B Message

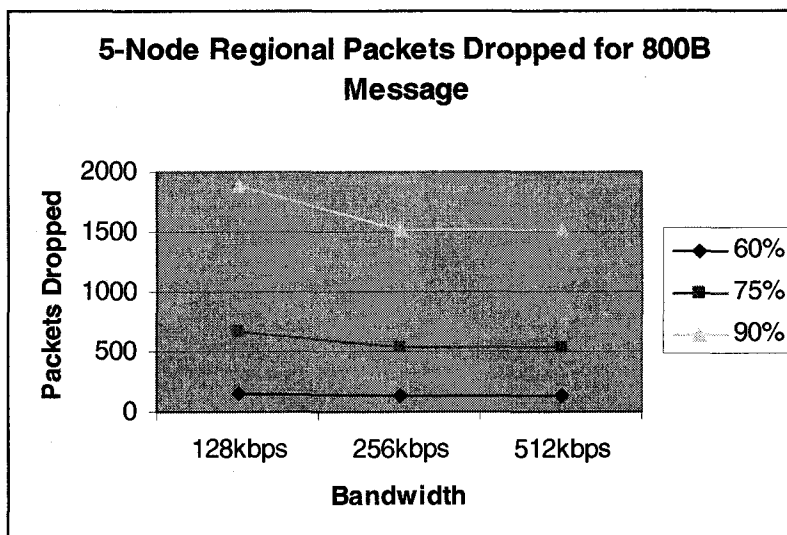


Figure 9.3: Regional Networks (5 Nodes) - Average Packet Dropped for 800B Message

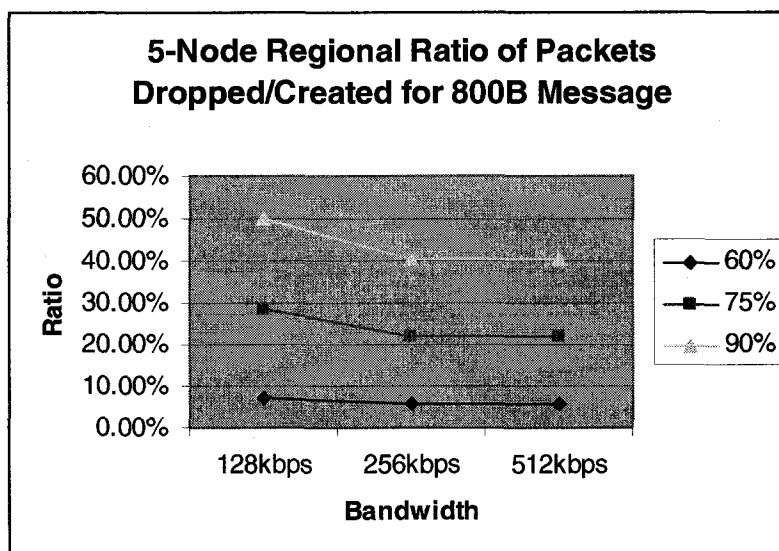


Figure 9.4: Regional Networks (5 Nodes) – Ratio, Packet Dropped/Created for 800B Message

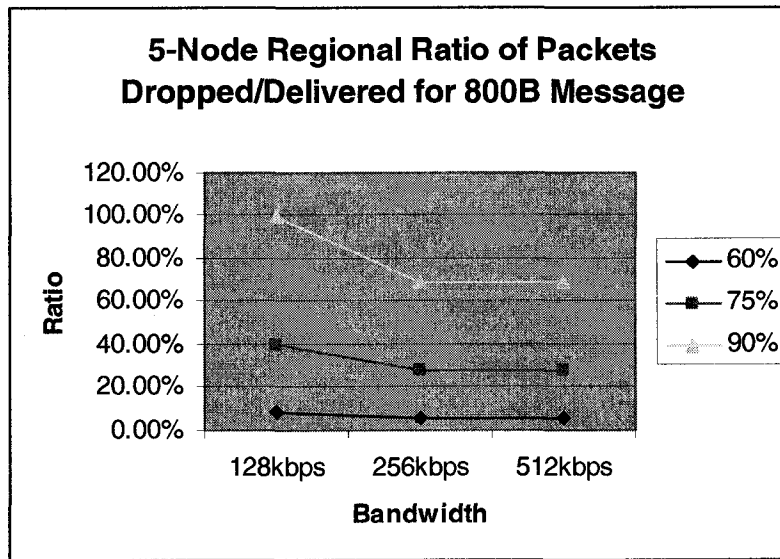


Figure 9.5: Regional Networks (5 Nodes) – Ratio Packet Dropped/Delivered for 800B Message

Regional Networks	Message + Response Sources: Packet Delay								
Bandwidth: 128kbps	5 Nodes, Warm Up: 5/s, Replication: 240/s								
Message Sizes: 400B	Packets Created			Packets Delivered			Packets Dropped		
Origin/Destination	60%	75%	90%	60%	75%	90%	60%	75%	90%
Physician Src									
Lab	1596	2219	4116	1396	1621	1990	200	598	2126
Hospital	1602	2238	4171	1418	1679	2130	184	559	2041
Patient	1682	2288	4109	1487	1676	2078	195	612	2031
Insurance	1568	2270	4125	1387	1702	2078	181	568	2047
Lab Src									
Physician	1397	2692	3864	1332	1816	2073	65	876	1791
Hospital	1369	2681	3881	1296	1871	2009	73	810	1872
Patient	1382	2639	3767	1305	1792	2050	77	847	1717
Insurance	1405	2716	3662	1218	1899	2014	187	817	1648
Hospital Src									
Physician	1440	2440	4046	1210	1785	2068	230	655	1978
Lab	1489	2334	4039	1264	1698	2081	225	636	1958
Patient	1441	2449	4013	1441	1795	2064	0	654	1949
Insurance	1439	2311	4109	1214	1671	2214	225	640	1895
Patient Src									
Physician	1556	2318	3875	1404	1742	2106	152	576	1769
Lab	1522	2382	3799	1389	1765	2027	133	617	1772
Hospital	1545	2299	3829	1305	1683	2053	240	616	1776
Insurance	1513	2311	3773	1386	1719	2089	127	592	1684
Average:	1497	2412	3949	1341	1745	2070	156	667	1878
	Dropped/Created			Dropped/Delivered					
Ratio:	10.42%	27.66%	47.57%	11.63%	38.24%	90.73%			

Table 9.3: Regional Networks (5 Nodes) - Packets Created, Delivered, Dropped, Dropped/Created and Dropped/Delivered for 400B Message

Regional Networks	Message + Response Sources: Packet Delay (cont'd)								
Bandwidth: 256kbps	5 Nodes, Warm Up: 5/s, Replication: 240/s								
Message Sizes: 400B	Packets Created			Packets Delivered			Packets Dropped		
Origin/Destination	60%	75%	90%	60%	75%	90%	60%	75%	90%
Physician Src									
Lab	1596	2219	4116	1451	1765	2339	145	454	1777
Hospital	1602	2238	4171	1467	1803	2484	135	435	1687
Patient	1682	2288	4109	1534	1814	2413	148	474	1696
Insurance	1568	2270	4125	1431	1826	2435	137	444	1690
Lab Src									
Physician	1397	2692	3864	1344	1993	2448	53	699	1416
Hospital	1369	2681	3881	1300	2027	2395	69	654	1486
Patient	1382	2639	3767	1312	1944	2370	70	695	1397
Insurance	1405	2716	3662	1325	2049	2370	80	667	1292
Hospital Src									
Physician	1440	2440	4046	1266	1931	2477	174	509	1569
Lab	1489	2334	4039	1308	1821	2489	181	513	1550
Patient	1450	2449	4013	1278	1951	2461	172	498	1552
Insurance	1439	2311	4109	1262	1793	2597	177	518	1512
Patient Src									
Physician	1556	2318	3875	1423	1851	2459	133	467	1416
Lab	1522	2382	3799	1416	1893	2377	106	489	1422
Hospital	1545	2299	3829	1421	1800	2408	124	499	1421
Insurance	1513	2311	3773	1399	1828	2433	114	483	1340
Average:	1497	2412	3949	1371	1881	2435	126	531	1514
	Dropped/Created			Dropped/Delivered					
Ratio:	8.42%	22.02%	38.34%	9.20%	28.24%	62.18%			

Regional Networks	Message + Response Sources: Packet Delay								
Message Sizes: 400B	5 Nodes, Warm Up: 5/s, Replication: 240/s								
Average Packet Delay	Packets Created			Packets Delivered			Packets Dropped		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	1497	2412	3949	1341	1745	2070	156	667	1878
256kbps	1497	2412	3949	1371	1881	2435	126	531	1514
512kbps	1497	2412	3949	1371	1881	2435	126	531	1514
	Dropped/Created			Dropped/Delivered					
128kbps	10.42%	27.66%	45.77%	11.63%	38.24%	90.73%			
256kbps	8.42%	22.02%	38.34%	9.20%	28.24%	61.18%			
512kbps	8.42%	22.02%	38.34%	9.20%	28.24%	61.18%			

Table 9.4: Regional Networks (5 Nodes) - Average Packets Created, Delivered, Dropped, Dropped/Created and Dropped/Delivered for 400B

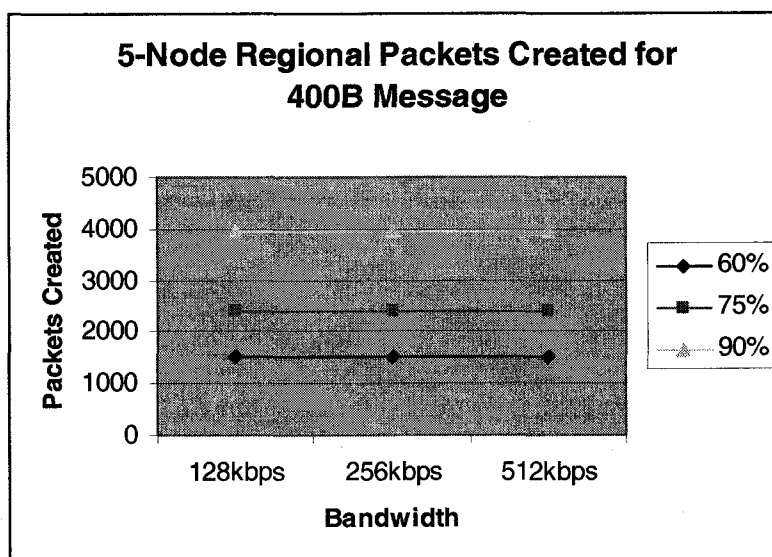


Figure 9.6: Regional Networks (5 Nodes) – Packets Created for 400B Message

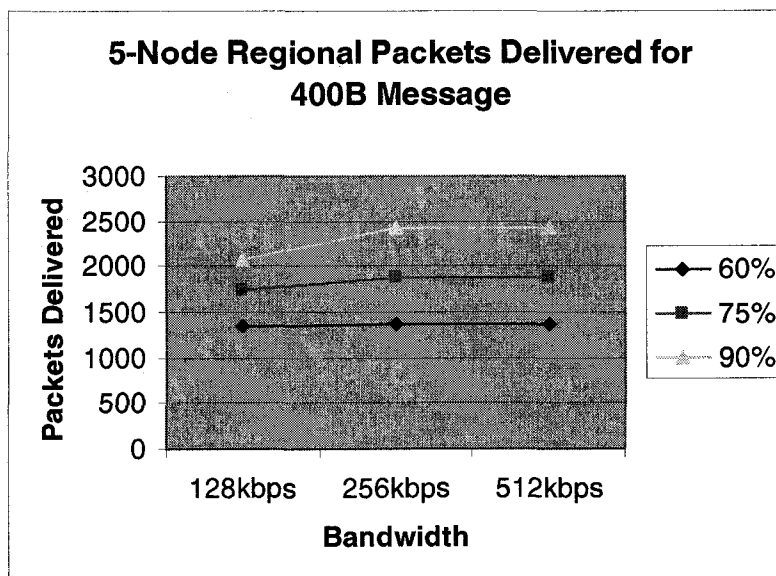


Figure 9.7: Regional Networks (5 Nodes) – Packet Delivered for 400B Message

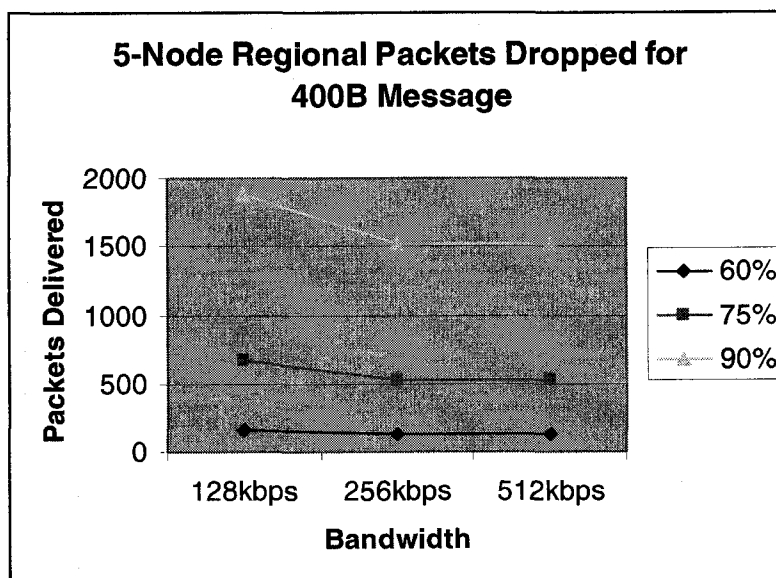


Figure 9.8: Regional Networks (5 Nodes) – Packets Dropped for 400B Message

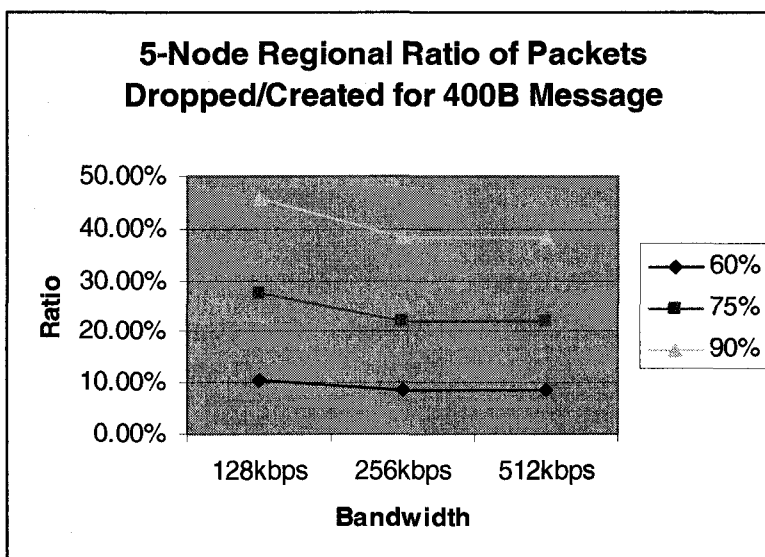


Figure 9.9: Regional Networks (5 Nodes) – Ratio Packet Dropped/Created for 400B Message

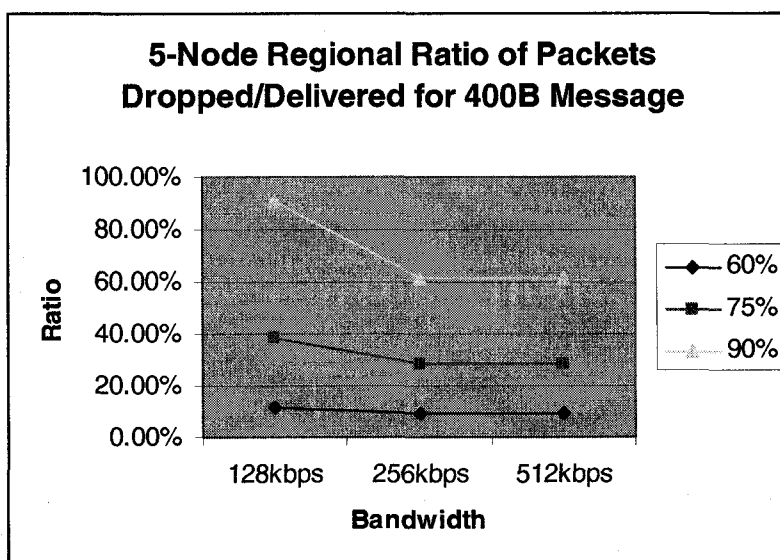


Figure 9.10: Regional Networks (5 Nodes) – Ratio Packet Dropped/Delivered for 400B Message

Average Packet Delay (MS) – 800B and 400B Messages

For 800B message size, the average packet delay is 662, 855, and 1065 (128kbps), 291, 351, and 399 (256kbps), and 145, 175, and 199 (512kbps). The decrease in packet delay is 56.04%, 58.95%, and 62.53% from 128kbps to 256kbps and 50.17%, 50.14%, and 50.12%, from 256kbps to 512kbps. For 400B message size, the average packet delay is 611, 787, and 958 (128kbps), 270, 326, and 368 (256kbps), and 135, 163, and 184 (512kbps). The decrease in packet delay is 55.81%, 58.57%, and 61.58% from 128kbps to 256kbps, and 50% for all three capacities from 256kbps to 512kbps. These statistics are given from Tables 9.5 and 9.6 and graphs are depicted in Figures 9.11 and 9.13.

Regional Networks	Message + Response Sources: Average Packet Delay (MS)					
5 Nodes	Warm Up: 5/s, Replication: 240/s					
Message Size	800B			400B		
Bandwidth: 128kbps	60%	75%	90%	60%	75%	90%
Origin/Destination						
Physician Src						
Lab	702	874	1099	675	779	954
Hospital	690	888	1015	660	775	918
Patient	670	867	1086	664	788	938
Insurance	665	896	1029	679	787	970
Lab Src						
Physician	626	839	1037	579	836	1003
Hospital	674	839	1046	549	811	938
Patient	678	842	1082	561	780	973
Insurance	664	858	1038	566	721	974
Hospital Src						
Physician	659	871	1090	593	786	1017
Lab	694	871	1111	597	807	940
Patient	654	886	1106	593	812	951
Insurance	652	906	1069	582	780	977
Patient Src						
Physician	631	800	1042	618	772	980
Lab	658	804	1125	626	787	928
Hospital	652	811	1030	614	782	922
Insurance	626	833	1041	616	788	940
Average:	662	855	1065	611	787	958

Table 9.5: Regional Networks (5 Nodes) - Average Packet Delay (MS) for 800B and 400B Message

Regional Networks	Message + Response Sources: Packet Delay(MS) (cont'd)					
5 Nodes	Warm Up: 5/s, Replication: 240/s					
Message Size	800B			400B		
Bandwidth:256kbps	60%	75%	90%	60%	75%	90%
Origin/Destination						
Physician Src						
Lab	301	350	403	292	327	374
Hospital	303	353	392	287	321	360
Patient	286	356	398	289	327	362
Insurance	284	353	390	298	322	371
Lab Src						
Physician	279	351	401	262	343	375
Hospital	296	345	397	243	320	366
Patient	298	349	391	252	320	371
Insurance	295	356	391	252	331	374
Hospital Src						
Physician	290	350	409	273	323	372
Lab	307	357	402	264	327	368
Patient	283	358	395	269	337	367
Insurance	287	364	402	261	326	367
Patient Src						
Physician	278	341	412	270	316	367
Lab	289	343	398	275	324	372
Hospital	290	337	399	268	320	366
Insurance	282	346	397	266	327	360
Average:	291	351	399	270	326	368

Regional Networks 5 Nodes	Message + Response Sources: Average Packet Delay(MS) (Cont'd)					
5 Nodes	Warm Up: 5/s, Replication: 240/s					
Message Size	800B			400B		
Bandwidth: 512kbps	60%	75%	90%	60%	75%	90%
Origin/Destination						
Physician Src						
Lab	151	175	202	146	164	187
Hospital	151	177	196	143	161	180
Patient	143	178	199	145	164	181
Insurance	142	177	195	149	161	185
Lab Src						
Physician	140	175	201	131	172	187
Hospital	148	173	199	122	161	183
Patient	149	175	195	126	160	186
Insurance	148	178	195	126	165	187
Hospital Src						
Physician	145	175	205	137	162	186
Lab	154	179	201	132	163	184
Patient	132	179	198	134	169	183
Insurance	144	182	201	131	163	184
Patient Src						
Physician	139	171	206	135	158	184
Lab	144	171	199	138	162	186
Hospital	145	168	199	134	160	183
Insurance	141	173	198	133	163	180
Average:	145	175	199	135	163	184

Regional Network	Message + Response Sources: Packet Delay(MS)					
5 Nodes	Warm Up: 5/s, Replication: 240/s					
Message Size	800B			400B		
Bandwidth Capacity	60%	75%	90%	60%	75%	90%
128kbps	662	855	1065	612	788	958
256kbps	291	351	399	270	326	368
512kbps	145	175	199	135	163	184

Table 9.6: Regional Networks (5 Nodes) - Average Packet Delay (MS) for 800B and 400B Message

Average Packet Delay (MS) - IM_ATM and Experimental IM_ATM

Bandwidth – 128kbps-512kbps, Message Size – 46B (800B)

The average packet delay (in milliseconds) for IM_ATM is 6.822, 8.020, and 10.508 (128kbps), 3.447, 4.378, and 5.226 (256kbps), and 1.722, 1.877, and 2.627 (512kbps), the decrease in packet delay is 49.91%, 45.41, and 35.80% from 128kbps to 256kbps, and 50.00%, 57.12%, and 61.05% from 256kbps to 512kbps. The average packet delay for Experimental IM_ATM is 38.61, 65.01, and 96.63 (128kbps), 18.81, 32.50, and 54.75 (256kbps), and 9.63, 16.25, and 26.44 (512kbps). The decrease in packet delay is 51.28%, 50%, and 43.34% from 128kbps to 256kbps, 48.80%, 50.00%, and 51.70% from 256kbps to 512kbps.

Bandwidth – 128kbps-512kbps, Message Size – 46B (400B)

The average packet delay (MS) for IM_ATM is 13.20, 17.67, and 25.40 (128kbps), 6.601, 8.842, and 12.702 (256kbps), and 3.300, 4.419, and 6.351 (512kbps). The decrease in packet delay is 50.00% for all three capacities from 128kbps to 256kbps, and from 256kbps to 512kbps. The average packet delay (MS) for Experimental IM_ATM is 77.88, 126.13, and 194.11 (128kbps), 38.81, 63.06, and 96.63 (256kbps), and 19.38, 31.5, and 48.31 (512kbps). The decrease in packet delay for all three capacities is about 50% from 128kbps to 256kbps, and from 256kbps to 512kbps.

Average Percentage of Utilization - IM_ATM and Experimental IM_ATM

Networks

Bandwidth – 128kbps-512kbps, Message Size – 46B (800B)

The average percentage of utilization for IM_ATM is 0.817%, 1.335%, 2.128% (128kbps), 0.409%, 0.666%, and 1.063% (256kbps), and 0.205%, 0.334%, and 0.535% (512kbps). The decrease in utilization is 49.94%, 50.11%, and 50.05% from 128kbps to 256kbps, and 49.88%, 49.85%, and 49.67% from 256kbps to 512kbps.

The average utilization (%) for Experimental IM_ATM is 3.499%, 5.743%, 9.612% (128kbps), 1.950%, 2.962%, and 4.816% (256kbps), and 0.871%, 1.436%, and 2.408% (512kbps). The decrease in utilization (%) is 44.27%, 48.42%, and 49.90% from 128kbps to 256kbps, and 55.33%, 51.52%, and 50.00% from 256kbps to 512kbps.

Bandwidth – 128kbps-512kbps, Message Size – 46B (400B)

The average percentage of utilization for Experimental IM_ATM is 7.171%, 11.492%, 18.674% (128kbps), 3.614%, 5.732%, and 9.337% (256kbps), and 1.798%, 3.268%, and 4.669% (512kbps). The decrease in utilization (%) is 49.60%, 50.12%, and 50.00% from 128kbps to 256kbps, and 52.25%, 43.00%, and 49.95% from 256kbps to 512kbps

Regional Networks	Message + Response Sources: Average Packet Delay(MS)								
Link: 1.544Mbps	5 Nodes, Warm Up: 5/s, Replication: 240/s								
Message Size	800B			IM_ATM			Experimental IM_ATM		
Bandwidth:128kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Origin/Destination									
Physician Src									
Lab	702	874	1099	7.220	8.840	9.670	40	64	117
Hospital	690	888	1015	6.740	9.580	10.170	38	63	114
Patient	670	867	1086	6.620	7.910	9.500	37	62	124
Insurance	665	896	1029	7.200	8.110	10.560	38	65	112
Lab Src									
Physician	626	839	1037	6.530	7.750	11.000	37	70	94
Hospital	674	839	1046	6.910	7.980	10.040	37	68	94
Patient	678	842	1082	6.450	7.500	10.540	38	72	93
Insurance	664	858	1038	6.490	8.181	10.510	39	72	95
Hospital Src									
Physician	659	871	1090	7.250	8.040	11.500	40	74	110
Lab	694	871	1111	6.710	7.590	11.260	43	70	107
Patient	654	886	1106	7.300	8.630	11.130	39	75	109
Insurance	652	906	1069	6.260	7.540	9.903	39	70	109
Patient Src									
Physician	631	800	1042	6.570	7.760	10.627	37	53	106
Lab	658	804	1125	6.910	7.340	10.620	38	54	104
Hospital	652	811	1030	6.950	7.710	10.630	38	53	103
Insurance	626	833	1041	7.044	7.860	10.470	39	55	102
Average:	662	855	1065	6.822	8.020	10.508	38.61	65.01	105.81

Table 9.7: Regional Networks (5 Nodes) - Packet Delay (MS) for 800B, IM_ATM, and Experimental IM_ATM

Regional Networks	Message + Response Sources: Average Packet Delay(MS) (Cont'd)								
Link: 1.544Mbps	5 Nodes, Warm Up: 5/s, Replication: 240/s								
Message Size	800B			IM_ATM			Experimental IM_ATM		
Bandwidth: 256kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Origin/Destination									
Physician Src									
Lab	301	350	403	3.594	4.419	4.840	19	32	58
Hospital	303	353	392	3.286	4.790	5.086	19	32	57
Patient	286	356	398	3.530	3.950	4.750	18	32	62
Insurance	284	353	390	3.420	4.049	5.280	19	32	56
Lab Src									
Physician	279	351	401	3.332	3.880	5.500	18	35	55
Hospital	296	345	397	3.390	3.980	5.200	18	34	54
Patient	298	349	391	3.490	3.780	5.270	19	36	54
Insurance	295	356	391	3.240	4.090	5.250	19	36	55
Hospital Src									
Physician	290	350	409	3.680	3.970	5.750	19	37	53
Lab	307	357	402	3.430	3.770	5.630	19	35	52
Patient	283	358	395	3.500	4.270	5.570	19	37	51
Insurance	287	364	402	3.552	3.770	4.951	19	35	51
Patient Src									
Physician	278	341	412	3.306	3.880	5.314	19	27	55
Lab	289	343	398	3.386	3.670	5.310	19	27	54
Hospital	290	337	399	3.611	3.850	5.320	19	26	54
Insurance	282	346	397	3.400	9.928	5.235	19	27	55
Average:	291	351	399	3.447	4.378	5.266	18.81	32.50	54.75

Regional Networks	Message + Response Sources: Average Packet Delay (MS) (cont'd)								
Link: 1.544Mbps	5 Nodes, Warm Up: 5/s, Replication: 240/s								
Message Size	800B			IM_ATM			Experimental IM_ATM		
Bandwidth: 512kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Origin/Destination									
Physician Src									
Lab	151	175	202	1.797	2.210	2.418	10	16	29
Hospital	151	177	196	1.643	1.396	2.543	10	16	28
Patient	143	178	199	1.764	1.977	2.375	9	16	31
Insurance	142	177	195	1.711	1.025	2.640	9	16	28
Lab Src									
Physician	140	175	201	1.643	1.938	2.750	9	17	24
Hospital	148	173	199	1.693	1.992	2.510	9	17	24
Patient	149	175	195	1.805	1.888	2.636	9	18	23
Insurance	148	178	195	1.700	2.045	2.627	10	18	24
Hospital Src									
Physician	145	175	205	1.666	1.986	2.875	9	19	27
Lab	154	179	201	1.687	1.897	2.814	10	17	27
Patient	132	179	198	1.746	2.131	2.783	9	19	27
Insurance	144	182	201	1.621	1.887	2.476	10	17	27
Patient Src									
Physician	139	171	206	1.842	1.941	2.657	10	13	26
Lab	144	171	199	1.713	1.835	2.655	11	14	26
Hospital	145	168	199	1.751	1.927	2.658	10	13	26
Insurance	141	173	198	1.776	1.964	2.617	10	14	26
Average:	145	175	199	1.722	1.877	2.627	9.63	16.25	26.44

Regional Networks	Message + Response Sources: Average Packet Delay (MS) (cont'd)								
Link: 1.544Mbps	5 Nodes, Warm Up: 5/s, Replication: 240/s								
Message Size	800B			IM_ATM			Experimental IM_ATM		
Bandwidth Capacity	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	662	855	1065	6.882	8.020	10.508	38.61	65.01	96.63
256kbps	291	351	399	3.447	4.378	6.746	18.81	32.50	54.75
512kbps	145	175	199	1.722	1.877	2.627	9.63	16.25	26.44

Table 9.8: Regional Networks (5 Nodes) - Average Packet Delay (MS) for 800B, IM_ATM, and Experimental IM_ATM

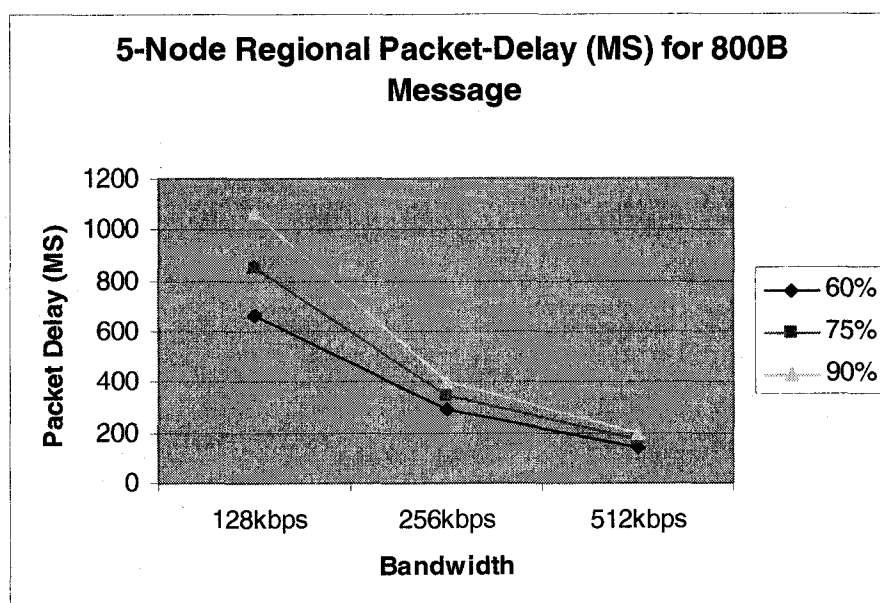


Figure 9.11: Regional Networks (5 Nodes) - Average Packet Delay (MS) for 800B Message

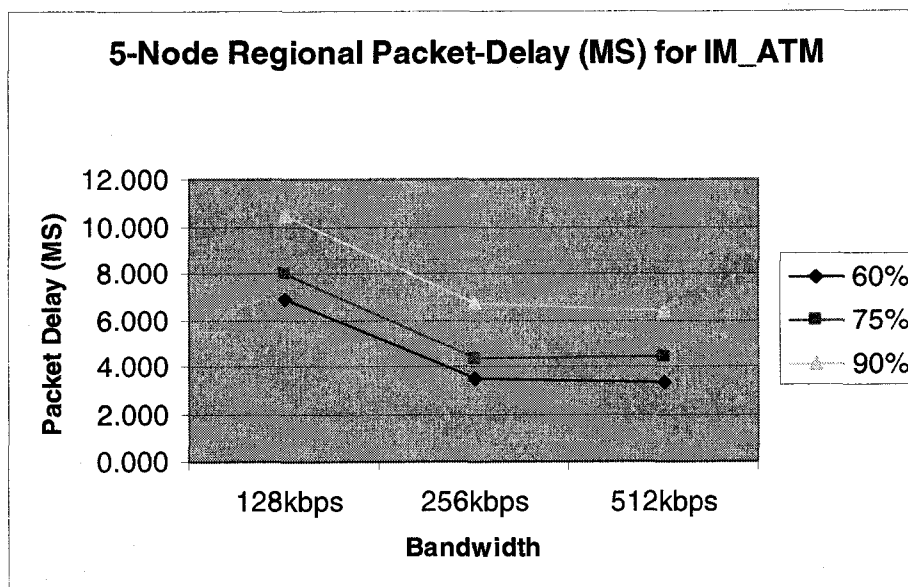


Figure 9.12: Regional Networks (5 Nodes) - Average Packet Delay (MS) for IM_ATM

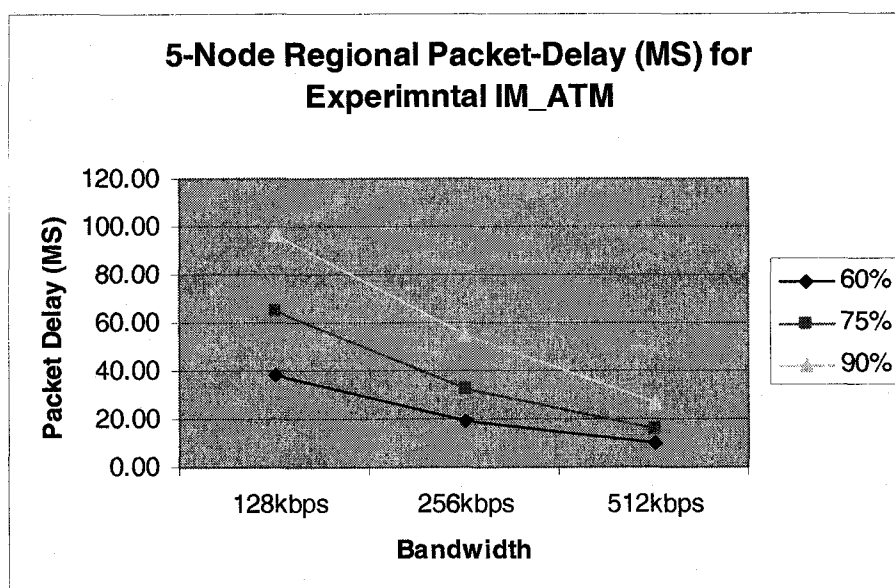


Figure 9.13: Regional Networks -Average Packet Delay (MS) for Experimental IM_ATM

Regional Networks	Message + Response Sources: Average Packet Delay (MS)								
Link: 1.544Mbps	5 Nodes, Warm Up: 5/s, Replication: 240/s								
Message Size	400B			IM_ATM			Experimental IM_ATM		
Bandwidth: 128kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Origin/Destination									
Physician Src									
Lab	675	779	954	12.410	17.910	27.023	82	117	213
Hospital	660	775	918	11.890	17.790	27.560	80	113	205
Patient	664	788	938	11.570	19.560	27.260	81	118	208
Insurance	679	787	970	12.060	20.400	27.800	83	114	205
Lab Src									
Physician	579	836	1003	13.530	16.660	25.910	67	149	194
Hospital	549	811	938	12.650	18.050	25.730	68	143	198
Patient	561	780	973	12.800	17.580	23.510	67	143	197
Insurance	566	721	974	13.100	18.311	25.740	68	142	192
Hospital Src									
Physician	593	786	1017	14.010	15.860	27.130	86	121	194
Lab	597	807	940	13.870	16.590	25.060	84	123	190
Patient	593	812	951	14.220	15.023	25.320	85	122	186
Insurance	582	780	977	14.560	15.550	25.080	85	123	187
Patient Src									
Physician	618	772	980	14.491	18.942	25.360	79	120	182
Lab	626	787	928	13.770	18.542	23.080	78	122	190
Hospital	614	782	922	13.190	18.129	23.780	77	126	187
Insurance	616	788	940	13.080	17.878	21.110	76	122	178
Average:	611	787	958	13.200	17.673	25.403	77.88	126.13	194.13

Table 9.9: Regional Networks (5 Nodes) - Packet Delay (MS) for 400B, IM_ATM, and Experimental IM_ATM

Regional Networks	Message + Response Sources: Average Packet Delay (MS) (Cont'd)								
Link: 1.544Mbps	5 Nodes, Warm Up: 5/s, Replication: 240/s								
Message Size	400B			IM_ATM			Experimental IM_ATM		
Bandwidth: 256kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Origin/Destination									
Physician Src									
Lab	292	327	374	6.210	8.950	13.511	41	59	106
Hospital	287	321	360	5.950	8.900	13.780	40	57	102
Patient	289	327	362	5.780	9.780	13.630	40	59	103
Insurance	298	322	371	6.029	10.200	13.900	41	57	102
Lab Src									
Physician	262	343	375	6.770	8.330	12.960	33	74	97
Hospital	243	320	366	6.330	9.020	12.860	33	71	99
Patient	252	320	371	6.400	8.900	11.760	33	72	98
Insurance	252	331	374	6.552	9.150	12.870	34	71	96
Hospital Src									
Physician	273	323	372	7.004	7.930	13.570	43	60	97
Lab	264	327	368	6.930	8.300	12.530	42	61	95
Patient	269	337	367	7.107	7.510	12.660	43	61	93
Insurance	261	326	367	7.280	7.760	12.540	43	62	93
Patient Src									
Physician	270	316	367	7.250	9.470	12.680	39	60	90
Lab	275	324	372	6.880	9.271	11.540	39	61	94
Hospital	268	320	366	6.600	9.060	11.891	39	63	93
Insurance	266	327	360	6.540	8.940	10.550	38	61	88
Average:	270	326	368	6.601	8.842	12.702	38.813	63.063	96.625

Regional Networks	Message + Response Sources: Average Packet Delay (MS) (Cont'd)								
Link: 1.544Mbps	5 Nodes, Warm Up: 5/s, Replication: 240/s								
Message Size	400B			IM_ATM			Experimental IM_ATM		
Bandwidth: 512kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Origin/Destination									
Physician Src									
Lab	146	164	187	3.100	4.480	6.760	20	29	53
Hospital	143	161	180	2.970	4.450	6.890	20	28	51
Patient	145	164	181	2.890	4.890	6.813	20	29	51
Insurance	149	161	185	3.020	5.100	6.952	21	29	51
Lab Src									
Physician	131	172	187	3.380	4.170	6.480	17	37	49
Hospital	122	161	183	3.160	4.510	6.430	16	36	49
Patient	126	160	186	3.200	4.400	5.880	17	36	49
Insurance	126	165	187	3.280	4.570	6.440	17	36	48
Hospital Src									
Physician	137	162	186	3.500	3.970	6.780	22	30	48
Lab	132	163	184	3.470	4.150	6.260	21	31	48
Patient	134	169	183	3.550	3.760	6.330	21	30	47
Insurance	131	163	184	3.640	3.880	6.270	21	31	47
Patient Src									
Physician	135	158	184	3.620	4.740	6.340	20	30	45
Lab	138	162	186	3.442	4.640	5.770	19	31	47
Hospital	134	160	183	3.300	4.530	5.950	19	31	46
Insurance	133	163	180	3.271	4.470	5.270	19	30	44
Average:	135	163	184	3.300	4.419	6.351	19.375	31.500	48.313

Regional Networks	Message + Response Sources: Average Packet Delay (MS)								
Link: 1.544Mbps	5 Nodes, Warm Up: 5/s, Replication: 240/s								
Message Size	400B			IM_ATM			Experimental IM_ATM		
Bandwidth Capacity	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	611	787	958	13.200	17.673	25.403	77.88	126.13	194.11
256kbps	270	326	368	6.601	8.842	12.702	38.81	63.06	96.63
512kbps	135	163	184	3.300	4.419	6.351	19.38	31.50	48.31

Table 9.10: Regional Networks (5 Nodes) - Average Packet Delay (MS) for 400B, IM_ATM, and Experimental IM_ATM

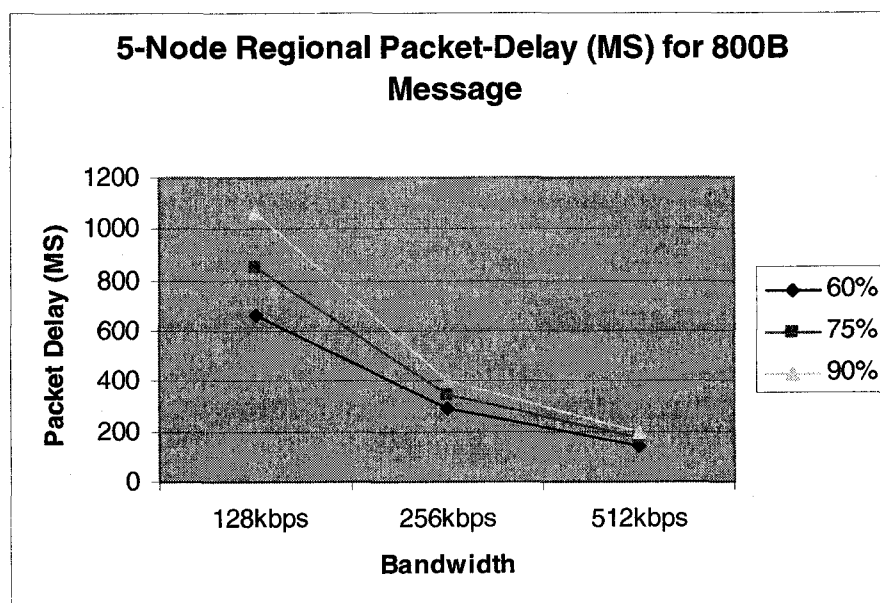


Figure 9.14: Regional Networks (5 Nodes) - Average Packet Delay (MS) for 400B Message

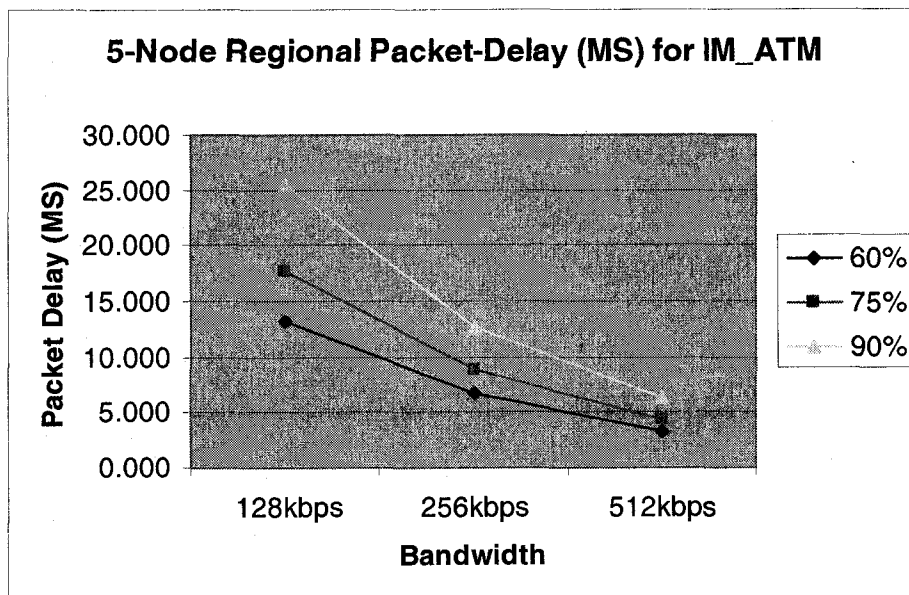


Figure 9.15: Regional Networks - Average Packet Delay (MS) for IM_ATM

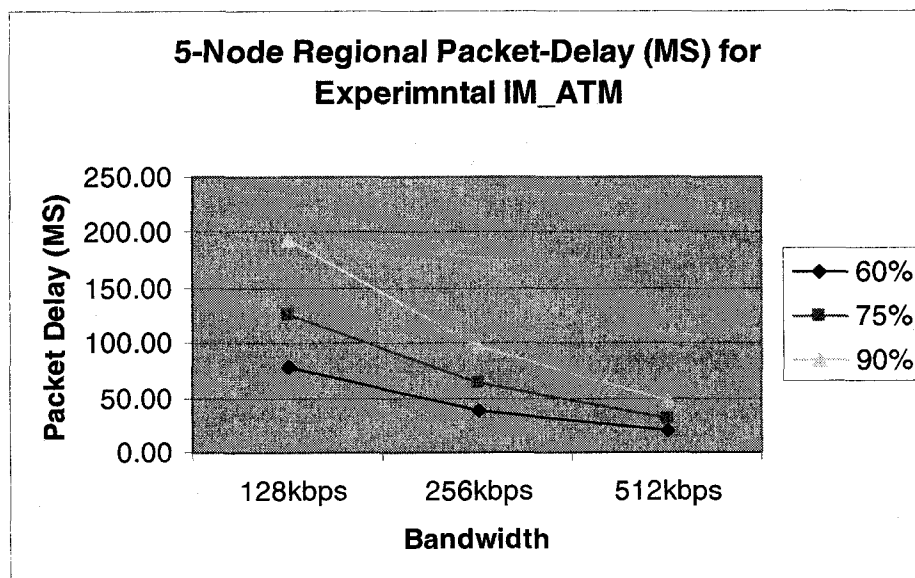


Figure 9.16: Regional Networks -Average Packet Delay (MS) for Experimental IM_ATM

Average Channel Link Utilization (%)

Bandwidth – 128kbps-512kbps, Message Size - 800B and 400B

For 800B message size, the average percentage of utilization 56.10%, 73.10%, and 86.00% (128kbps), 28.40%, 39.46%, and 50.80% (256kbps), and 14.23%, 19.60%, and 25.34% (512kbps). The decrease in utilization (%) is 49.38%, 46.01%, and 40.93% from 128kbps to 256kbps and 49.38%, 50.32%, and 50.11%, from 256kbps to 512kbps,

For 400B message size, the percentage of the average utilization is very similar to that of the 800B for all the three bandwidths, these statistics are given from Tables 9.11 to 9.14 and graphs are depicted in Figures 9.17 and 9.22.

Regional Networks: 5 Nodes	Average Percentage of Channel Utilization Warm Up: 5/s, Replication: 240/s					
Link: 1.544Mbps	800B			400B		
Bandwidth	60%	75%	90%	60%	75%	90%
128kbps						
Physician-Link	59	70	86	59	70	86
	56	74	87	56	74	87
HQ-Link	55	77	85	55	77	85
	57	72	84	57	72	84
Lab-Link	51	72	88	51	72	88
	57	73	86	57	73	86
Hosp-Link	58	72	86	58	72	86
	56	74	86	56	74	86
Patient-Link	57	74	85	57	74	85
	55	73	87	55	73	87
Average	56.10	73.10	86.00	56.10	73.10	86.00
256kbps						
Physician-Link	30	40	50	31	38	50
	27	39	51	29	40	51
HQ-Link	29	40	49	28	42	50
	31	39	52	29	38	50
Lab-Link	28	41	55	27	39	52
	27	40	50	29	39	50
Hosp-Link	29	37	50	29	38	50
	26	39	51	29	40	50
Patient-Link	29	39	50	29	39	50
	28	40	50	28	39	51
Average	28.40	39.46	50.80	28.80	39.20	50.40
512kbps						
Physician-Link	15	20	25	15	19	25
	14	19	25	14	20	26
HQ-Link	15	20	24	14	21	25
	15	20	26	15	19	25
Lab-Link	14	21	27	13	20	26
	14	20	25	15	19	25
Hosp-Link	14	18	25	15	19	25
	13	19	25	14	20	25
Patient-Link	14	19	25	15	19	25
	14	20	26	14	20	26
Average	14.23	19.60	25.34	14.40	19.60	25.30

Table 9.11: Regional Networks (5 Nodes) - Channel Utilization (%) for 400B and 800B Messages

IM_ATM Networks – Utilization (%)

Bandwidth – 128kbps-512kbps, Message Size – 46B (800B)

The average percentage of utilization for IM_ATM is 0.204%, 0.345%, 0.555% (128kbps), 0.110%, 0.173%, and 0.268% (256kbps), and 0.054%, 0.086%, and 0.139% (512kbps). The decrease in utilization (%) is 46.07%, 49.85%, and 51.17% from 128kbps to 256kbps, and 50.91%, 50.28%, and 43.13% from 256kbps to 512kbps.

Bandwidth – 128kbps-512kbps, Message Size – 46B (400B)

The average percentage of utilization for IM_ATM is 0.817%, 1.335%, 2.128% (128kbps), 0.409%, 0.666%, and 1.063% (256kbps), and 0.205%, 0.334%, and 0.535% (512kbps). The decrease in utilization (%) is 49.94%, 50.11%, and 50.05% from 128kbps to 256kbps, and 49.88%, 49.85%, and 49.67% from 256kbps to 512kbps.

Experimental IM_ATM – Average Utilization (%)

Bandwidth – 128kbps-512kbps, Message Size – 46B (800B)

The average percentage of utilization for experimental IM_ATM is 3.499%, 5.743%, 9.612% (128kbps), 1.950%, 2.962%, and 4.816% (256kbps), and 0.871%, 1.436%, and 2.408% (512kbps). The decrease in utilization (%) is 44.27%, 48.42%, and 49.90% from 128kbps to 256kbps, and 55.33%, 51.52%, and 50.00% from 256kbps to 512kbps.

Bandwidth – 128kbps-512kbps, Message Size – 46B (400B)

The average percentage of utilization for experimental IM_ATM is 7.171%, 11.492%, 18.674% (128kbps), 3.614%, 5.732%, and 9.337% (256kbps), and 1.798%, 3.268%, and 4.669% (512kbps). The decrease in utilization (%) is 49.60%, 50.12%, and 50.00% from 128kbps to 256kbps, and 52.25%, 43.00%, and 49.95% from 256kbps to 512kbps.

Regional Networks- ACCESS LINK STATS: 5 Nodes						
Average % UTIL, Warm Up: 5/s, Replication: 240/s						
Link: 1.544Mbps	Message: 800B			Message: 400B		
Bandwidth capacity	60%	75%	90%	60%	75%	90%
128kbps	56.31	72.95	86.01	56.10	73.10	86.01
256kbps	28.40	39.46	50.83	28.80	39.20	50.40
512kbps	14.23	19.62	25.34	14.40	19.60	25.30

Table 9.12: Regional Networks (5 Nodes) - Average Channel Utilization (%) for 800B and 400B Message

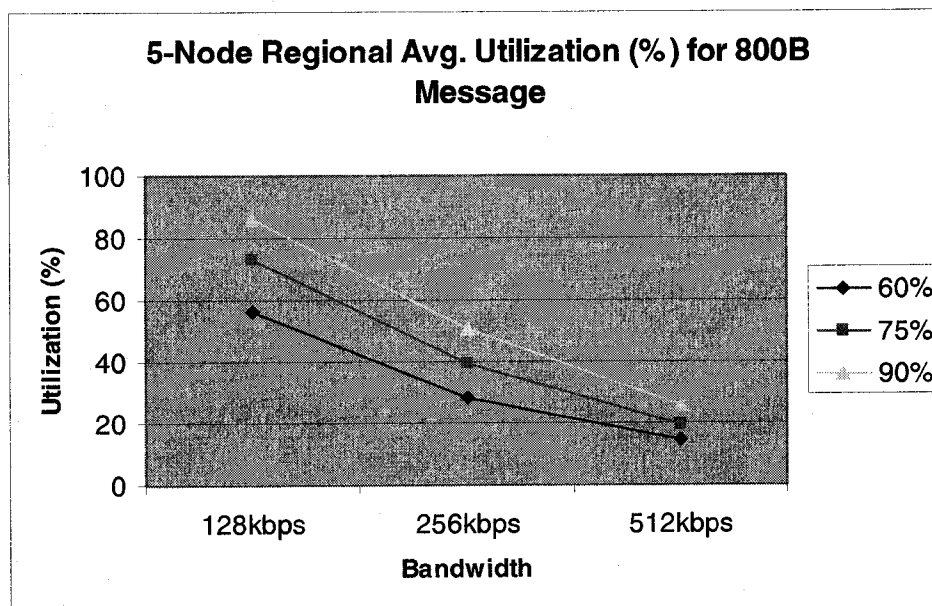


Figure 9.17: Regional Networks (5 Nodes) – Average Channel Utilization (%) - 800B Message

Regional Networks: 5Nodes	Average Channel Utilization (%) Warm Up: 5/s, Replication: 240/s								
	800B			IM_ATM			Experimental IM_ATM		
Utilization (%)	60%	75%	90%	60%	75%	90%	60%	75%	90%
Bandwidth									
128kbps									
Physician-Link	59	70	86	0.220	0.356	0.513	3.639	5.860	9.972
	56	74	87	0.205	0.338	0.589	3.446	5.751	9.357
HQ-Link	55	77	85	0.191	0.375	0.585	3.311	5.934	8.750
	57	72	84	0.228	0.350	0.556	3.629	5.651	9.895
Lab-Link	51	72	88	0.201	0.341	0.565	3.773	6.549	10.840
	57	73	86	0.194	0.369	0.594	3.401	5.625	9.254
Hosp-Link	58	72	86	0.214	0.306	0.576	3.360	5.009	9.859
	56	74	86	0.198	0.327	0.520	3.511	5.813	9.622
Patient-Link	57	74	85	0.194	0.345	0.537	3.412	5.363	8.756
	55	73	87	0.197	0.339	0.516	3.509	5.874	9.815
Average	56.10	73.10	86.00	0.204	0.345	0.555	3.499	5.743	9.612
256kbps									
Physician-Link	30	40	50	0.105	0.178	0.256	1.820	2.930	4.976
	27	39	51	0.117	0.169	0.295	1.723	2.876	4.786
HQ-Link	29	40	49	0.111	0.188	0.292	1.656	2.968	4.377
	31	39	52	0.111	0.175	0.278	3.814	2.826	4.947
Lab-Link	28	41	55	0.111	0.185	0.283	1.887	3.275	5.418
	27	40	50	0.108	0.171	0.297	1.700	2.713	4.627
Hosp-Link	29	37	50	0.111	0.153	0.288	1.680	2.505	4.930
IM_ATM, and	26	39	51	0.101	0.164	0.260	1.756	2.907	4.810
Patient-Link	29	39	50	0.114	0.173	0.168	1.706	3.682	4.378
	28	40	50	0.112	0.170	0.258	1.754	2.938	4.907
Average	28.40	39.46	50.80	0.110	0.173	0.268	1.950	2.962	4.816
512kbps									
Physician-Link	15	20	25	0.052	0.089	0.128	0.910	1.465	2.488
	14	19	25	0.058	0.084	0.147	0.820	1.438	2.393
HQ-Link	15	20	24	0.057	0.094	0.146	0.828	1.484	2.188
	15	20	26	0.058	0.088	0.139	0.907	1.413	2.474
Lab-Link	14	21	27	0.056	0.085	0.141	0.943	1.637	2.709
	14	20	25	0.054	0.092	0.149	0.850	1.406	2.314
Hosp-Link	14	18	25	0.055	0.076	0.144	0.840	1.252	2.465
	13	19	25	0.041	0.082	0.130	0.878	1.453	2.405
Patient-Link	14	19	25	0.057	0.086	0.134	0.853	1.341	2.189
	14	20	26	0.056	0.085	0.129	0.877	1.469	2.454
Average	14.23	19.60	25.34	0.054	0.086	0.139	0.871	1.436	2.408

Table 9.13: Regional Networks (5 Nodes) - Channel Utilization (%) for 800B, IM_ATM, and Experimental IM_ATM

Regional Networks-ACCESS LINK STATS: 5 Nodes									
Average % UTIL, Warm Up: 5/s, Replication: 240/s									
Message Size	800B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	56.31	72.95	86.01	0.817	1.335	2.218	3.499	5.743	9.612
256kbps	28.40	39.46	50.83	0.409	0.666	1.063	1.950	2.962	4.816
512kbps	14.23	19.62	25.34	0.205	0.334	0.535	0.871	1.436	2.408

Table 9.14: Regional Networks (5 Nodes) - Average Channel Utilization (%) for 800B, IM_ATM, and Experimental IM_ATM

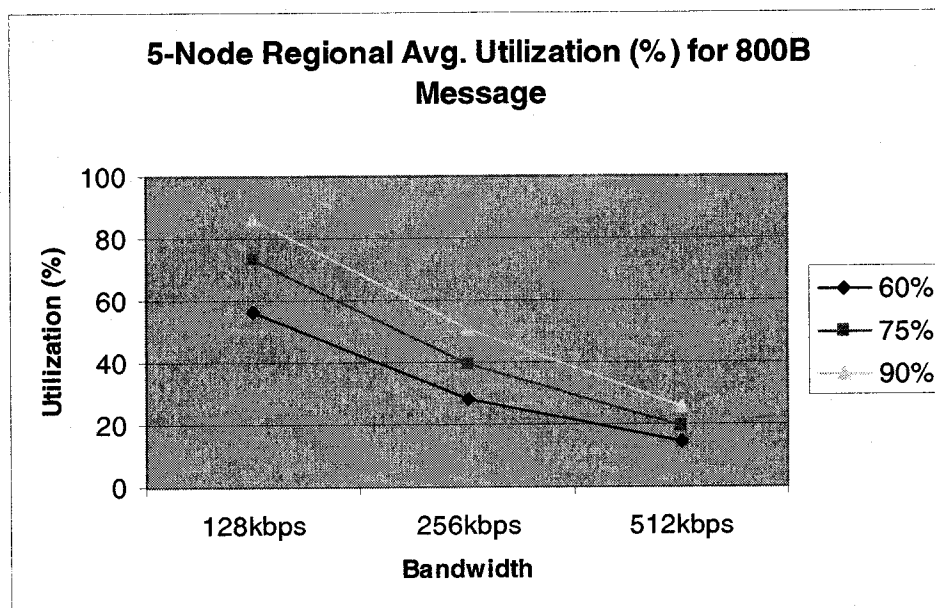


Figure 9.17: Regional Networks (5 Nodes) – Average Channel Utilization (%) - 800B Message

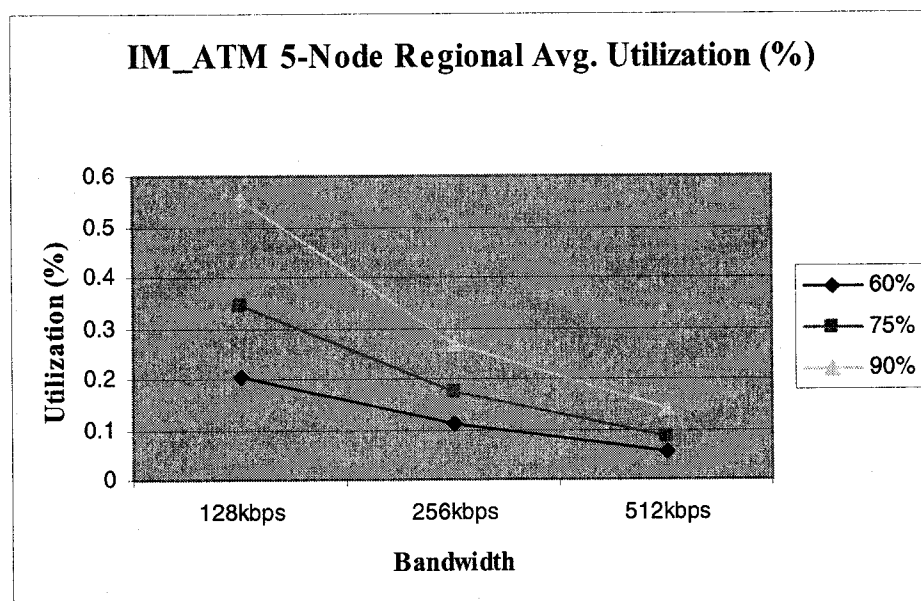


Figure 9.18: 5-Node Regional Average Channel Utilization (%) for IM_ATM

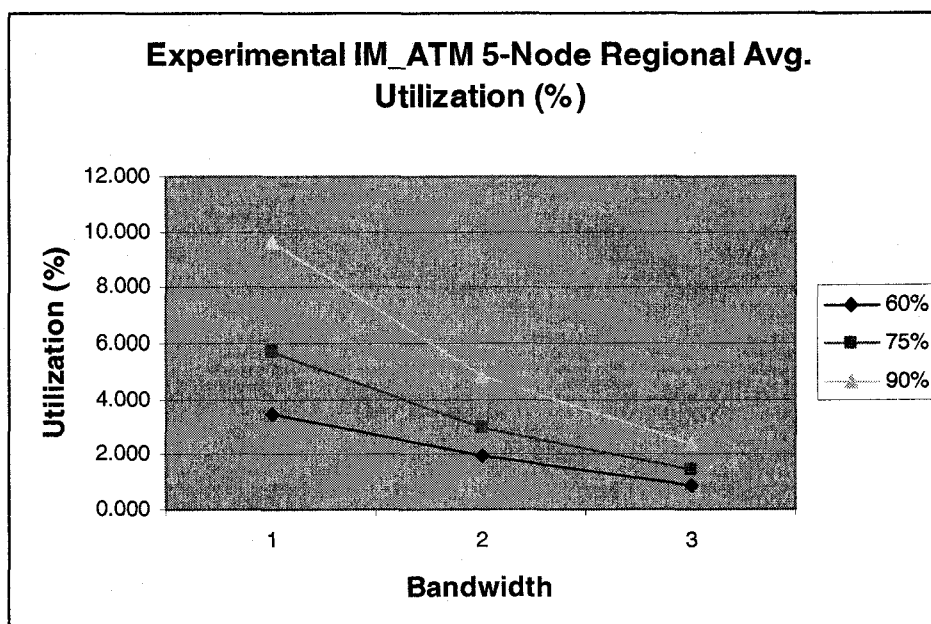


Figure 9.19: 5-Node Regional Average Channel Utilization (%) for Experimental IM_ATM

Regional Networks - 5 Nodes									
Average % Utilization, Warm Up: 5/s, Replication: 240/s									
Message Size	400B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	56.10	73.10	86.01	0.204	0.345	0.555	7.171	11.492	18.674
256kbps	28.80	39.20	50.40	0.110	0.173	0.268	3.614	5.732	9.337
512kbps	14.40	19.60	25.30	0.054	0.086	0.139	1.798	3.268	4.669

Table 9.15: Regional Networks (5-Nodes)- Average Channel Utilization (%)

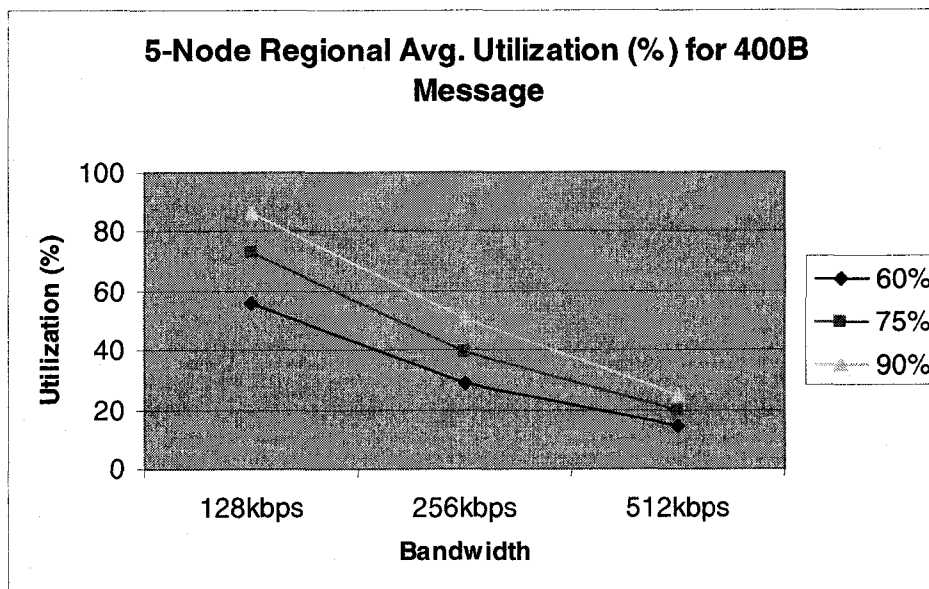


Figure 9.20: Regional Networks (5 Nodes) –Average Channel Utilization (%) - 400B Message

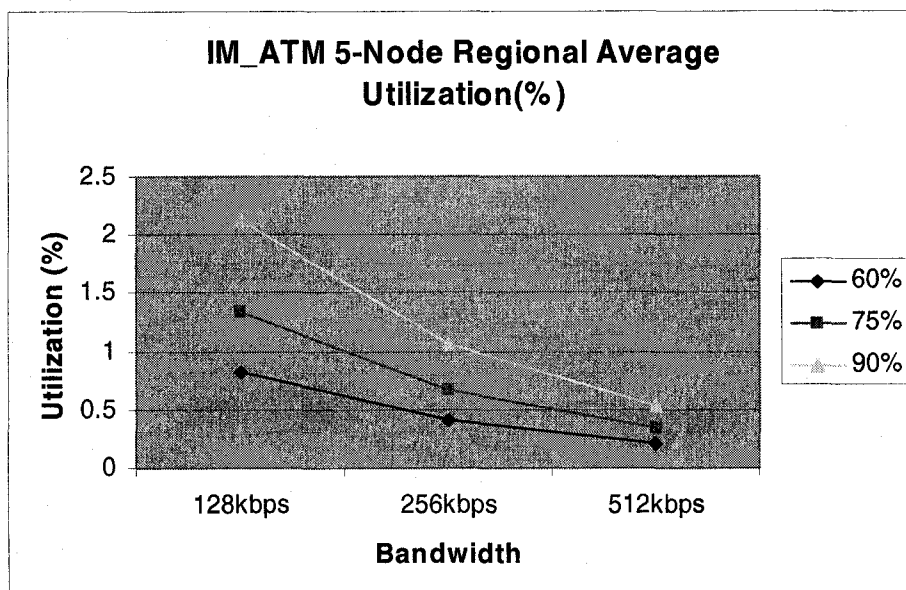


Figure 9.21: Regional Networks (5 Nodes) – Average Channel Utilization (%) for IM_ATM

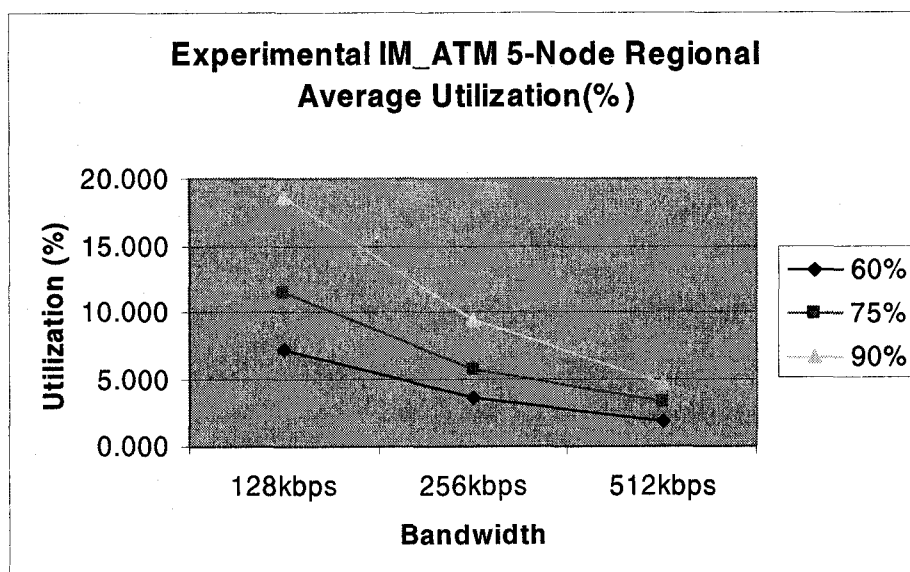


Figure 9.22: Regional Networks (5 Nodes) – Average Channel Utilization (%) for Experimental IM_ATM

9.1.2. Regional Networks/Nine Nodes

There are nine nodes created altogether in each network model; representing Physician, Patient, Insurance, Imaging, Insurance, Consultant, Hospital, Pharmacy, and Laboratory. One source each node, each source is only sending information to pre-defined destinations. In the nine-node regional networks only 800 and 400 bytes message sizes for the traditional and 46 bytes for IM_ATM and Experimental IM_ATM networks are tested, and each of the message size is examined with three bandwidth intensities: 60%, 75%, and 90%.

Simulation data of Packets Created, Packets Delivered, and Packets Dropped are collected. The total number of Packets Created, Packets Delivered, and Packets Dropped, ratio of Packets Dropped/Created and Packets Dropped/Delivered, Average Packets Delay in milliseconds and Average Maximum Packets Delay in milliseconds are calculated. The statistics are shown from Tables 9.16 to 9.23 and graphs are depicted from Figures 9.23 to 9.39.

Analysis

Packets Created, Delivered, Dropped, Dropped/Created, Dropped/Delivered

Bandwidth – 128kbps, 256kbps and 512kbps, Message Size - 800B and 400B

For 800B message, the average number of packets created is 430, 699, and 1456 for all three bandwidth capacities of 128kbps, 256kbps and 512kbps, respectively. Packets delivered is 377, 483, and 553 (128kbps), 388, 512, and 744 (256kbps and 512kbps), and packets dropped 53, 216, and 903 (128kbps), and 42, 187, and 712 (256kbps and 512kbps).

The average number of packets created for 256kbps and 512kbps is equal to that of 128kbps. The reason for this is that the same message size and constant IAT, the number of packets created remains constant even though the bandwidth is increased to 512kbps.

However, the number of packets delivered is to Packets delivered is 377, 483, and 553 (128kbps), and 388, 512 and 744 (256kbps and 512kbps) and packets dropped 53, 216, and 903 (128kbps), and 42, 187, and 712 (256kbps and 512kbps). Packets Delivered increase by 2.3%, 5.7%, and 25.67% from 128kbps to 256kbps, remain unchanged from 256kbps to 512kbps. The packets dropped decrease by 20.75%, 13.43%, and 21.15%

The ratio of packets dropped/created is 12.23%, 30.86%, and 62.01% (128kbps), and 9.76%, 26.70%, and 48.91% (256kbps and 512kbps); packets dropped/delivered 13.94%, 44.63%, and 163.24% (128kbps), and 10.81%, 36.43%, and 95.73% (256kbps and 512kbps). The ratio of packets dropped/created, and packets dropped/delivered decrease from 128kbps to 256kbps because of the availability of the higher bandwidth.

There are no packets dropped for the IM_ATM and Experimental IM_ATM networks.

Regional - 9 Nodes	Message + Response Sources: Packet Delay								
Bandwidth: 128kbps	Warm Up: 5/s, Replication: 240/s								
Message sizes: 800B	Packets Created			Packets Delivered			Packets Dropped		
Origin/Destination	60%	75%	90%	60%	75%	90%	60%	75%	90%
Physician Src									
Lab	424	806	1603	372	497	545	52	309	1058
Insurance	463	837	1618	416	538	480	47	299	1138
Patient	457	847	1561	409	547	622	48	300	939
Pharmacy	478	817	1581	433	531	608	45	286	973
Consultant	402	778	1581	360	502	660	42	276	921
Image	455	826	1555	398	542	586	57	284	969
Hospital	427	796	1602	389	531	510	38	265	1092
Lab Src									
Physician	404	786	1450	368	530	512	36	256	938
Insurance	341	743	1526	307	503	561	34	240	965
Hospital	428	710	1463	401	482	514	27	228	949
HQ	395	769	1474	363	527	649	32	242	825
IMAGE	424	712	1448	389	516	584	35	196	864
Patient	395	741	1493	355	518	590	40	223	903
Pharmacy	415	719	1440	374	487	658	41	232	782
Hospital Src									
Physician	442	562	1301	364	438	452	78	124	849
Lab	471	529	1317	395	399	435	76	130	882
IMAGE	437	579	1372	365	425	576	72	154	796
HQ	440	580	1333	350	451	512	90	129	821
Insurance	434	541	1295	367	394	415	67	147	880
Patient	457	555	1324	380	424	551	77	131	773
Pharmacy	448	578	1349	387	425	574	61	153	775
Consultant	412	567	1342	351	426	573	61	141	769
Average:	429.50	699.00	1455.82	376.95	483.32	553.05	52.55	215.68	902.77
	Dropped/Created			Dropped/Delivered					
Ratio:	12.23%	30.86%	62.01%	13.94%	44.63%	163.24%			

Table 9.16: Regional Networks (9 Nodes) - Packets Created, Delivered, and Dropped for 800B Message

Regional - 9 Nodes	Message + Response Sources: Packet Delay (cont'd)								
Bandwidth: 256bps	Warm Up: 5/s, Replication: 240/s								
Message size: 800B	Packets Created			Packets Delivered			Packets Dropped		
Origin/Destination	60%	75%	90%	60%	75%	90%	60%	75%	90%
Physician Src									
Lab	424	806	1603	384	567	790	40	239	813
Insurance	463	837	1618	427	594	773	36	243	845
Patient	457	847	1561	421	586	794	36	261	767
Pharmacy	478	817	1581	442	582	762	36	235	819
Consultant	402	778	1581	368	554	795	34	224	786
IMAGE	455	826	1555	413	305	737	42	521	818
Hospital	427	796	1602	398	571	796	29	225	806
Lab Src									
Physician	404	786	1450	372	583	749	32	203	701
Insurance	341	743	1526	317	553	798	24	190	728
Hospital	428	710	1463	406	539	775	22	171	688
HQ	395	769	1474	370	576	785	25	193	689
IMAGE	424	712	1448	393	554	737	31	158	711
Patient	395	741	1493	364	565	744	31	176	749
Pharmacy	415	719	1440	384	531	792	31	188	648
Hospital Src									
Physician	442	562	1301	375	466	667	67	96	634
Lab	471	529	1317	406	428	655	65	101	662
IMAGE	437	579	1372	382	463	712	55	116	660
HQ	440	580	1333	372	470	641	68	110	692
Insurance	434	541	1295	382	428	684	52	113	611
Patient	457	555	1324	396	449	694	61	106	630
Pharmacy	448	578	1349	399	446	740	49	132	609
Consultant	412	567	1342	356	462	743	56	105	599
Average:	429.50	699.00	1455.82	387.59	512.36	743.77	41.91	186.64	712.05
	Dropped/Created			Dropped/Delivered					
Ratio:	9.76%	26.70%	48.91%	10.81%	36.43%	95.73%			

Regional – 9 Nodes	Message + Response Sources: Packet Delay (cont'd)								
Bandwidth: 512kbps	Warm Up: 5/s, Replication: 240/s								
Message sizes: 800B	Packets Created			Packets Delivered			Packets Dropped		
Origin/Destination	60%	75%	90%	60%	75%	90%	60%	75%	90%
Physician Src									
Lab	424	806	1603	384	567	790	40	239	813
Insurance	463	837	1618	427	594	773	36	243	845
Patient	457	847	1561	421	586	794	36	261	767
Pharmacy	478	817	1581	442	582	762	36	235	819
Consultant	402	778	1581	368	554	795	34	224	786
IMAGE	455	826	1555	413	305	737	42	521	818
Hospital	427	796	1602	398	571	796	29	225	806
Lab Src									
Physician	404	786	1450	372	583	749	32	203	701
Insurance	341	743	1526	317	553	798	24	190	728
Hospital	428	710	1463	406	539	775	22	171	688
HQ	395	769	1474	370	576	785	25	193	689
IMAGE	424	712	1448	393	554	737	31	158	711
Patient	395	741	1493	364	565	744	31	176	749
Pharmacy	415	719	1440	384	531	792	31	188	648
Hospital Src									
Physician	442	562	1301	375	466	667	67	96	634
Lab	471	529	1317	406	428	655	65	101	662
IMAGE	437	579	1372	382	463	712	55	116	660
HQ	440	580	1333	372	470	641	68	110	692
Insurance	434	541	1295	382	428	684	52	113	611
Patient	457	555	1324	396	449	694	61	106	630
Pharmacy	448	578	1349	399	446	740	49	132	609
Consultant	412	567	1342	356	462	743	56	105	599
Average:	429.50	699.00	1455.82	387.59	512.36	743.77	41.91	186.64	712.05
	Dropped/Created			Dropped/Delivered					
Ratio:	9.76%	26.70%	48.91%	10.81%	36.43%	95.73%			

Regional Networks	Message + Response Sources: Packet Delay								
9 Nodes	Warm Up: 5/s, Replication: 240/s								
Message size: 800B	Packets Created			Packets Delivered			Packets Dropped		
Capacity	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	429.50	699.00	1455.82	376.95	483.32	553.05	52.55	215.68	902.77
256kbps	429.50	699.00	1455.82	387.59	512.36	743.77	41.91	186.64	712.05
512kbps	429.50	699.00	1455.82	387.59	512.36	743.77	41.91	186.64	712.05

Table 9.17: Regional Networks (9 Nodes) - Average Packets Created, Delivered, and Dropped for 800B Message

Regional – 9 Nodes	Warm Up: 5/s, Replication: 240/s					
Message size: 800B	Dropped/Created			Dropped/Delivered		
Capacity	60%	75%	90%	60%	75%	90%
128kbps	12.23%	30.86%	62.01%	13.94%	44.63%	163.24%
256kbps	9.76%	26.70%	48.91%	10.81%	36.43%	95.73%
512kbps	9.76%	26.70%	48.91%	10.81%	36.43%	95.73%

Table 9.18: Regional Networks (9 Nodes) – Ratio of Packets Dropped/Created, and Packets Dropped/Delivered for 800B Message

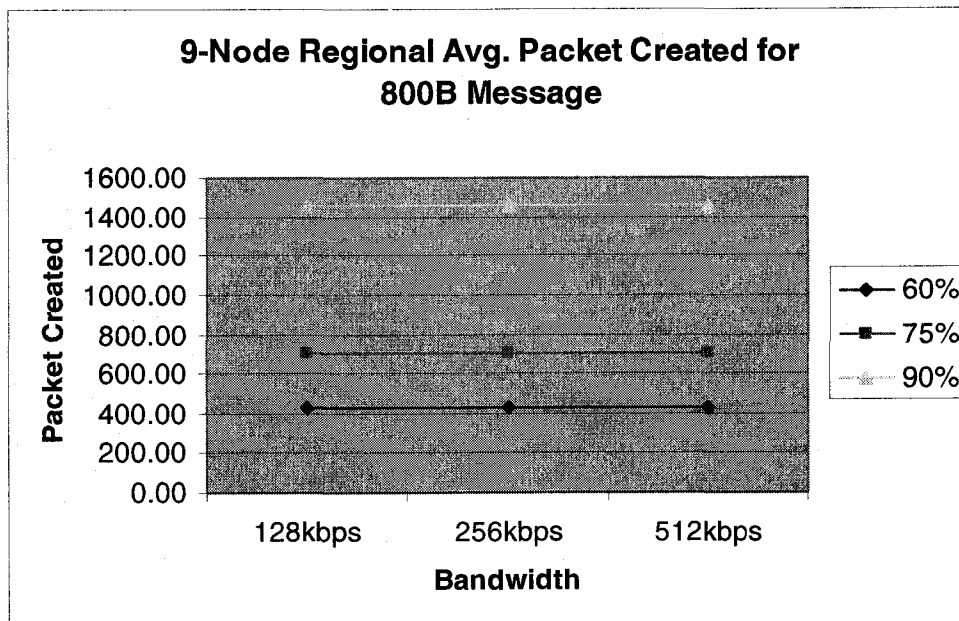


Figure 9.23: Regional Networks (9 Nodes) – Average Packets Created for 800B Message

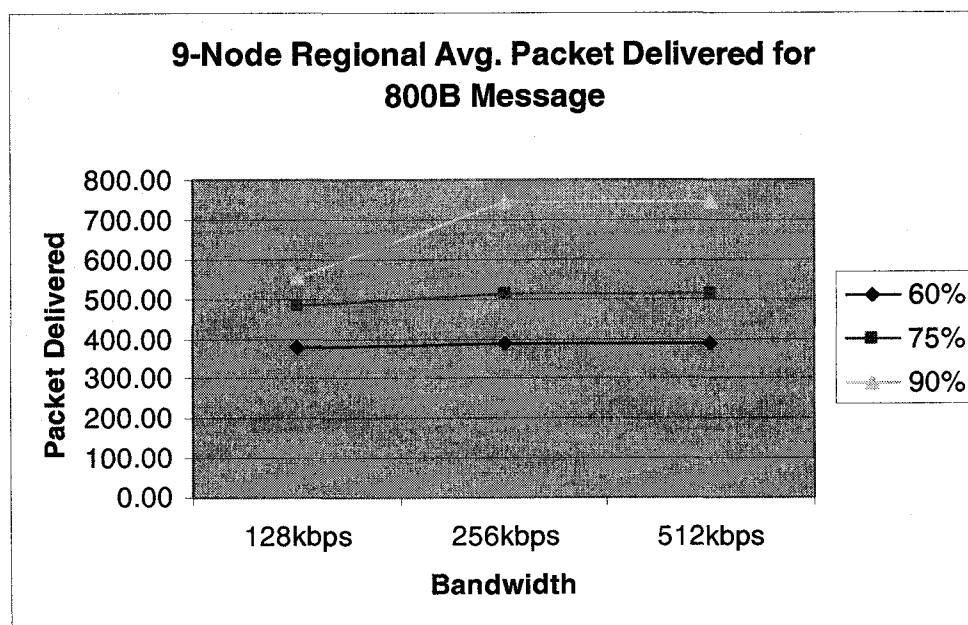


Figure 9.24: Regional Networks (9 Nodes) – Average Packets Delivered for 800B Message

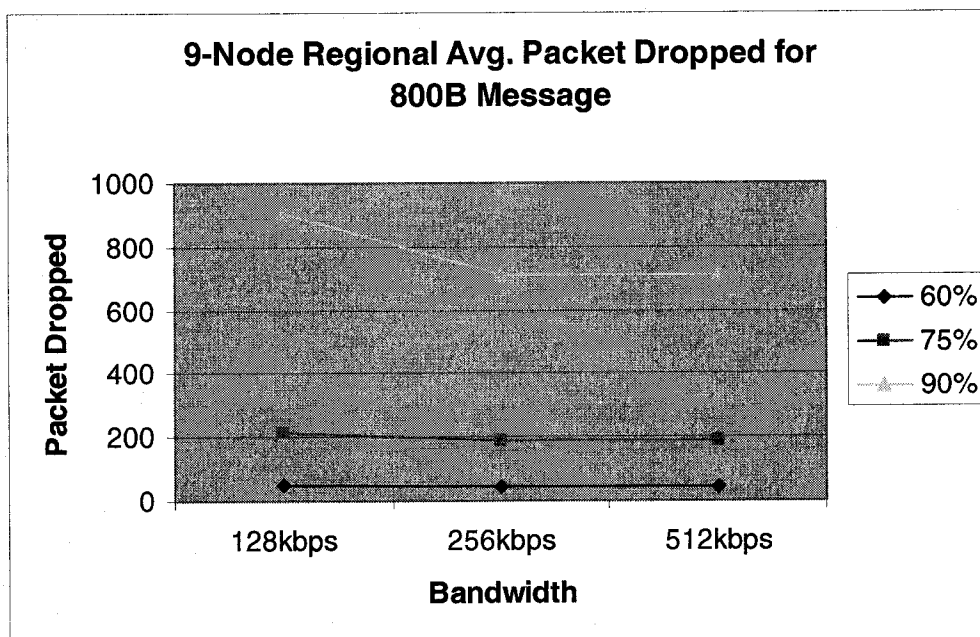


Figure 9.25: Regional Networks (9 Nodes) – Average Packets Dropped for 800B Message

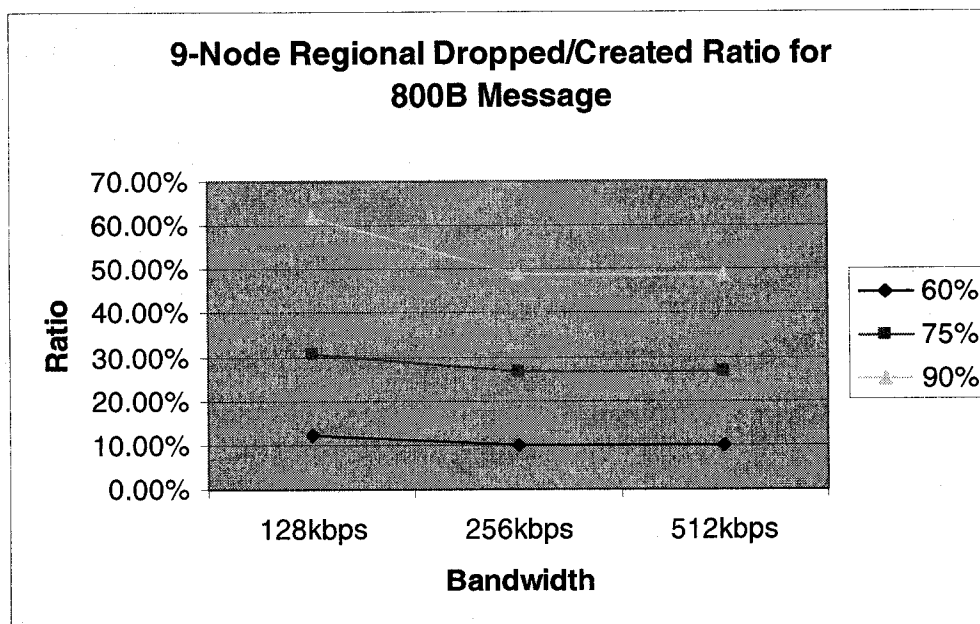


Figure 9.26: Regional Networks (9 Nodes) – Ratio of Packets Dropped/Created for 800B Message

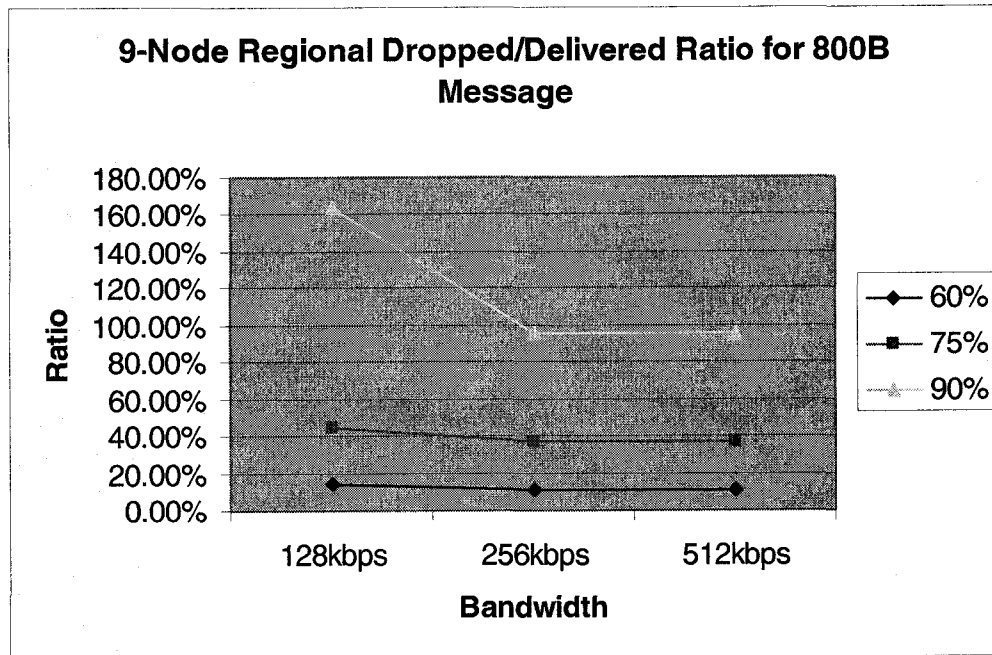


Figure 9.27: Regional Networks (9 Nodes) – Ratio of Packets Dropped/Delivered for 800B Message

Average Packet Delay (MS) – 800B and 400B Messages

For 800B message size, the average packet delay (MS) is 733, 1081, and 1706 (128kbps), 306, 373, and 431 (256kbps), and 153, 162, and 181 (512kbps). The decrease in packet delay is 58.00%, 65.50%, and 74.73% from 128kbps to 256kbps and 50.00%, 55.56%, and 58.00%, from 256kbps to 512kbps. For 400B message size, the average packet delay (MS) is 622, 963, and 1755 (128kbps), 288, 352, and 407 (256kbps), and 194, 164, and 201 (512kbps). The decrease in packet delay is 53.69%, 63.45%, and 76.81% from 128kbps to 256kbps, and 32.63%, 53.25%, and 50.63% from 256kbps to 512kbps.

Regional – 9 Nodes	Message + Response Sources: Packet Delay(MS)					
Link:1.544Mbps	Warm Up: 5/s, Replication: 240/s					
Message Size	800B			400B		
Bandwidth	60%	75%	90%	60%	75%	90%
128kbps	733.02	1081.21	1706.00	621.53	962.50	1755.21
256kbps	306.13	373.31	431.25	287.78	351.95	407.41
512kbps	153.19	162.23	181.09	193.77	163.78	201.06

Table 9.19: Regional Networks (9 Nodes) - Avg. Packet Delay (MS) for 800B and 400B Message

Regional Networks	Message + Response Sources: Packet Delay (MS)								
9 Nodes	Warm Up: 5/s, Replication: 240/s								
Link:1.544Mbps	800B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	733	1081	1706	12.73	18.86	34.50	79.17	124.26	280.86
256kbps	306	373	431	6.32	8.73	17.27	39.60	61.93	111.08
512kbps	153	162	181	3.09	3.77	8.64	19.91	31.43	71.57

Table 9.20: Regional Networks (9 Nodes) - Average Packet Delay (MS) for 800B, IM_ATM, and Experimental IM_ATM

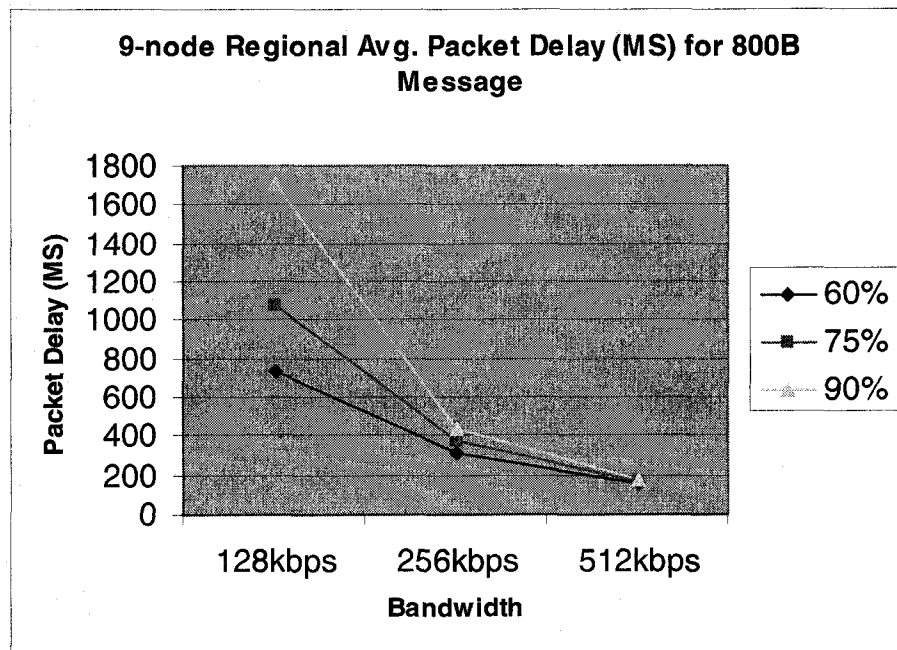


Figure 9.28: Regional Networks (9 Nodes) –Average Packets Delay (MS) for 800B Message

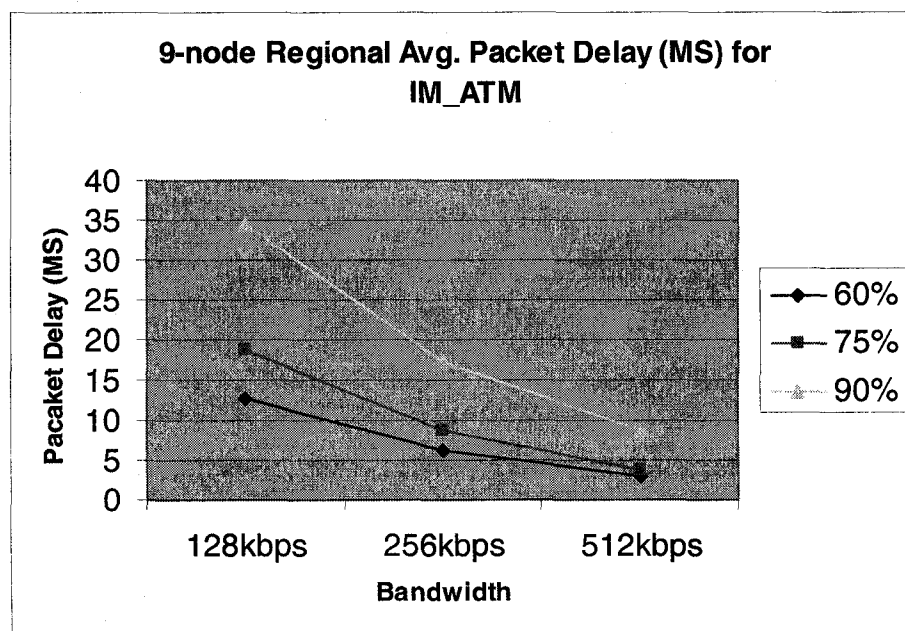


Figure 9.29: Regional Networks (9 Nodes) –Average Packets Delay (MS) for IM_ATM

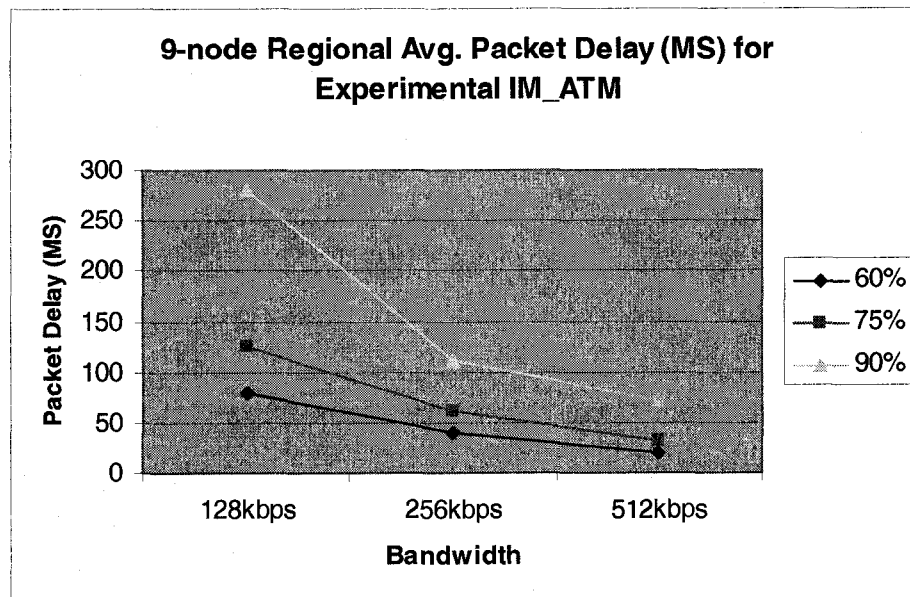


Figure 9.30: Regional Networks (9 Nodes) –Average Packets Delay (MS) for Experimental IM_ATM

Average Packet Delay (MS) - IM_ATM Networks

Bandwidth – 128kbps-512kbps, Message Size – 46B (800B)

The average packet delay (MS) for IM_ATM is 12.73, 18.86, and 34.50 (128kbps), 6.32, 8.73, and 17.27 (256kbps), and 3.09, 3.77, and 8.64 (512kbps). The decrease in packet delay (MS) is 50% for 128kbps to 256kbps, and 256kbps to 512kbps, for all three capacities. The average packet delay (MS) for the experimental IM_ATM is 79.17, 124.26, and 280.86 (128kbps), 39.60, 61.93, 111.08 (256kbps), and 19.91, 31.43, and 71.57 (512kbps). The decrease in packet delay is 49.36%, 50.00%, and 60.50% from 128kbps to 256kbps, 50%, 50.00%, and 34.13% from 256kbps to 512kbps.

Bandwidth – 128kbps-512kbps, Message Size – 46B (400B) Message

The average packet delay (MS) for IM_ATM is 13.07, 17.71, and 34.70 (128kbps), 6.57, 8.72, and 18.23 (256kbps), and 3.29, 3.75, and 8.49 (512kbps). The decrease in packet delay is 50% from 128kbps to 256kbps, and 50.00% from 256kbps to 512kbps, for all three capacities. The average packet delay (MS) for the experimental IM_ATM is 77.64, 117.01, and 289.11 (128kbps), 40.71, 60.14, and 140.02 (256kbps), and 20.00, 29.43, and 71.86 (512kbps). The decrease in packet delay is 47.56%, 48.71%, and 51.56% from 128kbps to 256kbps, 50.00% from 256kbps to 512kbps for all capacities.

Regional –9Nodes	Message + Response Sources: Packet Delay (MS)								
Link: 1.544Mbps	Warm Up: 5/s, Replication: 240/s								
Message Size	400B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	621.53	962.50	1755.21	13.07	17.71	34.70	77.64	117.01	289.11
256kbps	287.78	351.95	407.41	6.57	8.72	18.23	40.71	60.14	140.02
512kbps	193.77	163.78	201.06	3.29	3.75	8.49	20.00	29.43	71.86

Table 9.21: Regional Networks (9 Nodes) – Average Packet Delay (MS) for 400B, IM_ATM, and Experimental IM_ATM

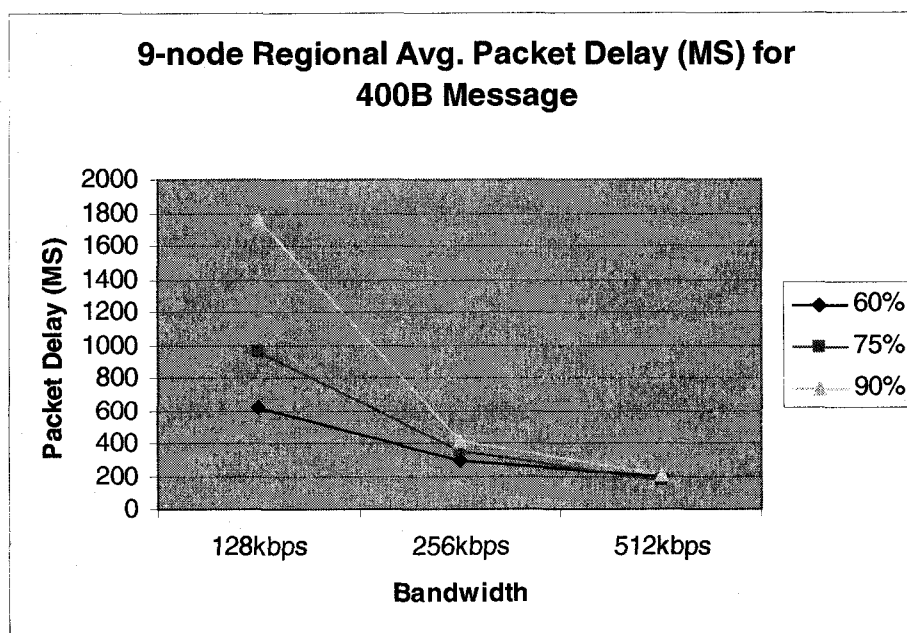


Figure 9.31: Regional Networks (9 Nodes) –Average Packets Delay (MS) for 400B Message

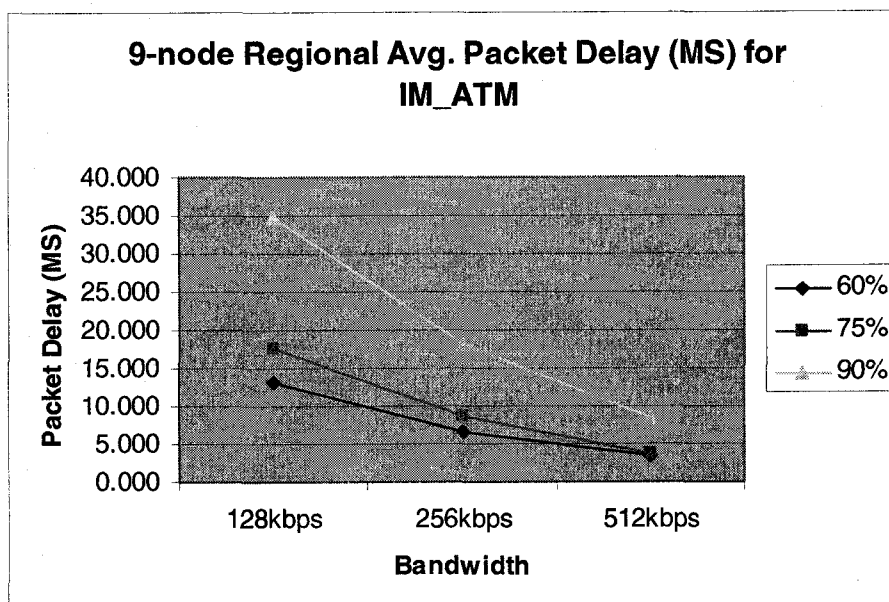


Figure 9.32: Regional Networks (9 Nodes) –Average Packets Delay (MS) for IM_ATM

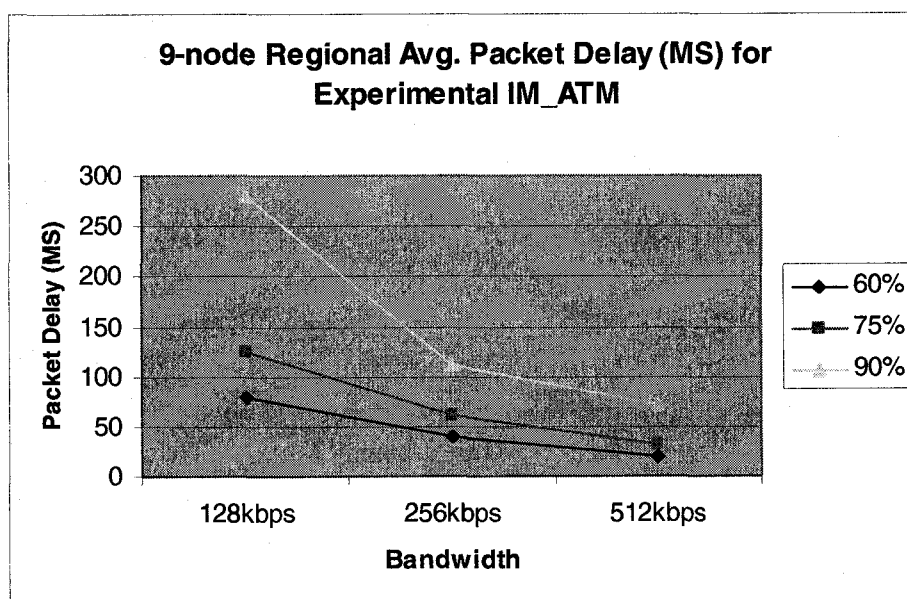


Figure 9.33: Regional Networks (9 Nodes) –Average Packets Delay (MS) for Experimental IM_ATM

Average Channel Link Utilization (%)

Bandwidth – 128kbps-512kbps, Message Size - 800B and 400B

For 800B message size, the average percentage of utilization is 58.50%, 73.44%, and 86.33% (128kbps), 30.11%, 39.78%, and 56.44% (256kbps), and 15.22%, 19.94%, and 28.22% (512kbps). The decrease in utilization (%) is 48.50%, 45.83%, and 34.63% from 128kbps to 256kbps and 49.40%, 49.80%, and 50.00%, from 256kbps to 512kbps,

For 400B message size, the percentage of average utilization is very similar to that of the 800B for all the three bandwidth capacities.

Average IM_ATM – Utilization (%)

Bandwidth – 128kbps-512kbps, Message Size – 46B (800B)

The average percentage of utilization for IM_ATM is 0.229%, 0.340%, 0.760% (128kbps), 0.115%, 0.165%, and 0.393% (256kbps), and 0.057%, 0.125%, and 0.191% (512kbps). The decrease in utilization (%) is 49.75%, 51.47%, and 48.28% from 128kbps to 256kbps, and 50.00%, 24.20.28%, and 512.39% from 256kbps to 512kbps.

Bandwidth – 128kbps-512kbps, Message Size – 46B (400B)

The average percentage of utilization for IM_ATM is 0.855%, 1.305%, 3.211% (128kbps), 0.428%, 0.652%, and 1.606% (256kbps), and 0.214%, 0.262%, and 0.803% (512kbps). The decrease in utilization (%) is 49.94%, 50.00%, and 50.14% from 128kbps to 256kbps, and 50.00%, 59.82%, and 50.00% from 256kbps to 512kbps.

IM_ATM (Experimental) – Utilization (%)

Bandwidth – 128kbps-512kbps, Message Size – 46B (800B)

The average percentage of utilization for experimental IM_ATM is 3.777%, 5.953%, 13.094% (128kbps), 1.888%, 2.976%, and 6.492% (256kbps), and 0.939%, 1.599%, and 3.234% (512kbps). The decrease in utilization (%) is 49.75%, 51.47%, and 48.28% from 128kbps to 256kbps, and 50.00%, 49.09%, and 51.39 from 256kbps to 512kbps.

Bandwidth – 128kbps-512kbps, Message Size – 46B (400B)

The average percentage of utilization for experimental IM_ATM is 7.700%, 11.593%, 28.043% (128kbps), 3.850%, 5.297%, and 13.987% (256kbps), and 1.961%, 2.898%, and 7.021% (512kbps). The decrease in utilization (%) is 50.00%, 54.30%, and 50.12% from 128kbps to 256kbps, and 49.06%, 45.29%, and 49.95% from 256kbps to 512kbps.

Regional Network	Average Channel Utilization (%)					
9 Nodes	Warm Up: 5/s, Replication: 240/s					
Message Size	800B			400B		
Bandwidth	60%	75%	90%	60%	75%	90%
128kbps	58.50	73.44	86.33	56.61	73.17	87.11
256kbps	30.11	39.78	56.44	25.22	39.22	56.89
512kbps	15.22	19.94	28.22	15.17	18.72	28.39
Regional – 9 Nodes	Average Channel Utilization (%), Warm Up: 5/s, Replication: 240/s					
Message Size	800B			IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%
128kbps						
Physician-Link	78	96	100	0.316	0.446	1.020
	58	77	91	0.244	0.339	0.743
HQ-Link	25	33	39	0.089	0.152	0.343
	60	73	91	0.258	0.375	0.738
Lab-Link	53	75	100	0.248	0.343	1.011
	76	95	100	0.273	0.443	0.994
Hosp-Link	77	95	92	0.335	0.478	0.825
	62	71	65	0.219	0.303	0.576
Patient-Link	42	53	91	0.144	0.228	0.775
	57	73	88	0.235	0.363	0.701
Imaging-Link	55	78	99	0.206	0.322	0.821
	63	79	92	0.236	0.417	0.811
Insurance-Link	60	72	90	0.230	0.328	0.949
	78	97	100	0.328	0.440	0.757
Pharmacy-Link	57	74	93	0.214	0.359	0.811
	64	79	96	0.255	0.337	0.762
Consult-Link	64	72	88	0.211	0.329	0.312
	24	30	39	0.089	0.122	0.727
Average	58.50	73.44	86.33	0.229	0.340	0.760

Table 9.22: Regional Networks (9 Nodes) – Average Channel Utilization (%) for 800B, IM_ATM, and Experimental IM_ATM

Regional – 9 Nodes	Average Channel Utilization (%): Warm Up: 5/s, Replication: 240/s (Cont'd)								
Message Size	800B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
256kbps									
Physician-Link	40	52	74	0.158	0.228	0.512	2.512	3.859	8.503
	30	42	57	0.122	0.170	0.371	1.860	3.418	6.649
HQ-Link	13	17	24	0.044	0.076	0.369	0.809	1.257	2.837
	31	39	57	0.129	0.188	0.365	1.910	2.916	6.675
Lab-Link	27	41	56	0.124	0.171	0.506	1.678	3.103	6.166
	39	52	75	0.137	0.222	0.497	2.468	3.842	8.692
Hosp-Link	40	52	74	0.168	0.139	0.413	2.470	3.909	8.582
	32	38	57	0.110	0.152	0.288	2.121	2.690	6.369
Patient-Link	22	29	40	0.072	0.114	0.388	1.355	2.245	4.523
	29	39	60	0.117	0.182	0.350	1.826	2.792	7.143
Imaging-Link	28	44	53	0.103	0.161	0.410	1.690	3.483	5.923
	32	43	63	0.118	0.208	0.406	2.027	3.189	7.276
Insurance-Link	31	38	57	0.115	0.164	0.474	1.929	2.859	6.466
	40	53	75	0.164	0.220	0.379	2.484	3.993	8.603
Pharmacy-Link	29	39	59	0.107	0.180	0.401	1.800	2.638	7.079
	33	43	58	0.128	0.168	0.381	2.091	3.274	6.743
Consult-Link	34	39	53	0.105	0.165	0.156	2.182	2.889	5.954
	12	16	24	0.044	0.061	0.401	0.780	1.220	2.664
Average	30.11	39.78	56.44	0.115	0.165	0.393	1.888	2.976	6.492

Regional – 9 Nodes	Average Channel Utilization (%): Warm Up: 5/s, Replication: 240/s (Cont'd)								
Message Size	800B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
512kbps									
Physician-Link	20	26	37	0.079	0.114	0.256	1.255	1.930	4.252
	15	21	28	0.061	0.085	0.186	0.930	1.709	3.325
HQ-Link	7	9	12	0.022	0.038	0.086	0.404	0.628	1.418
	16	20	28	0.064	0.094	0.195	0.955	1.458	3.338
Lab-Link	14	20	28	0.062	0.086	0.182	0.839	1.551	3.083
	20	26	37	0.068	0.111	0.253	1.234	1.921	4.346
Hosp-Link	20	27	37	0.084	0.120	0.249	1.235	1.955	4.291
	16	19	29	0.055	0.053	0.206	1.061	1.345	3.184
Patient-Link	11	15	20	0.036	0.054	0.144	0.678	1.122	2.161
	15	19	30	0.059	0.091	0.194	0.913	1.396	3.572
Imaging-Link	14	22	27	0.052	0.081	0.175	0.845	3.742	2.961
	16	21	32	0.059	0.104	0.205	1.013	1.593	3.638
Insurance-Link	15	19	28	0.058	0.082	0.203	0.964	1.429	3.122
	20	27	37	0.082	0.110	0.237	1.143	1.996	4.302
Pharmacy-Link	15	19	29	0.054	0.090	0.189	0.900	1.319	3.539
	17	22	30	0.064	0.084	0.203	1.046	1.637	3.371
Consult-Link	17	19	27	0.053	0.082	0.191	1.093	1.444	2.977
	6	8	12	0.022	0.031	0.078	0.390	0.610	1.332
Average	15.22	19.94	28.22	0.057	0.084	0.191	0.939	1.599	3.234
Regional Network	Average Channel Utilization: 9 Nodes, 245/s Replications								
Link: 1.544Mbps	9 Nodes, Replication Length: 245/s								
Message Size	800B			IM_ATM			Experimental IM_ATM		
Bandwidth Capacity	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	58.50	73.44	86.33	0.229	0.340	0.760	3.777	5.953	13.094
256kbps	30.11	39.78	56.44	0.115	0.165	0.393	1.888	2.976	6.492
512kbps	15.22	19.94	28.22	0.057	0.084	0.191	0.939	1.599	3.234

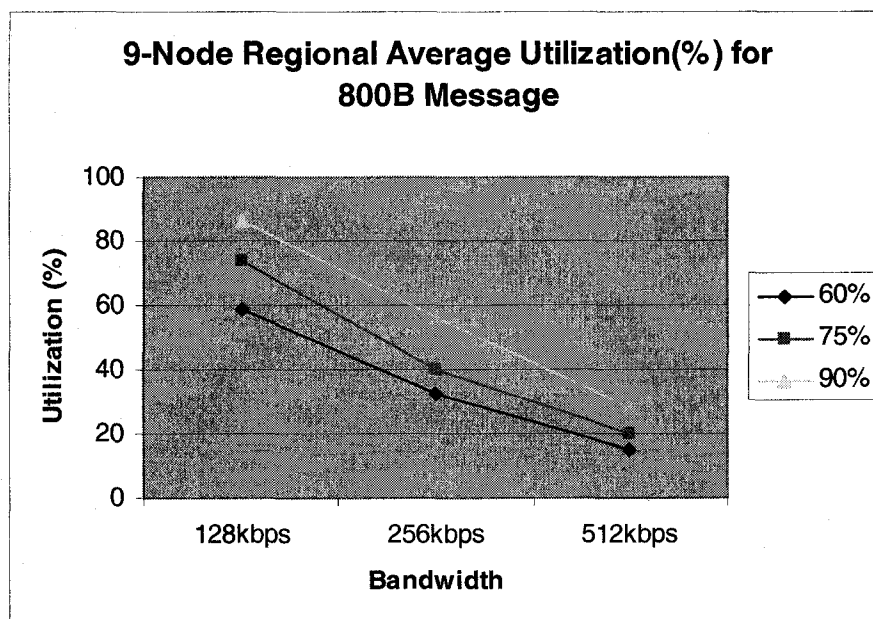


Figure 9.34: Regional Networks (9 Nodes) – Average Channel Utilization (%) for 800B Message

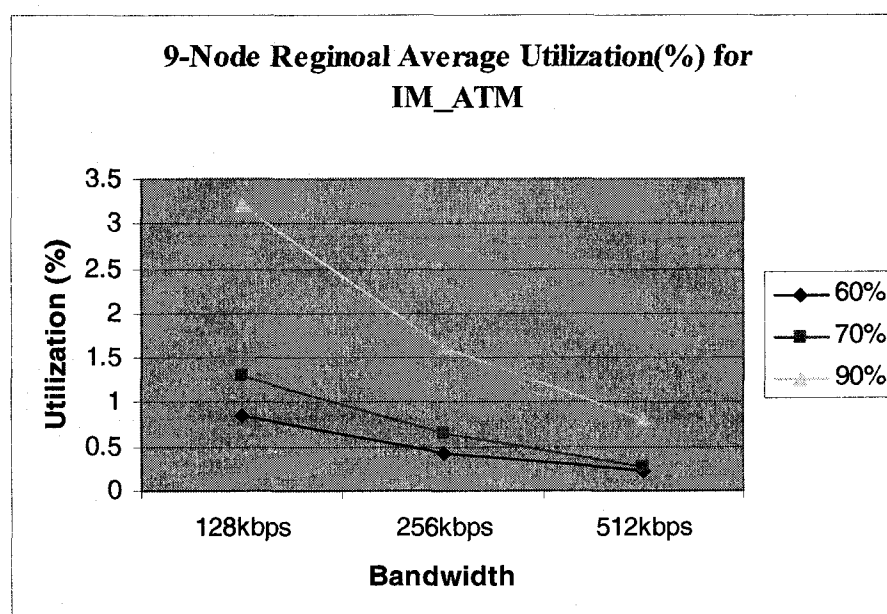


Figure 9.35: Regional Networks (9 Nodes) – Average Channel Utilization (%) for IM_ATM

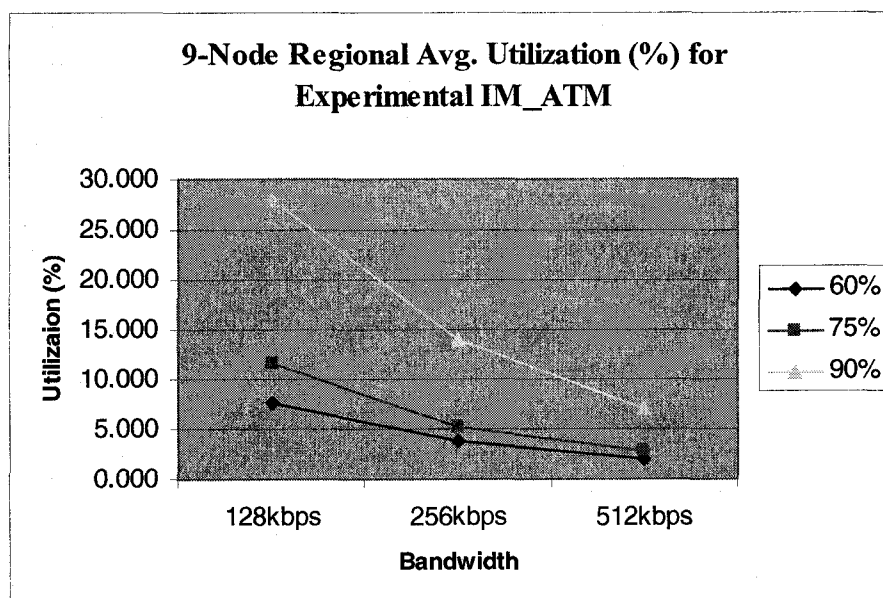


Figure 9.36: Regional Networks (9 Nodes) – Average Channel Utilization (%) for Experimental IM_ATM

Regional - 9 Nodes	Average Channel Utilization (%): Warm Up: 5/s, Replication: 240/s								
Message Size	400B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps									
Physician-Link	76	95	100	1.145	1.753	4.314	10.060	15.280	36.950
	58	71	92	0.927	1.284	3.182	7.553	10.940	27.170
HQ-Link	25	32	40	0.352	0.589	1.378	3.281	4.995	11.950
	59	73	90	0.756	1.318	3.415	7.960	11.320	27.540
Lab-Link	53	75	92	0.805	1.381	3.012	6.808	11.120	26.640
	76	94	100	1.140	1.725	4.196	10.100	15.190	36.960
Hosp-Link	78	96	100	1.163	1.742	4.286	10.340	15.520	36.990
	60	72	92	0.812	1.284	3.159	7.844	11.860	29.650
Patient-Link	42	53	68	0.611	0.949	2.423	5.521	8.293	20.700
	60	76	92	0.849	1.325	3.257	7.715	12.390	26.440
Imaging-Link	58	73	94	0.872	1.339	3.505	7.803	11.990	29.950
	64	81	98	0.892	1.432	3.409	8.297	12.550	29.890
Insurance-Link	58	77	93	0.906	1.231	3.533	7.481	12.170	28.640
	77	95	100	1.184	1.693	4.132	10.300	15.250	36.760
Pharmacy-Link	32	73	91	0.887	1.272	2.958	8.273	11.320	28.040
	62	79	99	0.886	1.364	3.449	8.232	12.390	30.800
Consult-Link	57	72	90	0.885	1.309	2.877	7.862	11.240	28.040
	24	30	37	0.321	0.497	1.311	3.166	4.864	11.670
Average	56.61	73.17	87.11	0.855	1.305	3.211	7.700	11.593	28.043

Table 9.23: Regional Networks (9 Nodes) – Average Channel Utilization (%) for 400B, IM_ATM, and Experimental IM_ATM

Regional – 9 Nodes	Average Channel Utilization (%): Warm Up: 5/s, Replication: 240/s (Cont'd)								
Message Size	400B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
256kbps									
Physician-Link	39	52	75	0.573	0.876	2.157	5.028	2.498	18.480
	30	38	57	0.464	0.642	1.591	3.776	5.659	13.590
HQ-Link	13	17	24	0.176	0.295	0.689	1.641	5.559	5.975
	3	39	58	0.378	0.659	1.708	3.980	7.593	13.770
Lab-Link	28	40	74	0.403	0.691	1.506	3.404	7.760	13.320
	39	52	75	0.57	0.863	2.098	5.052	5.928	18.490
Hosp-Link	40	52	57	0.582	0.871	2.143	5.170	4.147	17.500
	31	38	42	0.406	0.642	1.58	3.922	6.194	14.830
Patient-Link	22	28	57	0.306	0.474	1.212	2.761	5.996	10.360
	31	40	58	0.425	0.662	1.629	3.857	6.276	13.220
Imaging-Link	30	39	62	0.436	0.669	1.753	3.902	6.084	15.010
	3	43	58	0.446	0.716	1.705	4.148	7.627	14.950
Insurance-Link	29	42	75	0.453	0.616	1.766	3.741	5.659	14.320
	10	51	57	0.592	0.846	2.066	5.150	6.196	18.390
Pharmacy-Link	32	39	62	0.443	0.636	1.479	4.136	5.622	14.020
	32	42	55	0.443	0.682	1.724	4.116	2.432	15.410
Consult-Link	30	38	55	0.44	0.655	1.439	3.931	2.889	14.300
	12	16	23	0.161	0.249	0.655	1.583	1.220	5.835
Average	25.22	39.22	56.89	0.428	0.652	1.606	3.850	5.297	13.987

Regional -9 Nodes	Average Utilization (%)								
	Warm Up: 5/s, Replication: 240/s (Cont'd)								
Message Size	400B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
512kbps									
Physician-Link	20	26	37	0.286	0.353	1.078	2.514	3.821	9.241
	15	19	28	0.232	0.265	0.795	1.888	2.735	6.793
HQ-Link	7	9	12	0.088	0.123	0.344	0.820	1.249	2.987
	15	20	27	0.189	0.261	0.854	1.990	2.830	6.887
Lab-Link	14	26	29	0.201	0.241	0.753	1.702	2.780	6.659
	20	26	37	0.285	0.346	1.049	2.526	3.797	9.244
Hosp-Link	20	19	37	0.291	0.354	1.072	2.585	3.880	9.252
	16	14	29	0.203	0.250	0.790	1.961	2.964	7.413
Patient-Link	11	20	21	0.153	0.183	0.606	2.584	3.097	5.178
	15	19	29	0.212	0.261	0.814	1.380	2.998	6.610
Imaging-Link	14	22	29	0.218	0.256	0.876	1.951	3.138	7.506
	16	21	30	0.223	0.261	0.852	2.074	3.042	7.473
Insurance-Link	15	26	29	0.226	0.259	0.883	1.870	3.813	7.160
	20	20	37	0.296	0.353	1.033	2.575	2.830	9.194
Pharmacy-Link	15	21	29	0.222	0.275	0.739	2.068	3.098	7.011
	17	2	31	0.221	0.284	0.862	2.058	2.811	7.705
Consult-Link	17	19	28	0.220	0.285	0.719	1.966	1.216	7.152
	6	8	12	0.080	0.098	0.328	0.792	2.073	2.917
Average	15.17	18.72	28.39	0.214	0.262	0.803	1.961	2.898	7.021
Regional Network	Average Percentage of Channel Utilization								
9 Nodes	Warm Up: 5/s, Replication: 240/s								
Link: 1.544Mbps	400B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	56.61	73.17	87.11	0.855	1.305	3.211	7.700	11.593	28.043
256kbps	25.22	39.22	56.89	0.428	0.652	1.606	3.850	5.297	13.987
512kbps	15.17	18.72	28.39	0.214	0.262	0.803	1.961	2.898	7.021

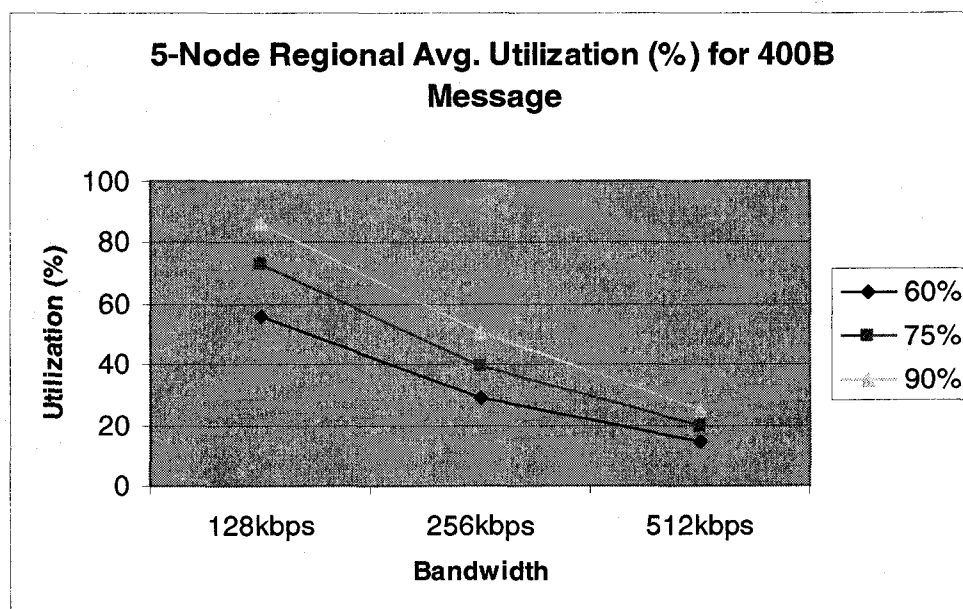


Figure 9.37: Regional Networks (9 Nodes) – Average Channel Utilization (%) for 400B Message

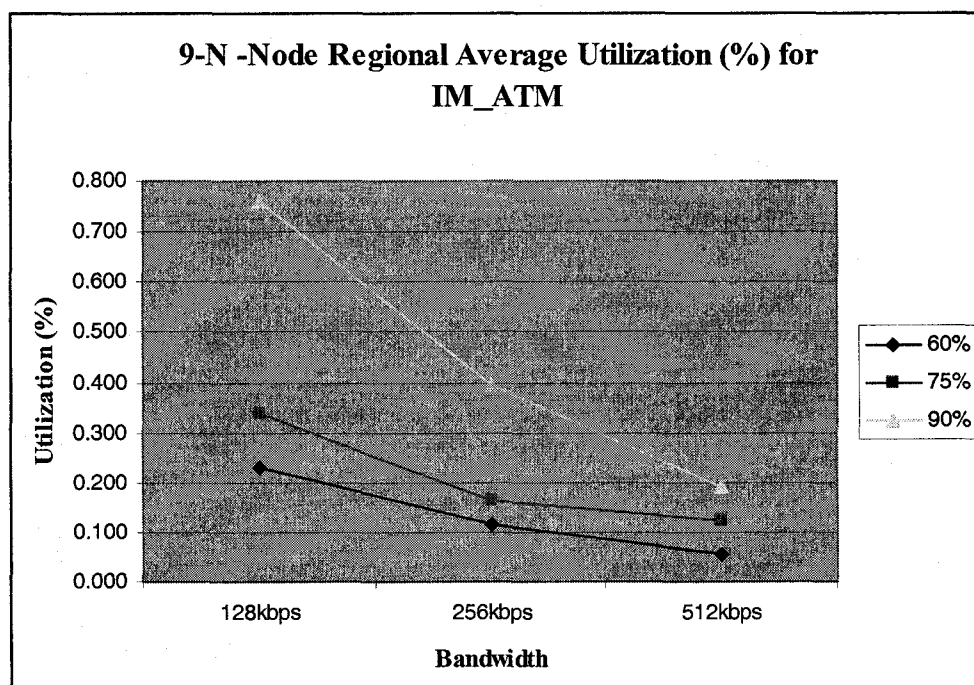


Figure 9.38: Regional Networks (9 Nodes) – Average Channel Utilization (%) for IM_ATM

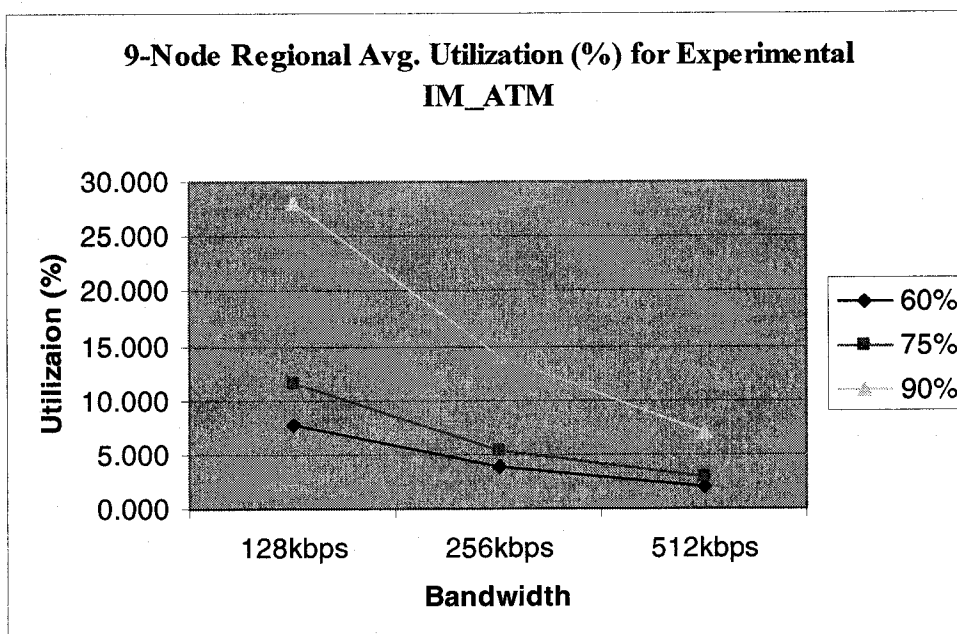


Figure 9.39: Regional Networks (9 Nodes) – Average Channel Utilization (%) for Experimental IM_ATM

9.2. National Networks – Single WAN Cloud

The Global Networks contain four international networks: BA (Baltic Nations), EA (East Asia), EU (Europe), and NA (North America), each international network consists of four WAN Clouds, represent four major cities, and each of them consists of many regional networks. I create a single WAN cloud for examination of each national network. Only NA (North America) WAN Cloud is selected for illustration. The five nodes (cities) are Boston, New York, Washington, Chicago, and Seattle. There are ten message sources and ten destinations for the WAN cloud, namely, Boston-New York, Boston-Washington, Boston-Chicago, Boston-Seattle, New York-Washington, New York-Chicago, New York-Seattle, Washington-Chicago, Washington-Seattle, and Chicago-Seattle. There are altogether twenty VCs (virtual circuits) for five nodes when each node sends messages to every other destination.

A link of 1.544Mbps is used for the network simulations. Message size of 100B, 250B, 500B, and 1000B are examined for the traditional calculations, and 46B is for the IM_ATM. There is a total of 108 simulation runs are performed for this model, and only a few samples are selected for presentations, the statistics are shown from Table 9.24 to 9.31 and graphs are depicted in Figure 9.40 to Figure 9.62.

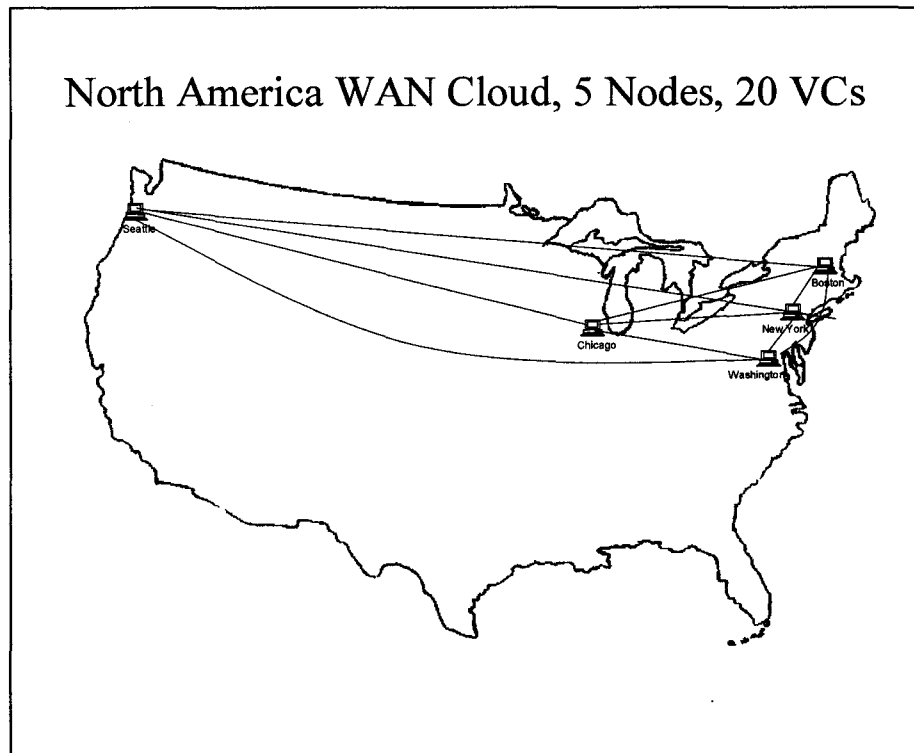


Figure 9.40: North American WAN connects five cities; Boston, New York, Washington, Chicago, and Seattle

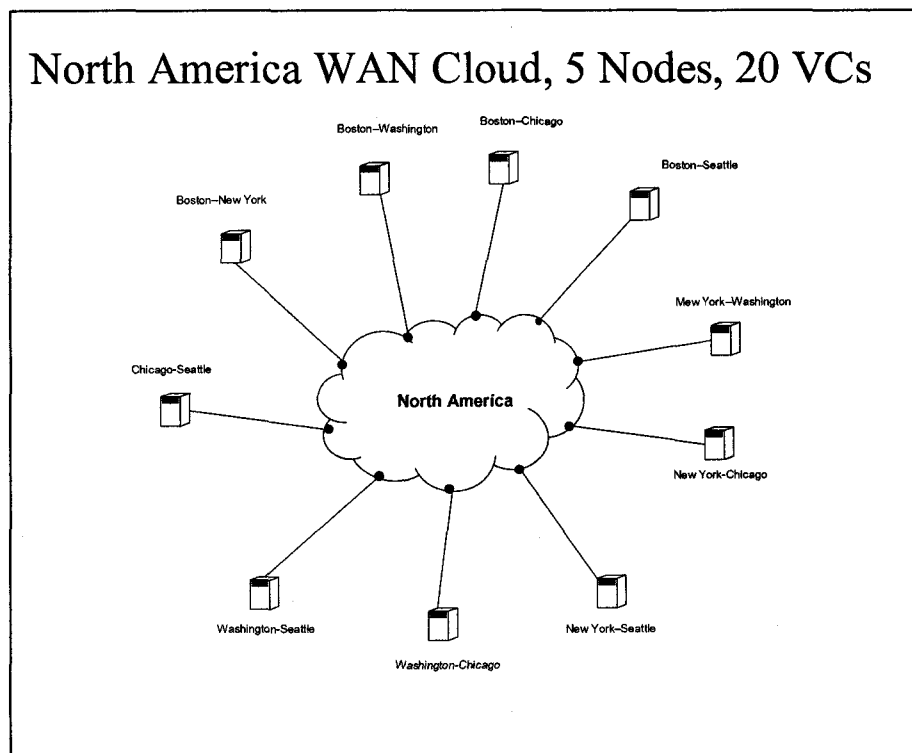


Figure 9.41: North American WAN Cloud (5 Nodes) with 10 Destinations and 20 Virtual Circuits

Analysis: Packets Created, Delivered, Dropped, Ratio of Packets Dropped/Created, and Packets Dropped/Delivered

Bandwidth – 128kbps, 256kbps and 512kbps, Message Size - 1000B and 500B

For 1000B message, the average number of packets created is 260, 393, and 640 (128kbps), 264, 401, and 655 (256kbps), 263, 419, and 664 (512kbps). The number of packets created increased by 1.50%, 2.00%, and 2.3% from 128kbps to 256kbps, and 0.00%, 4.34%, and 1.41% from 256kbps to 512kbps. The number of packets delivered is 236, 306, and 342 (128kbps), 243, 320, and 422 (256kbps), 230, 306, and 409 (512kbps). The number of packets delivered also increased by 2.51%, 6.10, and 15.00% from 128kbps to 256kbps, and 0.80%, 2.10%, and 3.60% from 256kbps to 512kbps. The average number of packets dropped is 24, 85, and 299 (128kbps), 22, 73, and 254 (256kbps), 19, 84, and 248 (512kbps). The number of packets dropped decreased by 9.30%, 14.10%, and 15.11% from 128kbps to 256kbps, and decreased by 13.61%, 13.10%, and 2.41% from 256kbps to 512kbps.

For 500B message, the average number of packets created is 539, 795, and 1459 (128kbps), 531, 815, and 1678 (256kbps), 530, 882, and 1536 (512kbps). The number of packets created increased by 1.50%, 2.00%, and 2.3% from 128kbps to 256kbps, and 0.00%, 4.34%, and 1.41% from 256kbps to 512kbps. The average number of packets delivered is 508, 615, and 690 (128kbps), 474, 664, and 919 (256kbps), 474, 700, and 906 (512kbps). The number of packets delivered also increased by 2.51%, 6.10, and 15.00% from 128kbps to 256kbps, and 0.80%, 2.10%, and 3.60% from 256kbps to 512kbps. The average number of packets dropped is 31, 179, and 769 (128kbps), 57, 151, and 759 (256kbps), 56, 182, and 630 (512kbps). The number of packets dropped decreased by

9.30%, 14.10%, and 15.11% from 128kbps to 256kbps, and decreased by 13.61%, 13.10%, and 2.41% from 256kbps to 512kbps.

For 1000B message, the ratio of packets dropped/created is 9.23%, 21.63%, and 46.72% (128kbps), and 8.33%, 18.20%, and 38.73% (256kbps), and 7.22%, 20.05%, and 37.35% (512kbps), and packets dropped/delivered 10.17%, 27.60%, and 87.68% (128kbps), and 9.09%, 22.26%, and 63.34% (256kbps), and 7.79%, 25.07%, and 59.62% (512kbps). For 500B message, the ratio of packets dropped/created is 5.71%, 22.57%, and 52.72% (128kbps), and 10.75%, 18.59%, and 45.24% (256kbps), and 10.58%, 20.65%, and 41.00% (512kbps), and the ratio of packets dropped/delivered is 6.06%, 29.14%, and 111.52% (128kbps), and 12.05%, 22.84%, and 82.62% (256kbps), and 11.84%, 26.03%, and 69.50% (512kbps).

WAN Cloud – 5 Nodes, 20 VCS	Message + Response Sources: Packet Delay								
Bandwidth: 128kbps	Warm Up: 5/s, Replication: 240/s								
Message Size: 1000B	Packets Created			Packets Delivered			Packets Dropped		
Origin/Destination	60%	75%	90%	60%	75%	90%	60%	75%	90%
NewYork-Chicago Src									
Boston-Washington	265	387	654	240	288	355	25	99	299
NewYork-Seattle	248	366	639	227	289	352	21	77	287
Chicago-Seattle	258	417	631	233	309	342	25	108	289
Boston-NewYork	236	394	648	218	300	364	18	94	284
Boston-Chicago	277	378	671	257	279	346	20	99	325
NewYork-Washington	271	419	621	247	303	331	24	116	290
Boston-Seattle	277	392	613	245	302	321	32	90	292
Washington-Seattle	256	395	652	232	391	334	24	4	318
Washington-Chicago	252	390	634	226	296	331	26	94	303
Average:	260.00	393.00	640.00	236.00	308.00	341.00	24.00	85.00	299.00
	Dropped/Created			Dropped/Delivered					
Ratio:	9.23%	21.63%	46.72%	10.17%	27.60%	87.68%			
Bandwidth: 256kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
NewYork-Chicago Src									
Boston-Washington	245	381	685	224	304	408	21	77	277
NewYork-Seattle	287	381	666	267	310	403	20	71	263
Chicago-Seattle	263	424	745	240	339	457	23	85	288
Boston-NewYork	293	435	734	263	356	449	30	79	285
Boston-Chicago	253	421	744	233	348	452	20	73	292
NewYork-Washington	268	423	752	245	345	453	23	78	299
Boston-Seattle	254	431	704	236	353	442	18	78	262
Washington-Seattle	235	426	736	223	344	446	12	82	290
Washington-Chicago	283	395	752	255	324	462	28	71	290
Average:	264.00	401.00	655.00	242.00	328.00	401.00	22.00	73.00	254.00
	Dropped/Created			Dropped/Delivered					
Ratio:	8.33%	18.20%	38.78%	9.09%	22.26%	63.34%			

Table 9.24: National Networks (5 Nodes) - Average Packets Created, Delivered, Dropped, Ratio of Dropped/Created, and Dropped/Delivered for 1000B Message

WAN Cloud	Message + Response Sources: Packet Delay (Cont'd)								
5 Nodes, 20 VCs,	Warm Up: 5/s, Replication: 240/s								
Message Size: 1000B	Packets Created			Packets Delivered			Packets Dropped		
Bandwidth: 512kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
NewYork-Chicago Src									
Boston-Washington	234	381	661	217	304	419	17	77	242
NewYork-Seattle	242	391	635	223	310	413	19	81	222
Chicago-Seattle	257	424	669	241	339	423	16	85	246
Boston-NewYork	285	435	672	272	356	395	13	79	277
Boston-Chicago	235	421	613	221	348	398	14	73	215
NewYork-Washington	248	423	649	231	345	396	17	78	253
Boston-Seattle	237	431	624	228	353	386	9	78	238
Washington-Seattle	251	426	635	227	344	421	24	82	214
Washington-Chicago	239	395	682	216	324	431	23	71	251
Average:	263.00	419.00	664.00	244.00	335.00	416.00	19.00	84.00	248.00
	Dropped/Created			Dropped/Delivered					
Rate:	7.22%	20.05%	37.35%	7.79%	25.07%	59.62%			
WAN Cloud	Message + Response Sources: Packet Delay								
5 Nodes, 20 VCs,	Warm Up: 5/s, Replication: 240/s								
Message Size: 1000B	Packets Created			Packets Delivered			Packets Dropped		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	260	393	640	236	308	341	24	85	299
256kbps	264	401	655	242	328	401	22	73	254
512kbps	263	419	664	244	335	416	19	84	248
Bandwidth	Dropped/Created			Dropped/Delivered					
128kbps	9.23%	21.63%	46.72%	10.17%	27.60%	87.68%			
256kbps	8.33%	18.20%	38.78%	9.09%	22.26%	63.34%			
512kbps	7.22%	20.05%	37.35%	7.79%	25.07%	59.62%			

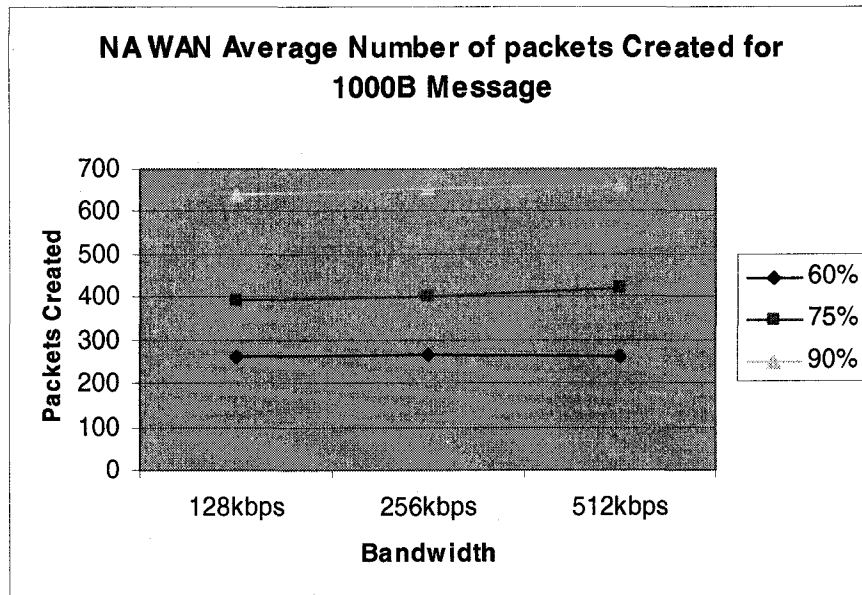


Figure 9.42: National Networks (5 Nodes) - Average Packets Created for 1000B Message

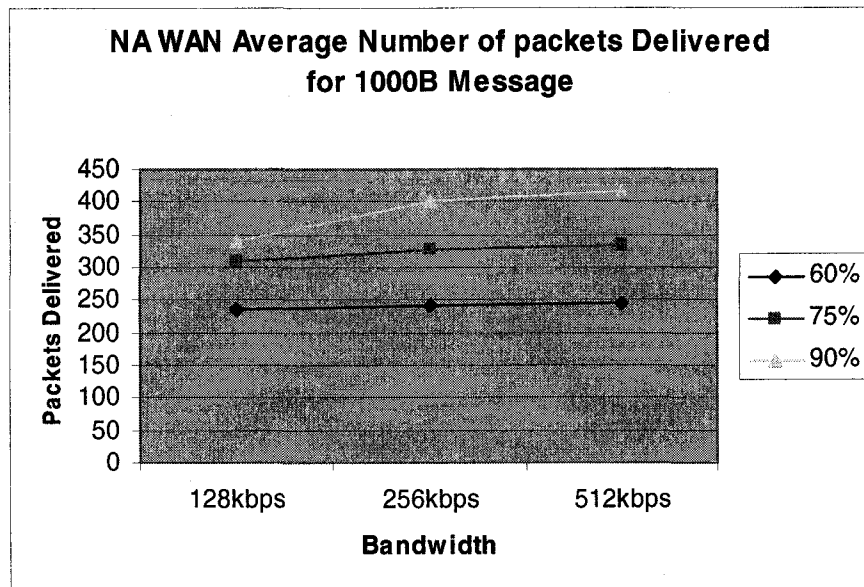


Figure 9.43: National Networks (5 Nodes) - Average Packets Delivered for 1000B Message

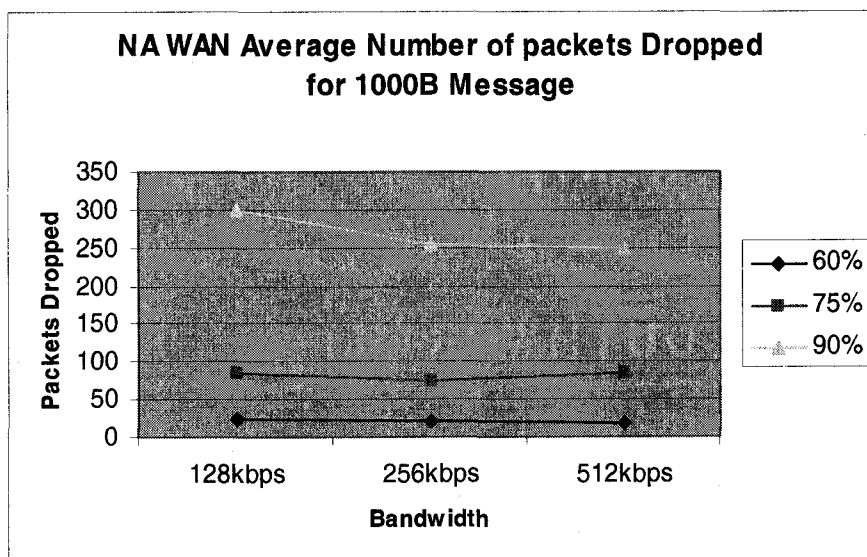


Figure 9.44: National Networks (5 Nodes) - Average Packets Dropped for 1000B Message

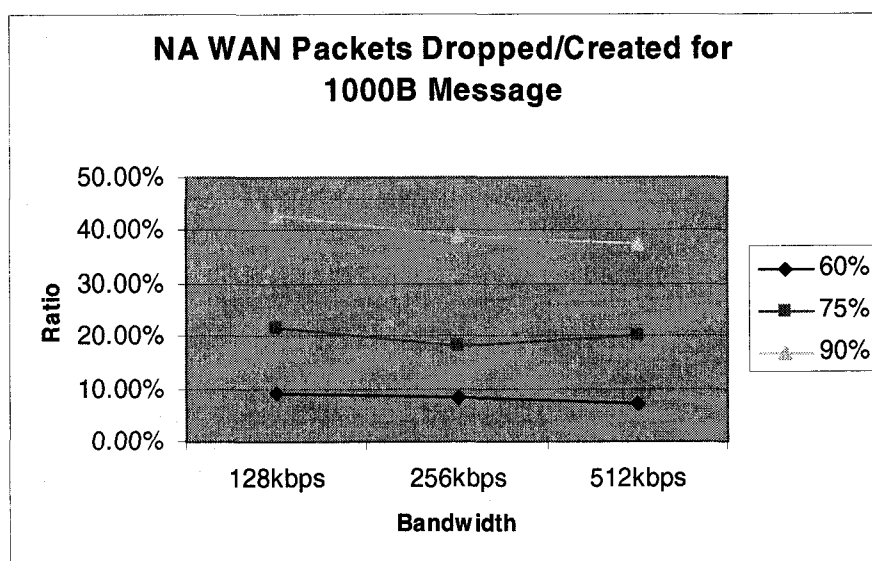


Figure 9.45: National Networks (5 Nodes) – Ratio of Packets Dropped/Created for 1000B Message

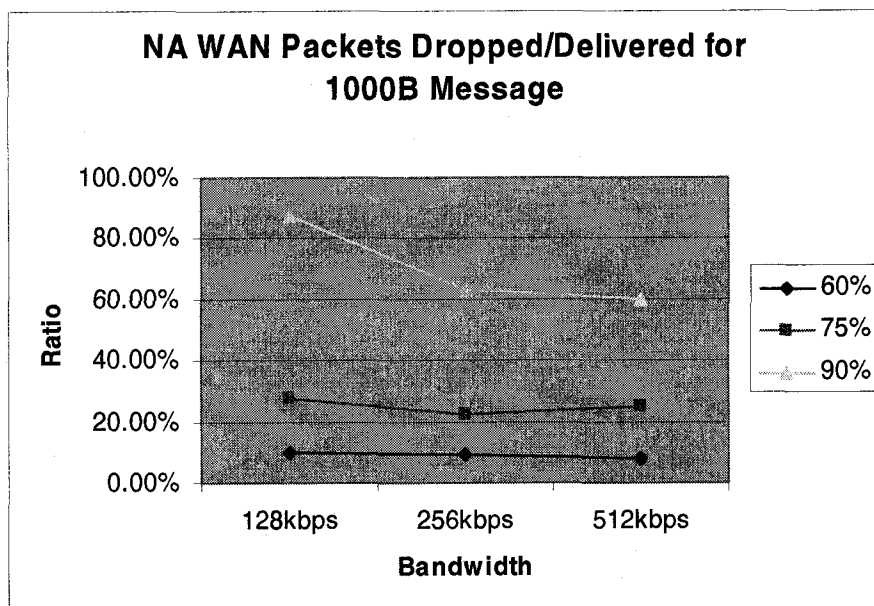


Figure 9.46: National Networks (5 Nodes) – Ratio of Packets Dropped/Delivered for 1000B Message

WAN Cloud – 5 Nodes, 20 VCs	Message + Response Sources: Packet Delay								
Bandwidth: 128kbps	Warm Up: 5/s, Replication: 240/s								
Message Size: 500B	Packets Created			Packets Delivered			Packets Dropped		
Origin/Destination	60%	75%	90%	60%	75%	90%	60%	75%	90%
NewYork-Chicago Src									
Boston-Washington	524	764	1534	516	592	762	8	172	772
NewYork-Seattle	542	812	1301	512	630	658	30	182	643
Chicago-Seattle	567	857	1478	516	657	672	51	200	806
Boston-NewYork	567	792	1441	530	616	640	37	176	801
Boston-Chicago	588	788	1463	536	610	671	52	178	792
NewYork-Washington	537	792	1495	509	615	682	28	177	813
Boston-Seattle	517	821	1493	490	649	718	27	172	775
Washington-Seattle	506	755	1459	469	582	708	37	173	751
Washington-Chicago	503	771	1469	496	587	698	7	184	771
Average:	539.00	794.67	1459.22	508.22	615.33	689.89	30.78	179.33	769.33
	Dropped/Created			Dropped/Delivered					
Ratio:	5.71%	22.57%	52.72%	6.06%	29.14%	111.52%			
Bandwidth: 256kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
NewYork-Chicago Src									
Boston-Washington	563	851	1640	497	683	891	66	168	749
NewYork-Seattle	517	819	1671	458	657	919	59	162	752
Chicago-Seattle	526	836	1668	471	679	915	55	157	753
Boston-NewYork	524	770	1670	463	638	916	61	132	754
Boston-Chicago	556	810	1716	494	654	913	62	156	803
NewYork-Washington	532	844	1649	472	698	904	60	146	745
Boston-Seattle	497	798	1705	453	655	957	44	143	748
Washington-Seattle	521	801	1655	462	646	914	59	155	741
Washington-Chicago	545	807	1725	497	662	939	48	145	786
Average:	531.22	815.11	1677.67	474.11	663.56	918.67	57.11	151.56	759.00
	Dropped/Created			Dropped/Delivered					
Ratio:	10.75%	18.59%	45.24%	12.05%	22.84%	82.62%			

Table 9.25: National Networks – Average Packets Created, Delivered, Dropped, Ratio of Packets Dropped/Created, and Packets Dropped/Delivered for 500B Message

WAN Cloud- 5 Nodes, 20 VCs	Message + Response Sources: Packet Delay (Cont'd)								
Bandwidth: 512kbps	Warm Up: 5/s, Replication: 240/s								
Message Sizes: 500B	Packets Created			Packets Delivered			Packets Dropped		
Origin/Destination	60%	75%	90%	60%	75%	90%	60%	75%	90%
New York-Chicago Src									
Boston-Washington	563	879	1520	497	708	892	66	171	628
New York-Seattle	517	878	1597	458	685	929	59	193	668
Chicago-Seattle	526	885	1522	470	703	907	56	182	615
Boston-New York	514	875	1555	463	695	919	51	180	636
Boston-Chicago	556	894	1514	494	724	911	62	170	603
New York-Washington	532	950	1450	472	747	840	60	203	610
Boston-Seattle	497	847	1575	453	686	919	44	161	656
Washington-Seattle	521	881	1529	462	674	910	59	207	619
Washington-Chicago	545	851	1559	497	678	927	48	173	632
Average:	530.11	882.22	1535.67	474.00	700.00	906.00	56.11	182.22	629.67
	Dropped/Created			Dropped/Delivered					
Ratio:	10.58%	20.65%	41.00%	11.84%	26.03%	69.50%			
WAN Cloud – 5 Nodes, 20 VCs	Message + Response Sources: Packet Delay								
Message Size: 500B	Warm Up: 5/s, Replication: 240/s								
	Packets Created			Packets Delivered			Packets Dropped		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	527.89	794.67	1459.22	508.22	615.33	689.89	19.67	179.33	768.33
256kbps	531.22	815.11	1677.67	471.11	663.56	918.67	57.11	157.56	759.01
512kbps	530.11	882.22	1535.67	474.00	700.00	906.00	56.11	182.22	629.67
Bandwidth	Dropped/Created			Dropped/Delivered					
128kbps	3.73%	22.57%	52.72%	3.87%	29.11%	111.52%			
256kbps	10.75%	18.59%	45.24%	12.05%	22.84%	82.60%			
512kbps	10.58%	20.65%	41.00%	11.84%	26.03%	69.50%			

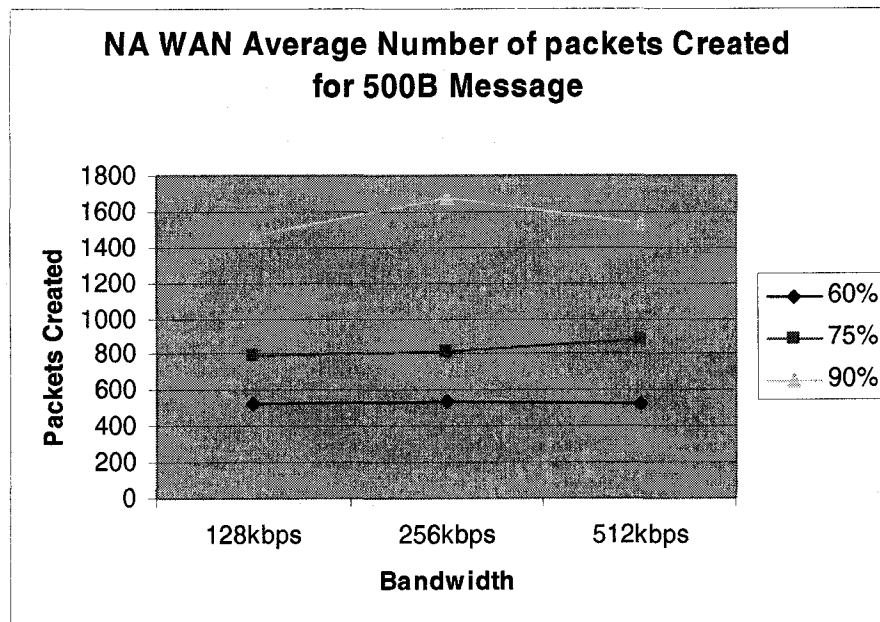


Figure 9.47: National Networks (5 Nodes) – Average Packets Created for 500B Message

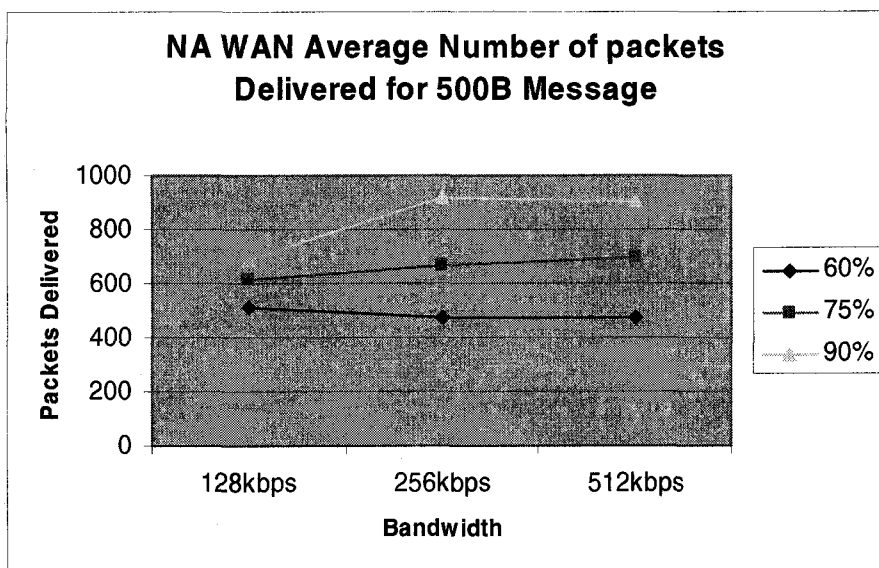


Figure 9.48: National Networks (5 Nodes) – Average Packets Delivered for 500B Message

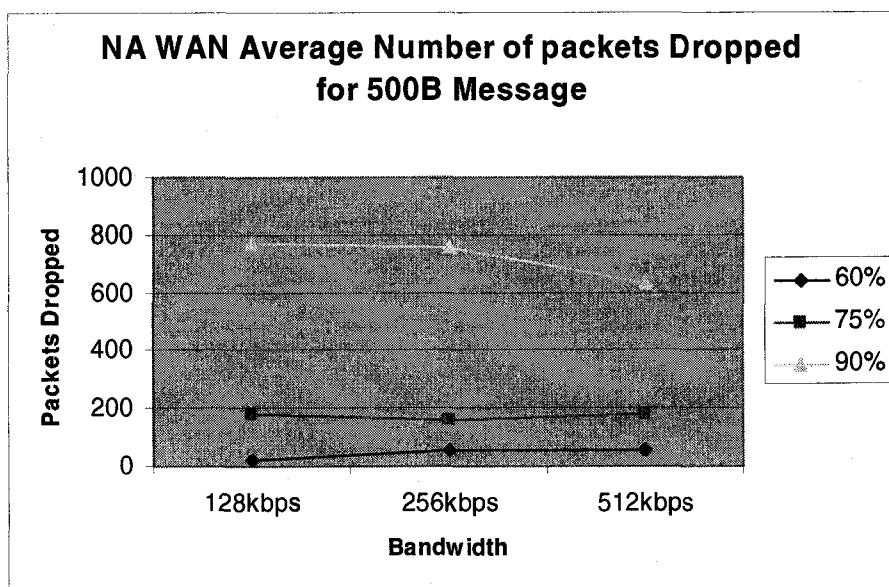


Figure 9.49: National Networks (5 Nodes) – Average Packets Dropped for 500B Message

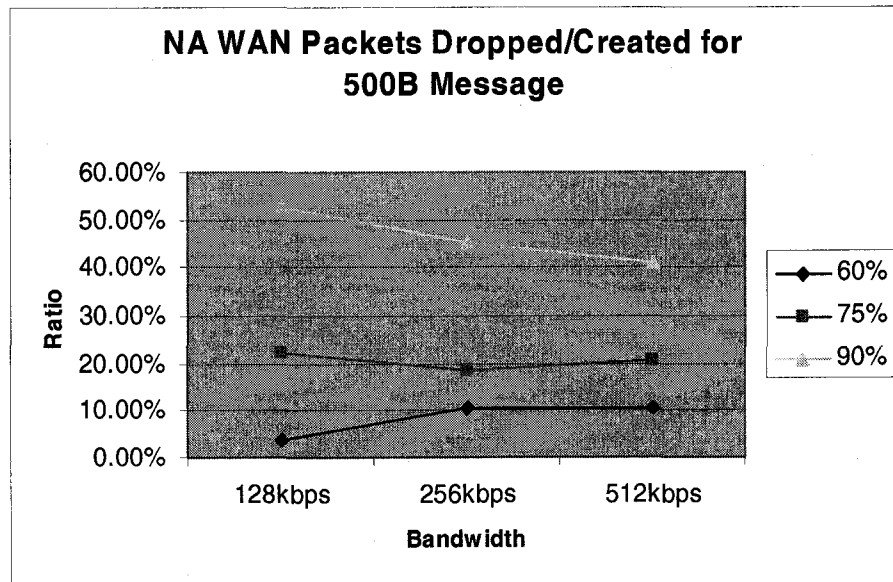


Figure 9.50: National Networks (5 Nodes) – Ratio, Dropped/Created for 500B Message

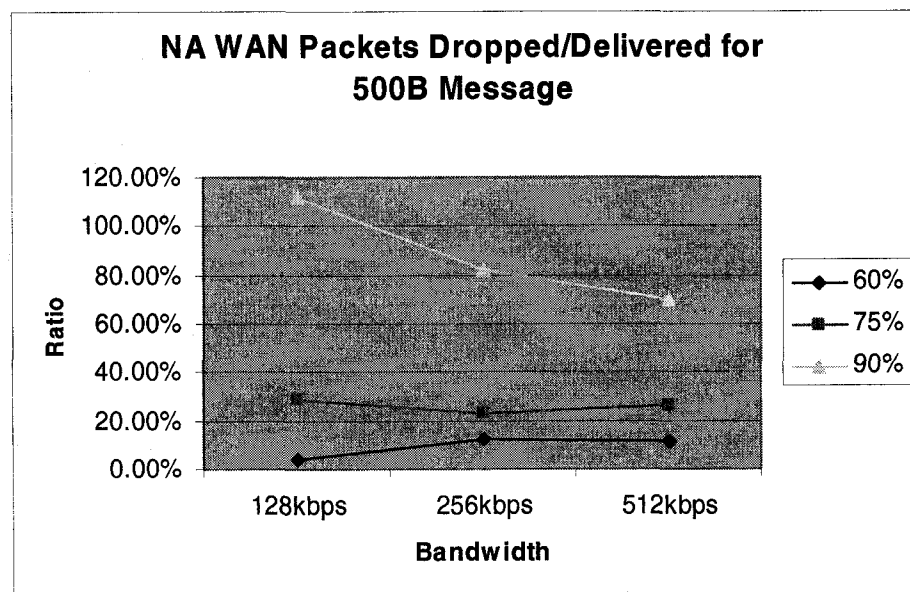


Figure 9.51: National Networks (5 Nodes) – Ratio, Dropped/Delivered for 500B Message

Average Packet Delay (MS)

Bandwidth – 128kbps-512kbps, Message Size - 1000B and 500B

For 1000B message size, the average packet delay (MS) is 678, 883, and 1012 (128kbps), 328, 441, and 518 (256kbps), and 250, 396, and 477 (512kbps). The decrease in packet delay is about 50% for all three capacities from 128kbps to 256kbps, and 23.78%, 10.00%, and 7.72%, from 256kbps to 512kbps. For 500B message size, the average packet delay (MS) is 610, 843, and 1013 (128kbps), 317, 396, and 525 (256kbps), and 280, 366, and 481 (512kbps). The decrease in packet delay is also about 50% from 128kbps to 256kbps, and 11.67%, 9.32%, and 8.38% from 256kbps to 512kbps. These statistical results are given from Tables 9.25 and 9.26 and graphs are depicted in Figures 9.44 and 9.45.

Average Packet Delay (MS) - IM_ATM and Experimental IM_ATM

Bandwidth – 128kbps-512kbps, Message Size – 46B (1000B)

The average packet delay (MS) for IM_ATM is 6.42, 7.07 and 8.03 (128kbps), 3.50, 3.77, and 4.25 (256kbps), and 1.98, 2.14, and 2.40 (512kbps). The decrease in packet delay is 45.48%, 46.67%, and 47.07% from 128kbps to 256kbps, and about 43.00% from 256kbps to 512kbps for all three capacities. For Experimental IM_ATM, the decrease in packet delay is 48.85%, 45.39%, and 45.62% from 128kbps to 256kbps, and 28.79%, 16.35%, and 17.49% from 256kbps to 512kbps.

Bandwidth – 128kbps-512kbps, Message Size – 46B (500B)

The average packet delay (MS) for IM_ATM is 10.97, 12.86, and 20.02 (128kbps), and 5.84, 7.11, and 10.83 (256kbps), and 3.40, 4.13, and 6.73 (512kbps). The decrease in packet delay is 46.76%, 44.71%, and 48.15% from 128kbps to 256kbps, and 41.78%, 41.91%, 35.16% and from 256kbps to 512kbps, for all three capacities. The average packet delay (MS) for the Experimental IM_ATM is 65.16, 93.38, and 158.57 (128kbps), and 35.60, 52.27, 85.71 (256kbps), and 28.73, 43.50, 73.72 (512kbps). The decrease in packet delay is 45.37%, 44.02%, and 45.95% from 128kbps to 256kbps, 19.30%, 16.78%, and 13.99% from 256kbps to 512kbps for all three capacities.

WAN Cloud	Message + Response Sources: Average Packet Delay (MS)					
5 Nodes, 20 VCs	Warm Up: 5/s, Replication: 240/s					
Link: 1.544Mbps	1000B			500B		
Bandwidth: 128kbps						
Origin/Destination	60%	75%	90%	60%	75%	90%
Chicago-Seattle						
NY-Chicago	668	873	1037	617	848	1028
NY-Seattle	684	921	1006	586	844	1027
Boston-Washington	684	911	990	631	847	1016
Boston-NY	665	888	1036	625	822	1021
Boston-Chicago	675	879	1028	624	844	1025
NY-Washington	663	886	1025	597	838	989
Boston-Seattle	687	849	1006	618	848	1013
Washington-Seattle	690	860	984	608	865	1014
Washington-Chicago	683	880	993	582	829	987
Average Delay:	677.67	883.00	1011.67	609.78	842.78	1013.33
Bandwidth: 256kbps						
Chicago-Seattle						
NY-Chicago	329	436	523	315	375	534
NY-Seattle	327	444	530	321	402	532
Boston-Washington	335	422	531	329	409	522
Boston-NY	328	453	515	311	402	510
Boston-Chicago	323	441	516	299	403	529
NY-Washington	350	433	517	333	393	535
Boston-Seattle	316	448	496	319	387	508
Washington-Seattle	328	447	534	309	394	526
Washington-Chicago	319	444	503	317	400	525
Average Delay:	328.33	440.89	518.33	317.00	396.11	524.56

Table 9.26: National Networks – Average Packet Delay for 1000B and 500B Message

WAN Cloud	Message + Response Sources: Average Packet Delay (MS) (Cont'd)					
5 Nodes, 20 VCs	Warm Up: 5/s, Replication: 240/s					
Link: 1.544Mbps	1000B			500B		
Bandwidth: 512kbps						
Chicago-Seattle						
NY-Chicago	242	379	471	274	351	485
NY-Seattle	253	387	479	283	368	477
Boston-Washington	243	399	484	284	375	478
Boston-NY	237	398	478	286	371	474
Boston-Chicago	246	388	467	285	369	482
NY-Washington	258	396	495	265	365	485
Boston-Seattle	252	421	475	292	364	487
Washington-Seattle	262	399	476	290	367	481
Washington-Chicago	257	397	475	265	363	479
Average Delay(MS)	250.00	396.00	477.78	280.44	365.89	480.89
WAN Cloud	Message + Response Sources: Average Packet Delay (MS)					
5 Nodes, 20 VCs	Warm Up: 5/s, Replication: 240/s					
Message Size	1000B			500B		
Bandwidth	60%	75%	90%	60%	75%	90%
128kbps	677.67	883.00	1011.67	609.78	842.78	1013.33
256kbps	238.33	440.89	518.33	317.00	396.11	524.56
512kbps	250.00	396.00	477.78	280.44	365.89	480.89

WAN Cloud	Message + Response Sources: Average Packet Delay (MS)								
5 Nodes, 20 VCs	Warm Up: 5/s, Replication: 240/s								
Link: 1.544Mbps	1000B			IM_ATM			Experimental IN_ATM		
Bandwidth: 128kbps									
Origin/Destination	60%	75%	90%	60%	75%	90%	60%	75%	90%
Chicago-Seattle									
NY-Chicago	668	873	1037	6.55	6.95	7.90	33.71	50.61	72.85
NY-Seattle	684	921	1006	6.47	7.13	8.06	37.49	50.48	76.34
Boston-Washington	684	911	990	6.31	7.55	7.98	32.67	52.40	77.05
Boston-NY	665	888	1036	6.23	7.31	8.10	32.66	53.40	74.69
Boston-Chicago	675	879	1028	6.47	7.49	8.09	34.21	53.33	78.78
NY-Washington	663	886	1025	6.23	6.98	8.07	36.02	50.51	77.69
Boston-Seattle	687	849	1006	6.22	6.51	7.62	34.53	54.99	78.10
Washington-Seattle	690	860	984	6.74	7.13	8.15	32.11	55.87	76.45
Washington-Chicago	683	880	993	6.59	6.60	8.31	34.00	48.94	81.50
Average Delay:	677.67	883.00	1011.67	6.42	7.07	8.03	34.16	52.28	77.05
Bandwidth: 256kbps									
NY-Chicago	329	436	523	3.51	3.71	4.19	15.49	27.86	40.08
NY-Seattle	327	444	530	3.48	3.81	4.27	18.33	27.81	41.97
Boston-Washington	335	422	531	3.36	4.02	4.23	17.21	28.64	42.20
Boston-NY	328	453	515	3.36	3.89	4.29	18.54	28.99	40.56
Boston-Chicago	323	441	516	3.48	3.99	4.28	16.32	29.31	42.82
NY-Washington	350	433	517	3.36	3.69	4.27	16.31	27.60	42.41
Boston-Seattle	316	448	496	3.44	3.49	4.05	18.11	28.98	41.22
Washington-Seattle	328	447	534	3.36	3.78	4.31	17.36	30.38	41.67
Washington-Chicago	319	444	503	4.13	3.55	4.39	19.56	28.26	44.18
Average Delay:	328.33	440.89	518.33	3.50	3.77	4.25	17.47	28.65	41.90

Table 9.27: National Networks – Packet Delay for 1000B, IM_ATM, and Experimental IM_ATM Message

WAN Cloud	Message + Response Sources: Average Packet Delay (MS) (Cont'd)								
5 Nodes, 20 VCs	Warm Up: 5/s, Replication: 240/s								
Link: 1.544Mbps	1000B			IM_ATM			Experimental IM_ATM		
Bandwidth: 512kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Chicago-Seattle									
NY-Chicago	242	379	471	1.99	2.09	2.35	12.34	22.35	33.36
NY-Seattle	253	387	479	1.98	2.14	2.38	12.29	22.15	34.54
Boston- Washington	243	399	484	1.92	2.25	2.36	12.32	22.57	35.03
Boston-NY	237	398	478	1.92	2.19	2.38	11.31	22.18	33.54
Boston-Chicago	246	388	467	2.03	2.23	2.38	13.25	22.74	35.39
NY-Washington	258	396	495	1.99	2.08	2.27	12.21	21.96	34.97
Boston-Seattle	252	421	475	1.92	1.98	2.39	13.63	23.51	34.64
Washington- Seattle	262	399	476	2.06	2.13	2.44	12.56	21.61	33.88
Washington- Chicago	257	397	475	2.03	2.18	2.66	12.01	23.01	35.79
Average Delay:	250.00	396.00	477.78	1.98	2.14	2.40	12.44	22.45	34.57

WAN Cloud – 5 Nodes, 20 VCs	Message + Response Sources: Average Packet Delay (MS)								
Bandwidth:128kbps	Warm Up: 5/s, Replication: 240/s								
Link: 1.544Mbps	500B			IM_ATM			Experimental IM_ATM		
Origin/Destination	60%	75%	90%	60%	75%	90%	60%	75%	90%
Chicago-Seattle									
NY-Chicago	617	848	1028	10.54	13.21	20.49	64.03	92.67	176.38
NY-Seattle	586	844	1027	10.76	11.35	21.99	66.77	88.27	165.21
Boston- Washington	631	847	1016	11.45	13.91	19.95	64.18	89.79	167.31
Boston-NY	625	822	1021	10.33	11.23	17.61	66.20	94.09	168.33
Boston-Chicago	624	844	1025	11.11	12.48	19.69	68.71	95.26	168.13
NY-Washington	597	838	989	11.31	13.30	20.74	64.33	93.24	169.21
Boston-Seattle	618	848	1013	10.53	13.91	19.61	63.93	95.65	166.23
Washington- Seattle	608	865	1014	11.61	13.48	20.13	61.49	99.25	156.33
Washington- Chicago	582	829	987	11.12	12.88	20.01	66.81	92.24	165.11
Average Delay:	609.78	842.78	1013.33	10.97	12.86	20.02	65.16	93.38	166.92
Bandwidth:256kbps									
NY-Chicago	315	375	534	5.64	6.91	10.21	34.75	51.43	85.99
NY-Seattle	330	402	532	5.73	7.50	10.17	36.24	49.99	88.53
Boston- Washington	329	409	522	6.06	6.56	10.89	35.14	50.21	86.15
Boston-NY	341	402	510	5.54	7.14	10.29	35.54	52.11	84.86
Boston-Chicago	328	403	529	5.91	7.54	10.87	36.21	52.52	86.99
NY-Washington	333	393	535	6.04	7.68	10.45	37.22	54.11	82.00
Boston-Seattle	336	387	508	5.59	6.79	9.96	34.99	52.47	86.91
Washington- Seattle	336	394	526	6.17	7.04	10.00	34.77	54.39	82.74
Washington- Chicago	317	400	525	5.90	6.85	10.57	35.56	53.23	87.22
Average Delay:	329.44	396.11	524.56	5.84	7.11	10.38	35.60	52.27	85.71

Table 9.28: National Networks – Packet Delay for 500B, IM_ATM, and Experimental IM_ATM Message

WAN Cloud	Message + Response Sources: Average Packet Delay (MS) (Cont'd)								
5 Nodes, 20 VCs	Warm Up: 5/s, Replication: 240/s								
Link: 1.544Mbps	500B			IM_ATM			Experimental IM_ATM		
Origin/Destination	60%	75%	90%	60%	75%	90%	60%	75%	90%
Chicago-Seattle									
NY-Chicago	274	351	485	3.27	3.98	6.56	27.70	42.67	72.84
NY-Seattle	283	368	477	3.33	4.23	7.23	28.60	43.33	74.56
Boston-Washington	284	375	478	3.50	3.99	6.71	27.67	42.56	73.11
Boston-NY	286	371	474	3.24	4.04	6.50	28.56	44.99	69.13
Boston-Chicago	285	369	482	3.42	4.37	7.31	29.55	44.56	73.56
NY-Washington	265	365	485	3.54	4.15	6.45	27.89	43.97	78.51
Boston-Seattle	292	364	487	3.31	3.91	6.38	29.31	43.70	76.31
Washington-Seattle	290	367	481	3.57	4.33	6.71	30.32	43.11	72.14
Washington-Chicago	265	363	479	3.39	4.18	6.71	28.97	43.10	73.36
Average Delay:	280.44	365.89	480.89	3.40	4.13	6.73	28.73	43.55	73.72

WAN Cloud	Message + Response Sources: Average Packet Delay (MS)								
5 Nodes, 20 VCs	Warm Up: 5/s, Replication: 240/s								
Link: 1.544Mbps	1000B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	677.67	883.00	1011.67	6.42	7.07	8.03	34.16	52.28	77.05
256kbps	328.33	440.89	518.33	3.50	3.77	4.25	17.47	28.55	41.90
512kbps	250.00	396.00	477.78	1.98	2.14	2.40	12.44	22.45	34.57
WAN Cloud	Message + Response Sources: Average Packet Delay (MS)								
5 Nodes, 20 VCs	Warm Up: 5/s, Replication: 240/s								
Link: 1.544Mbps	500B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	609.78	842.78	1013.33	10.97	12.86	20.02	65.16	93.38	158.57
256kbps	317.00	396.11	524.56	5.84	7.11	10.38	35.60	52.27	85.71
512kbps	280.44	365.89	480.89	3.40	4.13	6.73	28.73	43.5	73.72

Table 9.29: National Networks – Average Packet Delay for 1000B, 500B, IM_ATM, and Experimental IM_ATM Messages

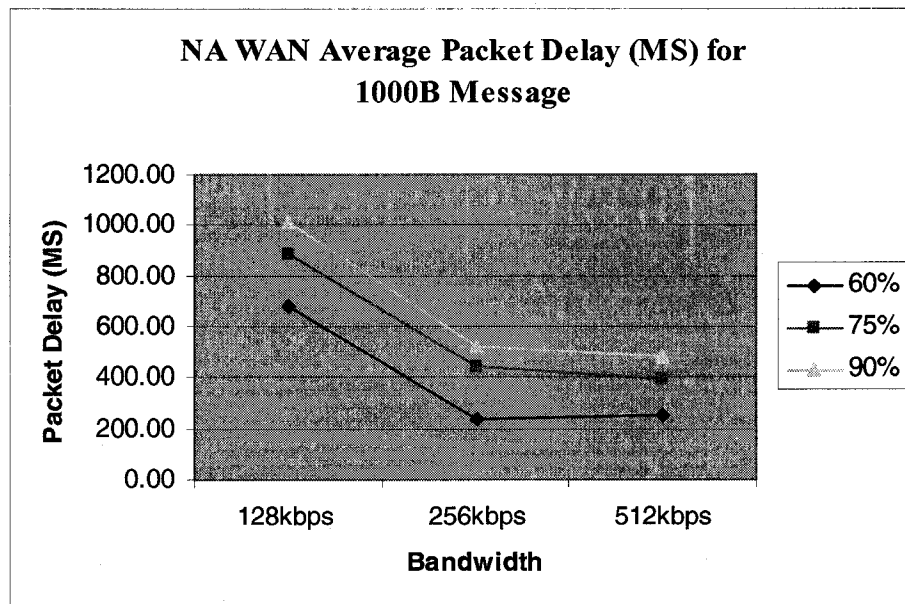


Figure 9.52: National Networks (5 Nodes) - Packets Delay (MS) for 1000B Message

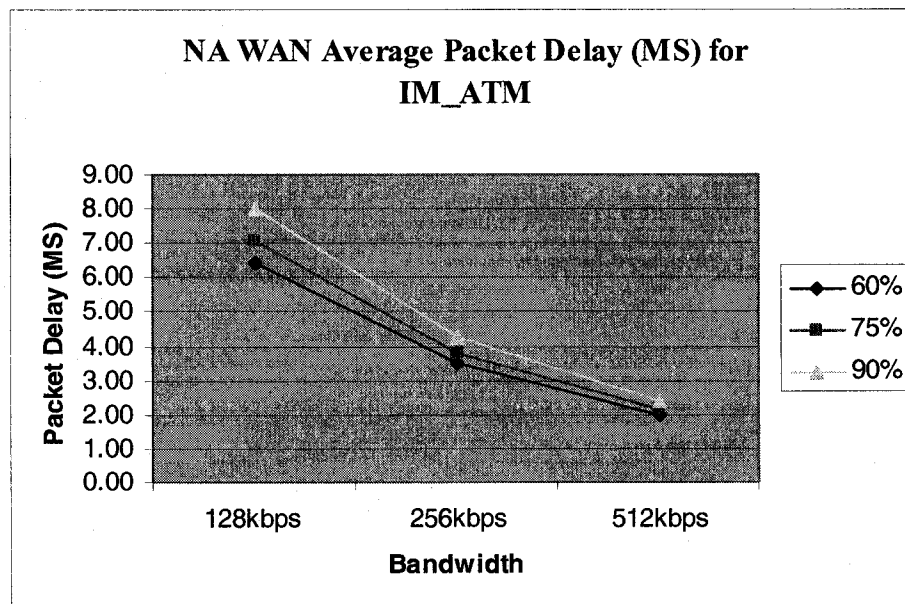


Figure 9.53: National Networks (5 Nodes) – Average Packets Delay (MS) for IM_ATM

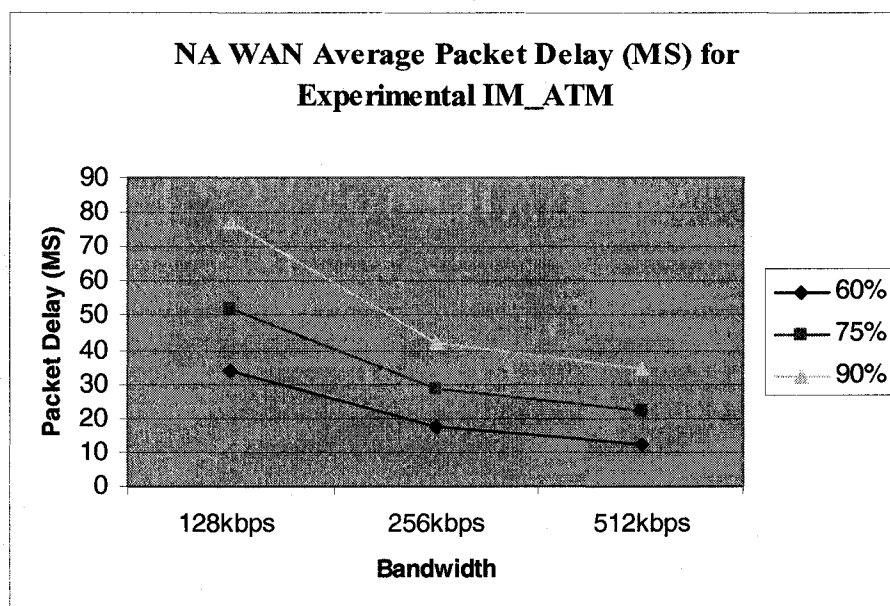


Figure 9.54: National Networks (5 Nodes) – Average Packet Delay (MS) for Experimental IM_ATM

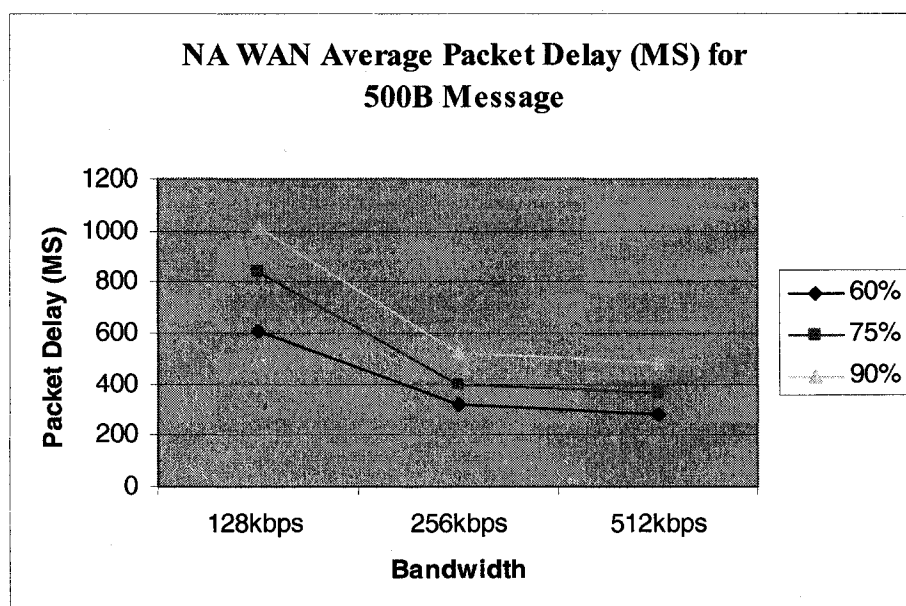


Figure 9.55: National Networks (5 Nodes) - Packets Delay (MS) for 500B Message

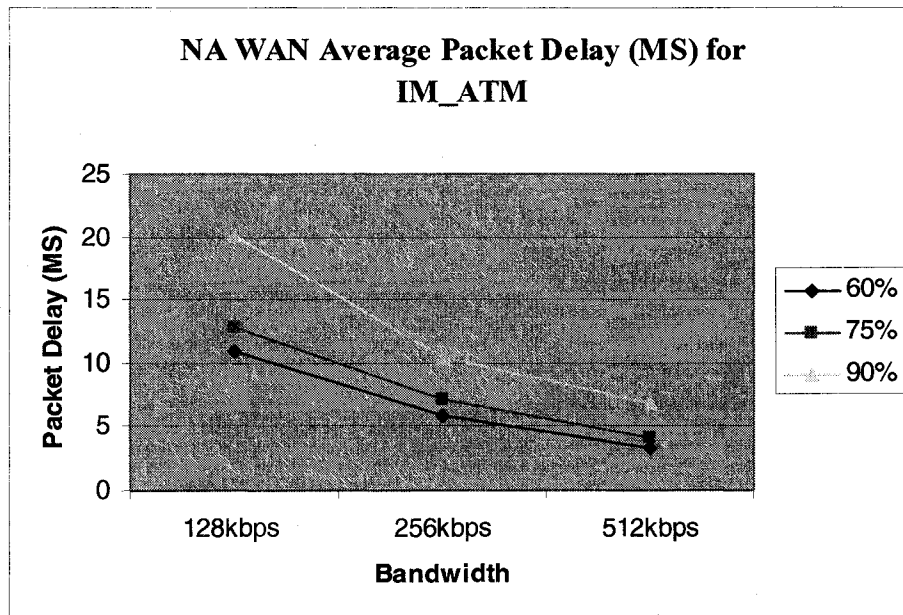


Figure 9.56: National Networks (5 Nodes) – Average Packet Delay (MS) for IM_ATM

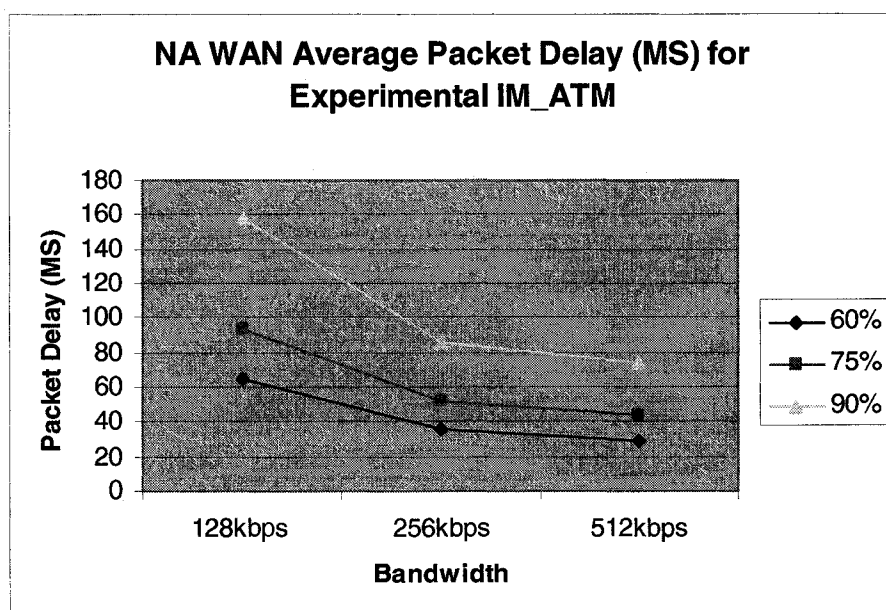


Figure 9.57: National Networks (5 Nodes) – Average Packet Delay (MS) for Experimental IM_ATM

Average Access Link Utilization (%)

Message Size - 1000B and 500B

For 1000 bytes message, the average link utilization is 55.29%, 71.54%, and 81.99% (128kbps), 28.36%, 38.66%, and 48.70% (256kbps), and 13.78%, 19.33%, and 24.56% (512kbps). The decrease in link utilization is 48.70%, 45.96%, and 40.60% from 128kbps to 256kbps, and 50% for all three bandwidth intensities from 256kbps to 512kbps.

For 500 bytes message, the average link utilization is very similar to that of the 1000 bytes for all the three bandwidth intensities. These statistics are given from Tables 9.31 to 9.32 and graphs are depicted in Figures 9.50 and 9.55.

Average Utilization (%) - IM_ATM and Experimental IM_ATM

The average utilization for IM_ATM network is 0.123%, 0.217%, 0.315% (128kbps), 0.079%, 0.106%, and 0.156% (256kbps), and 0.039%, 0.059%, and 0.97% (512kbps). The decrease in utilization is 46.07%, 49.85%, and 51.17% from 128kbps to 256kbps, and 50.91%, 50.28%, and 43.13% from 256kbps to 512kbps for all three intensities.

The average utilization for experimental IM_ATM networks is 2.879%, 4.529%, 7.092% (128kbps), 1.416%, 2.219%, and 3.391% (256kbps), and 0.715%, 1.128%, and 1.745% (512kbps). The decrease in utilization is 50.82%, 51.00%, and 52.19% from 128kbps to 256kbps, and 49.44%, 49.17%, and 48.54% from 256kbps to 512kbps.

Message Size – 46B (500B) , IM_ATM

The average link utilization is 0.523%, 0.778%, 1.475% (128kbps), 0.266%, 0.385%, and 0.738% (256kbps), and 0.133%, 0.182%, and 0.369% (512kbps). The decrease in utilization is 49.14%, 50.51%, and 49.97% from 128kbps to 256kbps, and 50.00%, 52.72%, and 50.00% from 256kbps to 512kbps.

Message Size – 46B (500B), Experimental IM_ATM

The average link utilization for Experimental IM_ATM is 5.731%, 9.546%, 16.064% (128kbps), 2.868%, 4.654%, and 7.925% (256kbps), and 1.456%, 2.345%, and 4.002% (512kbps). The decrease in utilization is 49.96%, 51.25%, and 50.67% from 128kbps to 256kbps, and 49.23%, 49.61%, and 49.50% from 256kbps to 512kbps.

The statistics are shown from Table 9.31 and Table 9.32, and the charts are depicted from Figure 9.50 to 9.55.

WAN Cloud	ACCESS LINK STATS: Average Utilization (%)								
5 Nodes, 20 VCs	Warm Up: 5/s, Replication: 240/s								
Link: 1.544Mbps	1000B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	55.29	71.54	81.99	0.123	0.217	0.315	2.879	4.529	7.092
256kbps	28.36	38.66	48.70	0.079	0.106	0.156	1.416	2.219	3.391
512kbps	13.78	19.33	24.56	0.039	0.059	0.097	0.715	1.128	1.745

Table 9.30: National Networks – Average Link Utilization (%) for 1000B, IM_ATM and Experimental IM_ATM

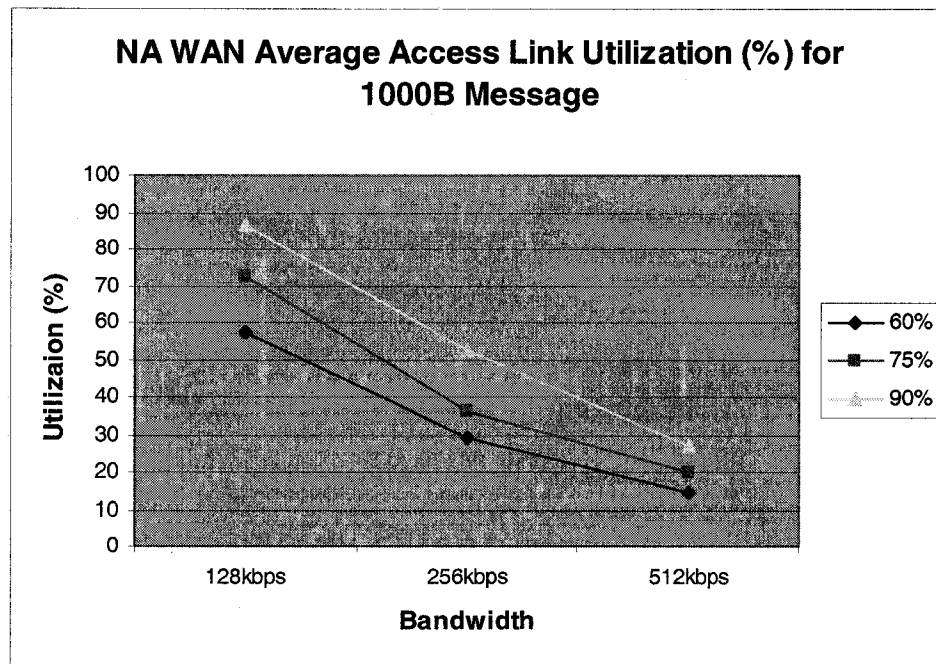


Figure 9.58: National Networks (5 Nodes) – Average Link Utilization (%) for 1000B Message

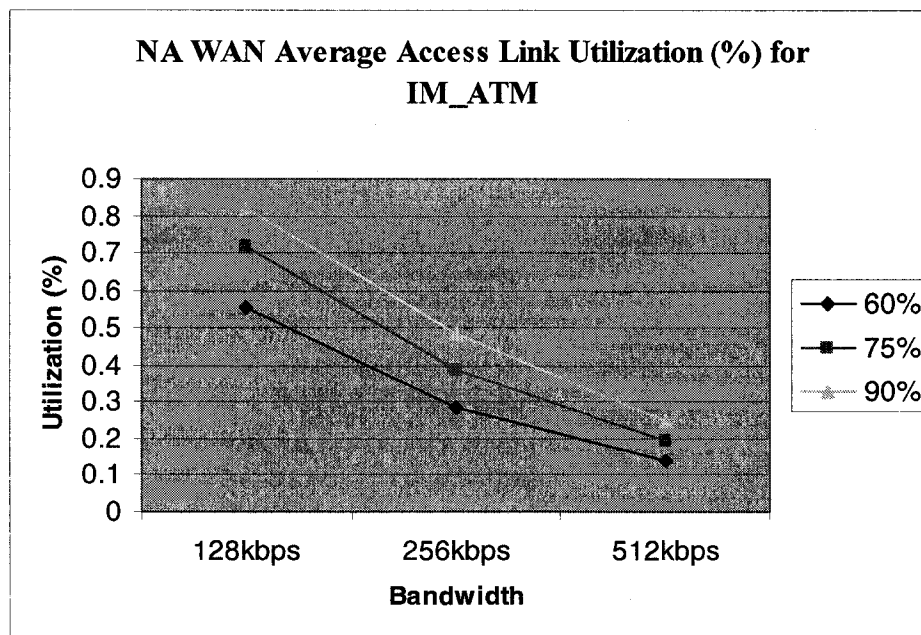


Figure 9.59: National Networks (5 Nodes) – Average Link Utilization (%) for IM_ATM

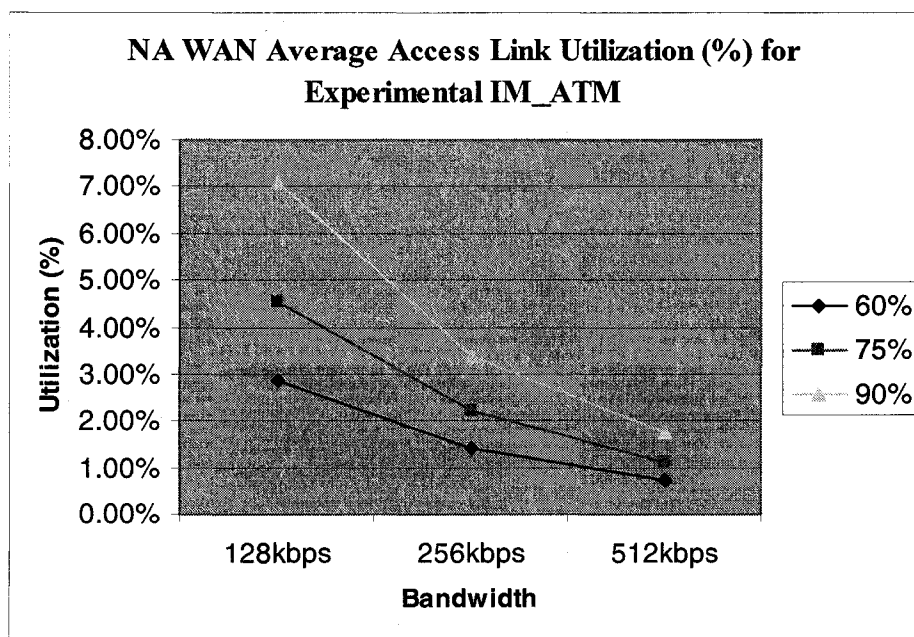


Figure 9.60: National Networks (5 Nodes) – Average Link Utilization (%) for Experimental IM_ATM

WAN Cloud	ACCESS LINK STATS: Average Utilization (%)								
5 Nodes, 20 VCs	Warm Up: 5/s, Replication: 240/s								
Message Size	500B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	57.11	72.35	86.55	0.523	0.778	1.475	5.731	9.546	16.064
256kbps	28.92	36.23	52.66	0.266	0.385	0.738	2.868	4.654	7.925
512kbps	14.51	19.86	27.01	0.133	0.182	0.369	1.456	2.345	4.002

Table 9.31: National Networks – Average Link Utilization (%) for 500B, IM_ATM and Experimental

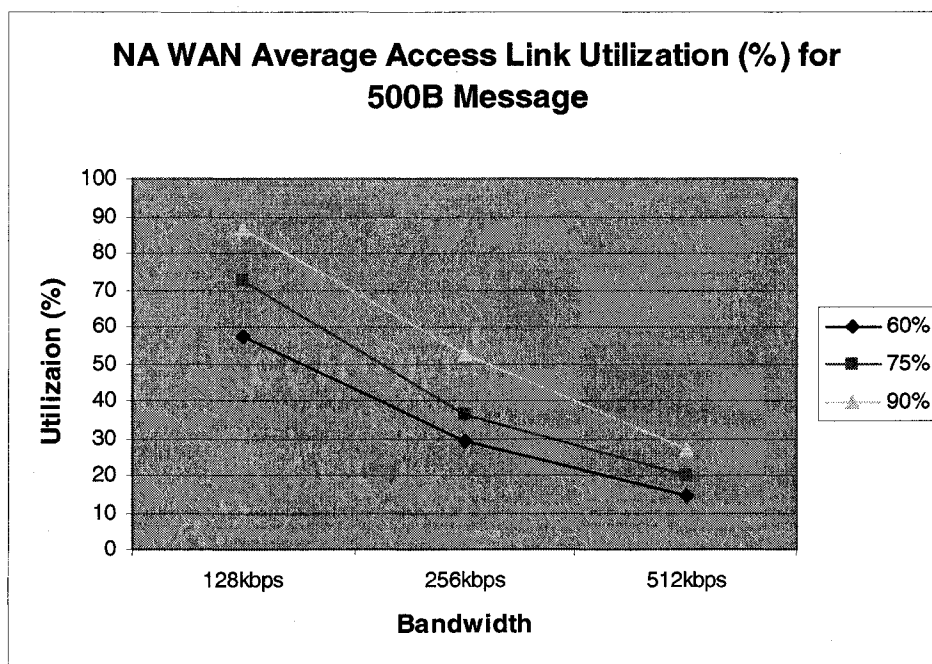


Figure 9.61: National Networks (5 Nodes) – Average Link Utilization (%) for 500B Message

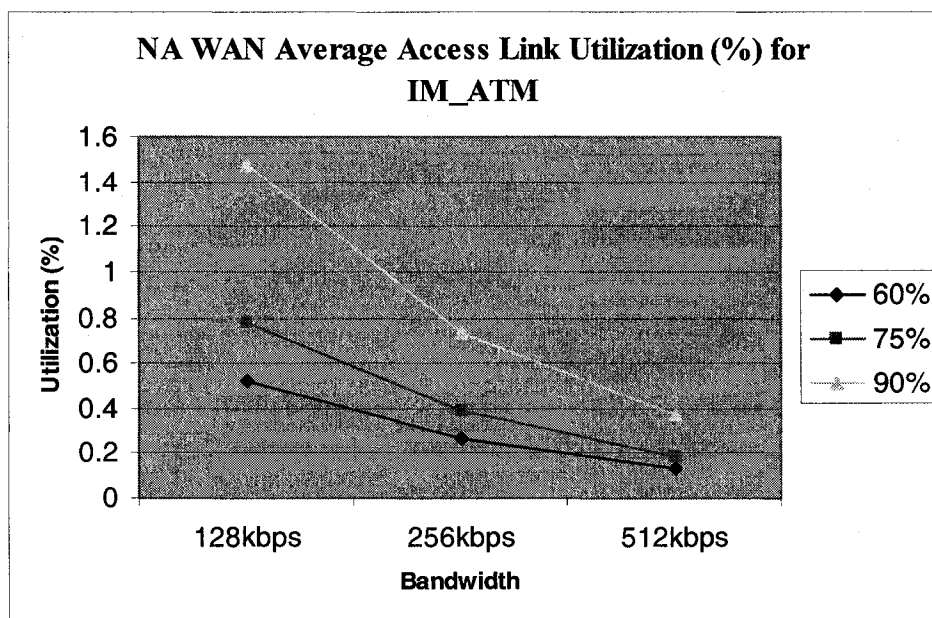


Figure 9.62: National Networks (5 Nodes) – Average Link Utilization (%) for IM_ATM

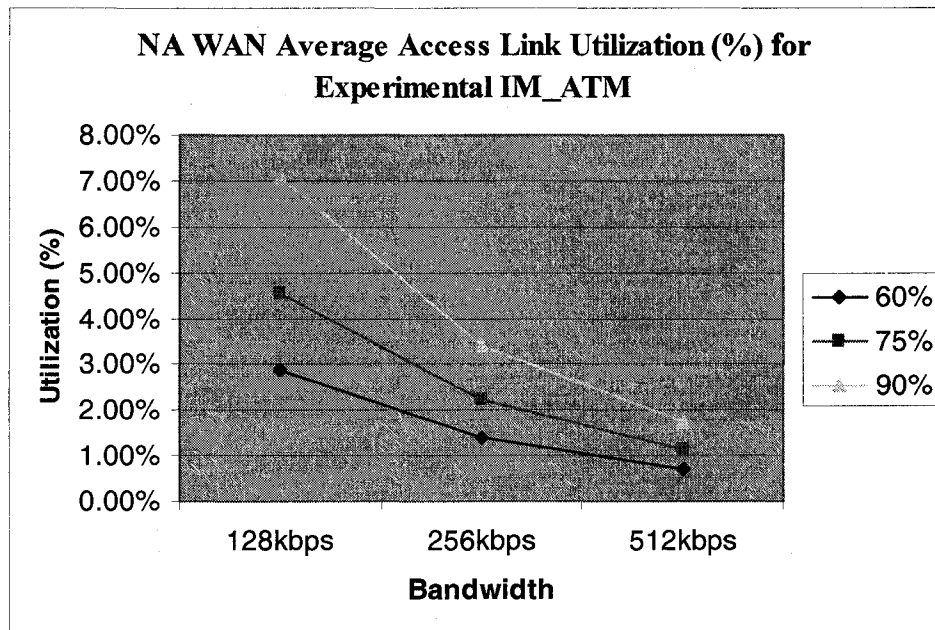


**Figure 9.63: National Networks (5 Nodes) – Average Link Utilization (%) for
Experimental IM_ATM**

9.3. International Networks – Three WAN Clouds

There are three WAN Clouds, two levels, GLOBE WAN Cloud connects two other WAN Clouds; EU (Europe), and NA (North America) WANs and each of these consists of five nodes. Each node represents five major cities in the region; each source is sending messages to every other respective destination in this model. The five cities in the EU WAN are: Paris, Frankfurt, Brussel, Milano, and London, and in the NA WAN are: Boston, New York, Chicago, Washington, and Seattle (Figure 9.64 and 9.65). 1.544Mbps is used for the link rate. The traditional networks are tested with the message sizes of 400 and 800 bytes the IM_ATM with 46 bytes, each of the message size is examined with 128kbps, 256kbps, and 512kbps bandwidths, and each bandwidth consists of three traffic intensities; 60%, 75%, and 90%. Only a few samples are chosen for the presentations. The statistics are shown from Table 9.32 to 9.39 and the graphs are depicted from Figure 9.66 to 9.87.

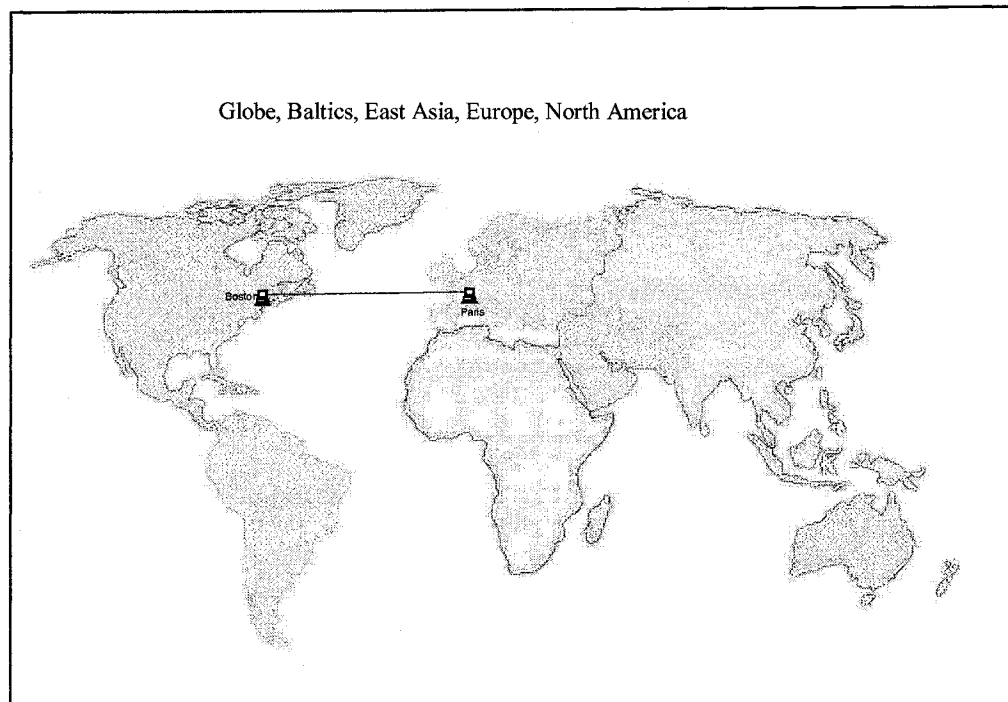


Figure 9.64: International Networks connects East Asia, Europe, and North America

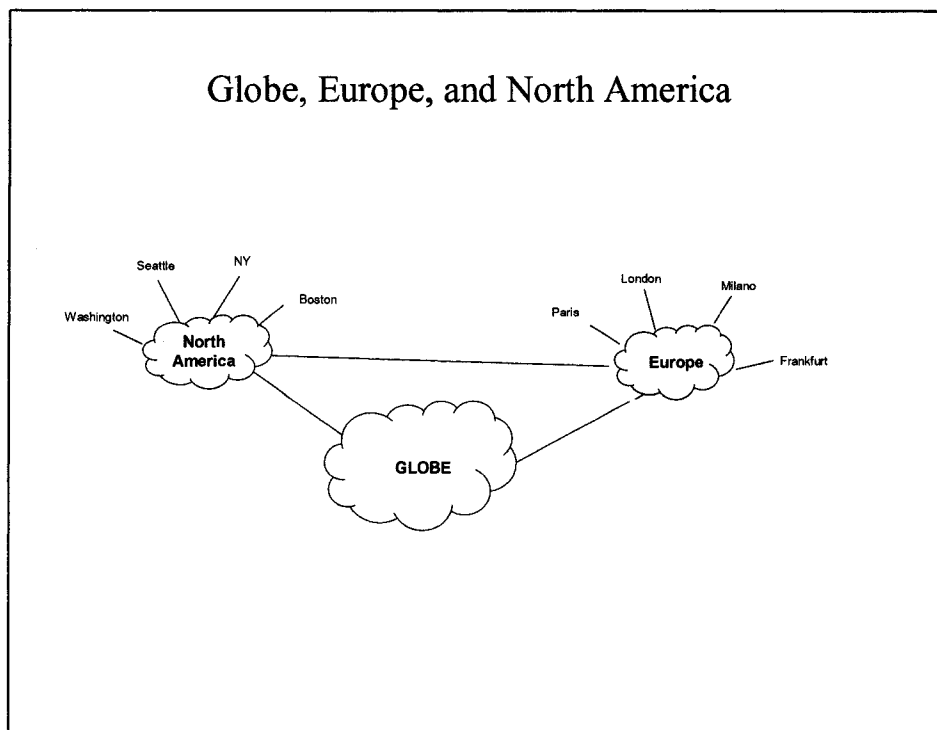


Figure 9.65: 3 WAN Clouds International Networks connects East Asia, Europe, and North America

Analysis: Packets Created, Delivered, Dropped, Ratio of Dropped/Created, and Ratio of Dropped/Delivered

Average Bandwidth – 128kbps, 256kbps and 512kbps, Message Size - 800B

The average number of packets created is 333, 501, and 902 (128kbps), 336, 520, and 962 (256kbps), and 318, 437, and 935 (512kbps), packets delivered is 302, 376, and 455 (128kbps), 287, 420, and 562 (256kbps), and 295, 365, and 549 (512kbps), and packets dropped is 32, 125, and 477 (128kbps), 22, 100, and 400 (256kbps), and 24, 73, and 387 (512kbps) for three traffic intensities, respectively.

The average number of packets created increases by 3.46%, 4.37% from 128kbps to 256kbps, and decreases by 5.36%, 15.96%, and 2.60% from 256kbps to 512kbps. The number of packets delivered increases by 5.65%, 10.48%, and 19.00% from 128kbps to 256kbps, and increases by 4.43%, 10.48%, and 19.00% from 128kbps to 256kbps, and decreases by 4.74%, 14.00%, and 2.31% from 256kbps to 512kbps. The number of packets dropped decreases by 37.50%, 20.00%, and 10.51%, and has very slight increase from 256kbps to 512kbps.

The ratio of packets dropped/created is 9.56%, 25.00%, and 49.58% (128kbps), 6.05%, 19.22%, and 41.59% (256kbps), and 7.40%, 16.62%, and 41.03% (512kbps). The ratio of and packets dropped/delivered is 10.57%, 33.33%, and 98.32% (128kbps), 6.44%, 23.80%, and 71.20% (256kbps), and 7.99%, 19.93%, and 70.45 (512kbps) for all three capacities.

The ratio of and packets dropped/delivered decreases by 39.07%, 28.60%, and 28.16% from 128kbps to 256lbs, and experiences minor increase from 216kbps to 512kbps.

Average Bandwidth – 128kbps, 256kbps and 512kbps, Message Size - 400B

The average number of packets created is 678, 1007, and 1868 (128kbps), 677, 1022, and 1790 (256kbps-512kbps). The average number of packets delivered 610, 752, and 913 (128kbps), 616, 827, and 1075 (256kbps-512kbps), and the average number of packets dropped 69, 255, 895 (128kbps), 63, 185, and 714 (256kbps-512kbps) for three intensities, respectively.

The statistics for the average number of packets created is: -0.15%, + 1.47%, and -4.18% from 128kbps to 256kbps, the there is not change for 256kbps and 512kbps, for the average number of packets delivered is: +1.00%, +9.10%, and +15.07% from 128kbps to 256kbps, and again it remains the same from 216kbps to 512kbps.

The ratio of packets dropped/created is 10.18%, 25.32%, and 47.91% (128kbps), 9.31%, 19.08%, and 39.89% (256kbps-512kbps). The ratio of and packets dropped/delivered is 11.31%, 33.91%, and 98.03% (128kbps), 10.23%, 23.58%, and 66.42% (256kbps-512kbps) for all three capacities. The ratio of and packets dropped/delivered decreases by 9.54%, 30.46%, and 32.25% from 128kbps to 256kbps, and there is no change from 256kbpb to 512kbps.

Again, there are no packets dropped for IM_ATM and Experimental IM_ATM networks, all the packets created are delivered to the destinations.

3 WAN Clouds	Message + Response Sources: Packet Delay								
5 Nodes each	Warm Up: 5/s, Replication: 240/s								
Message Size: 800B	Packets Created			Packet Delivered			Packet Dropped		
Bandwidth:128kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Origin/Destination									
NY / src:									
London	344	541	886	313	395	467	31	146	419
Milano	350	500	881	318	373	422	32	127	459
Frankfurt	329	507	909	303	381	453	26	126	456
Seattle	338	518	912	310	383	457	28	135	455
Washington	299	472	943	276	352	497	23	120	446
Chicago	364	529	914	330	409	453	34	120	461
Brussel	317	464	894	263	344	429	54	120	465
Paris	334	466	879	306	358	473	28	108	406
Boston	326	515	903	295	389	444	31	126	459
Average:	333	501	902	302	376	455	32	125	447
	Dropped/Created			Dropped/Delivered					
Ratio:	9.56%	25.00%	49.58%	10.57%	33.33%	98.32%			
Bandwidth:256kbps									
NY / src:									
London	331	505	990	314	413	576	17	92	414
Milano	324	508	997	303	397	584	21	111	413
Frankfurt	316	540	978	305	430	562	21	110	416
Seattle	349	513	967	332	429	565	17	84	402
Washington	310	539	977	289	430	579	21	109	398
Chicago	357	517	923	330	420	530	27	97	393
Brussell	348	507	946	322	419	559	26	88	387
Paris	357	516	932	332	430	551	25	86	381
Boston	331	537	946	313	414	550	18	123	396
Average:	336	520	962	316	420	562	20	100	400
	Dropped/Created			Dropped/Delivered					
Ratio:	6.05%	19.22%	41.59%	6.44%	23.80%	71.20%			

Table 9.32: International Networks – Packets Created, Delivered, and Dropped for 800B Message

3 WAN Clouds	Message + Response Sources: Packet Delay (Cont'd)								
5 Nodes each	Warm Up: 5/s, Replication: 240/s								
Message Size: 800B	Packets Created			Packet Delivered			Packet Dropped		
Bandwidth: 512kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Origin/Destination									
NY / src:									
London	312	484	972	295	420	575	17	64	397
Milano	330	428	948	310	348	571	20	80	377
Frankfurt	315	418	934	287	361	545	28	57	389
Seattle	319	468	930	287	377	535	32	91	395
Washington	299	453	966	277	382	562	22	71	404
Chicago	300	414	916	281	338	541	19	76	375
Brussel	358	431	977	324	357	578	34	74	399
Paris	330	411	870	309	334	485	21	77	385
Boston	302	428	904	283	364	546	19	64	358
Average:	318	437	935	295	365	549	24	73	387
	Dropped/Created			Dropped/Delivered					
Ratio:	7.40%	16.62%	41.33%	7.99%	19.93%	70.45%			

3 WAN Clouds	Message + Response Sources: Packet Delay								
5 Nodes each	Warm Up: 5/s, Replication: 240/s								
Message Size: 800B	Packets Created			Packet Delivered			Packet Dropped		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	333	501	902	302	376	455	32	125	447
256kbps	336	520	962	316	420	562	20	100	400
512kbps	318	437	935	295	365	549	24	73	387
Ratio:	Dropped/Created			Dropped/Delivered					
128kbps	9.56%	25.00%	49.58%	10.57%	33.33%	98.32%			
256kbps	6.05%	19.22%	41.59%	6.44%	23.80%	71.20%			
512kbps	7.40%	16.62%	41.33%	7.99%	19.93%	70.45%			

Table 9.33: International Networks – Average Packets Created, Delivered, Dropped, Dropped/Created, and Dropped/Delivered for 800B Message

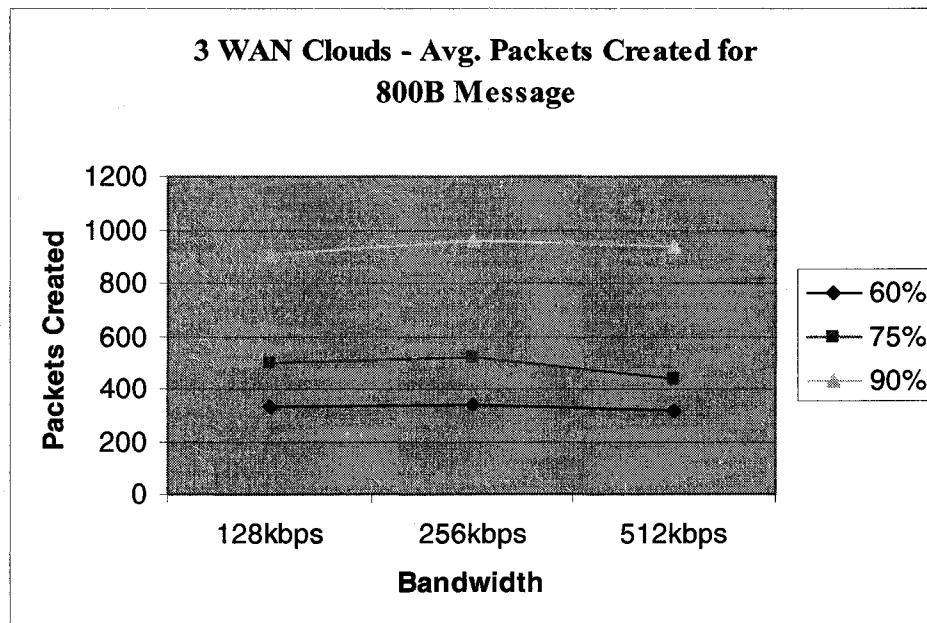


Figure 9.66: International Networks – Average Packets Created for 800B Message

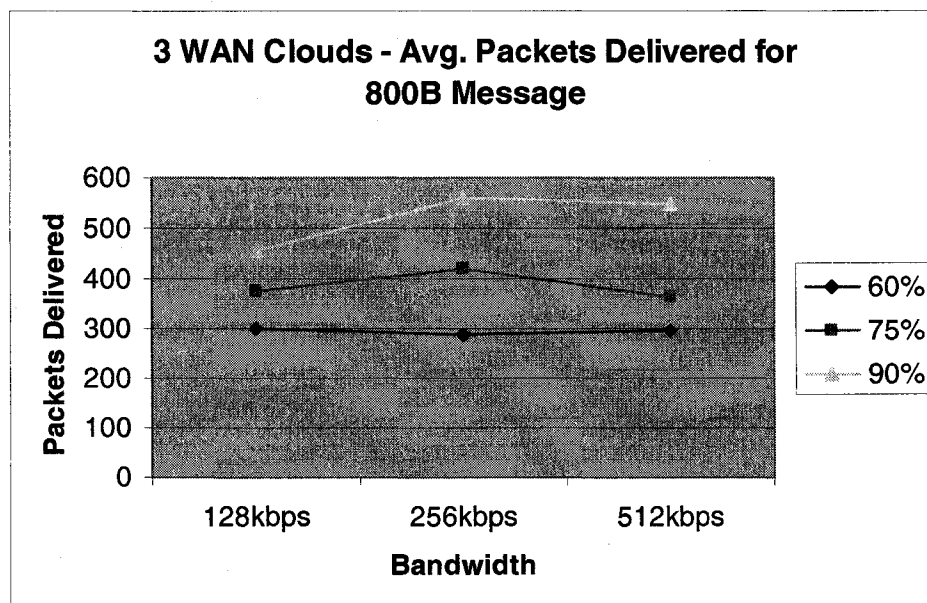


Figure 9.67: International Networks – Average Packets Delivered for 800B Message

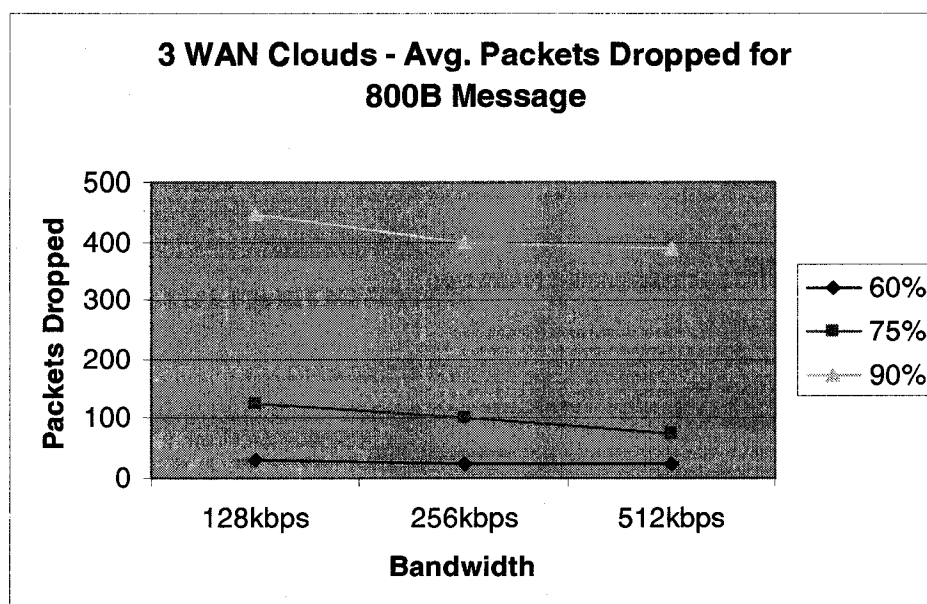


Figure 9.68: International Networks – Average Packets Dropped for 800B Message

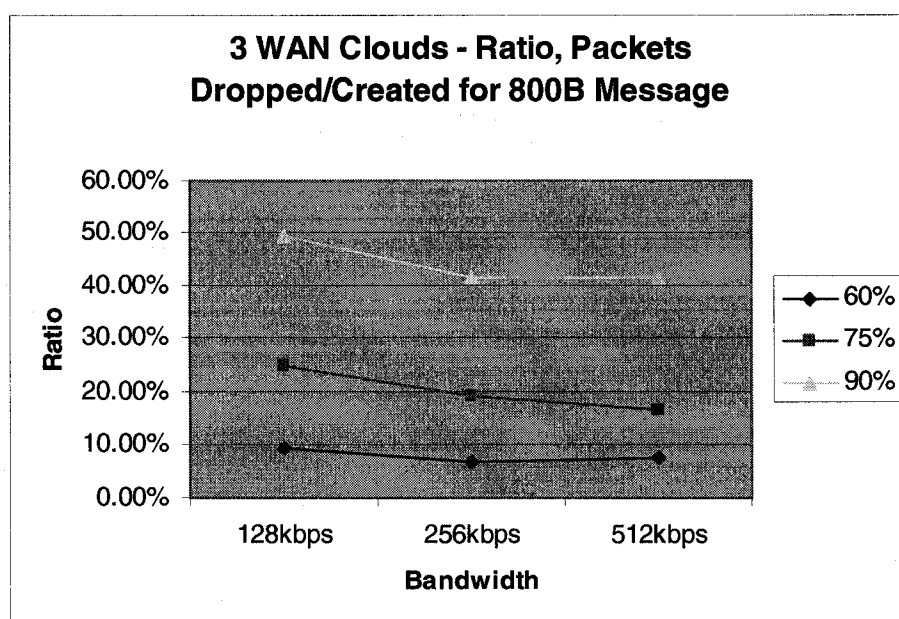


Figure 9.69: International Networks – Ratio of Packets Dropped/Created for 800B Message

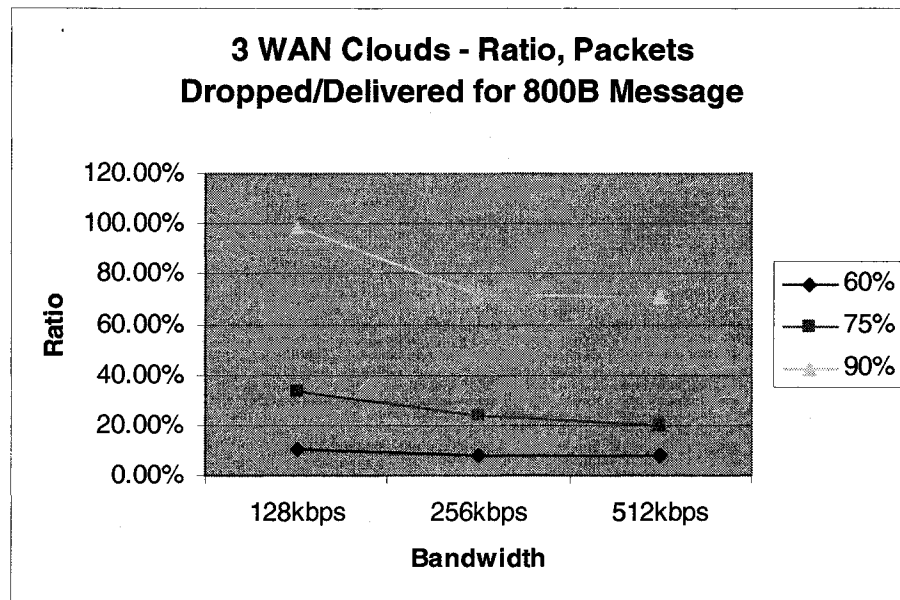


Figure 9.70: International Networks – Ratio of Packets Dropped/Delivered for 800B Message

3 WAN Clouds	Message + Response Sources: Packet Delay								
5 Nodes each	Warm Up: 5/s, Replication: 240/s								
Message Sizes:400B	Packets Created			Packet Delivered			Packet Dropped		
Bandwidth: 128kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Origin/Destination									
Frankfur / Src									
London	708	1062	1971	635	795	962	73	267	1009
Milano	631	1011	2038	581	739	934	50	272	1104
NY	713	1012	2006	638	750	953	75	262	1053
Seattle	674	1007	2010	607	726	944	67	281	1066
Washing	693	994	2007	620	734	977	73	260	1030
Chicago	680	1070	2034	630	763	966	50	307	1068
Brussel	688	1032	2009	619	772	984	69	260	1025
Paris	680	1014	1981	617	759	955	63	255	1026
Boston	699	1056	2044	634	803	965	65	253	1079
Average:	685	1029	2011	620	760	960	65	269	1051
	Dropped/Created			Dropped/Delivered					
Ratio:	9.49%	26.11%	52.27%	10.48%	35.33%	109.49%			
Bandwidth: 256kbps									
Frankfur / Src									
London	726	1155	1571	653	927	1004	73	228	567
Milano	713	1046	1729	658	851	1130	55	195	599
NY	739	1095	1696	687	874	1081	52	221	615
Seattle	757	1063	1644	695	844	1058	62	219	586
Washing	716	1116	1730	656	894	1132	60	222	598
Chicago	729	1051	1678	676	873	1120	53	178	558
Brussel	727	1127	1684	665	913	1087	62	214	597
Paris	755	1044	1666	685	865	1105	70	179	561
Boston	700	1042	1604	643	847	1027	57	195	577
Average:	729	1082	1667	669	876	1083	60	206	584
	Dropped/Created			Dropped/Delivered					
Ratio:	8.29%	19.01%	35.05%	9.04%	23.47%	53.96%			

Table 9.34: International Networks – Packets Created, Delivered, and Dropped for 400B Message

3 WAN Clouds	Message + Response Sources: Packet Delay (Cont'd)								
5 Nodes each	Warm Up: 5/s, Replication: 240/s								
Message Sizes: 400B	Packets Created			Packet Delivered			Packet Dropped		
Bandwidth: 512kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Origin/Destination									
Frankfur / Src									
London	726	1155	1571	653	927	1004	73	228	567
Milano	713	1046	1729	658	851	1130	55	195	599
NY	739	1095	1696	687	874	1081	52	221	615
Seattle	757	1063	1644	695	844	1058	62	219	586
Washington	716	1116	1730	656	894	1132	60	222	598
Chicago	729	1051	1678	676	873	1120	53	178	558
Brussel	727	1127	1684	665	913	1087	62	214	597
Paris	755	1044	1666	685	865	1105	70	179	561
Boston	700	1042	1604	643	847	1027	57	195	577
Average:	729	1082	1667	669	876	1083	60	206	584
	Dropped/Created			Dropped/Delivered					
Ratio:	8.29%	19.01%	35.05%	9.04%	23.47%	53.96%			
3 WAN Clouds	Message + Response Sources: Packet Delay								
Link: 1.544Mbps	5 Nodes Each, Rep. Length: 245/s								
Message Sizes: 400B	Packets Created			Packet Delivered			Packet Dropped		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	685	1029	2011	620	760	960	65	269	1051
256kbps	729	1082	1667	669	876	1083	60	206	584
512kbps	729	1082	1667	669	876	1083	60	206	584
	Dropped/Created			Dropped/Delivered					
Ratio:									
128kbps	9.49%	26.11%	52.27%	10.48%	35.33%	109.49%			
256kbps	8.29%	19.01%	35.05%	9.04%	23.47%	53.96%			
512kbps	8.29%	19.01%	35.05%	9.04%	23.47%	53.96%			

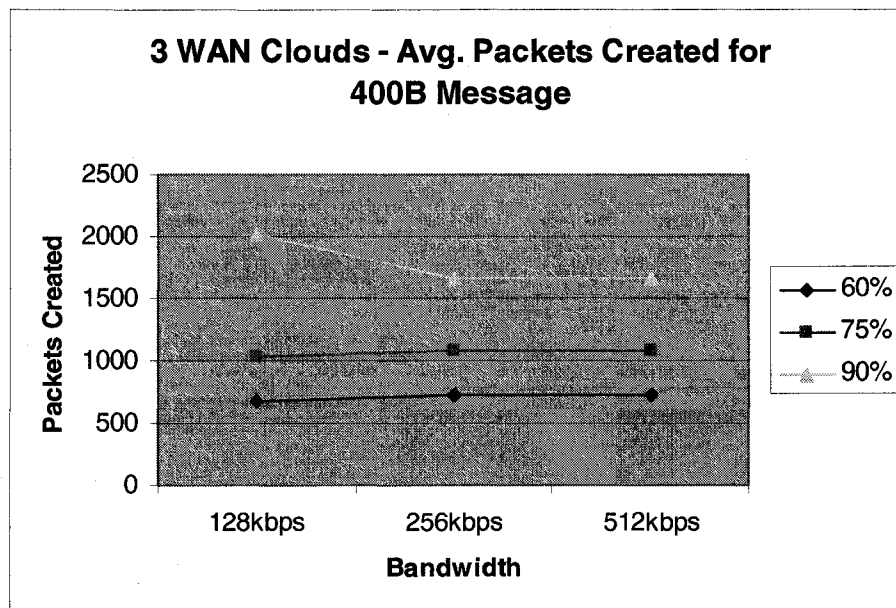


Figure 9.71: International Networks – Average Packets Created for 400B Message

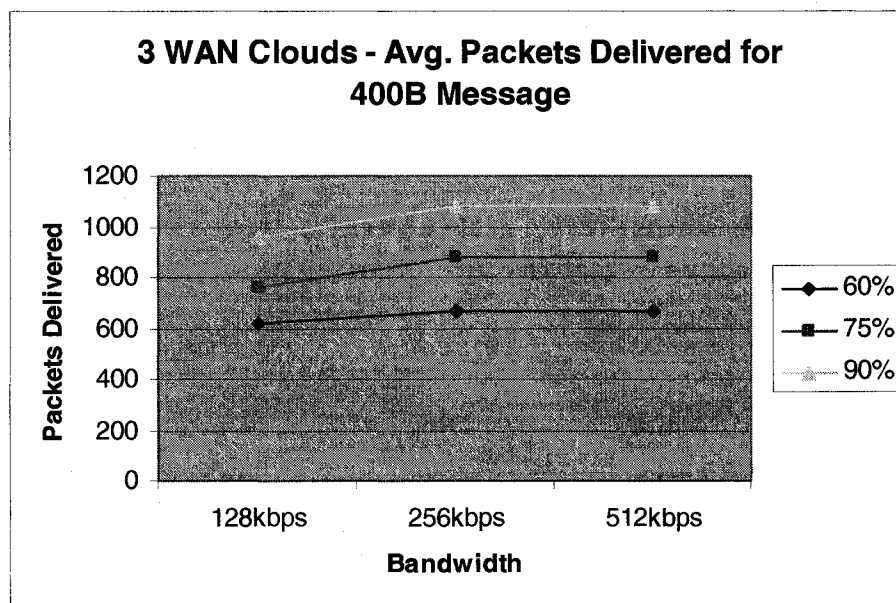


Figure 9.72: International Networks – Average. Packets Delivered for 400B Message

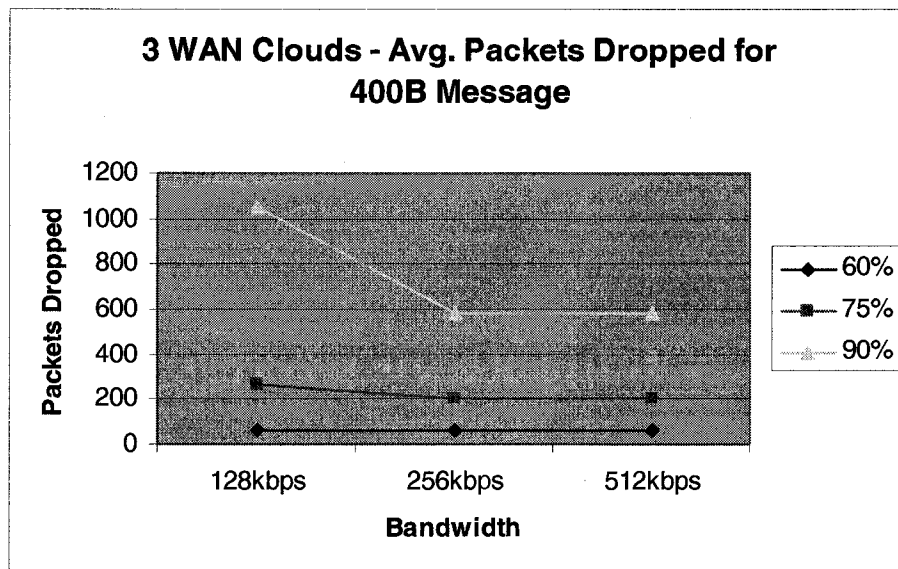


Figure 9.73: International Networks – Average Packets Dropped for 400B Message

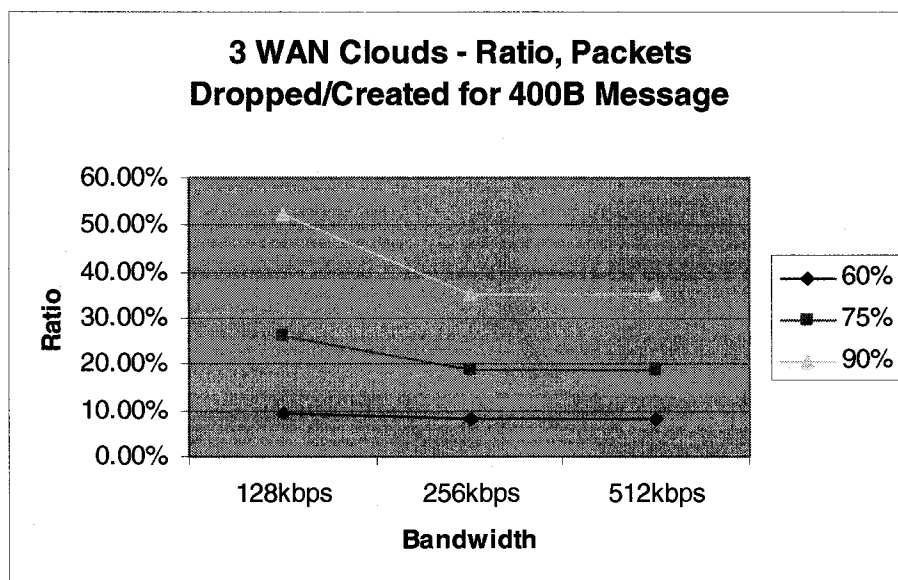


Figure 9.74: International Networks – Ratio of Packets Dropped/Created for 400B Message

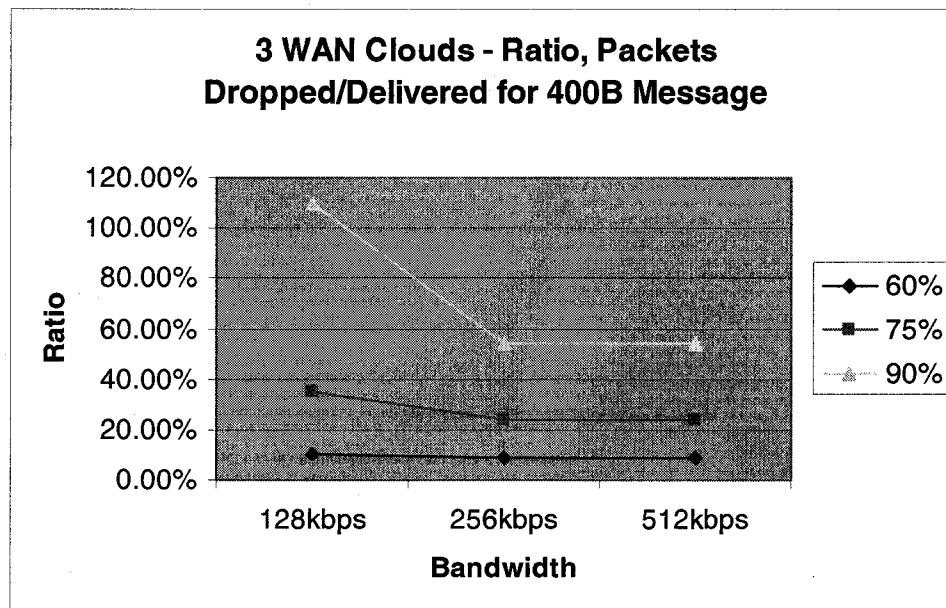


Figure 9.75: International Networks – Ratio of Packets Dropped/Delivered for 400B Message

Average Packet Delay (MS)

Message Size - 800B and 400B

For 800 bytes message size, the average packet delay is 736, 965, and 1202 (128kbps), 427, 478, and 535 (256kbps), and 294, 309, and 343 (512kbps), the average packets delay decreases by 42.00%, 50.45%, and 55.50% from 128kbps to 256kbps, and by 31.15%, 35.48%, and 35.88% from 256kbps to 512kbps.

For 400 bytes message size, the average packet delay is 713, 880, and 1082 (128kbps), 353, 401, and 445 (256kbps), and 217, 249, and 270 (512kbps), the average packets delay decreases by 50.50%, 54.45%, and 58.86% from 128kbps to 256kbps, and by 38.36%, 38.02%, and 39.33% from 256kbps to 512kbps.

Average Packet Delay (MS) - IM_ATM and Experimental IM_ATM Networks

Message Size – 46B (800B)

The average packet delay for IM_ATM is 36.49, 38.17, and 41.61 (128kbps), 32.41, 33.15 and 34.88 (256kbps), and 30.26, 30.58, and 31.50 (512kbps). The decrease in packet delay is 11.18%, 13.15%, and 16.17% from 128kbps to 256kbps, and is 6.63%, 7.75%, and 9.69% from 256kbps to 512kbps for all three capacities. Packet Delay for Experimental IM_ATM is 79.29, 109.89, and 160.17 (128kbps), 51.95, 68.91 and 93.89 (256kbps), and 44.56, 48.517, and 59.52 (512kbps) for all three intensities, the decrease in packet delay is 34.47%, 37.30%, and 41.38% from 128kbps to 256kbps, 14.23%, and 29.60%, and 36.60 from 256kbps to 512kbps.

Message Size – 46B (400B)

The average packet delay for IM_ATM is 42.42, 49.45, and 56.89 (128kbps), and 37.78, 38.56, and 44.38 (256kbps), and 32.59, 33.56, and 36.39 (512kbps), the decrease in packet delay is 10.94%, 22.80%, and 21.99% from 128kbps to 256kbps, and 13.74%, 12.97%, 17.23% and from 256kbps to 512kbps, for all three intensities. The average packet delay for the experimental IM_ATM is 134.67, 181.67, and 291.67 (128kbps), and 69.44, 98.49, 149.30 (256kbps), and 55.01, 64.10, 88.90 (512kbps). The decrease in packet delay is 48.44%, 45.75%, and 48.81% from 128kbps to 256kbps, 20.78%, 34.92%, and 40.46% from 256kbps to 512kbps for all three intensities, respectively.

3 WAN Clouds	Message + Response Sources: Packet Delay(MS)								
5 Nodes each	Warm Up: 5/s, Replication: 240/s								
Link: 1.544Mbps	800B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	736.23	965.11	1201.69	36.492	38.170	41.606	79.278	109.89	160.17
256kbps	427.11	478.22	535.17	32.413	33.149	34.883	51.946	68.910	93.889
512kbps	294.06	308.57	343.13	30.264	30.582	31.499	44.556	48.517	59.519

Table 9.35: International Networks – Average Packet Delay (MS) for 800B, IM_ATM, and Experimental Message

3 WAN Clouds	Message + Response Sources: Average Packet Delay (MS)								
5 Nodes Each	Warm Up: 5/s, Replication Length: 245/s								
Link: 1.544Mbps	400B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	713.19	880.33	1082.31	42.42	49.45	56.89	134.67	181.61	291.67
256kbps	353.01	401.01	445.23	37.78	38.56	44.38	69.44	98.49	149.30
512kbps	217.61	248.55	270.13	32.59	33.56	36.39	55.01	64.10	88.90

Table 9.36: International Networks – Average Packet Delay (MS) for 400B, IM_ATM, and Experimental IM_ATM Message

Average Packet Delay in Milliseconds (MS)

Bandwidth – 128kbps-512kbps, Message Size - 800B and 400B

For 800 bytes message, the average packet delay is 736, 965, and 1202 (128kbps), 427, 478, and 535 (256kbps), and 294, 309, and 343 (512kbps), the average packet delay decreases by 42.00%, 50.45%, and 55.50% from 128kbps to 256kbps, and by 31.15%, 35.48%, and 35.88% from 256kbps to 512kbps.

For 400 bytes message, the average packet delay is 713, 880, and 1082 (128kbps), 353, 401, and 445 (256kbps), and 217, 249, and 270 (512kbps), the average packets delay decreases by 50.50%, 54.45%, and 58.86% from 128kbps to 256kbps, and by 38.36%, 38.02%, and 39.33% from 256kbps to 512kbps.

Average Packet Delay (MS) - IM_ATM and Experimental IM_ATM Networks

Message Size – 46B (800B)

The average packet delay for IM_ATM networks is 36.49, 38.17, and 41.61 (128kbps), 32.41, 33.15 and 34.88 (256kbps), and 30.26, 30.58, and 31.50 (512kbps). The decrease in packet delay is 11.18%, 13.15%, and 16.17% from 128kbps to 256kbps, and is 6.63%, 7.75%, and 9.69% from 256kbps to 512kbps for all three intensities. Packet Delay for Experimental IM_ATM networks is 79.29, 109.89, and 160.17 (128kbps), 51.95, 68.91 and 93.89 (256kbps), and 44.56, 48.517, and 59.52 (512kbps) for all three intensities, the decrease in packet delay is 34.47%, 37.30%, and 41.38% from 128kbps to 256kbps, 14.23%, and 29.60%, and 36.60 from 256kbps to 512kbps.

Message Delay (MS) – IM_ATM and Experimental IM_ATM Networks

Message Size – 46B (800B)

The average packet delay for IM_ATM is 42.42, 49.45, and 56.89 (128kbps), and 37.78, 38.56, and 44.37 (256kbps), and 32.59, 33.56 and 36.39 (512kbps), the decrease in packet delay is 10.94%, 22.02%, and 22.00% from 128kbps to 256kbps, and 13.74%, 12.95%, 18.00% and from 256kbps to 512kbps, for all three intensities. The average packet delay for the Experimental IM_ATM is 134.67, 181.61, and 291.67 (128kbps), 69.44, 55.01, and 88.90 (256kbps), and 55.01, 64.10, and 88.90 (512kbps). The packet delay decrease by 48.43%, 45.77%, and 48.81% from 128kbps to 256kbps, 20.79%, 35.02%, and 40.46% from 256kbps to 512kbps for all three intensities, respectively.

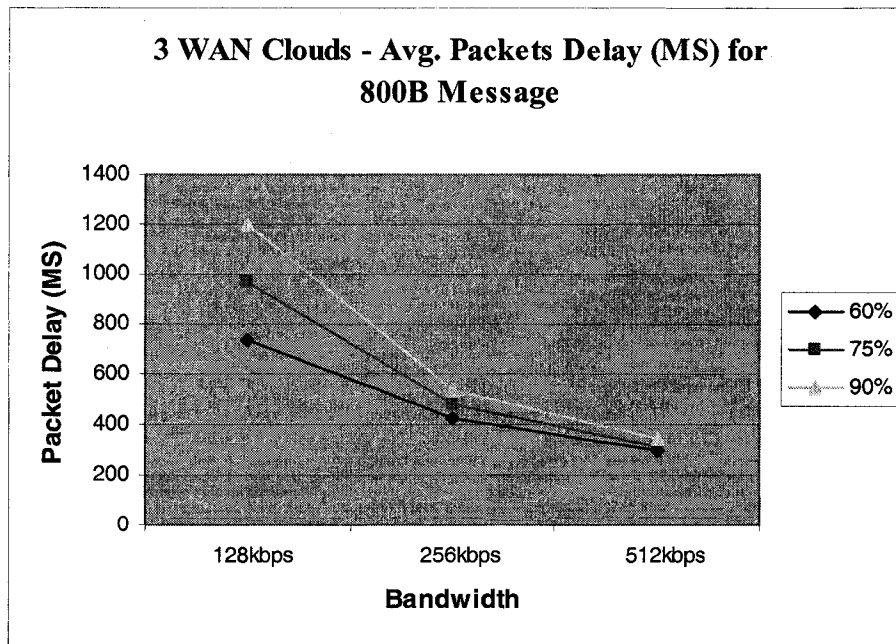


Figure 9.76: International Networks – Average Packet Delay (MS) for 800B Message

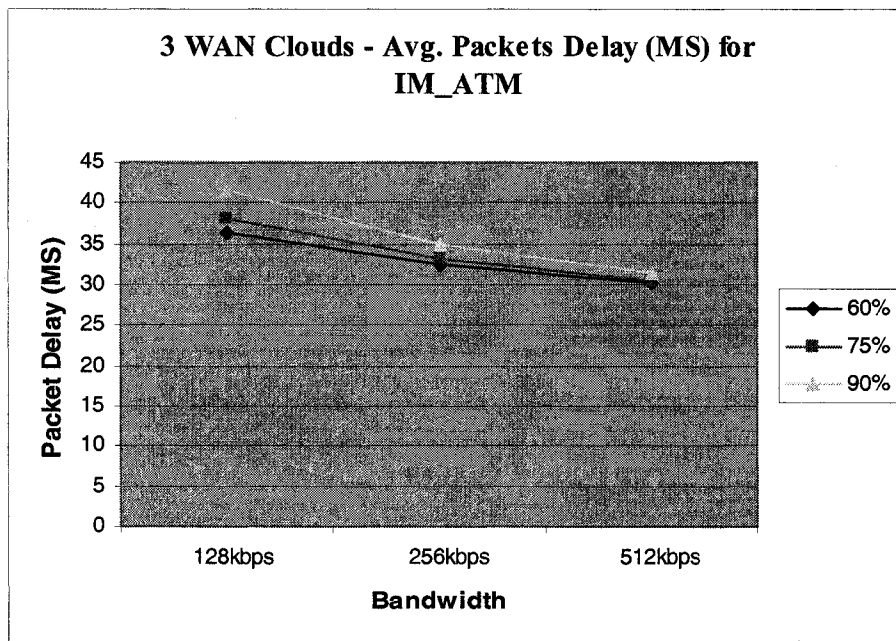


Figure 9.77: International Networks – Average Packet Delay (MS) for IM_ATM Message

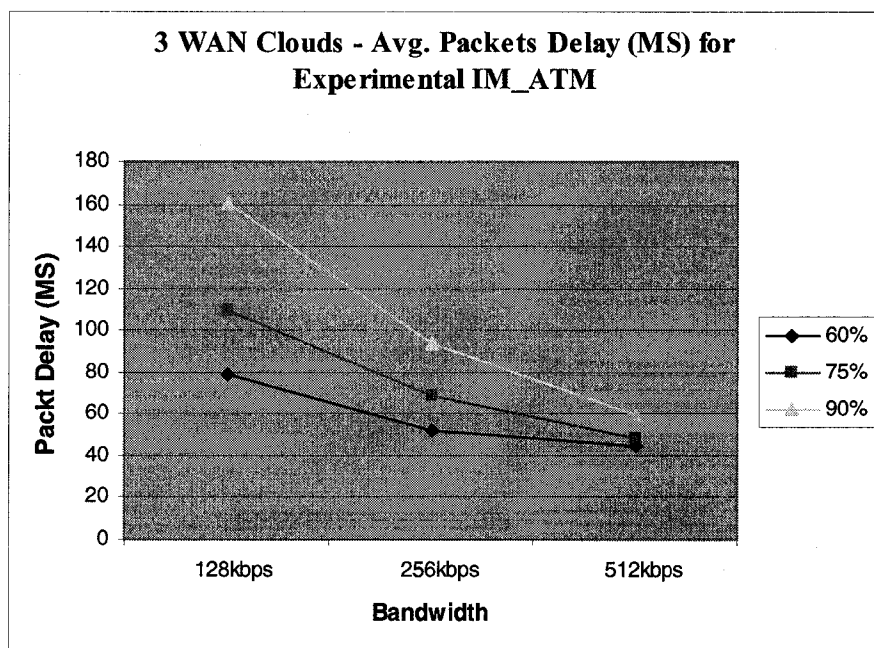


Figure 9.78: International Networks – Average Packet Delay (MS) for Experimental IM_ATM Message

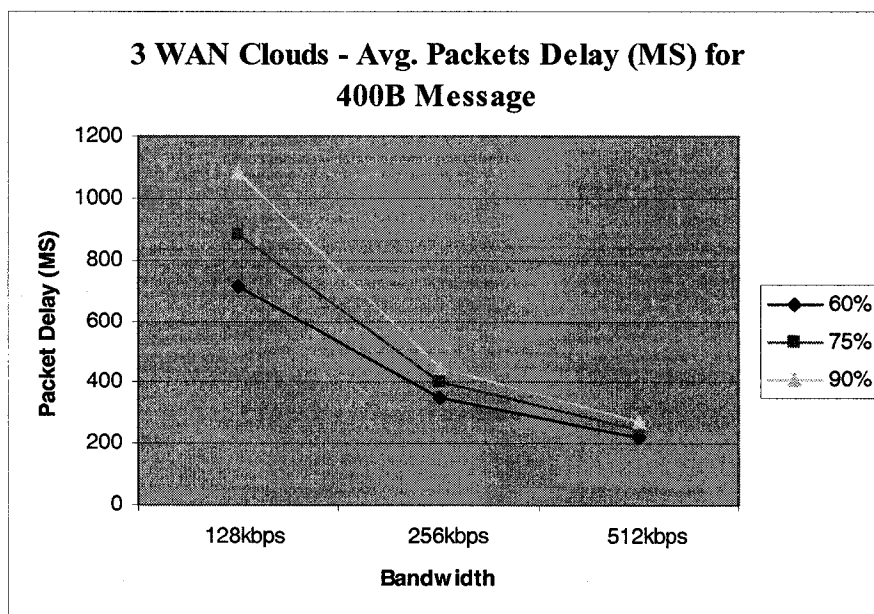


Figure 9.79: International Networks – Average Packet Delay (MS) for 400B Message

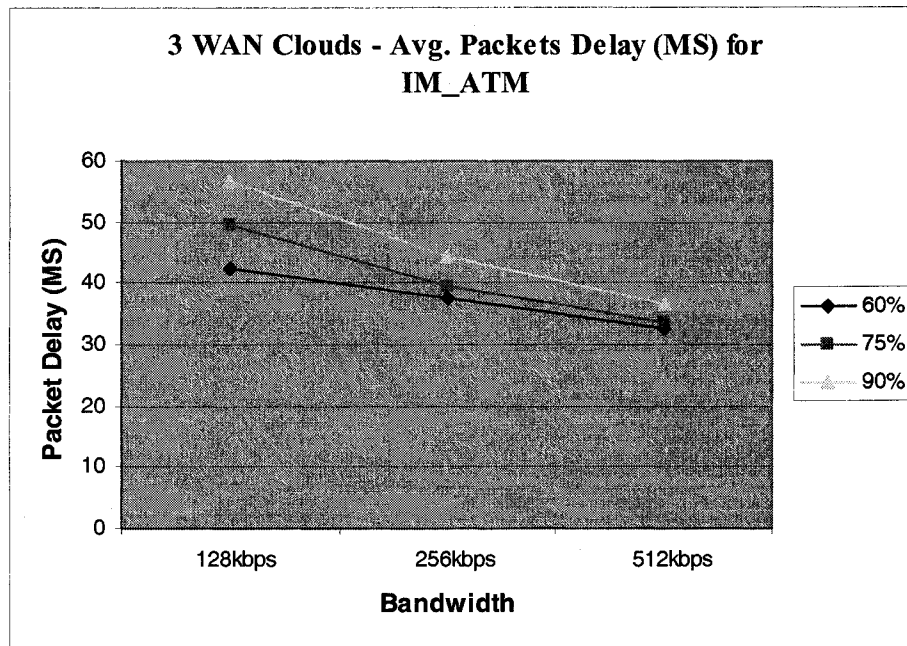


Figure 9.80: International Networks – Average Packet Delay (MS) for IM_ATM

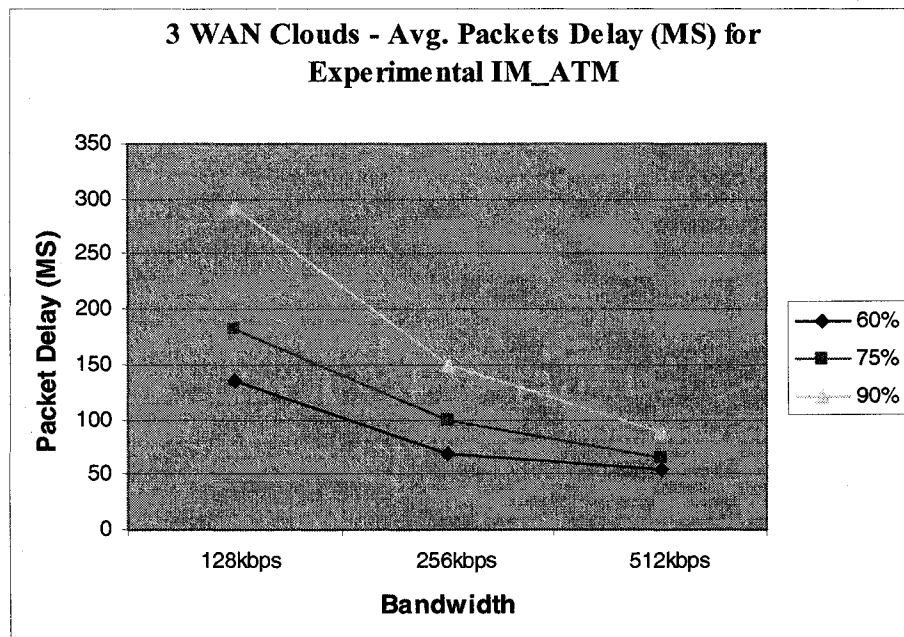


Figure 9.81: International Networks – Average Packet Delay (MS) for Experimental IM_ATM

Average Percentage of Access Stats Link Utilization

Bandwidth – 128kbps, 256kbps and 512kbps, Message Size - 800B and 400B

For 800 bytes message, the average utilization is 57.67%, 73.71%, and 87.65% (128kbps), 29.14%, 39.09%, and 51.88% (256kbps), and 14.82%, 19.31%, and 26.07% (512kbps). The decrease in utilization is 49.47%, 46.95%, and 40.81% from 128kbps to 256kbps and 49.14%, 50.40%, and 49.75%, from 256kbps to 512kbps,

For 400 bytes message, the average utilization is very similar to that of the 800 bytes for all the three bandwidth intensities. These statistics are given in Tables 9.39 and graphs are shown in Figures 9.74 and 9.75.

Average Utilization (%) - Message Size – 46B (800B)

IM_ATM Networks

The average utilization for IM_ATM is 0.266%, 0.408%, 0.743% (128kbps), 0.137%, 0.204%, and 0.370% (256kbps), and 0.065%, 0.104%, and 0.185% (512kbps). The decrease in utilization is 48.50%, 50.00%, and 50.00% from 128kbps to 256kbps, and 52.56%, 49.02%, and 50.00% from 256kbps to 512kbps.

Experimental IM_ATM Networks

The average utilization for experimental IM_ATM is 4.443%, 7.085%, 12.447% (128kbps), 2.197%, 3.534%, and 6.228% (256kbps), and 1.125%, 1.775%, and 3.114% (512kbps). The decrease in utilization is approximately 50.00% from 128kbps to

256kbps for all three capacities, and 48.79%, 50.34%, and 50.00% from 256kbps to 512kbps.

Average Utilization (%) - Message Size – 46B (400B)

IM_ATM Networks

The percentage of average link utilization is 1.060%, 1.584%, 2.912% (128kbps), 0.534%, 0.798%, and 1.430% (256kbps), and 0.271%, 0.404%, and 0.695% (512kbps). The decrease in utilization is approximately 50% from 128kbps to 256kbps, and from 256kbps to 512kbps for all three capacities.

Experimental IM_ATM Networks

The average link utilization for Experimental IM_ATM networks is 9.250%, 13.990%, 24.910% (128kbps), 4.605%, 6.990%, and 12.295% (256kbps), and 4.605%, 6.990%, and 12.295% (512kbps). The decrease in utilization is approximately 50% from 128kbps to 256kbps and from 256kbps to 512kbps for all three intensities.

The statistics are shown in Tables 9.40 and the charts from Figure 9.76 to 9.77.

3 WAN Clouds	Average Percentage of Access Links Utilization					
5 Nodes each	Warm Up: 5/s, Replication: 240/s					
Link: 1.544Mbps	800B			400B		
Bandwidth	60%	75%	90%	60%	75%	90%
GLOBE WAN						
128kbps	13.54	17.00	20.25	13.62	16.79	20.41
256kbps	13.46	18.01	24.14	13.32	17.83	23.61
512kbps	13.65	17.87	24.05	13.71	17.83	23.72
NA WAN						
128kbps	58.11	73.42	87.42	58.85	73.20	87.90
256kbps	29.63	39.62	51.96	29.62	40.30	52.90
512kbps	14.51	19.27	25.98	14.91	20.14	26.50
EU WAN						
128kbps	57.23	73.99	87.77	58.80	72.58	88.50
256kbps	28.65	38.55	51.79	29.91	39.61	52.11
512kbps	14.73	19.34	26.15	14.95	19.89	26.30

Table 9.37: International Networks – Average Access Link Utilization (%) for 800B and 400B Message

3 WAN Clouds	Average Percentage of Access Links Utilization								
5 Nodes each	Warm Up: 5/s, Replication: 240/s								
Link: 1.544Mbps	800B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
NA & EU WAN									
128kbps	57.67	73.71	87.65	0.266	0.408	0.743	4.443	7.085	12.447
256kbps	29.14	39.09	51.88	0.137	0.204	0.370	2.197	3.534	6.228
512kbps	14.82	19.31	26.07	0.065	0.104	0.185	1.125	1.755	3.114

Table 9.38: International Networks – Average Access Link Utilization (%) for 800B, IM_ATM and Experimental IM_ATM Message

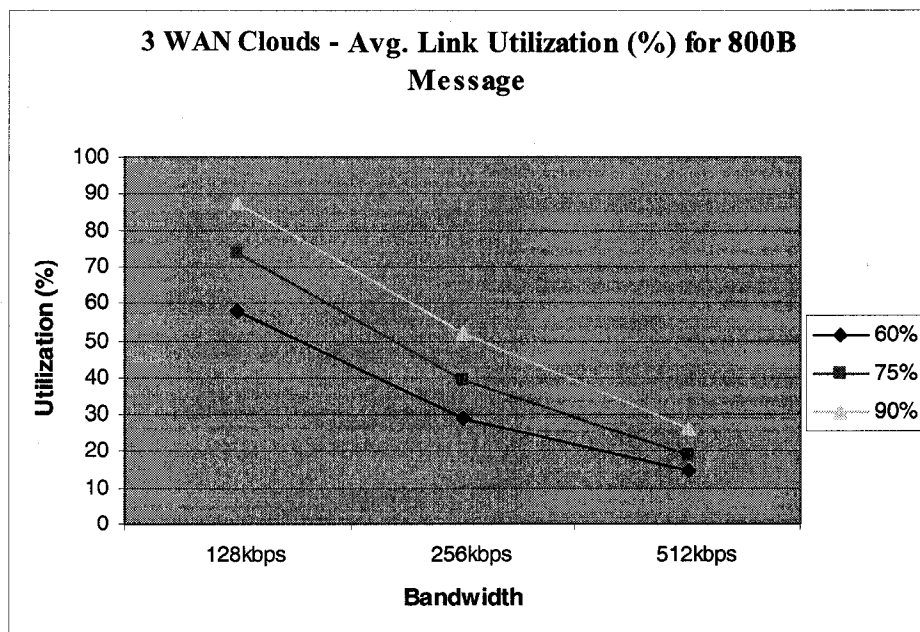


Figure 9.82: International Networks – Average Link Utilization (%) for 800B Message

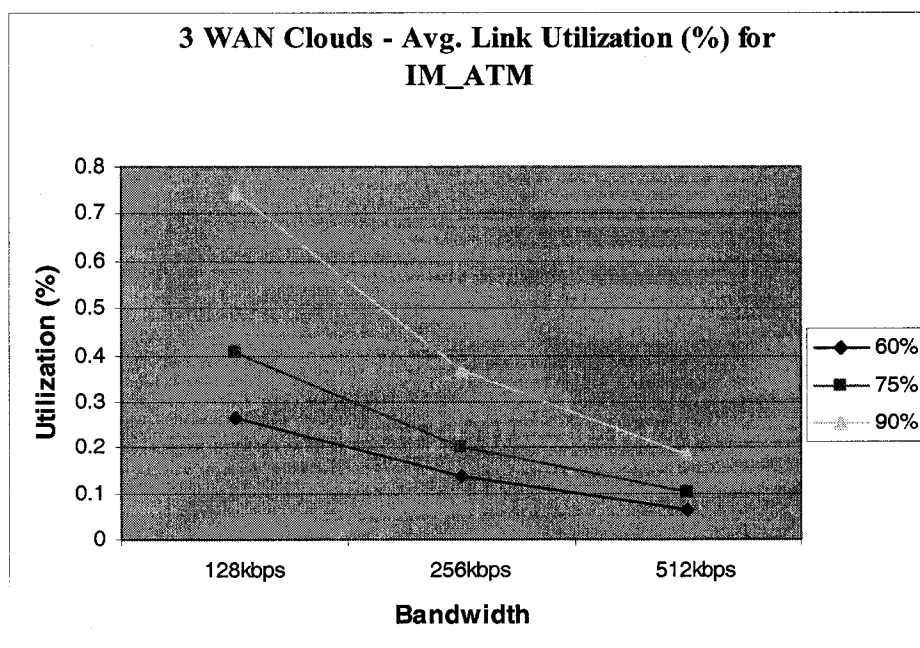


Figure 9.83: International Networks – Average Link Utilization (%) for IM_ATM Message

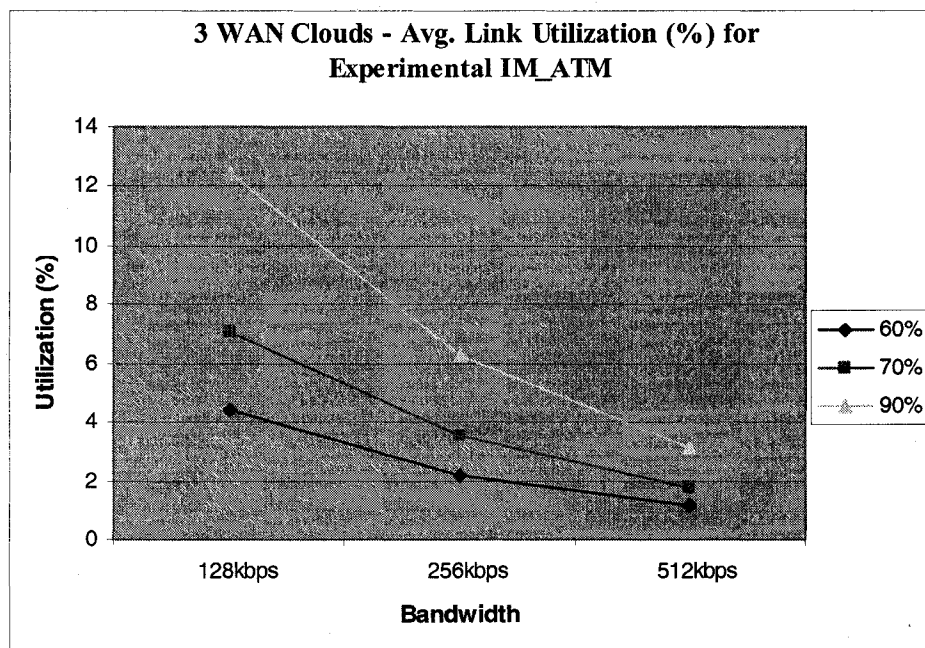


Figure 9.84: International Networks – Average Link Utilization (%) for Experimental IM_ATM Message

NA & EU WAN 5 Nodes each	Average Percentage of Access Links Utilization								
Link: 1.544Mbps	400B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	58.83	73.39	88.20	1.060	1.584	2.912	9.250	13.990	24.910
256kbps	29.77	39.96	52.51	0.534	0.798	1.430	4.605	6.990	12.295
512kbps	14.93	20.02	26.40	0.271	0.404	0.695	2.300	3.460	6.210

Table 9.39: International Networks – Average Access Link Utilization (%) for 400B, IM_ATM, and Experimental IM_ATM Message

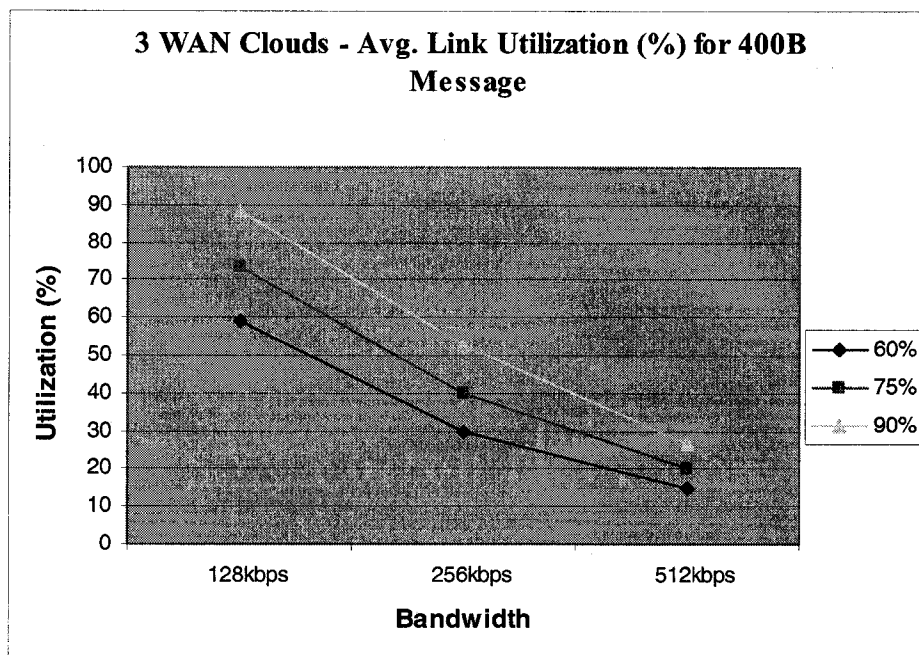


Figure 9.85: International Networks – Average Link Utilization (%) for 400B Message

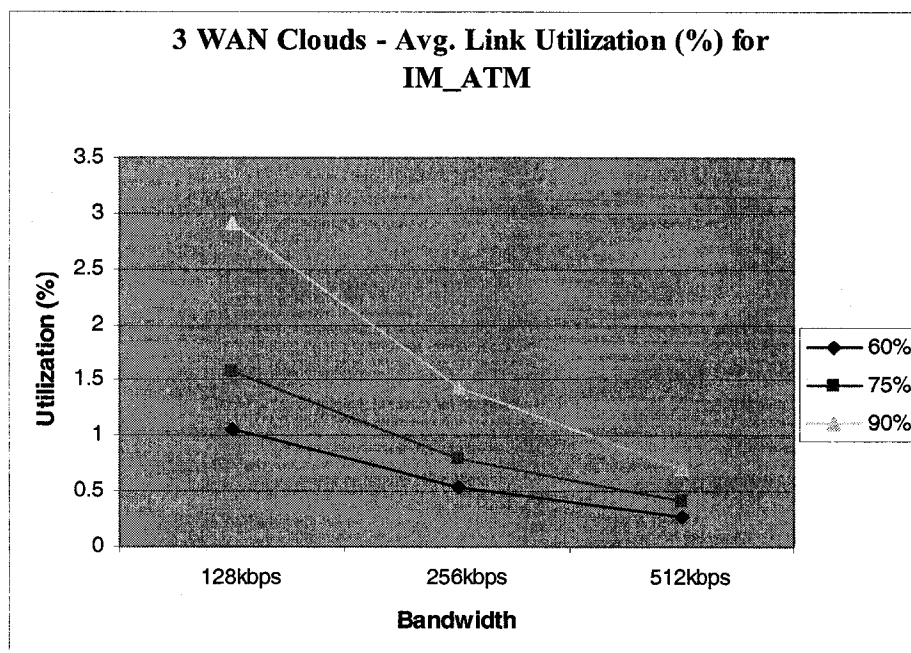


Figure 9.86: International Networks – Average Link Utilization (%) for IM_ATM Message

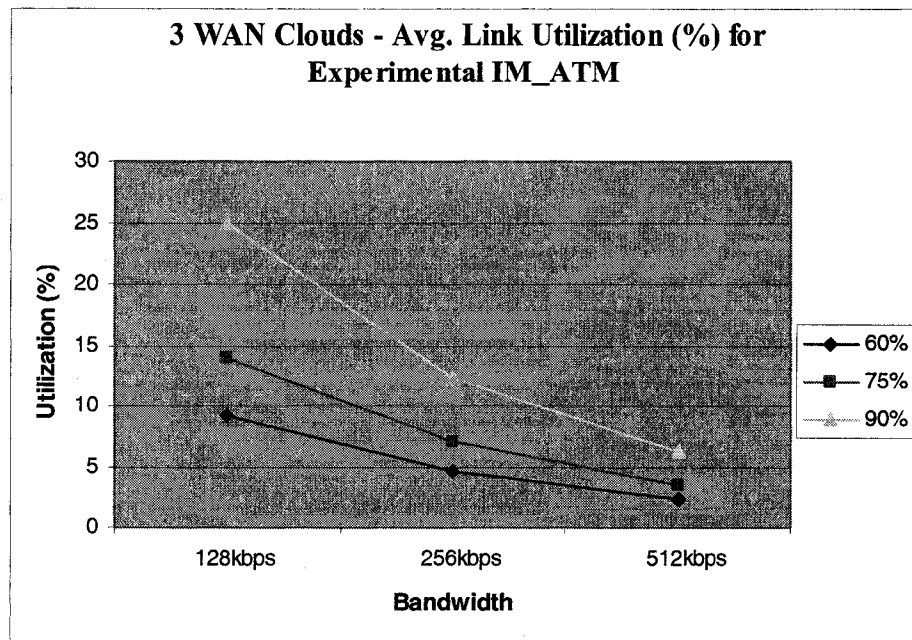


Figure 9.87: International Networks – Average Link Utilization (%) for Experimental IM_ATM Message

9.4. Global Networks – Five WAN Clouds

There are three level WAN Clouds in this model, the first level GLOBE WAN connects other four second level International WANs, namely, NA (North America), BA (Baltic Nations), EU (Europe), and EA (East Asia) and each second level node in terms connected to a third level Nodes represent major cities in the each region, each WAN has five destination nodes here, every node is sending messages to every destination node in this model. The cities are Boston, New York, Chicago, Washington, and Seattle in NA, Tallinn, Kaunas, Riga, and Vilnius in BA, London, Paris, Frankfurt, Brussel, and Milano in EU (Europe), Beijing Tokyo, Singapore, and HK in EA (See Figure 9.88 and 9.89). 1.544Mbps is used as the link and again bandwidth of 128kbps, 256kbps, and 512kbps are used for calculation of the network traffic, and capacity of 60%, 75%, and 90% are examined. The simulations are performed for 400B and 800B messages. The following samples are chosen for the presentations.

Simulation data for Packets Created, Packets Delivered, and Packets Dropped are collected. I calculated the total number of Packets Created, Packets Delivered, and Packets Dropped, ratio of Packets Dropped/Created and Packets Dropped/Delivered, Average Packets Delay (milliseconds) and Average Maximum Packets Delay (milliseconds). The statistics are shown from Tables 9.40 to 9.52 and graphs are depicted from Figures 9.90 to 9.111.

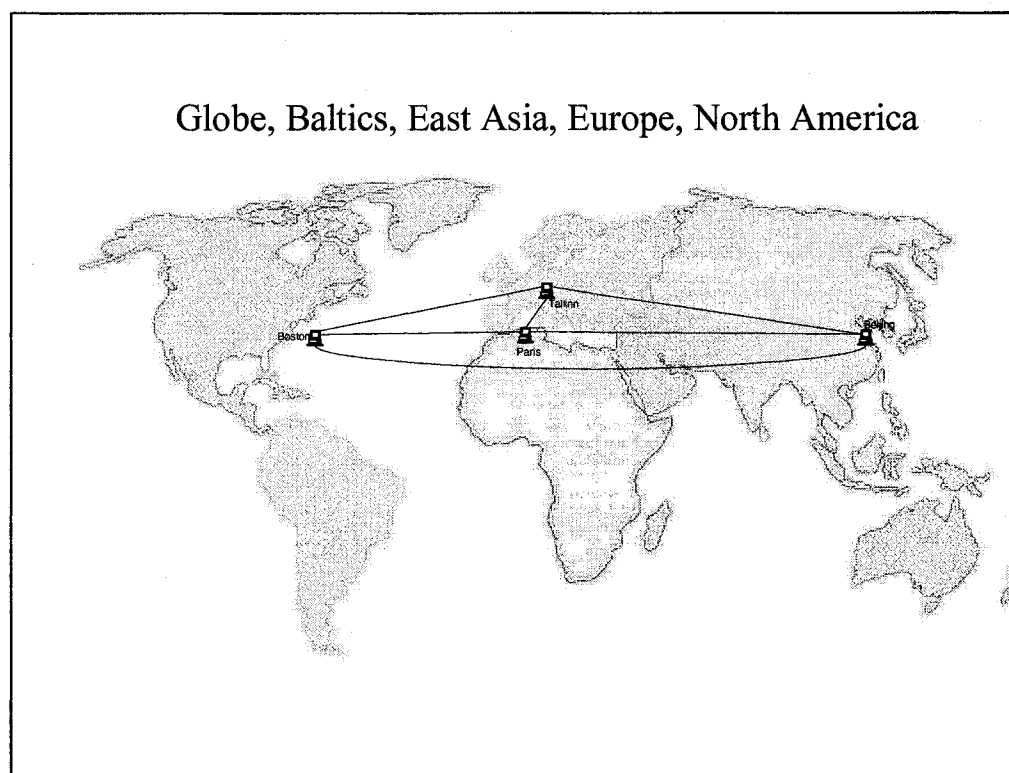


Figure 9.88: Global Networks connects Baltic Nations, East Asia, Europe, and North America

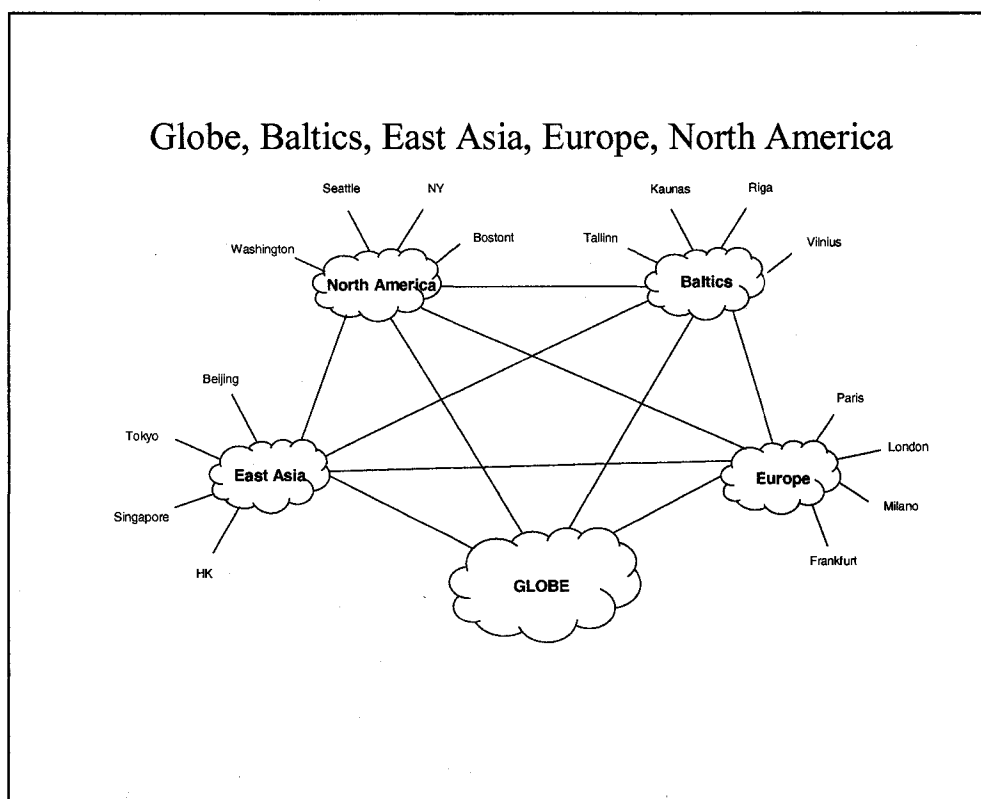


Figure 9.89: 5 WAN Clouds Global Networks connects Baltic Nations, East Asia, Europe, and North America

Analysis: Packets Created, Delivered, Dropped, Ratio of Dropped/Created, and Dropped/Delivered

Bandwidth – 128kbps, 256kbps and 512kbps, Message Size - 800B and 400B

For 800 bytes message, the average number of packets created is 399, 434, and 1816 (128kbps), 271, 402, and 2007 (256kbps) and 259, 470, and 2120 (512kbps). The differences are +9.71%, +7.37%, and -9.52% from 128kbps to 256kbps, and -4.43%, +14.47%, and +5.33% from 256kbps to 512kbps. The average number of packets delivered is 226, 258, and 305 (128kbps), 223, 307, and 451 (256kbps), and 211, 311, and 444 (512kbps), the differences of average number of packets delivered are -1.33%, +15.96, and +32.37% from 128kbps to 256kbps, and -5.83%, -1.29%, and -1.33% from 256kbps to 512kbps. The average number of packets dropped is 74, 176, and 1783 (128kbps), 48, 130, and 1557 (256kbps), and 48, 159, and 1658 (512kbps), the differences are -35.14%, -26.14%, and -12.68% from 128kbps to 256kbps, +0.00%, +18.24%, and +6.10% from 256kbps to 512kbps.

The ratio of packets dropped/created is 24.64%, 40.58%, and 85.39% (128kbps), and 17.71, 32.32, and 77.55% (256kbps), and 22.10%, 34.98%, and 78.01% (512kbps), the ratio decreases by 28.13%, 20.35%, and 9.18% from 128kbps to 256kbps, and increases by 19.86%, 7.60%, and 0.00% from 256kbps to 512kbps. The ratio of dropped/delivered is 32.69%, 68.30%, and 584.16% (128kbps), and 21.52%, 42.32%, and 354.47% (256kbps), and 28.37%, 53.80%, and 354.65 (512kbps). These statistics are given from Tables 9.42 to 9.44 and graphs are shown in Figures 9.78 to 9.82.

For 400 bytes message, the average number of packets created is 503, 213, and 5837 (128kbps), 448, 916, and 5951 (256kbps and 512kbps). The differences are -10.93%, +76.74%, and +1.92% from 128kbps to 256kbps-512kbps. The average number of packets delivered is 429, 111, and 619 (128kbps), 411, 605, and 890 (256kbps-512kbps), the differences are -4.20%, +81.65%, and +31.22% from 128kbps to 256kbps-512kbps. The average number of packets dropped is 74, 101.82, and 5218 (128kbps), 37, 302, and 5052 (256kbps – 512kbps), the differences are -50.00%, +66.25%, and -3.18% from 128kbps to 256kbps-512kbps.

The ratio of packets dropped/created is 14.69%, 47.74%, and 89.39% (128kbps), and 8.29%, 33.92%, and 84.88% (256kbps-512kbps), it decreases by 43.57%, 28.95%, and 5.05% from 128kbps to 256kbps-512kbps. The ratio of dropped/delivered is 17.21%, 91.53% and 842.63% (128kbps), 9.04%, 51.32% and 561.57% (256kbps-512kbps). The ratio dropped/delivered increases 47.47%, 43.93%, and 33.36% from 128kbps to 256kbps-512kbps. These statistics are given in Tables 9.45, and graphs are shown in Figures 9.83 to 9.87.

There are no packets dropped for the IM_ATM and Experimental IM_ATM calculations.

5 WAN Clouds	Message + Response Sources: Packet Delay								
4 Nodes each	Warm Up: 5/s, Replication: 240/s								
Message Sizes: 800B	Packets Created			Packets Delivered			Packets Dropped		
Bandwidth: 128kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Origin/Destination									
Vilnius/ Src:									
Riga	292	460	2122	231	278	285	61	182	1837
Kaunus	299	444	2045	222	260	313	77	184	1732
London	297	451	2171	210	243	308	87	208	1863
Milano	282	491	2103	206	272	306	76	219	1797
Frankfurt	305	448	2173	232	261	336	73	187	1837
NY	316	461	2069	236	276	296	80	185	1773
Seattle	301	481	2068	230	277	296	71	204	1772
Washington	317	450	2041	241	246	297	76	204	1744
Tokyo	315	481	2058	250	272	291	65	209	1767
Singapore	276	466	2039	196	261	303	80	205	1736
HK	296	484	2085	230	261	327	66	223	1758
Average:	299.64	465.18	2088.55	225.82	264.27	305.27	73.82	200.91	1783.27
Ratio:	Dropped/Created			Dropped/Delivered					
	24.64%	43.19%	85.38%	32.69%	76.02%	584.16%			
Bandwidth: 256kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Vilnius/ Src:									
Riga	262	414	2040	217	284	451	45	130	1589
Kaunus	275	389	1990	227	266	444	48	123	1546
London	278	391	2002	216	276	464	62	115	1538
Milano	260	387	2049	215	277	466	45	110	1583
Frankfurt	270	410	2012	226	286	446	44	124	1566
NY	294	411	2027	248	281	460	46	130	1567
Seattle	259	399	1956	211	281	432	48	118	1524
Washington	280	395	2078	223	275	474	57	120	1604
Tokyo	272	415	1999	227	607	448	45	192	1551
Singapore	268	391	1941	219	265	417	49	126	1524
HK	258	420	1988	220	279	455	38	141	1533
Average:	270.55	402.00	2007.45	222.64	307.00	450.64	47.91	129.91	1556.82
Ratio:	Dropped/Created			Dropped/Delivered					
	17.71%	32.32%	77.55%	21.52%	42.32%	345.47%			

Table 9.40: Global Networks – Packets Created, Delivered, and Dropped for 800B Message

5 WAN Clouds	Message + Response Sources: Packet Delay (Cont'd)								
4 Nodes each	Warm Up: 5/s, Replication: 240/s								
Message Sizes: 800B	Packets Created			Packets Delivered			Packets Dropped		
Bandwidth: 512kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Vilnius/ Src:									
Riga	268	478	2157	220	309	483	48	169	1674
Kaunas	240	480	2002	201	323	416	39	157	1586
London	272	465	2129	228	307	452	44	158	1677
Milano	250	470	2138	211	311	444	39	159	1694
Frankfurt	266	487	2086	216	316	421	50	171	1665
NY	278	468	2148	213	320	434	65	148	1714
Seattle	241	457	2143	203	288	456	38	169	1687
Washington	275	477	2045	226	342	426	49	135	1619
Tokyo	245	464	2152	192	315	460	53	149	1692
Singapore	233	460	2122	195	292	455	38	168	1667
HK	276	466	2005	215	303	441	61	163	1564
Average:	258.55	470.18	2102.45	210.91	311.45	444.36	47.64	158.73	1658.09
Ratio:	Dropped/Created			Dropped/Delivered					
	18.42%	33.76%	78.86%	22.59%	50.96%	373.14%			

5 WAN Clouds	Message + Response Sources: Packet Delay								
4 Nodes each	Warm Up: 5/s, Replication: 240/s								
Message Sizes:400B	Packets Created			Packets Delivered			Packets Dropped		
Bandwidth:128kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Vilnius/ Src:									
Riga	533	825	6002	421	408	642	112	417	5360
Kaunus	481	833	5815	400	411	602	81	422	5213
London	469	818	5734	389	411	633	80	407	5101
Milano	476	833	5879	399	389	628	77	444	5251
Frankfurt	509	812	5691	416	454	586	93	358	5105
NY	494	815	5806	411	411	605	83	404	5201
Seattle	522	809	5800	430	409	602	92	400	5198
Washington	512	821	5956	418	422	622	94	399	5334
Tokyo	514	831	5913	421	409	673	93	422	5240
Singapore	501	822	5842	406	405	599	95	417	5243
HK	484	821	5774	393	411	620	91	410	5154
Average:	502.55	821.82	5837.45	429.45	422.73	619.27	90.09	499.09	5218.18
Ratio:	Dropped/Created			Dropped/Delivered					
	18.03%	48.54%	89.39%	22.76%	94.45%	842.63%			
Bandwidth: 256kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Vilnius/ Src:									
Riga	401	935	6040	370	629	891	31	306	5149
Kaunus	470	910	5893	429	621	877	41	289	5016
London	440	908	6041	406	579	893	34	329	5148
Milano	467	879	5913	426	582	888	41	297	5025
Frankfurt	439	889	5849	406	574	935	33	315	4914
NY	438	949	5936	401	616	910	37	333	5026
Seattle	441	920	5995	399	614	850	42	306	5145
Washington	442	914	5977	402	620	888	40	294	5089
Tokyo	450	977	5997	407	635	945	43	342	5052
Singapore	481	911	5815	444	605	894	37	306	4921
HK	463	886	6006	433	585	924	30	301	5082
Average:	448.36	916.18	5951.09	411.18	605.45	899.55	37.18	310.73	5051.55
Ratio:	Dropped/Created			Dropped/Delivered					
	8.29%	33.92%	84.88%	9.04%	51.32%	561.57%			

Table 9.41: Global Networks – Packets Created, Delivered, and Dropped for 400B Message

5 WAN Clouds	Message + Response Sources: Packet Delay (Cont'd)								
4 Nodes each	Warm Up: 5/s, Replication: 240/s								
Message Sizes: 400B	Packets Created			Packets Delivered			Packets Dropped		
Bandwidth:512kbps	60%	75%	90%	60%	75%	90%	60%	75%	90%
Vilnius/ Src:									
Riga	401	935	6040	370	629	891	31	306	5149
Kaunas	470	910	5893	429	621	877	41	289	5016
London	440	908	6041	406	579	893	34	329	5148
Milano	467	879	5913	426	582	888	41	297	5025
Frankfurt	439	889	5849	406	574	935	33	315	4914
NY	438	949	5936	401	616	910	37	333	5026
Seattle	441	920	5995	399	614	850	42	306	5145
Washington	442	914	5977	402	620	888	40	294	5089
Tokyo	450	977	5997	407	635	945	43	342	5052
Singapore	481	911	5815	444	605	894	37	306	4921
HK	463	886	6006	433	585	924	30	301	5082
Average:	448.36	916.18	5951.09	411.18	605.45	899.55	37.18	310.73	5051.55

5 WAN Clouds	Message + Response Sources: Packet Delay								
4 Nodes each	Warm Up: 5/s, Replication: 240/s								
Message Sizes: 800B	Packets Created			Packets Delivered			Packets Dropped		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	299.64	433.91	2088.82	225.82	264.82	305.27	73.83	201.09	1783.27
256kbps	270.55	402.00	2007.45	222.64	307.00	450.64	47.91	129.91	1556.82
512kbps	258.55	470.18	2120.45	210.91	311.45	444.36	47.64	158.73	1658.09
Ratio:	Dropped/Created			Dropped/Delivered					
128kbps	24.64%	43.58%	85.39%	32.69%	76.30%	584.16%			
256kbps	17.71%	32.32%	77.55%	21.52%	42.32%	345.47%			
512kbps	18.10%	34.08%	78.65%	23.37%	50.80%	372.65%			

Table 9.42: Global Networks – Average Packets Created, Delivered, Dropped, Ratio of Packets Dropped/Created, and Dropped/Delivered for 800B Message

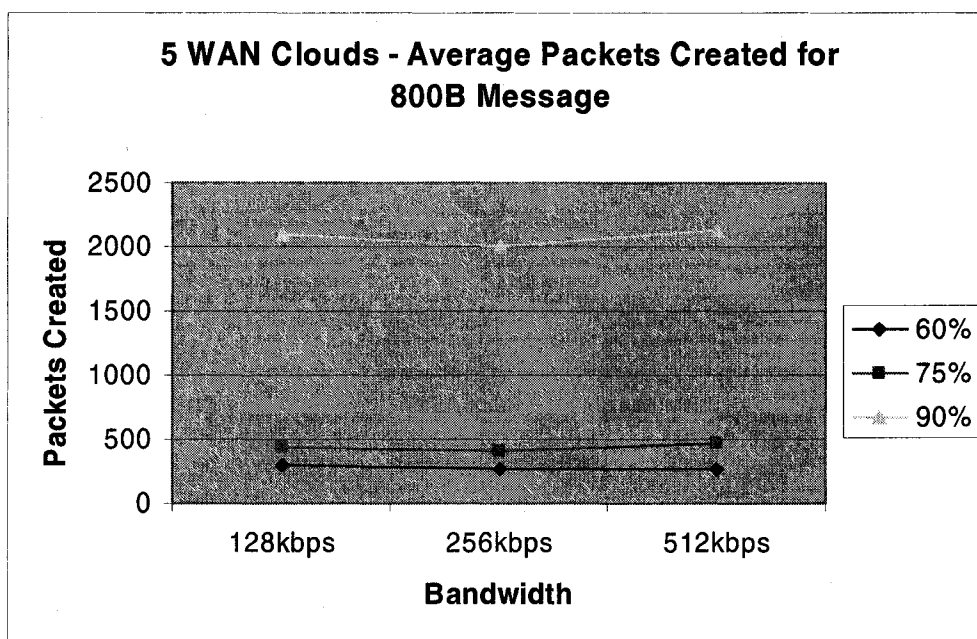


Figure 9.90: Global Networks – Average Packets Created for 800B Message

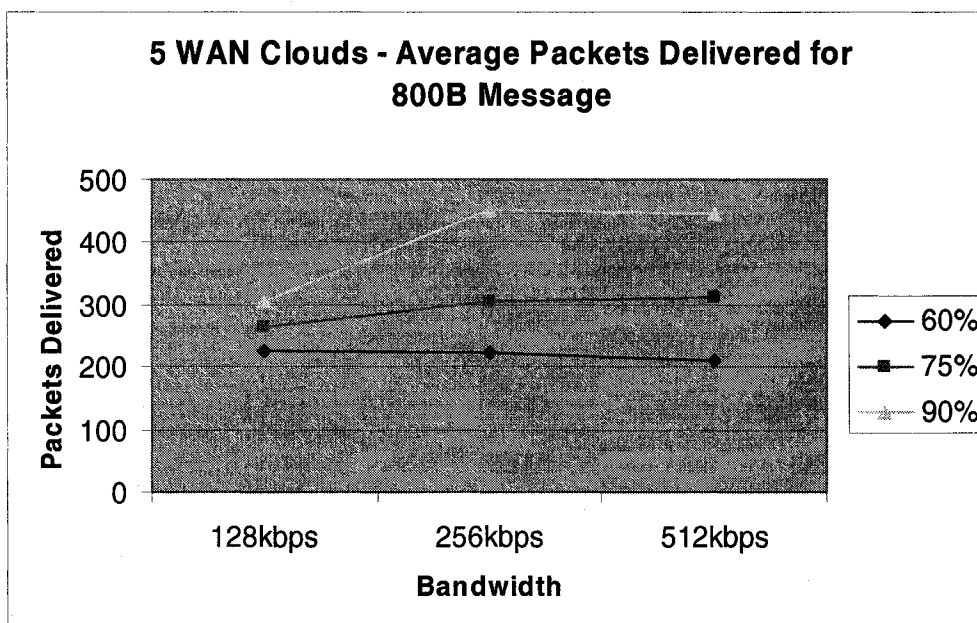


Figure 9.91: Global Networks – Average Packets Delivered for 800B Message

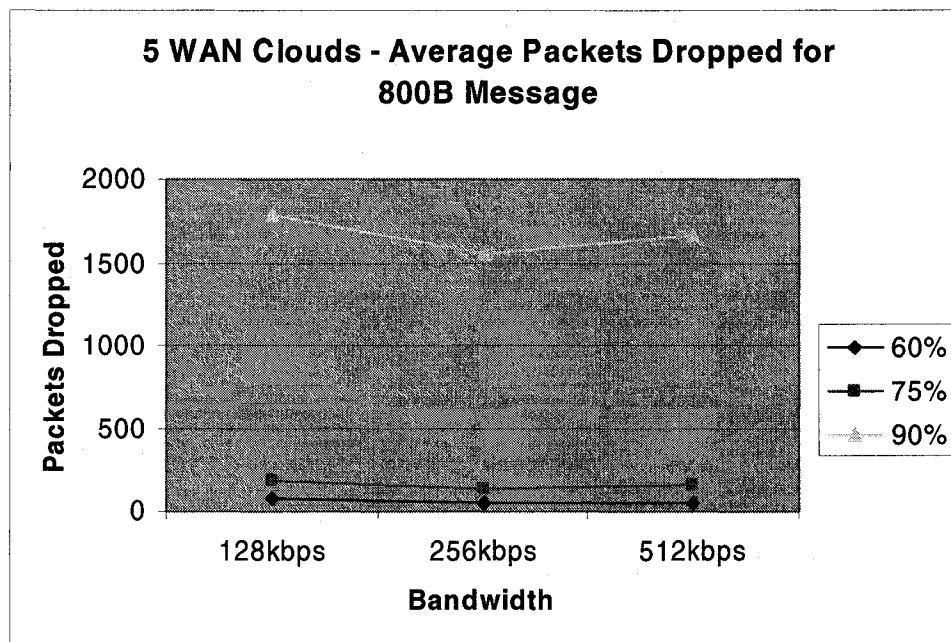


Figure 9.92: Global Networks – Average Packets Created for 800B Message

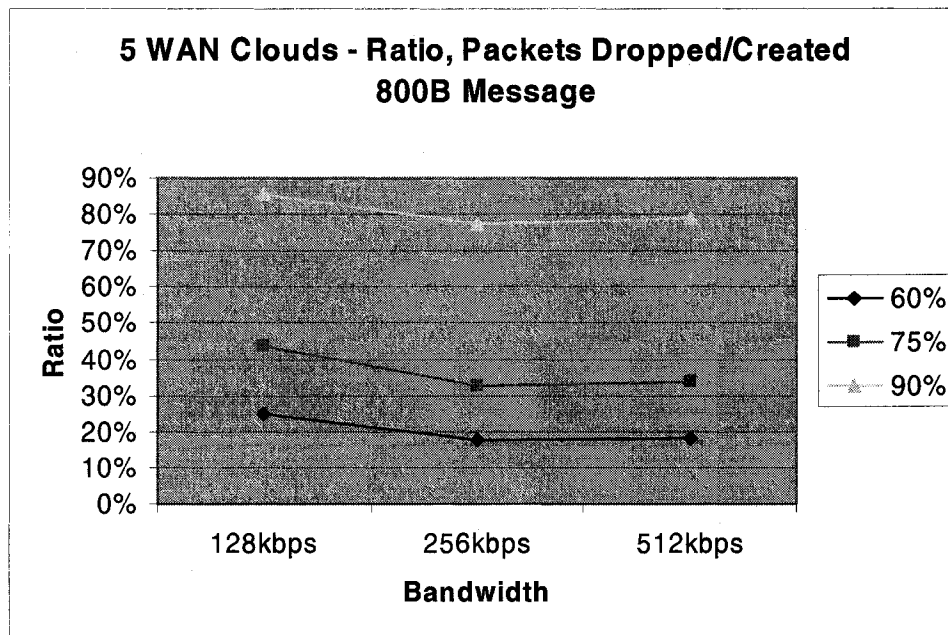


Figure 9.93: Global Networks – Ratio of Dropped/Created for 800B Message

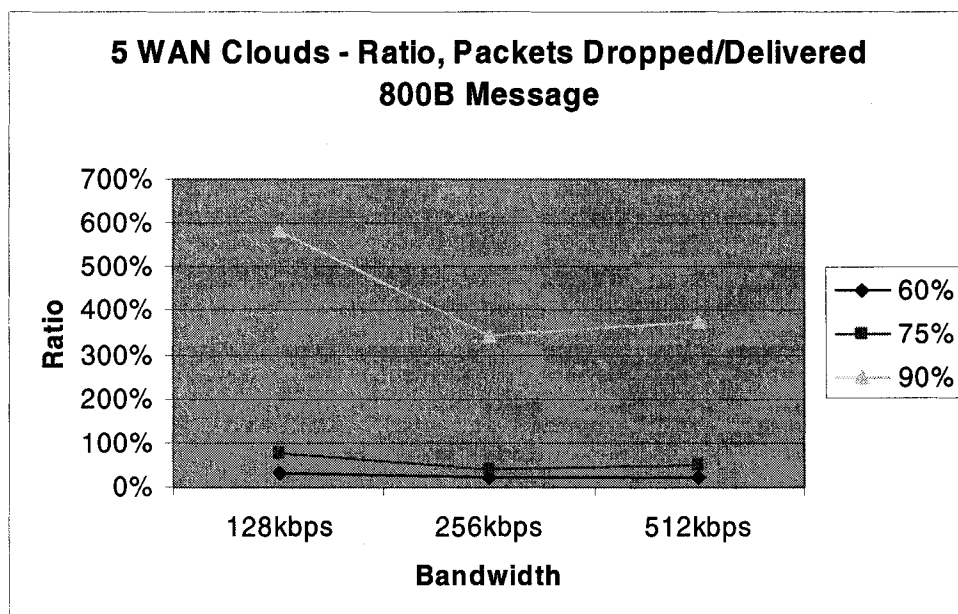


Figure 9.94: Global Networks – Ratio of Dropped/Delivered for 800B Message

5 WAN Clouds	Message + Response Sources: Packet Delay								
4 Nodes each	Warm Up: 5/s, Replication: 240/s								
Message Sizes: 400B	Packets Created			Packets Delivered			Packets Dropped		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	503.27	822.27	5837.45	429.36	423.45	619.27	73.91	388.82	5218.18
256kbps	448.36	916.18	5951.09	411.18	605.45	899.55	37.18	301.73	5051.55
512kbps	448.36	916.18	5951.09	411.18	605.45	899.55	37.18	301.73	5051.55
Ratio:	Dropped/Created			Dropped/Delivered					
128kbps	18.54%	48.86%	89.39%	22.76%	94.45%	842.63%			
256kbps	8.29%	33.92%	84.88%	9.04%	51.32%	561.57%			
512kbps	8.29%	33.92%	84.88%	9.04%	51.32%	561.57%			

Table 9.43: Global Networks – Average Packets Created, Delivered, and Dropped for 400B Message

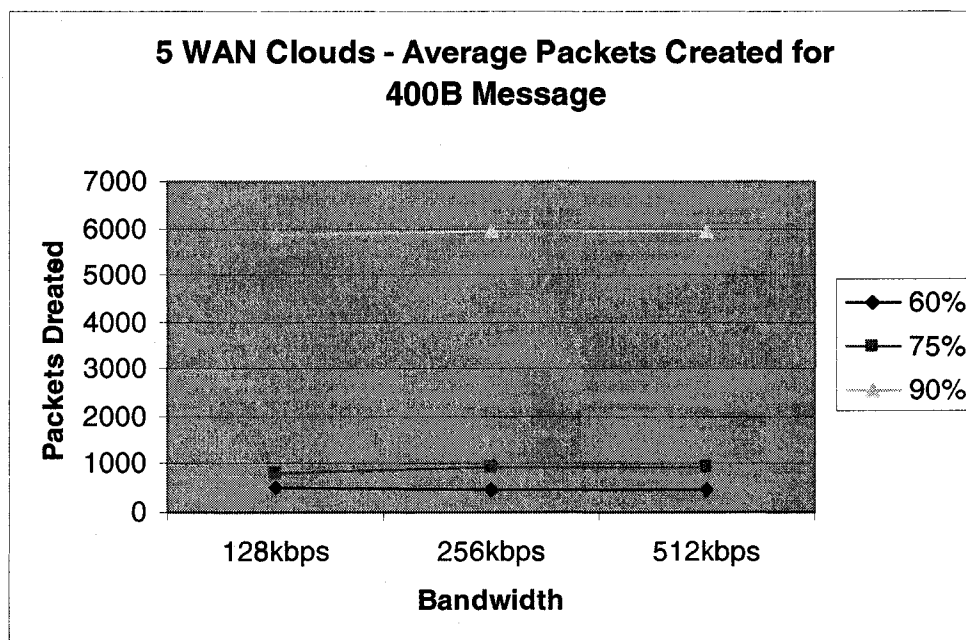


Figure 9.95: Global Networks – Average Packets Created for 400B Message

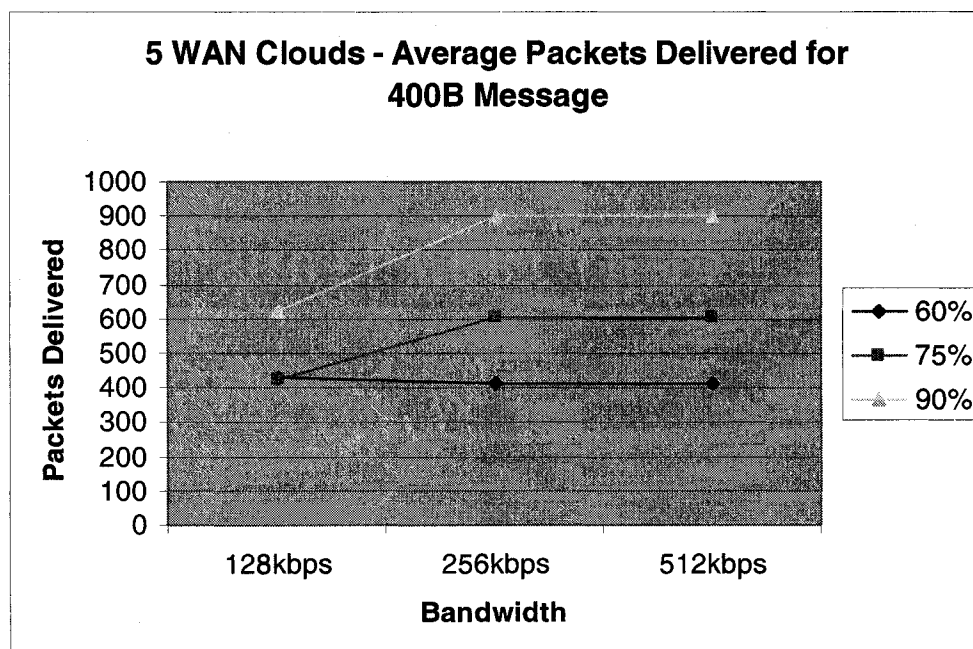


Figure 9.96: Global Networks – Average Packets Delivered for 400B Message

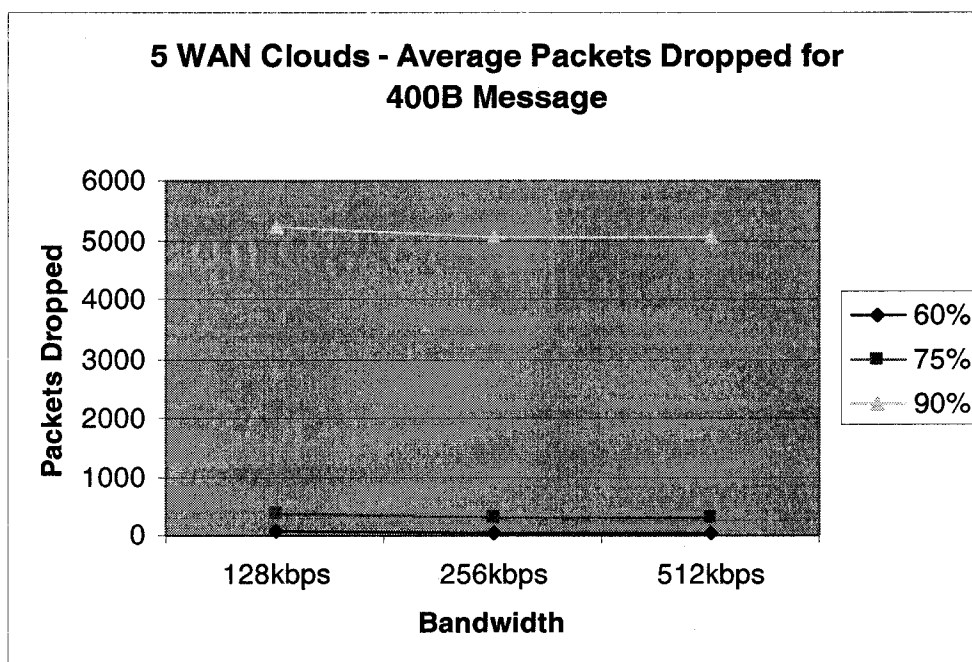


Figure 9.97: Global Networks – Average Packets Dropped for 400B Message

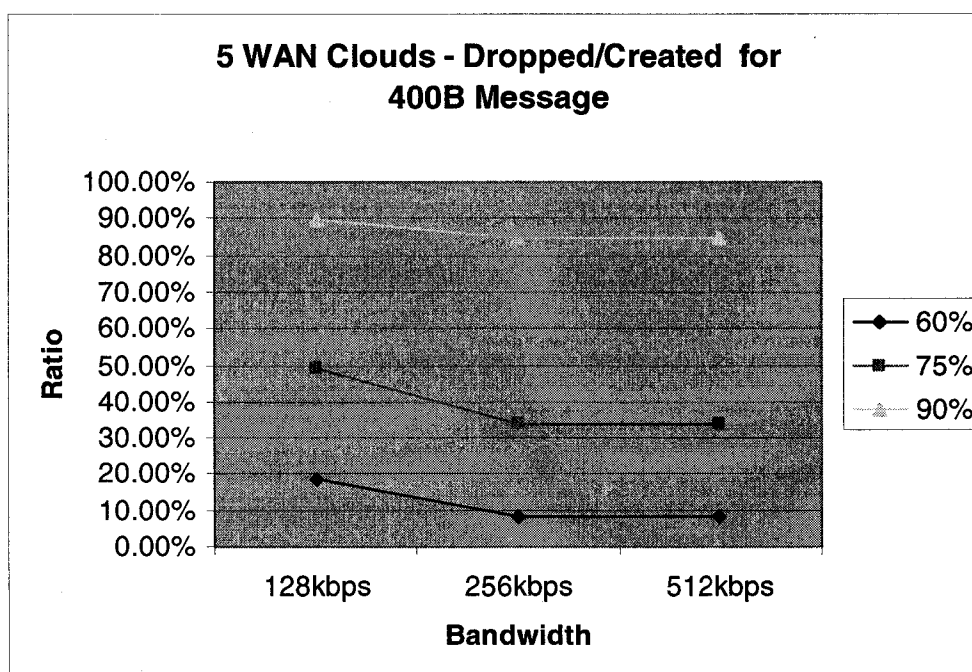


Figure 9.98: Global Networks – Ratio of Packets Dropped/Created for 400B Message

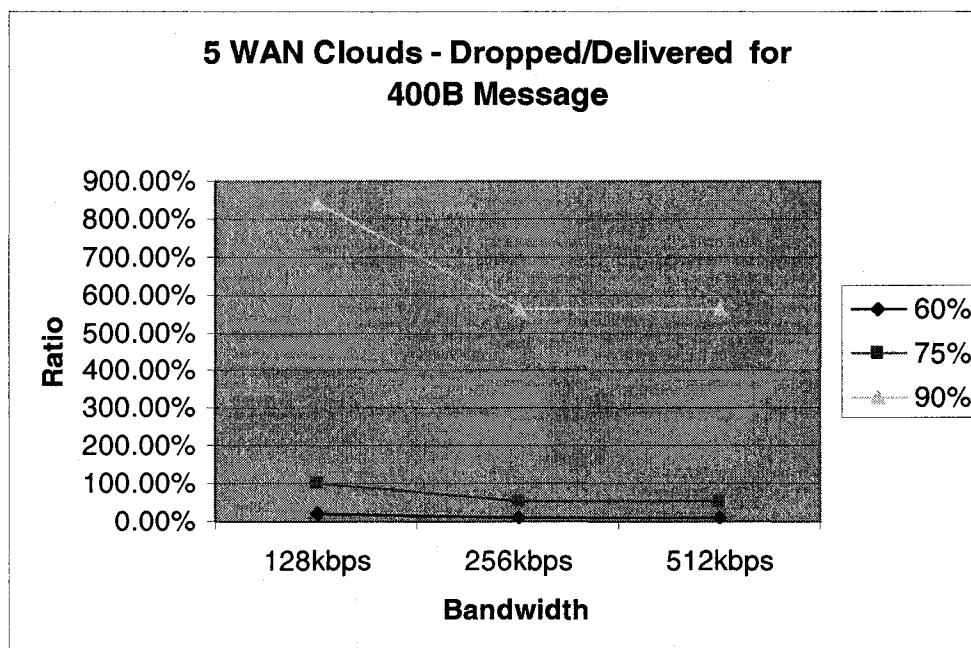


Figure 9.99: Global Networks – Ratio of Packets Dropped/Delivered for 400B Message

Average Packet Delay (MS)

Bandwidth – 128kbps-512kbps, Message Size - 800B and 400B

For 800 bytes message, the average packet delay is 1031, 1084, and 1312 (128kbps), 523, 569, and 644 (256kbps), and 365, 393, and 424 (512kbps), the average packets delay decreases by 49.27%, 47.51%, and 50.91% from 128kbps to 256kbps, and by 30.21%, 30.93, and 34.16% from 256kbps to 512kbps.

For 400 bytes message, the average packet delay is 812, 1002, and 1237 (128kbps), 406, 472, and 533 (256kbps), and 261, 295, and 326 (512kbps), the average packets delay decreases by 50.00%, 52.89%, and 56.91% from 128kbps to 256kbps, and by 35.71%, 37.50%, and 38.84% from 256kbps to 512kbps.

Average Packet Delay (MS) - IM_ATM and Experimental IM_ATM Networks

Bandwidth – 128kbps, 256kbps, and 512kbps, Message Size – IM_ATM 46B (800B)

The average packet delay for IM_ATM networks is 45.73, 47.55, and 72.91 (128kbps), 41.55, 42.28, and 52.55 (256kbps), and 39.08, 39.73, and 44.72 (512kbps). The decrease in packet delay is 9.14%, 11.08 %, and 27.92% from 128kbps to 256kbps, and is 5.94 %, 6.03% and 14.90% from 256kbps to 512kbps for all three intensities. Packet Delay for Experimental IM_ATM networks is 104.64, 155.36, and 541.18 (128kbps), 70.82, 96.09, and 232.45 (256kbps), and 53.55, 64.45, and 149.55 (512kbps) for all three intensities, the decrease in packet delay is 32.32%, 38.15%, and 57.05% from 128kbps to 256kbps, 24.39%, and 32.93%, and 35.66% from 256kbps to 512kbps.

Message Delay (MS) – 46B (400B) IM_ATM and Experimental IM_ATM Networks

The average packet delay for IM_ATM is 54.91, 67.27, and 189.09 (128kbps), 45.55, 53.18, and 104.91 (256kbps), and 40.91, 45.09, and 70.82 (512kbps), the decrease in packet delay is 17.05%, 20.95%, and 44.52% from 128kbps to 256kbps, and 10.19%, 15.24%, 32.49% and from 256kbps to 512kbps, for all three intensities. The average packet delay for the Experimental IM_ATM is 155.35, 254.73, and 1022.91 (128kbps), 96.09, 129.64, and 364.82 (256kbps), and 66.45, 83.18, and 88.65 (512kbps). The packet delay decreases by 38.15%, 49.11%, and 64.34% from 128kbps to 256kbps, 30.85%, 35.84%, and 75.70% from 256kbps to 512kbps for all three capacities. The statistics are shown from Table 9.48, and the charts are depicted from Figure 9.92 and 9.93.

5 WAN Clouds	Message + Response Sources: Packet Delay (MS)					
Link: 1.544Mbps	Bandwidth: 128kbps					
Message Size	800B			400B		
Bandwidth	60%	75%	90%	60%	75%	90%
128kbps	1031	1084	1312	812	1002	1237
256kbps	523	569	644	406	472	533
512kbps	365	393	424	261	295	326

Table 9.44: Global Networks – Average Packet Delay for 800B and 400B Message

5 WAN Clouds	Message + Response Sources: Packet Delay (MS)								
Link: 1.544Mbps	4 Nodes Each, Replication Length: 245/s								
Message Size	800B			IM_ATM			IM_ATM 46B -Experimental		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	1031	1084	1312	45.73	47.55	72.91	104.64	155.36	541.18
256kbps	523	569	644	41.55	42.28	52.55	70.82	96.09	232.45
512kbps	365	393	424	39.08	39.73	44.72	53.55	64.45	149.55

Table 9.45: Global Networks - Average Packet Delay for 800B, IM_ATM and Experimental Message

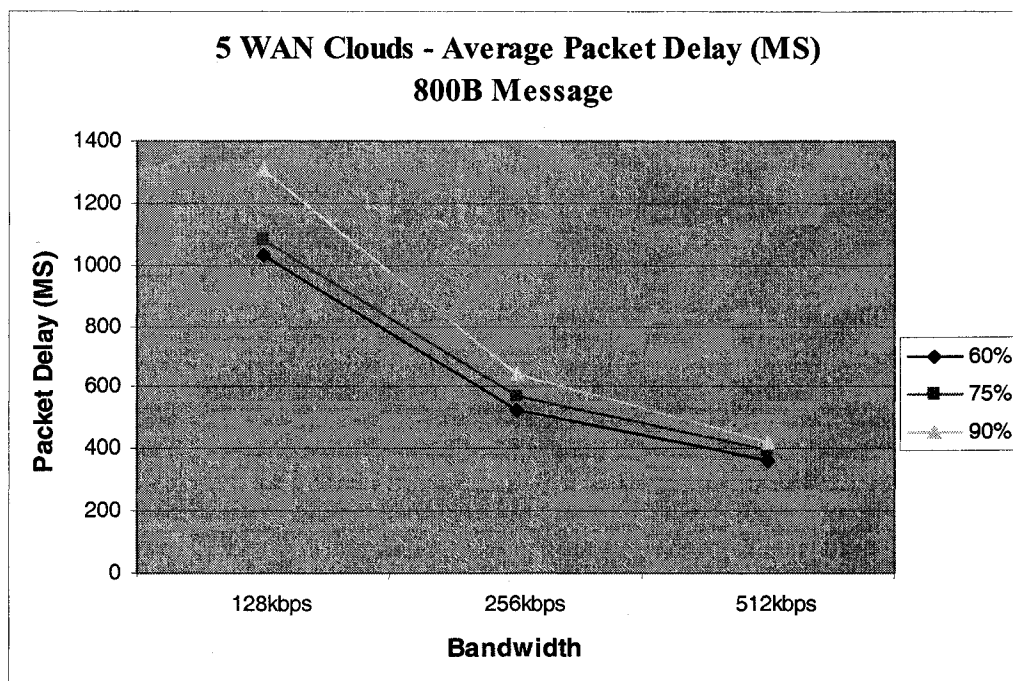


Figure 9.100: Global Networks – Average Packet Delay (MS) for 800B Message

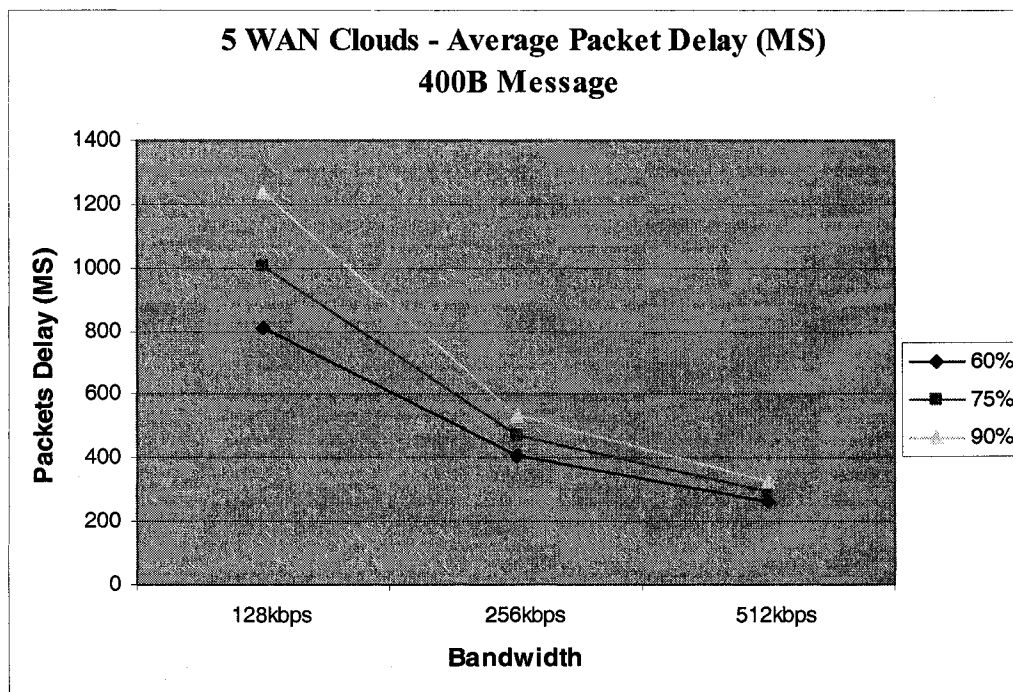


Figure 9.101: Global Networks – Average Packet Delay (MS) for 400B Message

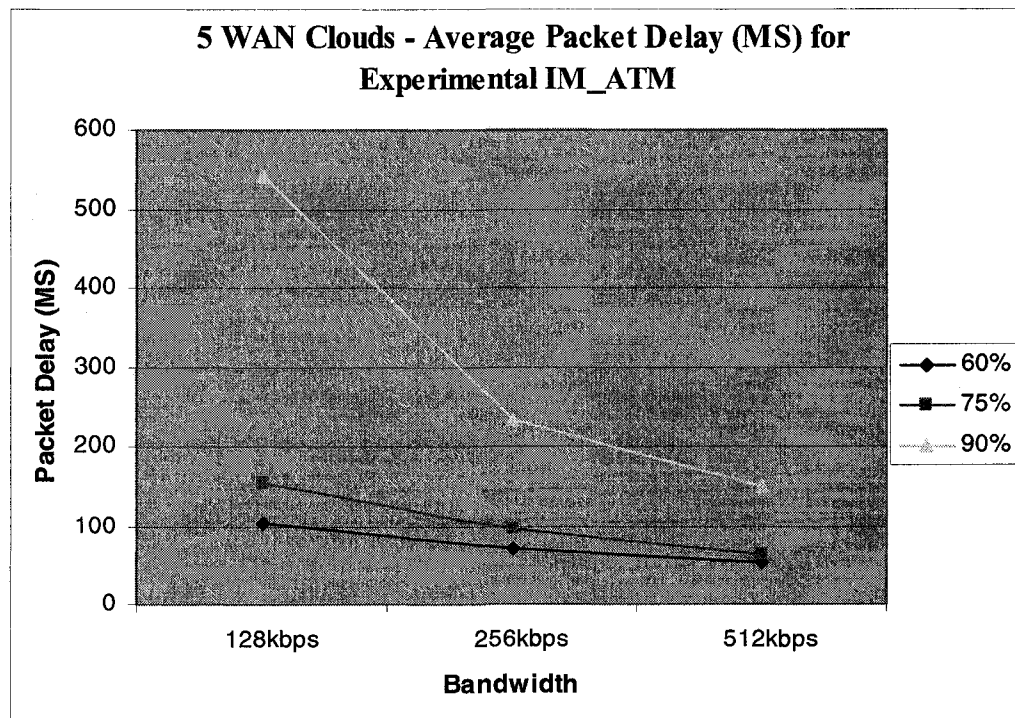


Figure 9.102: Global Networks Average Packet Delay (MS) for Experimental IM_ATM Message

5 WAN Clouds	Message + Response Sources: Packet Delay (MS)								
4 Nodes each	Warm Up: 5/s, Replication: 240/s								
Link: 1.544Mbps	400B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
128kbps	812	1002	1237	54.91	67.27	189.09	155.35	254.73	1022.91
256kbps	406	472	533	45.55	53.18	104.91	96.09	129.64	364.82
512kbps	261	295	326	40.91	45.09	70.82	66.45	83.18	88.65

Table 9.46: Global Networks – Average Packet Delay for 800B and 400B Message

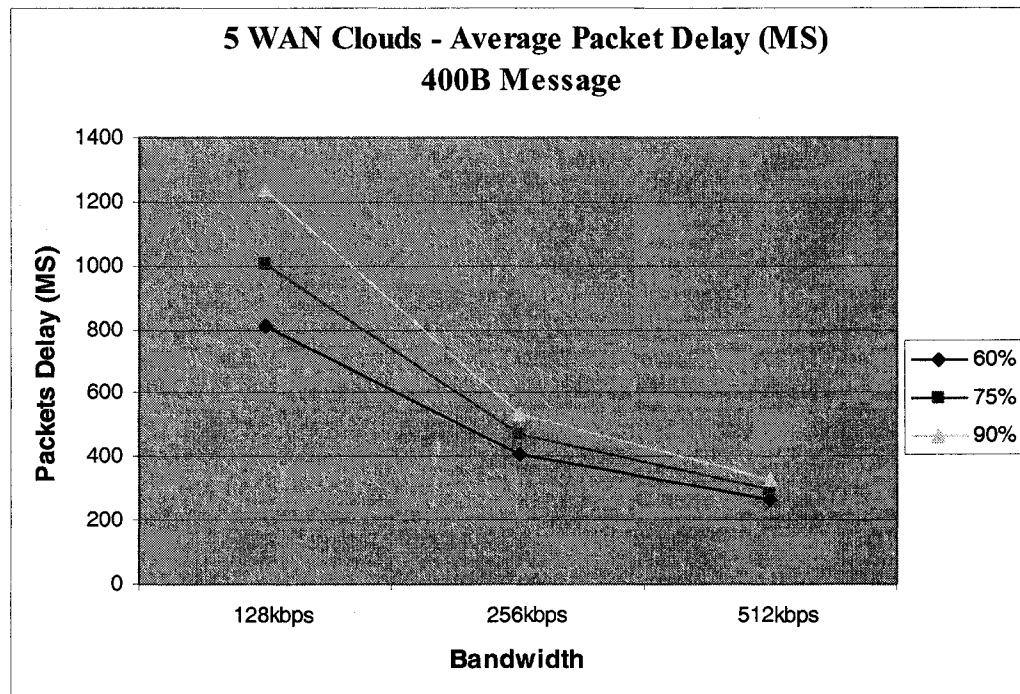


Figure 9.103: Global Networks – Average Packet Delay (MS) for 400B Message

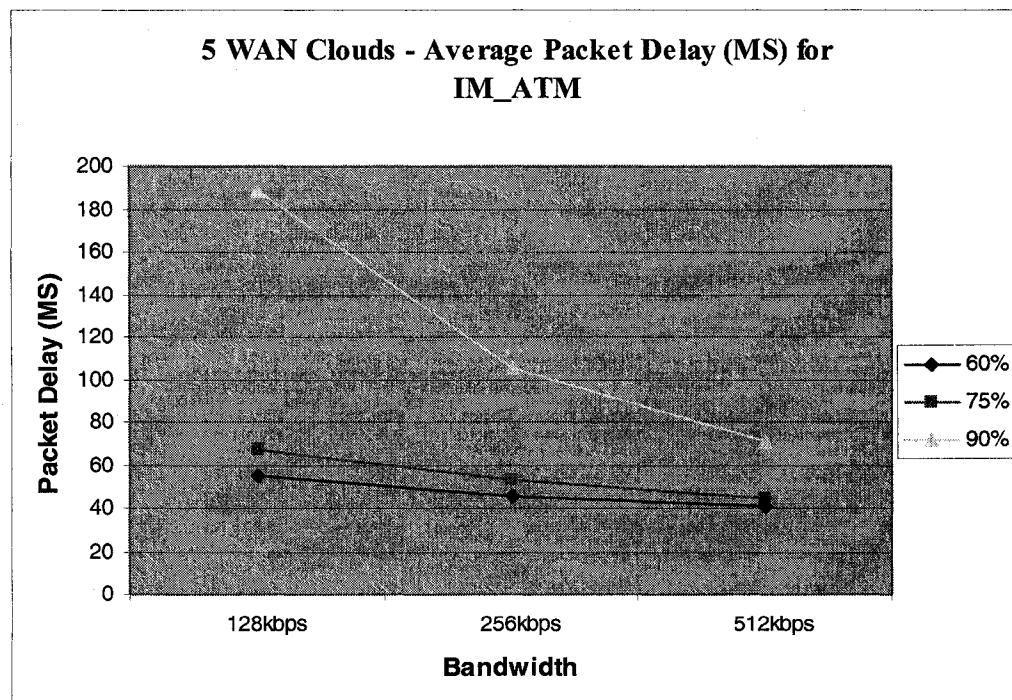


Figure 9.104: Global Networks – Average Packet Delay for IM_ATM Message

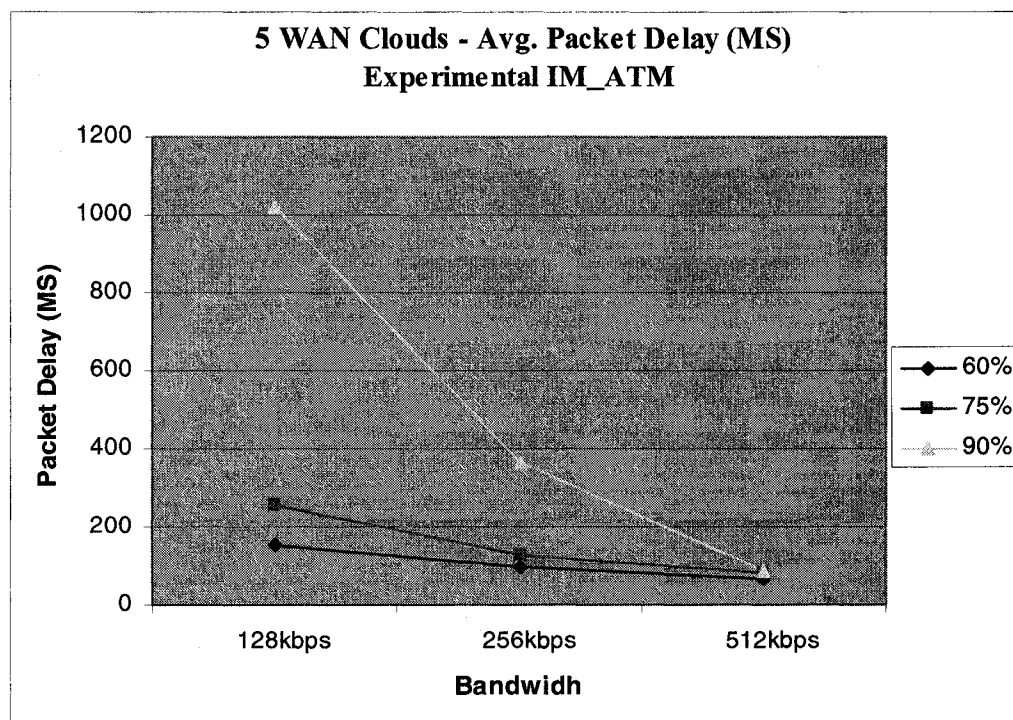


Figure 9.105: Global Networks – Average Packet Delay for Experimental IM_ATM Message

Average Access Link Stats Utilization (%)**Bandwidth – 128kbps, 256kbps, and 512kbps, Message Size - 800B and 400B**

For 800 bytes message, the average utilization is 57.77%, 72.55%, and 84.50% (128kbps), 30.66%, 41.03%, and 60.29% (256kbps), and 15.36%, 20.88%, and 29.68% (512kbps). The decrease in utilization is 46.93%, 43.45%, and 28.65% from 128kbps to 256kbps, and 49.90%, 49.11%, and 50.77% from 256kbps to 512kbps,

For 400 bytes message, the average utilization is very similar to that of the 800 bytes message for all the three bandwidth intensities.

5 WAN Clouds	Average Percentage of Access Links Utilization					
4 Nodes each	Warm Up: 5/s, Replication: 240/s					
Link: 1.544Mbps	800B			400B		
Bandwidth	60%	75%	90%	60%	75%	90%
GLOBE WAN						
128kbps	13.35	16.79	19.61	12.89	16.68	19.81
256kbps	14.20	19.13	27.78	13.15	19.35	28.95
512kbps	14.29	19.34	26.51	13.43	19.35	28.95
NA WAN						
128kbps	56.75	72.85	84.12	55.15	72.72	85.63
256kbps	30.58	40.68	60.31	28.02	42.46	63.05
512kbps	15.32	20.91	29.67	14.41	21.22	31.52
BA WAN						
128kbps	58.67	72.18	84.53	56.57	70.72	85.61
256kbps	30.94	41.73	60.02	29.27	41.39	62.92
512kbps	15.39	21.21	29.76	13.80	20.18	31.21
EA WAN						
128kbps	57.17	72.67	84.42	55.47	72.71	85.52
256kbps	30.71	40.74	60.45	28.37	41.98	63.01
512kbps	15.31	20.45	29.61	14.18	21.03	31.97
EU WAN						
128kbps	58.50	72.50	84.94	55.60	73.84	85.67
256kbps	30.41	40.95	60.39	29.03	41.82	62.58
512kbps	15.41	20.95	29.69	13.93	20.91	31.38

Table 9.47: Global Networks – Access Link Utilization (%) for 800B and 400B Message

5 WAN Clouds	Average Percentage of Access Links Utilization					
4 Nodes each	Warm Up: 5/s, Replication: 240/s					
Link: 1.544Mbps	800B			400B		
Bandwidth	60%	75%	90%	60%	75%	90%
Average						
128kbps	57.77	72.55	84.50	55.70	72.50	85.53
256kbps	30.66	41.03	60.29	28.67	41.91	62.89
512kbps	15.36	20.88	29.68	14.08	20.84	31.77

Table 9.48: Global Networks – Average Access Link Utilization (%) for 800B and 400B Message

Average Access Link Utilization (%) - IM_ATM and Experimental IM_ATM

Bandwidth – 128kbps-512kbps, Message Size – IM_ATM 46B (800B)

The average percentage of utilization for IM_ATM Networks is 0.308%, 0.508%, 2.378% (128kbps), 0.156%, 0.255%, and 1.191% (256kbps), and 0.077%, 0.130%, and 0.583% (512kbps). The decrease in utilization is 49.35%, 49.80%, and 49.91% from 128kbps to 256kbps, and 50.64%, 49.02%, and 51.05% from 256kbps to 512kbps.

The average utilization for Experimental IM_ATM networks is 5.401%, 8.974%, 38.940% (128kbps), 2.786%, 4.402%, and 19.217% (256kbps), and 1.125%, 1.755%, and 3.114% (512kbps). The utilization percentage decreases by 48.42%, 50.95%, and 50.65% from 128kbps to 256kbps, and 59.62%, 60.13%, and 83.80% from 256kbps to 512kbps.

Bandwidth – 128kbps-512kbps, Message Size – IM_ATM 46B (400B)

The average utilization for IM_ATM networks is 1.037%, 2.059%, 12.141% (128kbps), 0.503%, 1.485%, and 5.932% (256kbps), and 0.253%, 0.511%, and 2.978% (512kbps). The decrease in utilization is 51.49%, 27.88%, and 51.14% from 128kbps to 256kbps, and 49.70%, 65.59%, and 49.80% from 256kbps to 512kbps.

5 WAN Clouds	Average Percentage of Access Links Utilization								
4 Nodes each	Warm Up: 5/s, Replication: 240/s								
Link: 1.544Mbps	800B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
GLOBE WAN									
128kbps	13.35	16.79	19.61	0.070	0.120	0.550	1.231	2.038	8.921
256kbps	14.20	19.13	27.78	0.071	0.119	0.539	1.231	2.038	8.929
512kbps	14.29	19.34	26.51	0.071	0.121	0.539	1.231	2.028	8.985
NA WAN									
128kbps	56.75	72.85	84.12	0.307	0.513	2.347	5.361	8.903	39.138
256kbps	30.58	40.68	60.31	0.160	0.260	1.187	2.847	4.453	19.648
512kbps	15.32	20.91	29.67	0.078	0.132	0.592	1.342	2.168	9.848
BA WAN									
128kbps	58.67	72.18	84.53	0.298	0.512	2.397	5.581	9.003	38.590
256kbps	30.94	41.73	60.02	0.158	0.252	1.193	2.789	4.283	18.905
512kbps	15.39	21.21	29.76	0.077	0.133	0.581	1.323	2.189	9.792
EA WAN									
128kbps	57.17	72.67	84.42	0.320	0.509	2.451	5.356	9.001	38.923
256kbps	30.71	40.74	60.45	0.153	0.255	1.188	2.693	4.369	19.203
512kbps	15.31	20.45	29.61	0.078	0.128	0.573	1.351	2.256	9.911
EU WAN									
128kbps	58.50	72.50	84.94	0.307	0.497	2.318	5.295	8.978	39.112
256kbps	30.41	40.95	60.39	0.153	0.253	1.196	2.813	4.501	19.112
512kbps	15.41	20.95	29.69	0.075	0.127	0.585	1.337	2.140	9.658

Table 9.49: Global Networks – Access Link Utilization (%) for 800B, IM_ATM and Experimental Message

5 WAN Clouds	Average Percentage of Access Links Utilization								
4 Nodes each	Warm Up: 5/s, Replication: 240/s								
Message Size	800B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
Average									
128kbps	57.77	72.55	84.50	0.308	0.508	2.378	5.401	8.974	38.940
256kbps	30.66	41.03	60.29	0.156	0.255	1.191	2.786	4.402	19.217
512kbps	15.36	20.88	29.68	0.077	0.130	0.583	1.125	1.755	3.114

Table 9.50: Global Networks – Average Access Link Utilization (%) for 800B, IM_ATM and Experimental IM_ATM Message

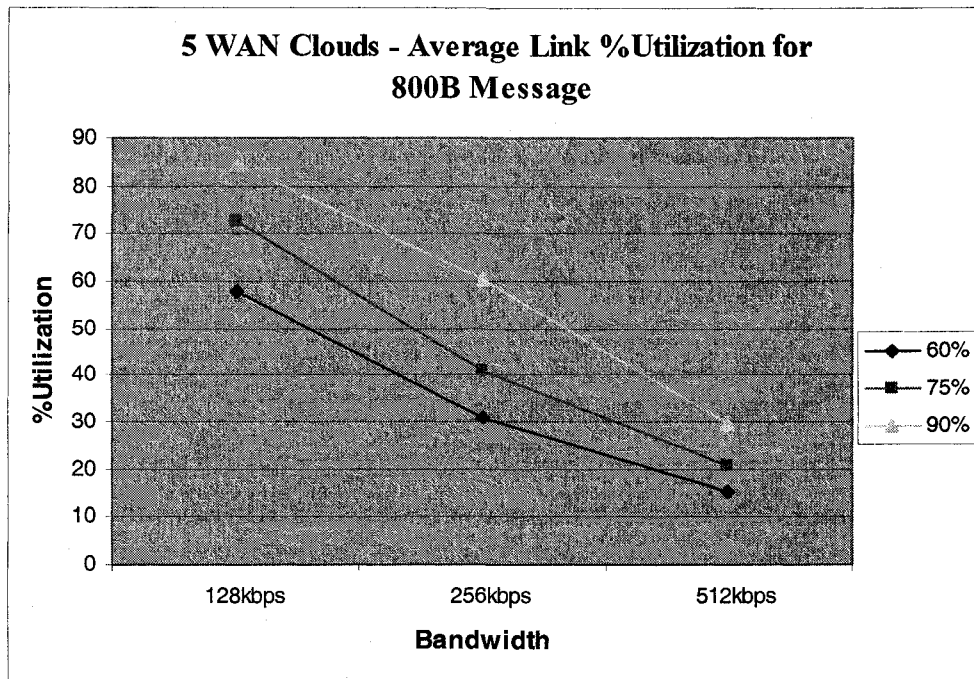


Figure 9.106: Global Networks – Average Access Link Utilization (%) for 800B Message

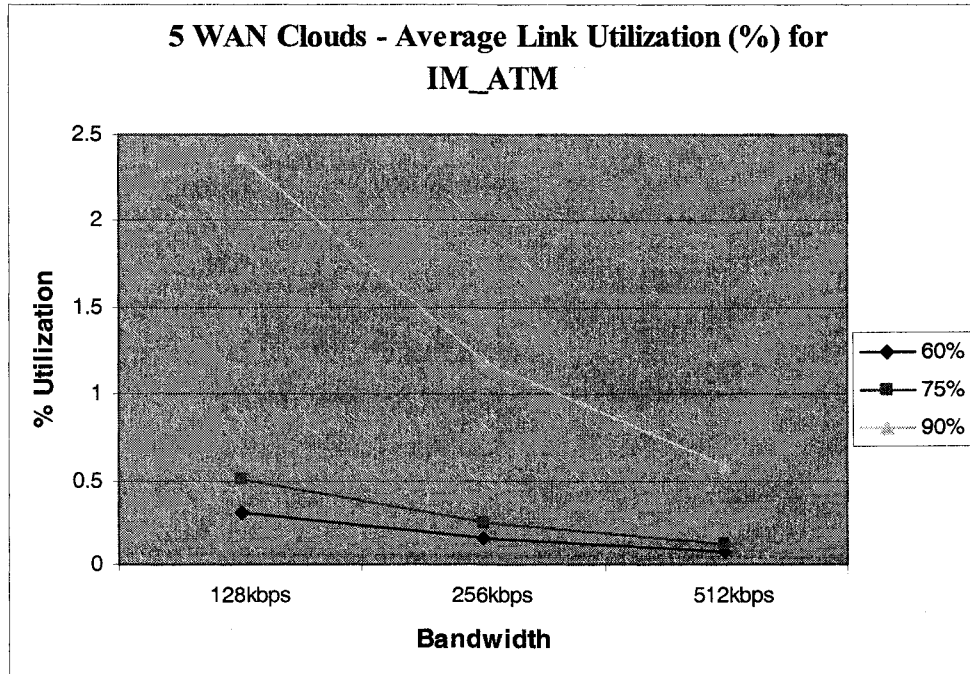


Figure 9.107: Global Networks – Average Access Link Utilization (%) for 800B Message

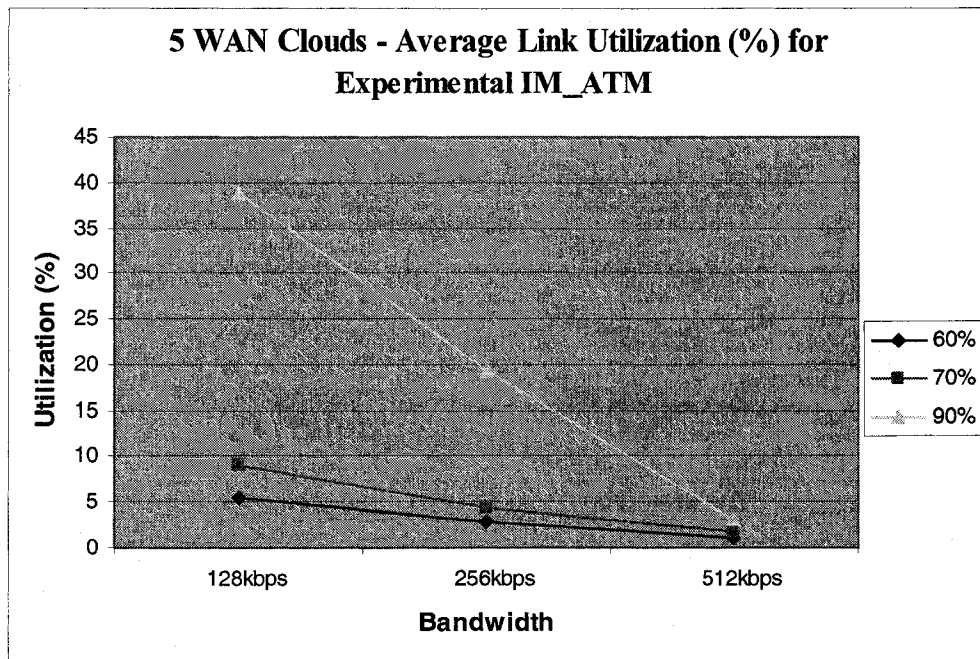


Figure 9.108: Global Networks – Average Access Link Utilization (%) for Experimental IM_ATM Message

5 WAN Clouds	Average Percentage of Access Links Utilization								
4 Nodes each	Warm Up: 5/s, Replication: 240/s								
Message Size	400B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
GLOBE WAN									
128kbps	12.89	16.68	19.81	0.239	0.474	2.818	2.038	4.074	16.589
256kbps	13.15	19.35	28.95	0.239	0.465	2.769	2.038	3.926	19.066
512kbps	13.43	19.35	28.95	0.239	0.465	2.769	2.038	3.926	18.040
NA WAN									
128kbps	55.15	72.72	85.63	1.065	2.053	12.172	8.904	17.176	72.245
256kbps	28.02	42.46	63.05	0.505	1.485	5.865	4.453	8.473	41.933
512kbps	14.41	21.22	31.52	0.247	0.497	2.932	2.227	4.237	20.323
BA WAN									
128kbps	56.57	70.72	85.61	1.060	2.025	12.165	9.003	17.454	71.698
256kbps	29.27	41.39	62.92	0.520	1.560	6.007	4.503	8.629	41.633
512kbps	13.80	20.18	31.21	0.258	0.520	3.070	2.250	4.312	20.055
EA WAN									
128kbps	55.47	72.71	85.52	1.017	2.055	12.054	8.818	17.189	72.961
256kbps	28.37	41.98	63.01	0.490	1.498	5.967	4.893	8.641	41.654
512kbps	14.18	21.03	31.97	0.258	0.510	2.777	2.237	4.277	20.666
EU WAN									
128kbps	55.60	73.84	85.67	1.007	2.102	12.173	8.548	17.603	70.453
256kbps	29.03	41.82	62.58	0.498	1.611	5.887	4.489	8.537	41.525
512kbps	13.93	20.91	31.38	0.255	0.498	3.038	2.149	4.270	20.357

Table 9.51: Global Networks – Access Link Utilization (%) for 400B, IM_ATM, and Experimental IM_ATM Message

5 WAN Clouds	Average Percentage of Access Links Utilization								
4 Nodes each	Warm Up: 5/s, Replication: 240/s								
Message Size	400B			IM_ATM			Experimental IM_ATM		
Bandwidth	60%	75%	90%	60%	75%	90%	60%	75%	90%
Average									
128kbps	55.70	72.50	85.53	1.037	2.059	12.141	8.82	17.36	71.84
256kbps	28.67	41.91	62.89	0.503	1.485	5.932	4.59	8.57	41.56
512kbps	14.08	20.84	31.77	0.253	0.511	2.978	3.35	6.48	28.35

Table 9.52: Global Networks – Average Access Link Utilization (%) for 400B, IM_ATM and Experimental IM_ATM Message

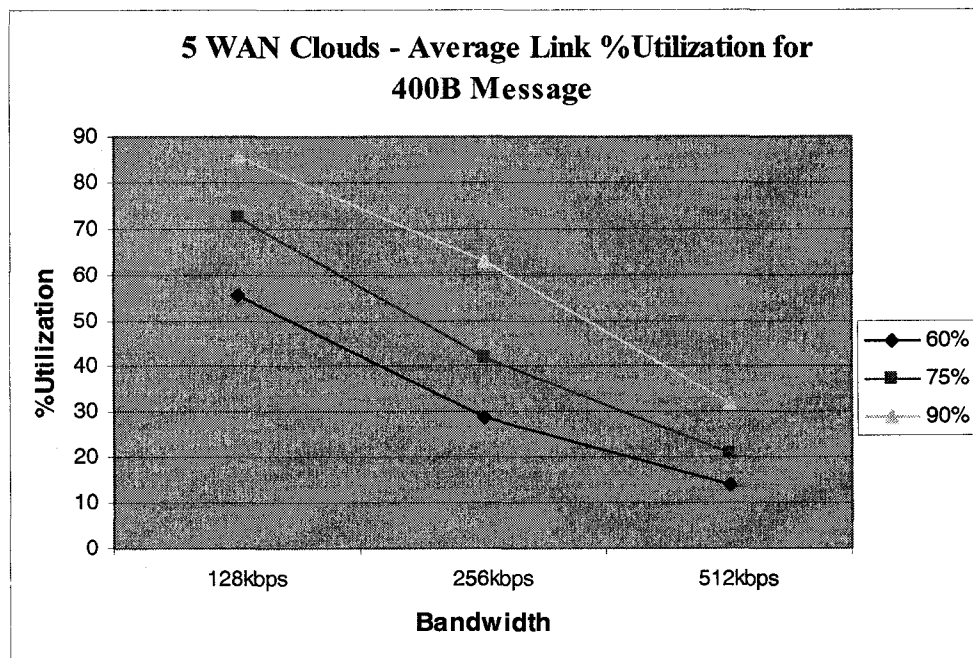


Figure 9.109: Global Networks – Average Access Link Utilization (%) for 400B Message

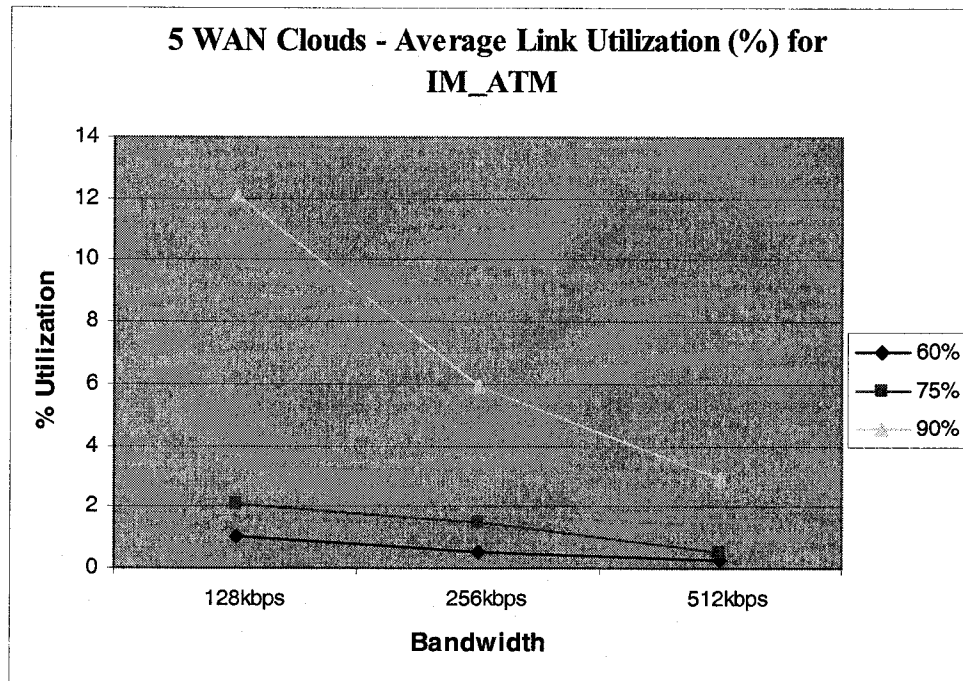


Figure 9.110: Global Networks – Average Access Link Utilization (%) for IM_ATM Message

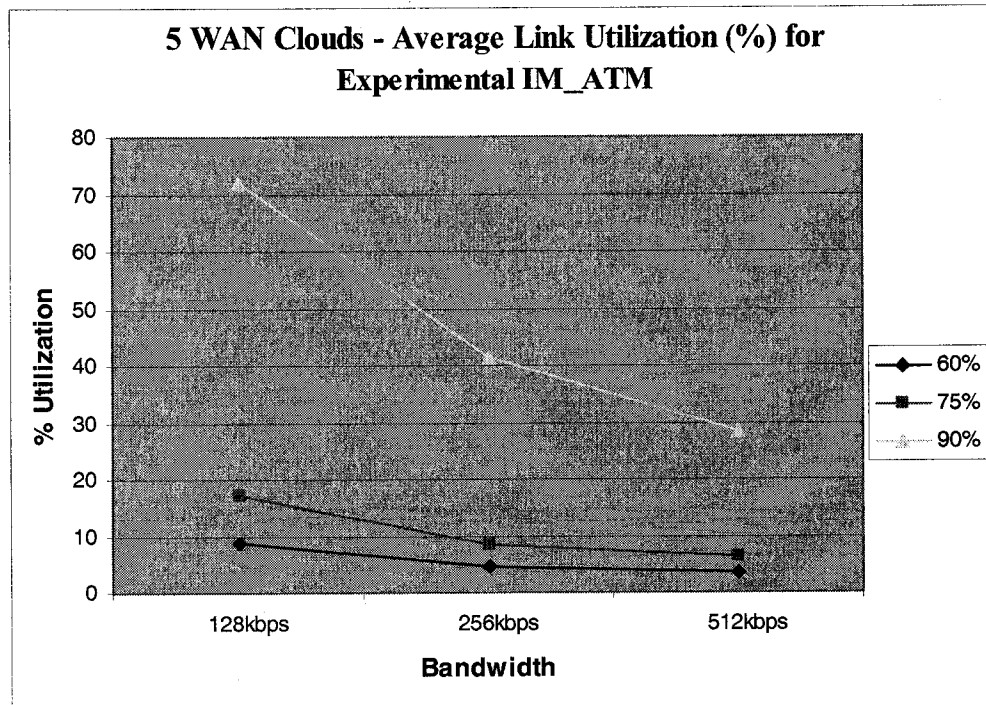


Figure 9.111: Global Networks – Average Access Link Utilization (%) for Experimental IM_ATM Message

Chapter 10

10. SIMULATION AND SIMULATION RESULTS

In this study, I designed and created five different networks, namely: 5-Node Regional Networks, 9-Node Regional Networks, Single WAN Cloud, Three Wan Clouds (two-level), and Five WAN clouds (three-level). Two sets of experiments were examined and analyzed with simulation runs for the above networks; in the first set, same IATs (Inter Arrival Time) were used for 128kbps, 256kbps, and 512kbps, three bandwidth capacities: 60%, 75%, and 90% and different message sizes (100B, 200B, 400B, and 800B for traditional, 46B for the IM_ATM, and Experimental IM_ATM networks are used for observation of the above bandwidths, in the second set, the IATs were adjusted according to the bandwidths. Because of the huge volume of data from simulation runs, only some of the simulation results were chosen for presentations.

For each of the five networks, the results of the simulations were presented, discussed, and analyzed for each of the following:

- (1) Traditional Frame Relay Networks
- (2) IM_ATM Networks

(3) Experimental IM_ATM networks

For ease of analysis and cross comparison, spread sheets and graphs were prepared for all the statistics: (1) Received Message Counts; (2) Frames Delivered; (3) Frames Dropped; (4) Packets Created, Delivered, and Dropped; (5) Packet Delay (Number of Packet Created, Delivered, and Dropped); (6) Packet Delay (MS) (Milliseconds); (7) Percentage of Channel Utilization (%); and (8) Percentage of Access Link Stats Utilization (%) for all the networks.

The simulation statistics of Packets Created, Packets Delivered, Packets Dropped, Ratio of Packets Dropped/Packets Created and Ratio of Packets Dropped/Packets Delivered, and Packet Delay (MS) were calculated for comparison of transmission delays between different bandwidths of all the traditional networks. Since there are no dropped cells, only Message Delay (MS) were calculated for the IM_ATM and Experimental IM_ATM networks. The average percentage for utilization were used to compare how much the networks can sustain the traffic volume. The ratio from 128kbps to 256kbps and the ratio from 256kbps to 512kbps were also compared within all bandwidths of the five networks. These measures showed the efficiency between different bandwidths.

The analysis of the simulation results led to the following overall conclusions:

1. Message and Response Sources – Packets Created, Packets Delivered and Packets Dropped

It is found that the drop rate for all the traditional networks is decreased, when the bandwidths increased, more packets passed and less errors resulted. As traffic intensifies, the drop rate increases and there will be more packets lost and an increase in error rate. The network's performance subsequently degraded.

However, there are no dropped cells for any of the IM_ATM or Experimental IM_ATM networks – all cells created are delivered to their destinations successfully.

2. Message and Response Sources – Dropped/Created and Dropped/Delivered ratio

All networks follow the same pattern as stated in (1).

3. Message and Response Sources – Average Packet Delay (MS)

The differences of Average Packet Delay from 128kbps to 256kbps and from 256kbps to 512kbps are calculated and used to compare all bandwidths used for simulations. In general, the average number of packet delays decreases when the bandwidth increases, but increases when the traffic intensifies. Overall, the traditional networks show significant increase in Packet Delay when the networks are saturated. But

for Packet Switching Networks, Packet Delay (MS) is not the most optimal approach to evaluate the network performance.

4. Average Percentage of Utilization – Channel Link/Access Link Stats Utilization

With the traditional networks, the average percentage of channel/access link utilization is about 56%, 73% and 86% when running the traffic capacities of 60%, 75%, and 90% for 128kbps bandwidth respectively; the percentage of utilization increases as the traffic intensity increases.

The difference of average utilization percentage from 128kbps to 256kbps and from 256kbps to 512kbps decrease as the bandwidth increase. The average utilization percentage of IM_ATM or Experimental IM_ATM networks only run a fraction of that of the traditional ones. These measures can reflect the network's QoS (Quality of Services), when a network has minimal usage, there are a lot more of functions can be added to it. The statistics collected show that even the most remotely possible functions can also be implemented.

5. Ratio of Packets Dropped and Packets Delivered

The Ratio of Packets Dropped and Packets Delivered also increase with the average link utilization (%). This is especially the case, when the capacity reaches 90%, the networks become saturated, more than half of the packets are dropped, and this is true

with all the traditional networks. The percentage of access link utilization follows the same pattern.

6. **IM_ATM** medical networks have been proven to be able to perform much more functions, to provide support for the transmission of medical information, to serve multiple demands and expand value to patients, to health care industry and other scientific fields. This is especially a big help for the developing countries, since the bandwidths are so scarce there.
7. **IM_ATM** networks utilize optical fiber as transmission medium, which provides support for high-speed, high-capacity broadband networks. Since there are no cells dropped for all IM-ATM networks, they have been proven to be more valuable to all network designs – local, regional, national, and global.
8. **ATM** is now experiencing more success. Many health care industries have adopted ATM for their backbone. The market projection for deployment of ATM to support WAN and MAN backbones is even larger.
9. **The Health Care Delivery System** continues to increase in both volume and complexity. Recent statistics show that it accounts for more than fifteen percent of gross domestic product of the United States. It is expected that it would increase substantially.

Appendix A

A1. NETWORK ANALYSIS and QUEUING THEORY

- **Network Analysis**

The network analysis involves two types of variables: dynamic and static. The dynamic variables, such as traffic characteristics, are expressed in terms of statistical probabilities and probability distribution functions. For traffic attributes, which are a time dependent component of the analysis, we rely upon queuing theory concepts so that we may perform an efficient analysis of the effect of different traffic patterns on a network. The static variables, such as characteristics of nodes and links, account for the major components of the network and must be enumerated for proper analysis. The queuing theory plays a crucial role in the analysis of networks regardless of the switching method. It enables us to identify probability distributions for events under varying conditions.

In a telecommunication network, the number and the size of messages arriving at a node may vary with time resulting in different probability distributions at different times. This type of statistical behavior is called a stochastic process. A type of stochastic

process that is especially useful when modeling networks is the Poisson process. We have an approximate Poisson process with parameter $\lambda > 0$ if the following are satisfied:

- The numbers of change occurring in non-overlapping intervals are independent.
- The probability of exactly one change in a sufficiently short interval of length h is approximately λh .
- The probability of two or more changes in a sufficiently short interval is essentially zero.

The above definition implies that the Poisson process has the Markov property, which is sometimes called the memory-less property. That is to say that the probability that an event takes place does not depend on the events that have already taken place. Instead this probability depends on the time interval between the two events. Consequently, if a process is a Poisson process with rate λ , then it has a Poisson distribution which has the probability of x events (arrivals) taking place in any time interval of length $t > 0$ as the Poisson p.d.f. (probability density function) with the mean and variance each equal to λ .

$$f(x) = e^{-\lambda t} (\lambda t)^x / x!, \quad x = 0, 1, 2, \dots$$

The random variables associated with a Poisson distribution are discrete random variables. For modeling and analysis of mathematical models it more helpful to work with continuous random variables. Fortunately, if we consider the time between two consecutive arrivals (inter-arrival time, IAT) rather than number of arrivals within a time

interval, we find that it has continuous random variables with a negative exponential distribution. This distribution has the probability function where $x > 0$ is the waiting time between two arrivals, with the mean equal to $1/\lambda$ and variance equal to $1/\lambda^2$. The exponential function also preserves the Markov property that is to say that the distribution of the wait time does not depend on the amount of time that has already passed.

$$\lambda e^{-\lambda x}$$

Where $x > 0$ is the waiting time between two arrivals, with the mean equal to $1/\lambda$ and variance equal to $1/\lambda^2$. The exponential function also preserves the Markov property that is to say that the distribution of the wait time does not depend on the amount of time that has already passed.

The Markov property of the Poisson process is very useful when modeling arrivals to a queue at a node. The arriving messages may come from many different nodes, therefore are independent of each other. Hence the number of arrivals within a time interval is independent of other arrivals, depending only on the length of the time interval.

As with all statistical models, it must be pointed out that the empirical data obtained from observations may not exactly follow the Poisson process. However, the nice mathematical properties of the Poisson process enable one to build and analyze a

queuing system model easily. Fortunately, the assumption of a Poisson process can be justified on the grounds other than those of analytical convenience. The Poisson distribution, like the normal distribution, turns up as the limiting distribution of large sums.

There is increasing dependence on computing and communication networks in the day-to-day operation of all types of organizations. As these networks become larger and more complex the design and management of the system becomes an ever more challenging task. New applications of communication and computing networks are constantly being explored. How to organization decide which combinations of technology and applications are right for them as needs grow, the investment and operating costs increase. As the organization places more dependence on its network to support its critical business operations, the risk of failure caused by poor network performance or availability may have serious problems.

- **Queuing Theory**

Before a network is designed and modeled, predetermined performance criteria such as throughput, delay times, and cost must be evaluated in order to ensure the proper function of the network. The evaluation may be conducted on two levels: the network level and nodal level. The network level of the evaluation entails studying the general characteristics of the network; nodes and connected links. The node level focuses on the attributes of a single node and its related characteristics. The network level involves two types of variables: static and dynamic. The dynamic level, such as traffic characteristics are expressed in terms of statistical probabilities and probability distribution functions. Queuing theory concepts are used for analysis the traffic patterns, since they are time dependent component of the analysis. The static variables, such as characteristics of nodes and links, must be enumerated for proper analysis.

A queue is a waiting line in which the incoming data units wait for service. The size of queue may be either finite or infinite. The service discipline determines the order in which these units may be serviced. FIFO (First in first out) and priority are most commonly used service discipline schemes utilized when modeling network traffic activity. The servers are those units within the queuing system which process the information. There may be one or more servers working in parallel. Each server completes the service of a unit before starting to serve the next. The time each server spent on service is called service time. The input source has two characteristics: population size and distribution function. The population size refers to the number of information units (frame, packet, or cell) that may be needed at any time for the service. This number may be finite or infinite. The distribution function defines the way the information units arrive at the queuing system.

Queuing theory, is the theory of congestion, is the branch of operations research which explores the relationships between demand on a service system and the delays suffered by the users of that system. The term queuing systems here refer to a generic model which comprises three elements: a user source, a queue, and a service facility that contains one or more identical servers in parallel. Thus, each user of a queuing system is generated by a user source, passes through the queue where the user may remain for a nonnegative period of time (including possibly zero time), and then is processed by a single server-because of the parallel arrangement of servers. Once a user has left any one of the servers in the system, after obtaining service there, the user is considered to have left the queuing system as well.

In view of the description given above, a queuing network can now be defined as a set of interconnected queuing systems. Thus, in a queuing network, the user sources for some of the queuing systems in the network may be other queuing systems in the same network. It can also be inferred that the analysis of models of queuing systems, as we have defined them here, provides the building blocks for the analysis of queuing networks.

Simulation is a powerful tool which can be used to analyze many complex problems. However, before simulation is chosen as the solution method, every effort should be made to solve the problem mathematically, especially, the models developed for queuing problems.

To describe queuing system information must be supplied for the system:

- About the user generating process (i.e., the arrival process of users at the system).
- About the queue discipline [i.e., the order in which users obtain access to the service facility, once (and if) they join the queue].
- About the service process.
- Standard queuing theory terminology and notation:
 - State of system = number of messages in a queuing system
 - Queue Length = number of messages waiting for service to begin
or state of system minus number of messages being served

- $N(t)$ = number of messages in queuing system at time t ($t \geq 0$).
- $P_n(t)$ = Probability of exactly n messages in queuing system at time t , given number at time 0.
- S = number of services (parallel tasks) in queuing system
- λ = mean arrival rate (expected number of arrivals per unit time) of new messages when n messages are in system.
- μ_n = mean service rate for system (expected number of messages completing service per unit time) when n messages are in the system.

The following are the assumptions:

$\lambda_n = \lambda \forall n$, is the mean arrive rate is independent on a number of messages being in system, also because λ_n is the mean arrival rate while the system in state n ($n=0, 1, 2, \dots$) and P_n is the proportion of time when the system is in state n , then

$$\lambda = \sum_{n=0}^{\infty} \lambda_n P_n$$

$\mu_n = \mu \forall n \geq 1$ and $s = 1$, mean service rate is a constant per only busy server.

$\mu_n = s\mu \forall n \geq s$, mean service rate is a constant when all s servers are busy.

Then the following is true:

$1/\lambda$ = expected inter-arrival time.

$1/\mu$ = expected service time.

$\rho = \lambda / (s\mu)$ = utilization factor for the service facility, i.e. the fraction of the system's service capacity ($s\mu$) that is being utilized on the average by arriving messages (λ).

If $\rho > 1$, the state of the system will grow and can lead to the system outage over time (during bursts of traffic). This situation has to be monitored.

When system begins operation the state of the system depends on initial state and elapsed time. The system is said to be in steady-state condition when it becomes essentially independent of the initial state and the elapsed time. The probability distribution of the state of the system remains the same over time. The following notation is used for the system in steady-state condition:

P_n = probability of exactly n messages in queuing system.

L = expected number of messages in queuing system, $L = \sum_{n=0}^{\infty} nP_n$

L_q = expected queue length, $L_q = \sum_{n=0}^{\infty} (n - s) P_n$

W = waiting time in system for each individual message.

W_q = waiting time in queue for each individual message.

The following have been proven [34]:

$L = \lambda W$, $L_q = \lambda W_q$, $W = W_q + 1/\mu$. This relationship was used for the study.

Note that the system can reach the steady-state condition only and only if

$$\rho = \lambda / (s\mu) < 1.$$

The so-called birth-and-death process is an important process in the queuing theory; it is a special type of continuous time Markov Chain.

A stochastic process is an indexed collection of random variable $\{X_t\}$, where the index t runs through a given set T . Stochastic process describes behavior of a system operating over some period of time T . The random system is observed at particular points of time, say $t = 0, 1, 2, \dots$. Thus the stochastic process $\{X_t\} = \{X_0, X_1, X_2, \dots\}$ provide a mathematical representation of how the status of the physical system evolves over time. Time can be discrete or continuous.

A continuous time stochastic process $\{X(t'); t' \geq 0\}$ is a continuous time Markov chain if it has the Markovian property which in turn can be defined as follows:

$$P\{X(t+s) = j | X(s) = i \text{ and } X(r) = x(r)\} = P\{X(t+s) = j | X(s) = i\},$$

$$\forall i, j = 0, 1, \dots, M \text{ and } \forall r \geq 0, s > r, \text{ and } t > 0, \text{ where}$$

$t' = r$ is the past time

$t' = s$ is the current time

$t' = s+t$ is time units into the future

$P\{X(t+s) = j | X(s) = i \text{ and } X(r) = x(r)\}$ is a transition probability. We will consider only stationary transition probabilities which are independent of s , such that

$$P\{X(t+s) = j | X(s) = i\} = P\{X(t) = j | X(0) = i\} \quad \forall s > 0. \text{ Another notation:}$$

$p_{ij}(t) = P\{X(t) = j | X(0) = i\}$ where $p_{ij}(t)$ is continuous time transition probability

function and $\lim_{t \rightarrow 0} p_{ij}(t) = 1$ if $i=j$, $\lim_{t \rightarrow 0} p_{ij}(t) = 0$ if $i \neq j$.

The most important probability distribution in queuing theory is the exponential distribution that can be expressed as follows:

$f_T(t) = \alpha e^{-\alpha t} \quad \forall t \geq 0$ and $f_T(t) = 0$ for $t < 0$ where T is inter-arrival or service (event) time with parameter α . This function is strictly decreasing $\forall t \geq 0$. Let $X(t)$ be the number of events by time t ($t \geq 0$). Then $X(t)$ has a Poisson distribution if

$$P\{X(t) = n\} = \frac{(\alpha t)^n e^{-\alpha t}}{n!}, \text{ for } n = 0, 1, 2, \dots$$

For $n = 0$ $P\{X(t) = 0\} = e^{-\alpha t}$ which is the probability that the first event occurs after time t .

The mean of this Poisson distribution is $E\{X(t)\} = \alpha t$, so that the expected number of events per unit time is α . In other words, α is the mean rate at which the events (arrival or service) occur. The event counting process on a continuing basis is called a Poisson process with parameter α . In application to arrivals with mean arrival rate $\alpha = \lambda$ it is called Poisson input process with parameter λ . The queuing model in this case has a Poisson input.

Balance equation expresses a key principle in queuing theory:

$$\text{Rate In} = \text{Rate Out}$$

In other word, for any state of the system n ($n = 0, 1, 2, \dots$) mean entering (arrival) rate = mean leaving (service) rate.

The assumptions for the birth-and-death model are the following:

The arrival (birth) probability distribution is Poisson input with parameter λ_n .

The service completion (death) probability distribution is Poisson exponential distribution with parameter μ_n .

$$\mu_1 P_1 = \lambda_0 P_0, \dots, = \lambda_{n-1} P_{n-1} + \mu_{n+1} P_{n+1} = (\lambda_n + \mu_n) P_n \text{ for } n = 0, 1, 2, \dots$$

Let define $C_n = 1$ for $n = 0$ and denote $\text{define } C_n = \frac{\lambda_{n-1} \lambda_{n-2} \dots \lambda_0}{\mu_n \mu_{n-1} \dots \mu_1}$, for

$n = 1, 2, \dots$ Then the steady-state probabilities are: $P_n = C_n P_0$, for $n = 0, 1, 2, \dots$

$$\text{Given } \sum_{n=0}^{\infty} P_n = 1 \Rightarrow \left(\sum_{n=0}^{\infty} C_n \right) P_0 = 1 \Rightarrow P_0 = \left(\sum_{n=0}^{\infty} C_n \right)^{-1}.$$

The performance of a queuing system is measured by the following key parameters: L, L_q, W, W_q . It can be obtained after calculating P_n .

Overall formulas based on balance equation and birth-and-death process are presented in the following:

$P_n(t)$ = Probability of exactly n messages in queuing system at time t , given number at time 0.

s = number of services (parallel tasks) in queuing system.

λ_n = mean arrival rate (expected number of arrivals per unit time) of new messages when n messages are in system.

μ_n = mean service rate for system (expected number of messages completing service per unit time) when n messages are in the system.

$\lambda_n = \lambda \forall n$, is the mean arrive rate is independent on a number of messages being in system.

Results of the Exponential Queuing Model [34] are presented below:

$\mu_n = s\mu \quad \forall n \geq s$, mean service rate is a constant when all s servers are busy.

$1/\lambda$ = expected inter-arrival time.

$1/\mu$ = expected service time.

$\rho = \lambda / (s\mu)$ = utilization factor for the service facility, i.e. the fraction of the system's service capacity ($s\mu$) that is being utilized on the average by arriving messages (λ).

L = expected number of messages in queuing system.

L_q = expected queue length (excludes messages being served).

W = waiting time in system (includes service time) for each individual message.

W_q = waiting time in queue (excludes service time) for each individual message.

$$C_n = 1 \text{ for } n = 0 \text{ and } C_n = \frac{\lambda_{n-1} \lambda_{n-2} \dots \lambda_0}{\mu_n \mu_{n-1} \dots \mu_1}, \text{ for } n = 1, 2, \dots$$

$$P_n = C_n P_0, \text{ for } n = 0, 1, 2, \dots \quad P_0 = \left(\sum_{n=0}^{\infty} C_n \right)^{-1}$$

$$\rho = \lambda / (s\mu) < 1 \quad \lambda = \sum_{n=0}^{\infty} \lambda_n P_n$$

$$L = \sum_{n=0}^{\infty} n P_n \quad L_q = \sum_{n=1}^{\infty} (n-s) P_n$$

$$W = L/\lambda$$

$$W_q = L_q/\lambda$$

The most typical and widely used model in queuing theory is **M/M/s**, i.e. inter-arrival times are independently and identically distributed according to Poisson input, service times are independently and identically distributed according to another exponential distribution, and the number of servers is s . The result for single and multiple servers can be found in [34] and presented in the following:

For **M/M/s** Queuing Model:

$$\begin{aligned}
 &L = \frac{\lambda}{\mu - \lambda}, Lq = \frac{\lambda^2}{\mu(\mu - \lambda)}, W = \frac{1}{\mu - \lambda}, Wq = \frac{\lambda}{\mu(\mu - \lambda)} \text{ for } s = 1 \\
 &L = Lq + \frac{\lambda}{\mu}, Lq + \frac{P_0(\lambda/\mu)^s \rho}{s!(1 - \rho)^2}, W = Wq + \frac{1}{\mu}, Wq = \frac{Lq}{\lambda} \text{ for } s > 1
 \end{aligned}$$

The exponential distribution is not applicable when inter-arrival or service times are scheduled or regulated. Some results are available for queuing models involving non-exponential distributions.

Queuing model is used to determine most efficient way to operate a queuing system. Excessive service capacity is costly. Lack of service capacity would result in excessive waiting backlogs, and missing SLAs (Service Level Agreements). Finding an appropriate feasible balance between the service capacity (hardware platform, number of CPUs, etc.) and waiting time is a challenge. The result of non-exponential queuing model [34] is shown below:

For **M/G/1** Queuing Model with Poisson input and independent service times with the same $1/\mu$ mean probability distribution and variance σ^2 :

$$P_0 = 1 - \rho, \quad L = \rho + L_q, \quad L_q = \frac{\lambda^2 \sigma^2 + \rho^2}{2(1 - \rho)}, \quad W = W_q + \frac{1}{\mu}, \quad W_q = \frac{L_q}{\lambda}.$$

For **M/D/1** Queuing Model with degenerate (constant) service times where

$$\sigma^2 = 0, \quad L_q = \frac{\rho^2}{2(1 - \rho)}.$$

For **M/E_k/1** Queuing Model the Erlang service time distribution is as follows:

$$f(t) = \frac{(\mu k)^k}{(k-1)!} t^{k-1} e^{-k\mu t}, \quad \text{for } t \geq 0, \mu > 0, k = 1, 2, \dots - \text{shape parameter.}$$

Mean service rate is μ , variance $\sigma^2 = 1 / (k\mu^2)$.

$$L = \lambda W, \quad L_q = \frac{1+k}{2k} \frac{\lambda^2}{\mu(\mu - \lambda)}, \quad W = W_q + \frac{1}{\mu}, \quad W_q = \frac{1+k}{2k} \frac{\lambda}{\mu(\mu - \lambda)}.$$

To describe queuing network, information must be provided on how the queuing systems are interconnected, how they interact, and how users are assigned to the queuing systems. It should be obvious that there exist countless variations of queuing systems and networks.

Glossary

#

1ESS, 1A ESS, 2B ESS, 3ESS, 4ESS, 5ESS	precursor ESS systems introduced
2BIQ	two binary to one quaternary code for BRISDN
4ESS	Number 4 electronic switching systems for toll and trunk switching
5ESS	a generalized electronic switching system for most types of CS, PS, ISDN, subscriber loop carrier and trunk switching
5ESS 2000	modern platform and concept to contend with wireless, intelligent network functions and almost all of the routine 5ESS functions

A

AAL	ATM adaptation layer
ABR	Available bit rate
ABS	alternate billing service
ACP	action control point
ADPCM	adaptive delta pulse code modulation
AII	Active Input Interface
AIN	Advanced Intelligent Network
AIS	Alarm Indication Signal
AL	application layer
A-law, μ-law	Two different systems used to encode voice or audio signals which involve compression of the sampled signal according to a fixed formula.
ANSI	American National Standards Institute
AOI	Active Output Interface

AP	adjunct processors
APS	automatic protection switch
ARPANET	Advanced Research Project Agency Network
ASN	adjunct service node
ASP	adjunct service point
AT&T	American Telephone and Telegraph
ATE	ATM Terminating Equipment
ATM	asynchronous transfer mode
AWC	area wide centrex
AWC	American wire gauge

B

B Channel	A 64-kbps information bearing channel in ISDN
B1 Channel	the number one B channel of BRISDN service that is used to carry 64 kbps PCM voice data for telephone service
B2 Channel	the number two B channel of BRISDN service that can be used to carry packet-switched data
BER	bit error rate
BIP	bit interleaved parity
BIS	Border Intermediate System
BISDN	broadband integrated services digital network
BRISDN	basic rate integrated services digital network
BSS	Broadband Switching System
BX.25	a specialized Bellcore protocol to communicate service management information and provides an interface for maintenance, security, and operations of the SCP

C

CA&O	centralized administration and coordination
CATV	cable television
CBR	Constant Bit Rate
CCAF	call control access function
CCF	call control function
CCIS	Common Channel Interoffice Signaling
CCIS6	Common Channel Interoffice Signaling 6
CCISS	Common Channel Interoffice Signaling System
CCISS6	Common Channel Interoffice Signaling System 6
CCISS7	Common Channel Interoffice Signaling System 7
CCITT	International Telegraph and Telephone Consultative Committee, now called ITU-T
CCS7	Common Channel Signaling 7
CCSS7	Common Channel Signaling System 7
CDV	Cell Delay Variation
CDVT	Cell Delay Variation Time
CEI	Connection Endpoint Identifier
CES	Circuit Emulation Service
Centrex	a widespread telephone-company switching service that uses Central Office switching equipment and to which customers connect via individual extension access lines
CF	control function
Channel	A transmission path between two points

Channel Bank	Channel terminal equipment used for combining (multiplexing) channels on a frequency-division or time-division basis
CIR	Committed Information Rate
Circuit-mode	Type of switching that causes a one-to-one correspondence between a call and a circuit
CLASS	customized local area special services
CLP	cell loss priority
CLR	cell loss ratio
CMISE	common management information service element
CNR	Complex Node Representation (ATM Forum, PNNI SWG)
CO	Central Office; a telephone company switching facility or center, at which a diversity of transmission channels, including subscribers' local loops terminate
CPCS	Common Part Convergence Sublayer
CPE	customer premises equipment
CPI	Common Part Indicator
CPU	central processing unit
CRS	Cell Relay Service
CS	Convergence Sublayer
CSMA/CA	carrier sense multiple access/collision avoidance
CSMA/CD	carrier sense multiple access/collision detect
CTD	cell transfer delay
CT	computed tomography
CU	computer unit

D

D-channel	delta channel; in ISDN a 16 kbps (BRISDN) signaling channel for basic rate access, or a 64 kbps (PRISDN) signaling channel with other access rates
DAP	data access point
DCP	database control point
DCs	developing countries
DCT	Discrete Cosine Transform. A mathematical process that converts a set of values into an equivalent representation as the sum of cosine functions.
DDSN	Digital Derived Services Network; the British Telecom IN
DLL	data link layer
DPCM	differential pulse code modulation
DQDB	distributed queue dual bus (IEEE 802.6).
DS1	Digital Signal 1, a formatted signal transmitted at 1.544 Mbps, usually referred to as T1 signal
DS2	Digital Signal 2, a formatted signal transmitted at 6.312 Mbps, usually referred to as T2 signal
DS3	standard third level digital carrier system used in the North America at 44.736 Mbps; also known as T3 signal
DS4	fourth level digital carrier system used in the North America at 274.176 Mbps; also known as T4 signal (Japanese equivalency at 397.2 Mbps)
DSP	digital signal processing
DSX	Digital Signal Cross-Connect
DTE	data terminal equipment
DTV	Digital TV

DXI Data Exchange Interface

E

EI	European transmission link with 2.048 Mbps of bandwidth capacity
ELAN	Emulated LAN (ATM Forum LANE)
EO	End office; the lowest level central office before distribution to customers or remote terminals
ESS	Electronic Switching System

F

FC	functional component, in IN/1+ and IN/2 environments
FDDI	Fiber Distributed Data Interface
FDM	frequency-division multiplexing
FDMA	frequency division multiple access
FEBE	Far End Block Error (SONET)
FECN	Forward Explicit Congestion Notification
Frame	In JPEG, a group of one or more scans. For the JPEG modes in common use a frame is indistinguishable from an image.

G

Gbps	gigabits per second
GFC	generic flow control
GHz	gigahertz
GNS	Green Number Service; in Europe, the so-called "Freephone" service provided by a typical IN/1
Group 3	This apparatus uses a digitized binary representation of the facsimile. Because it is a digital scheme, it can and does use data compression and is capable of transmitting an A4-size (210 x 297 mm) document in about a minute. The apparatus is standardized in recommendation T.4.
Group 4	This apparatus has the same speed requirement as Group 3. The apparatus is standardized in recommendation T.6, T.503, T.521, and T.563.

H

HO-channel	in ISDN, a 384-kbps user-to-user information transfer
HI-channel	in ISDN, a 1.536 Mbps user-to-user information
HDTV	high definition TV
HEC	header error check
HF	high frequency

I

IAT	Interarrival time- the time from the start of one message to the start of the next message
IDN	integrated digital network
IEC	International Electrotechnical Commission
IN	Intelligent Network

IN/1	The initial Bellcore release of the intelligent network
IN/I+	The evolution of the IN/ 1 architecture and some IN/1 elements.
IN/2	The final architecture of an intelligent network.
INAP	Intelligent network access point
INCM	intelligent networks conceptual model
IP	intelligent peripheral
ISDN	integrated services digital network
ISMS	Integrated services management systems
ISO	International Organization for Standardization
ITU-T	International Telecommunications Union /Telecommunications Standardization Sector; formerly known as CCITT.

K

KBPS	kilobits per second (1000 bits/second)

L

LAN	local area network. A type of high-speed (typically in the Mbps range) data communication arrangement, covering a limited geographical area, in which all parts of the transmission medium are under the control of a network administrator.
LANE	LAN emulation (ATM Forum)
LAPD	link access procedure for the D channel
LCD	loss of cell delineation
LEC	local exchange carrier
LF	low frequency
LIDB	line information database

M

MAN	metropolitan area network
MAS	memory administration system
MB	Megabyte
Mbps	Megabits per second (1,000,000 bits/second)
MBS	maximum burst size
MCR	minimum cell rate
MF	multifrequency
MFOS	multifunction operating system
MHz	megahertz
MUX	Multiplexer

N

NA	North America
NAP	network access point
NCP	network control point
NCS	network control system
NIDB	network information database
NL	network layer
NM	node manager
NNI	network-to-network interface.
No. 1 ESSTM	The number one ESS switching System.
NRM	network resource manager
NSCX	network service complex

NSP	network services control point corresponding to a SCP
NSSP	network services support point
NTT	Nippon Telephone and Telegraph
NTSC	National Television Standards Committee; the NTSC signal is the de facto standard governing the format of television transmission signals.

O

OC	optical carrier
OC-n	optical carrier nth level of multiplex
OSI	open system interconnection
OSI-RM	open system interconnection- reference model

P

PABX	private automatic branch exchange
PAL	phase alternating line
PBX	private branch exchange
PCM	pulse code modulation
PL	physical layer
PLT	payload type
PMS	physical medium sublayer
PNG	portable network group
PNSS	private network signaling system
POTS	plain old telephone service
PPS	packets per second
PPV	pay per view (with cable television)

PRISDN	primary rate ISDN
PRL	presentation layer
PSE	packet switching exchange
PSN	public/public switched network
PSTN	public switched telephone network
PTI	payload type identifier
PVC	permanent virtual circuit
PVN	private virtual networks

Q

Q.922	A standard Series of protocol definitions published by CCITT (now ITU-T).
Q.931	A standard Series of protocol definitions published by CCITT (now ITU-T).
QoS	quality of service

R

RABMN	remote area business message network
RAM	random access memory
RBOC	Regional Bell Operating Companies
RF	radio frequency

S

SA	service administration
SAR	segmentation and reassembly
SCE	service creation environment

SCF	service control function
SCL	service control logic
SCP	service control point
SDF	service data function
SL	session layer
SLI	service logic interpreter
SLP	service logic program
SM	switching module
SMAF	service management access function
SMDS	switched multimegabit data service
SMF	service management function
SMS	service management system
SMS/2	service management system/2
SNA	Systems Network Architecture (from IBM).
SONET	synchronous optical network
SPC	stored program control
SPE	synchronous payload envelop
SRF	specialized resource function
SS	switching system
SS7	Signaling System 7
SSF	service switching function
SSP	service switching point
SSP/2	service switching point/2

STE	Section Terminating Equipment (SONET)
STM	synchronous transport module level
STP	signaling transfer point
STS	synchronous transport signal/system
STS	synchronous transport signal
SU	signaling unit
T	
T1	A digital carrier facility used to transmit a DS-1 formatted digital signal at 1.544 Mbps, also called T1 carrier system.
TC	transmission convergence
TDM	time division multiplexing
Throughput	X.25 concept indicating the average information rate of a particular virtual circuit
TL	transport layer
U	
UCI	universal customer interface
UFD	A type of peripheral concentrator used with AFDs in the RFD
UHF	ultra high frequency
UISN	universal information service network
UNI	user network interface
V	
VBR	variable bit rate

VC	virtual circuit
VCI	virtual channel identifier
VFN	vendor feature node
VP	virtual path
VCL	virtual channel link (UNI 3.0)
VPI	virtual path interface
VPL	virtual path link (UNI 3.0)
VPN	virtual private network
VPT	virtual path terminator (UNI 3.0)
VSAT	very small aperture terminal

W

WAN	wide area network

X

X.21	Interface between data terminal equipment (DTE) and data circuit-terminating equipment (DCE) for synchronous operation on public circuit-switched networks.
X.25	A CCITT (now ITU-T) recommendation that specifies the interface between user data terminal equipment (DTE) and packet-switching data circuit-terminating equipment (DCE).
X.28	DTE/DCE interface for start-stop mode data terminal equipment accessing the packet assembly/disassembly facility (PAD) in a public data network situated in the same country.
X.29	Procedures for the exchange of control information and user data between a packet assembly/disassembly facility (PAD) and a packet-mode DET or another PAD.

X.75

Terminal and Transit call-control procedure and data transfer mechanisms on (typically) international circuits between packet-switched data networks.

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