# Dublin City University 

School of Electronic Engineering

# SIMULATION OF ATM MULTIPLEXER FOR 

## BURSTY SOURCES

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To my wife Shumin Peng and my family.

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## DECLARATION

I hereby declare that this dissertation is entirely of my own work and has not been submitted as an exercise to any other university.


Chen conger


#### Abstract

Asynchronous transfer mode ( ATM ) is a promising multiplexing and switching technique for implementing an integrated access as well as transport network and has been adopted by CCITT as a basis for the future broadband integrated services digital network ( BISDN ) The ATM technique allows digital communication of any type to share common transmission links and switching devices on a statistical multiplexing basis Information is transmıtted in the form of constant length cells In an ATM network, the major parameters to cause ATM network performance deterioration are the cell loss and the cell delay at the buffer queue in the ATM multiplexer Therefore, the performance parameters of an ATM multiplexer are specifically focused on the cell loss probabılity, the cell delay, and the distribution of queueing length at buffer in this study

The performance of an ATM multiplexer is studied, whose input consists of the superposition of homogeneous bursty ( ON/OFF ) sources, 1 e , all the superposed sources are characterızed by the bursty sources of the same parameter values The cell loss probability and the distribution of queuing length at buffer under different offered load and buffer size condıtions are evaluated

An ATM multiplexer with three priority classes is simulated using the priority assignment control method of [15] Under the priority assignment period $P$ and the priority assignment ratio $W_{n}$ in this method have been defined, the relationship between the traffic balance of classes and buffer size of each is studied The cell loss probabilıty and delay time of each class ( same sources and different sources between classes, are evaluated The results are useful to design a economic and effective ATM multiplexer


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## Chapter 1 Introduction


#### Abstract

The emergence of fibre optics technologies has promoted the rapid development of digital communication systems[1,2] Since about 1985, worldwıde actıvıtıes to evolve Integrated Services Digital Network (ISDN) into an Optıcal-fıbre-based universal Broadband ISDN (BISDN) have resulted in the first baseline standard documents, such as CCITT ${ }^{1}$ Recommendation $I$ 121[3] The introduction of BISDN has stimulated the emergence of a wide variety of new services Certain services have been presented in $\mathrm{Tl}^{2 \prime} \mathrm{~s}$ BISDN Baseline Document[4] and CCITT I 221 BISDN recommendations [5,6] These include


- Broadband video telephony
- Broadband video conference
- Vıdeo surveıllance
- Hıgh-volume file transfer

■ High-speed telefax

- Vıdeo maıl
- Broadband videotext

■ High definition television distribution
${ }^{1}$ CCITT $\quad$ The International Telegraph and

2 The $T 1$ committee is sponsored by the Exchange Carriers Standards Association (ECSA) and accredited by the American National Standards Institute (ANSI)

- Vıdeo retrieval

■ Hıgh-speed unrestrıcted dıgital information transmission etc

The above set is not exhaustive and there could be other BISDN services which will be popular in the BISDN era From the point of view of the source characteristics, these sources can be multi-media ( volce, data, and video ), multı-point ( broadcast, point-to-point, and multı-party ), and multı-rate ( from a few kb/s to several hundreds $\mathrm{mb} / \mathrm{s}$ ). From the point of view of the traffic-flow characterıstıcs, besıdes a broad range of bit rates from different sources, each source may have a time varying bit rate requirement over the duration of a connection. Different sources may exhıbıt a varying amount of burstiness In a word, these new services will have very diverse traffic flow characterıstics (e.g., bit rate and burstiness ) and quality of service ( QOS ) requirements. In this context, it is critical that the multiplexing and switching techniques in the BISDN used to support such a wide variety of new services, and the associated bandwidth management, be extremely flexıble.

### 1.1 BISDN Based on ATM

Traditional time division techniques , which divide bandwidth into a number of fixed capacity channel( e.g., Synchronous transfer mode: STM ), simply do not have this
required flexibility Packet-switched techniques, which allow variable-length packets, may not meet the stringent delay requirements specified for some services. Asychronous transfer mode ( ATM ) is a specific packet-oriented transfer method which uses an asynchronous time division multiplexing technıque[7] The multiplexed information is organızed into fixed-sıze packets, called cells. Each cell consists of two sections a cell header and a cell body. The cell header carries information such as the generic flow control(GFC)field, routing field(VPI/VCI), payload type(PT) field, cell loss priorıty(CLP) field, and header error control(HEC) field[8], The cell body carries the user data( For detalls, see Chapter 2 ). The ATM technique allows digital communications of any type to share common transmission channels and switching devices on a statistical multiplexing basis. The reason why ATM $1 s$ suitable for such a multimedia traffic environment is that it offers a great flexibility in bandwidth allocation through the assignment of fixed length cells. Therefore, ATM is a promising multiplexing and switching technique for umplementing an integrated access as well as the transport network and has been adopted by CCITT as the basis for the future BSIDN [9] The BISDN user-network interface 1s based on ATM over fıbre optic facılıties

### 1.2 Objectives and Summary of Thesis

The major benefit of the ATM technique is flexible and efficient allocation of communications bandwidth traffic statistics[10,11] But one of the major problem raised by the ATM technique is the definition of $a$ valid and efficient bandwidth assignment strategy. This strategy requires a full understanding of the impact of various kinds of traffic on the quality of service ( QOS ) of an ATM network The purpose of thas thesis is to address the performance of an ATM multiplexer using simulation methods. The inputs to the multiplexer consists of a number of volce sources, which are of a bursty nature. Only a single ATM output channel with a capacity of $150 \mathrm{mb} / \mathrm{s}$ is considered. For multiple QOS, an ATM multiplexer with three priority classes is also simulated using the priority assignment control method of [63] Generally speaking, the QOS 1s evaluated by cell loss probabılıty ( CLP ), the cell tıme delay, the buffer occupancy distribution, and the gap distrabution of the consecutively lost cells. Therefore, The cell loss probabılity, the distribution of queue length of the buffer under different offered load and buffer size conditions, and the probabilıty distribution of delay time are evaluated. In order to design a economic and effective ATM multiplexer the relationship between the traffic balance of classes and the buffer size of each class is also studied in this thesis

In Chapter 2, the state of development of switching, multiplexing, and transmission technologies is reviewed. This is done mainly for purpose of introducing an ATM multiplexer. The traffic process of a single bursty source is also discussed in this chapter.

The methods of generating random numbers are discussed in Chapter 3. Because, the random numbers of each probability distribution are derived from the uniform distribution, therefore emphasis is placed on the methods of generating random numbers with a uniform distribution. The chapter will also refer to the method of generating random numbers with a geometric distribution. In order to guarantee the quality of these random numbers, some methods of testing random numbers are also discussed in this Chapter.

In Chapter 4, The performance of an ATM multiplexer is studied, whose inputs consist of a number of homogeneous bursty ( ON/OFF ) sources, i.e., all the sources are characterized by bursty parameters of the same value. The cell loss probability and the distribution of queue length of the buffer under different offered load and buffer size conditions are evaluated.

In Chapter 5, an ATM multiplexer with three priority classes is simulated using the priority assignment control method of [?]. The relationship between the traffic balance
of classes and the buffer size of each class is studied in order to design a economic and effective ATM multiplexer. The cell loss probabılıty and delay time of each class are evaluated. Finally, conclusions are presented in Chapter 6.

## Chapter 2 Overview of Broadband ATM

## Multiplexer for Bursty Sources

### 2.1 Switching Technologies


#### Abstract

The step-by-step mechanical switch was invented by Strowger to replace manual switching in 1897[12] Mechanıcal means of providing interconnections were in turn replaced by electronic crossbar switches The earliest switching machines were Space Division Switches ( SDS )[13,14], for which a telephone conversation relied exclusively upon a single path in the switching network to facilitate a conversation The switching mechanism employed a toggling method, either mechanically or electronically, among electrical conductors There are two basic switching schemes in digital communications They are circuit switching and store-and-forward switching, and also there are two variants of store-and-ward switching message switching and packet switching (See Fig 21 ) Circuit switching is a much older technology than packet switching, and this technology has been used worldwide over the years for telephony Modern telephone systems and networks are used to transmit data, but volce has continued to constıtute the bulk of their traffac[15]




Fig 21 Switching techniques

## 211 Circuit switching

A circuit switched network is used to set up the traditional type of continuous connection between end points, namely, in circuit switching an electrical circuit is assigned and dedicated to each call and remains busy during the call Historically, circuit switching is an older technique that was designed originally for volce communication in the public switched telephone network (PSTN) With the advent of end-to-end digital communication, direct connections are now possible between digital devices operating at 56 or $64 \mathrm{~kb} / \mathrm{s}$ over the

PSTN[16] Circuit switching for broadband digital
communication will be expounded in section $2221(S T M)$

## 212 Message switching

In message swatching, the whole information or message( e g, a telegram, page of text, commercial letter ) is transmitted through the network as one block of data To this end, it carrıes the address of the recelver which is read and interpreted at each node of the network En route, the messages are sorted, stored in memory for a certain time, according to the congestion state of the rest of the route, and then transported as a single message Transmission $1 s$ typically unidırectional The transfer delay can be very long

## 213 Packet switchıng

The packet switching concept was first proposed in the early 1960s[17] by Paul Baran at the RAND Corporation whılst working on mılıtary communications systems, mainly to handle speech In packet switching, the information is broken up into pleces, called packet Packets move around the network, from switching centre to switching centre, on a store-and-forward basis The tradıtional packet switching model, based on X 25 interfaces, is implemented on all three of the lower layers of the OSI model( See [18] ) By 1976[14] the CCITT system had adopted the widely accepted X 25 standard for the data user interface to a public packet swatched network, allowing user equipment and
software to be developed as commercial products to utılıze packet switching services Packet switching is widely applıed to data and computer-based communications, and it is much more efficient for the transmission of data than carcult switching

## 214 Fast packet switching


#### Abstract

Fast packet switching is a telecommunication technology which combines features of statistical multıplexing and packet switching Unlıke normal packet switching networks, which are deslgned for data traffic, existing fast packet switching devices operate directly at the orıginal 24-channel, $1544 \mathrm{Mb} / \mathrm{s}$ PCM standard ( US, Japan, and Canada 1, and the 30 -channel, $2048 \mathrm{Mb} / \mathrm{s}$ PCM standard ( European countries ) To satisfy the needs of the multi-rate connections, fast packet switching is used[19] The linkage between Asynchronous Transfer Mode ( ATM ) and fast packet switching on which it is based will be outlined in section 2222


### 2.2 Multiplexing Techniques

Multiplexing is the operation which consists of grouping several channels, each assigned to a particular communication, in such a way as to transmit them simultaneously on the same physical medium( cable, carrier frequency of a radio link, satellıte, etc ) without maxing
or mutual interference At reception, a demultiplexing as perfect as possible allows these channels to be separated and restored to theur original form[20,15] The purpose of the multiplexing is to reduce the number of transmission links needed to carry the sources over some distance between nodes or access pounts

Multiplexing techniques were introduced in early telegraphy to allow simultaneous transmission of multiple signals over the same line[21] The multiplexing techniques consist of three types, e $g$, space division multiplexing, Frequency division multiplexing, and Time division multipleing But, two types of multiplexing techniques are in use today ( See Fig 22 )

1) Frequency Division Multıplexıng ( FDM )
2) Tıme Division Multıplexing ( TDM )

For TDM, bandwidth is shared by sources transmitting at different times For FDM, bandwidth is shared by sources transmitting at different frequencies or wavelengths For SDM, bandwidth is shared by sources transmıtting over

[^0]separate physical channels

Of the foregoing multiplexing methods, TDM is of most relevance to the current study and will be discussed further


Fig 22 Multiplexing techniques

## 221 Frequency divısion multıplexıng technıque

FDM is the oldest and most common type of multiplexing In FDM, each signal is allocated a discrete portion of the frequency spectrum It allows several analog volce slgnals ( or data channels ) to share the same line without interfering with each other Once multiplexed, these signals could be amplified and transmıtted at low
cost over a long distance. However, the cost of multiplexing, which grows linearly with the number of signals multiplexed, makes these wider band transissions suitable only for long distance and high volume routes for which the increased multiplexing cost can be justified. Therefore, the development of FDM tends to consolidate the long distance network into fewer routes with higher capacity.

### 2.2.2 Time division multiplexing techniques

Time division multiplexing was used in which a rotary switch connected the various signals to the transmission line. A basic problem then ( and now ) was the synchronization of the transmitting and receiving commutators. A practical solution introduced by Baodot in 1874 involved the insertion of a fixed synchronizing signal once during each revolution of the switch[14].

There are two major kinds of multiplexing modes in TDM. The first mode assumes a common time reference among the sources, which is denoted as a frame reference $d$. and is generally referred to as the Synchronous Transfer Mode ( STM ). In STM, the communication bandwidth assigned for each source is termed a Circuit multiplexing(See Fig. 2.3). The second mode assumes no frame reference, with the bits of each source having no implicit ownership, unlike STM, for which each slot is assigned an owner. Hence it is referred to as the Asychronous Transfer Mode ( ATM ). In

ATM, all information is packed into fixed-size slots called cells or packets, thus the communication bandwidth assigned for each source is termed a packet multiplexing ( See Fig.2.4 ). These two modes are discussed in Section 2.1.2.1 and Section 2.1.2.2 respectively.


Fig. 2.3 STM principle


Fig. 2.4 ATM principle

### 2.2.2.1 The synchronous transfer mode

Three TDM formats of the synchronous transfer mode have been discussed in detailed by Hui in[14,22]. They
are referred to as, single slot TDM, multi-window TDM, and multı-slot TDM

Suppose $N$ communication sources $S_{1}, S_{2}, \quad, S_{2}, S_{N}$ share a single high speed channel, and each source $S_{1}$ transmits at $a$ bit rate $b_{1}\left(b_{1}=b\right.$ is $a$ constant when all sources have the same bit rate )

Single Slot TDM Assuming that a common frame reference exists among the sources, which have the same rate $b$, each frame is divided into $N$ slots, where the bits of each source are placed in a chosen slot within a frame, and the source uses the same slot within consecutive frames Therefore, the transmission channel can be shared by at most $N=C / b$ sources This form is only suited to a single-rate environment, namely where all sources $S_{1}$ have the same rate $b$

Multı-Window TDM Bandwidth assignment becomes more complicated in multi-rate environments In a situation where there are $K$ types of sources of bit-rates $b_{k}, k$ windows are created within each frame for each type of source, in order for these to carry the multi-rate traffic In general, the multi-window TDM format represents all transmission formats which divide the capacity of a transmission channel to accommodate a fixed number of source types and a fixed number of services per source type As such, the network must choose, among the broad
range of source bit-rates, a set of standard bit-rates, and window sizes This format makes sharing of bandwidth inflexıble among service types

Multi-Slots TDM A more flexible TDM format results from removing the restriction that a source may be assigned a maximum of one slot within a frame These leads to the allocation of more flexible time slots and a circuit assigned for a source may have many slots ( see $[13,15]$ )

The above three formats have the same disadvantages in that the cholce of frames is very dıfficult for a multıservice environment, and the format depends on the transmıssion channel capacity $C$, as the number of slots in a frame $1 s$ given by $N=C / b$ ( b is a bit rate of the particular service type among the $K$ service types ) In addition, STM systems must accommodate peak transfer rates, thus they cannot transport different qualıty of services (QOS) efficiently STM is usually most usefully employed by fixed-rate services Higher-layer multiplexing and swatching would be required to make maximum use of an STM system

## 2222 The asynchronous transfer mode

There two basic forms of asynchronous multiplexing, e g , fixed length cells and varıable length cells

Fixed length cells The information to be transferred is packed into fixed_sized slots called "cells" or


Fig 25 Fixed length cell

Each cell consists of two sections a cell header and a cell body The cell header carries information such as generıc flow control(GFC)field, routing field(VPI/VCI), payload type(PT) field, cell loss priority(CLP) field, header error control(HEC) field, and reserved field(RES) The cell header structure vary with the interface, 1 e , User Network Interface(UNI) and Network Node Interface(NNI) (See Figs $26-27$ ), for example, the GFC function is unique for the UNI, the NNI does not have this functionality, Other header functions are common for both interfaces But the maxımum commonalıty between UNI and NNI is desired The cell structure at the UNI and NNI is described in this study The cell body carries the user information[8] ( See Figs $26-27$ )


Fig 26 Cell header structure at UNI

Bit


Fig 27 Header structure at NNI

There are two major factors in determining the proper cell length for ATM system First, the cell header uses up part of the communication bandwidth of the link, and it is inversely proportional to cell size 1 , consequently favouring long cells Second, a packetızation delay is needed for the source to collect the 1 bits for a cell This delay is given by $1 / I_{k}\left(I_{k}\right.$ is the bit rate of a single input source) Consequently, mınımızing packetızation delay requires choosing short cells A compromise has to be chosen between the packetization delay and transmission processing efficiency[26] The ATM cell is selected as a 5 octets header field and a 59 octets user information field in this study

Variable length cells Instead of fixed length slots, 1t 1 s often convenient to use long ( say 128 bytes or more ) vaıable length cells ( see Fig 28 ) Besides the label for ownership, the cell header should also contain the information for cell length to mark the end of the cell, as well as a flag to mark the beginning of the cell for varıable length cells, the variable delay before a packet is successfully transmitted depends on the probability distribution of cell lengths Therefore, very long cells may Jeopardize the timely delivery of other cells This complicates traffic engineering for controlling delay for this reason, variable length cells are often fragmented into smaller fixed length cells for transport

The asynchronous transfer mode (ATM) is based on fast packet switching ( fixed length cells ) to be a new transport ( multiplexing and switching ) technique $[23,27]$, which attempts to eliminate the disadvantages of STM Where there is no existing frame reference, the usable capacity can be dynamically assigned on demand Thus it achieves flexible bandwidth sharing by allowing the sources to seıze bandwidth when a sufficient number of bits are generated

In comparison to STM , ATM Multiplexing and switching are less dependent on considerations of bit rates for particular services ATM can flexibly support a wide varıety of servıces and is partıcularly apt as the bit_rate of each source is time_varying or bursty

Due to ATM advantages mentioned above, ATM is a promising multiplexing and switching technique for implementing an integrated access as well as transport network and has been adopted by CCITT study Group XVIII ( international ) and T1S1 ( North Amerıca ) as a basis for the future BSIDN structure

### 2.3 Evolution of Broadband ISDN

Traditionally, the aforementioned services were carried via separate networks, as for example, volce on telephone network, data on computer networks or local area
networks, video teleconferencing on private corporate network, and television on broadcast radio or cable networks These networks are largely designed for specific applications and are inflexible for other usages

The ideal situation is one in which a single network provides all these communication services, in order to achieve maximum economic value, based on shared usage The natural evolution of the public switched telephone network and the emergence of digital communication technology has led to the development of a concept known as the integrated service digital network (ISDN), which is built on the ability to provide integrated access to a myriad of services through a single $2 n t e r f a c e[20,28]$ In 1984, the Plenary Assembly of the CCITT adopted the $I$ series recommendations dealing with ISDN matters CCITT stated that " an ISDN is a network that provides end-to-end digital connectivity to support a wide range of services, including volce and non-voice services, to which users have access by a limited set of standard multipurpose usernetwork interfaces"[29] ISDN was not designed to support switching and transmission rates at the speeds necessary for the above-mentioned new service types, therefore, a new higher bandwidth method was needed About 1985, worldwide activities commenced to evolve ISDN into an optical-fibrebased universal broadband network Broadband ISDN (BISDN) extends these 1 mportant concepts of ISDN[5], to provide a universal, long_term transport capability for all
services[27.30] The Optical fibre transmission technology is the transport media of cholce for network integration, because its vast and reliable transmission capabılıty can accommodate all imaginable services Therefore, the BISDN access can be based on a single optical fibre for varıous services

There are two BISDN interfaces discussed indomestıc and international standards One is the User Network Interface ( UNI \}, and the other is the Network Node Interface( NNI ) The UNI and NNI frame stuctures are based on optical interface rates and formats specified inıtıally by CCITT[8] The BISDN architecture is showed by Fig 28


NT - Network termınation
AN - Access Node
UNI - User Network Interface
NNI - Network Node Interface

## Fig 28 BISDN architecture

However, integration within the network can entail
different meanings depending on which part of the network 1s being consıdered[3,31]
(1) Integrated access involves the sharing, among services from an end user, of a single interface to a single transmıssion link whıch connects the end-user to a larger network These links comprise the local access network ( LAN ) within the larger network A well integrated access network should provide flexible multiplexing of a maximum number of services ( this issue will be discussed further in Chapter 4 )
(2) Integrated transport involves the flexıble sharing, among services from many users, of highcapacity transmission channels aside from the local access network Integrated transport avoids the segregation of dıfferent traffic types and media onto different transmission channels The integration of media on the same channel may facılıtate easier interaction between media within the network
(3) Integrated switching consists of switching multırate, multı-media services within a single switching machine, with the emphasis on a single interconnection network An integrated switch


#### Abstract

should remove the necessity of putting in place an interconnection network whenever a novel service of distinct traffic mode is introduced An integrated switching network must be flexible and attain the delay and bandwidth requirements of each service


#### Abstract

The technological development of fiber optıcs, distributed processing, and HDTV ( Hıgh Definition Television , have accelerated the trend toward the development of BISDN


### 2.4 Broadband Services


#### Abstract

The introduction of BISDN should stimulate the emergence of a wide variety of new services In the business market segment, there is already a demonstrated need for hıgh-speed Local Area Networks ( LANs ) and LAN interconnects within buıldings and in campus enviroments The BISDN can extend these functions by interconnecting LANs from different locations into Metropolitan Area Networks ( MANs ) [6,32,33] and Wide Area Networks ( WANs ) The inıtial demand for broadband networks will lıkely be from business customers for high-speed date services The market for switched video services for both business and residential customers wall emerge later So far, The Local Area Networks ( LANs ) make possible a distributed processing environment consisting of Personal


Computers ( PCs ), print servers, file servers, workstations, minicomputers, and gateways Many workstations are attached to LANs However, in the future, high-speed workstations may be connected directly to a public broadband network in order to communicate with other directly attached workstations as well as with workstations, PCs, and servers attached to LANs served by the broadband network Host computers could be connected directly together or to high-speed peripherals via a direct channel connection High-speed distributed host computing can be supported by a broadband network in conjunction with approprıate channel extension equipment[37] (See Fig 2 8)

### 2.5 ATM Multiplexer for Bursty Sources

In the simpest case, the ATM transport network may be a point-to-point link, consisting of an access multiplexer, lınk, and demultiplexer In a full evolved network context, the ATM transport network could span several multiplexing, switching, and demultiplexing stages as shown in Fig 29 In either case, each node may contribute to the end-to-end cell loss and delay due to buffering In order to meet end-to-end transport $Q O S$ requirement, a reference connection must be assumed and an allocation of $Q O S$ requirements to each node in the reference connection must be made for this reason, this study focuses on an ATM multiplexer The sources of the ATM multiplexer, the state modes of the
sources, and the traffic processes will be firstly assumed in this section The performance of an ATM multiplexer without priority is studied It's input consists of superımposed of homogeneous bursty ( ON/OFF ) sources, ı e , all the superımposed sources are characterızed by the bursty sources of the same parameter values ( See Chapter 4 ) An ATM multiplexer with three priority classes is simulated using the priority assignment control method in Chapter 5


M
S.-. Switched ATM Core

Fig 29 ATM transport layer reference connection

## 251 Sources of ATM multıplexer

It is assumed that $N$ communication sources $S_{1}, S_{2}$, $S_{1}, \quad S_{N}$ share a single high speed ATM channel ( the bit rate $C=150 \mathrm{Mb} / \mathrm{s}$ in this study ), and each source $S_{1}$
transmits at a bit rate $b_{i}(t)$.

Then, according to the characteristic of the traffic flow, these sources $S_{i}$ may be divided into the following three forms:
A. The fixed bit rate, such as data information and full_motion video, etc.
B. The bursty ( i.e., the bit rate of each source is time_varying ), such as voice and still picture video, etc.
C. The bit rate is continuously varying, such as compressed full_motion video, etc.

It has already been noted in section 2.2.2.2 that when the above sources enter into the ATM multiplexer, all information is packetized into fixed_size cells (or packets), which are identified and switched by means of a label in the header.

### 2.5.2 State models of bursty sources

Many of the traffic sources that an ATM network supports display bursty characteristics. A bursty source emits cells periodically ( at a peak rate ) during a burst, which is of variable length. Silence periods are also of variable length. An example of this is conventional voice
telephony --- a telephone is communicating when in the active state, or not communicating when in the idle state This two state model is called "the alternating state process," which also suffices to describle other fix bıt rate communlcations ( see Fig 2 10a)

To save communication bandwidth, the telephone transmits only during these talk_spurt periods, thus, the traffic process becomes a three_state model ( see Fig 2 10b)

In ATM network, the talk_spurt is organized into multiple fixed length cells, so that, a volce call is expressed as a four_state model( see Fig 2 10c ) [12,34]

(a)

(b)

(c)

Fig 210 Multılevel traffic state models for telephony

## 253 Traffic processes of single bursty source

In an ATM multiplexer, all information such as data, volce, and video is conveyed using a fixed sized "cells" This means that the cell stream from a single bursty source 15 characterızed by arrivals at fixed intervals of $T$ during bursts with no arrivals during silences( see Fig 2 11) The successive burst and silence periods form an alternating renewal process, 1 e , all these time intervals are independent with each burst being of random length $X T$, and each sılence perıod of random length $Y S(Y S$ is a sılence perıod ) The number $X$ of cells in a burst is uniformlly distributed on the positive integers for single bursty source, the alternating states of idleness and bursts appear after the call is set up[35,36,37]


Fig 5 Multilevel traffic processes

For a volce source, it is necessary that the burst is digitized into a bit stream at $I=64 \mathrm{~kb} / \mathrm{s}$, and segmented into cells of $l=512$ bıts ( 1 e , 64 octets ) for transport over an ATM channel with a capacity of $C=150 \mathrm{Mb} / \mathrm{s}$ Therefore, the voice packetization period is $T=1 / I=8 \mathrm{~ms}$, entailing the source enters into the cell transmission state once every $V$ cell time, where $V$ equals the channel bıt rate divided by the source bıt rate in other words, a maxımum of 2344 volce bursts can be accommodated at a time on a capacity of $150 \mathrm{Mb} / \mathrm{s}$ ATM channel[13,38]

$$
V=\frac{C}{I}=\frac{150 \mathrm{Mb} / \mathrm{s}}{64 \mathrm{~kb} / \mathrm{s}} \approx 2344
$$

## Chapter 3 Random Number Generators


#### Abstract

The random numbers of varıous types of probabılıty distributions are important tools in traffic simulation The traffic flows are simulated by the random numbers of the corresponding distribution These probability distributions can be derived from the uniform distribution, so that, emphasis is placed on the methodology for generating (0-1) uniform random numbers $A s$ the quality of the generated random numbers directly effects the simulated results, evaluation and test of the methods of generating these numbers is undertaken


### 3.1 Generating Random Numbers

There are three distinct types of method for generating random numbers $[39,40]$, namely
(1) Manual methods
(2) Mechanical and/or electrical methods
(3) Digıtal computer methods

Undoubtedly, the last is most commonly used method of obtaining random numbers and involves the use of a
pseudo_random number generator.

The suitability of the various types of random number generators may be judged against the following six criteria.
(1) The random numbers should be uniformly distributed.
(2) Each random number should be statistically independent of all other random numbers in the sequence.
(3) Sequences should be reproducible.
(4) Sequences should be not repeated over a given span or period.
(5) The random number generator should be computationally fast.
(6) The software describing the generator should be as concise as possible.

Pseudo_random number generators are normally considered to satisfy these criteria.

Software which employs pseudo_random number generators

1s usually based upon the following congruence or residue methods
(a) The multiplicative congruence method
(b) The mixed ( or linear ) congruence method

Comparison of the mixed congruence method with the multiplicative congruence method indicates that its computation time is slower, but it can generate longer sequences that are not repeated over a given period The current study favours the mixed congruence method

The mixed congruence method is also called the linear congruence method, and uses a recursive expression to generate a sequence of numbers from a given initial value

This recursive expression $[45,46,41]$ is of the form

$$
\begin{equation*}
x_{1+1} \equiv \lambda x_{1}+C_{0} \quad(\bmod M) \quad 1=0,1,2,3, \tag{2}
\end{equation*}
$$

which can be expressed in algebraic form as

$$
\begin{equation*}
x_{i+1}=\lambda x_{1}+C_{0}-K_{1} M \quad 1=0,1,2,3, \tag{3}
\end{equation*}
$$

where $K_{1}$ is the integer part of the quatient of $\left(\lambda x_{1}+\right.$ $\left.C_{0}\right) / M$ So that, The equation 2 can be expressed in the following form

$$
\begin{gather*}
x_{1+1}=\lambda x_{1}+C_{0}-1 n \operatorname{teger}\left(\frac{\lambda x_{1}+C_{0}}{M}\right) M  \tag{4}\\
1=0,1,2,3
\end{gather*}
$$

The random numbers generated by equation 3 are in the range ( $0-M$ ) The maxımum span therefore is $M$

To obtain a sequence of uniformly distributed pseudo_random numbers between $0-1$, the above equation is divided by $M[45,47]$

$$
\begin{gather*}
\frac{x_{1+1}}{M}=\frac{\lambda x_{1}+C_{0}}{M}-1 n t e g e r\left(\frac{\lambda x_{1}+C_{0}}{M}\right)  \tag{5}\\
1=0,1,2,3
\end{gather*}
$$

Equation 4 can be expressed in the following form which is suitable for computation on a computer

$$
\begin{gather*}
x_{i+1}^{\prime}=\left(\lambda x_{1}^{\prime}+C\right)-\text { nnteger }\left(\lambda x_{i}^{\prime}+C\right) \\
x_{0}^{\prime}=\frac{x_{0}}{M}, \quad C=\frac{C_{0}}{M}  \tag{6}\\
1=1,2,3,
\end{gather*}
$$

where $x_{1}$ ' is the new sequence between $0-1$

The value of the modulus $M$ is of the form $2^{r}$ ( where $r$ is a positive integer ), which is the maxımum number of random values in a sequence generated by the muxed congruence method The parameters $\lambda, x_{0}, C_{0}$ and $M$ determine the statıstıcal quality of the random number generator, and by a suytable cholce of values for $x_{0}, \lambda, C_{0}$ and $M$, sufficlently long sequences may be obtained

To achleve the full perlod or span of $M$ pseudorandom numbers, the following are necessary conditions[45]
(a) The initial value $x_{0}$ must be any positive integer
(b) The multiplier constant $\lambda$ should be of the form

$$
\begin{equation*}
\lambda=4 \alpha+1 \tag{7}
\end{equation*}
$$

where $\alpha$ may be any positıve number
(c) The constant $C_{0}$ must be a positive odd number
(d) Since the vast majority of digital computers operate using binary numbers, the value of the modulus $M$ is of the form $2^{r}$ In most cases, $r$ is chosen to be the number of usable bits in the computer word In a computer having a word length of say 32 bits, $r$ would have a value of 31 , since
one bit is used as the sign bit This means, $M$ is chosen according to the capacity of the computer and the practical requirement $\left(x_{0}=324130\right.$, $C_{0}=156830, \lambda=444410, M=2^{31}$ in this thesis)

### 3.2 Generating Geometric Random Numbers

In this thesis, the input sources of an ATM multiplexer are bursty $A$ bursty source consists of cell arrivals occurring at fixed length intervals during bursts and no arrıvals at all during silences The burst and the sılence lengths are generated according to a geometric distribution as will be discussed in Chapter 4 Therefore, generating geometric random numbers to simulate every source input into the ATM multiplexer is of prime importance The random numbers forming geometric distribution are derıved from the uniform distrıbution, and the method for generating uniform random numbers has already been discussed in section 31

Suppose that a sequence of Bernoullı trials is continued until the first success occurs Let $\xi$ be the random variable which counts the number of trials before the trial at whıch the first success occurs ( $0 \leq \xi<\infty$ ) It assumes the value 0 if and only if the first trial yıelds a success, hence, with probabılıty $P(k)$ [42]

$$
\begin{equation*}
P(k)=q^{k} p \tag{8}
\end{equation*}
$$

where $p=1-q$
The expected value is given by

$$
\begin{equation*}
E[\xi]=\frac{q}{p} \tag{9}
\end{equation*}
$$

The average length of the burst and silence are 300 ms ( 220 cells ) and $450 \mathrm{~ms}(132352$ slots ) respectively, in this study Thus

$$
\begin{gather*}
g_{B}=\frac{220}{221}=09954751  \tag{10}\\
g_{S}=\frac{132352}{132353}=09999924
\end{gather*}
$$

Therefore, according to the above mentioned definition of geometric random variables $\xi$, a sequence of Bernoullı trials is continued until the first $x \geq q_{B}\left(q_{s}\right)($ The random number $x$ is taken from ( $0-1$ ) uniform random number generator ) $\xi$ is that obtained through counting the number of random numbers before the random number $x \geq g_{B}$ ( $q_{s}$ )

### 3.3 Test of The Statistical Characteristics of Pseudorandom

To obtain a sequence of uniformly distributed
pseudorandom numbers, the six criteria described previously should be fulfilled The requirements outlined in points 3 - 6 can be met by the methods discussed in the previous paragraph The first two criteria, 1 e , the unıformity and the independence of the random numbers, should be verıfied by using statistical tests The basic statistical tests required include
(a) Test of the parameters
(b) Test of the uniformıty ( or the distribution )
(c) Test of the independence

## 331 Test of parameters

The tests of the parameters include tests of the value of the mean, 1 th power sample moment, and varıance

The density function $[43,44]$ of the uniform random varıable $X$ on the interval ( $0-1$ ) is

$$
f(x)= \begin{cases}1 & 0 \leq x \leq 1  \tag{12}\\ 0 & \text { elsewhere }\end{cases}
$$

and the corresponding distribution function is

$$
F(x)= \begin{cases}0 & x<0  \tag{13}\\ x & 0 \leq x \leq 1 \\ 1 & x>1\end{cases}
$$

The mean, 2nd power sample moment, and varıance of the uniform random variable $X$ on the interval ( $0-1$ ) respectively are $[47,48,52]$

$$
\begin{gather*}
E(\xi)=\int_{0}^{1} x d x=\frac{1}{2} \\
E\left(\xi^{2}\right)=\int_{0}^{1} x^{2} d x=\frac{1}{3}  \tag{14}\\
D(\xi)=\int_{0}^{1}\left(x-\frac{1}{2}\right)^{2} d x=\frac{1}{12}
\end{gather*}
$$

The statistical estimator of the parameter of a random varıable $X$ can also be a random varıable which depends upon a random sample $x_{1}, x_{2}, x_{3}, \quad x_{N}$ The three most common statistical estimators are the sample mean $\bar{X}$, the 2nd power sample moment $\overline{X^{2}}$ and the sample variance $\overline{S^{2}}$ as defıned by

$$
\left.\begin{array}{c}
\bar{X}=\frac{1}{N} \sum_{i=1}^{N} x_{1}  \tag{14}\\
\overline{X^{2}}=\frac{1}{N} \sum_{i=1}^{N} x_{1}^{2} \\
2=\frac{1}{N} \sum_{i=1}^{N}\left(x_{1}-\bar{x}\right)^{2}
\end{array}\right\}
$$

As such, $\bar{X}$ is a statistical estımator of $E(\xi), \overline{X^{2}}$ of $E\left(\xi^{2}\right)$, and $\overline{S^{2}}$ of $D(\xi)$

The null hypothesises[47,49,50] can be tested as follows,

$$
\left.\begin{array}{l}
E(\xi)=\frac{1}{2}  \tag{15}\\
E\left(\xi^{2}\right)=\frac{1}{3} \\
D(\xi)=\frac{1}{12}
\end{array}\right\}
$$

whlch allows us to prove that $N$ random numbers are from the generator with a uniform distrabution

Given the value of a random sample $\boldsymbol{x}_{1}, \boldsymbol{x}_{2}, \boldsymbol{x}_{3}$, , $x_{N}$ from a (0-1) random number generator for the large sample case $(N \geq 30)$, the expression $[48,45]$ of the
test statistic is

$$
\begin{equation*}
U=\frac{\left(r-\mu_{0}\right)}{\left(\frac{\sigma}{\sqrt{N}}\right)} \tag{16}
\end{equation*}
$$

where $\bar{r}$ is the statistical value of one of the the equation 14, $\mu_{0}$ is a constant value of the corresponding parameter in the equation $15, \sigma / \sqrt{N}$ is a mean square deviation of the corresponding parameter in the equation 14 and $N$ is the capacity (or size, $N=2000$ in this case) of the random samples

To calculate the test statistic $U$, it is necessary that $\sigma^{2} / N$ is calculated, 1 e $, D(\bar{X}), D\left(\overline{X^{2}}\right)$, and $D\left(\overline{S^{2}}\right)$

For the large sample case $(N \rightarrow \infty)$, according to the central limit theorem, if $x_{1}, x_{2}, x_{3}, \quad, x_{N}$ have the same distribution, and $\sigma^{2}=D\left(\xi_{1}\right), \alpha=E\left(\xi_{1}\right)(1=1,2,3, N)$, $U$ is a asymptotic nomal distribution $N(\alpha, \sigma / \sqrt{N})$ Thus

According to the definıtion of the varıance[47], $D\left(\xi^{2}\right)$ is expressed by the following

$$
\left.\begin{array}{c}
\bar{x}=\frac{1}{N} \sum_{i=1}^{N} x_{1} \\
D(\bar{x})=\frac{\sigma^{2}}{N}=\frac{D(\xi)}{N}=\frac{1}{12 N}  \tag{17}\\
D\left(\bar{x}^{2}\right)=\frac{D\left(\xi^{2}\right)}{N}
\end{array}\right\}
$$

thus

$$
\begin{equation*}
D\left(\overline{x^{2}}\right)=\frac{4}{45 N} \tag{18}
\end{equation*}
$$

By the same method, $D\left(\overline{S^{2}}\right)$ is also solved

$$
\begin{equation*}
D\left(\widehat{s^{2}}\right)=\frac{D\left[\left(\xi-\frac{1}{2}\right)^{2}\right]}{N} \tag{19}
\end{equation*}
$$

since

$$
\begin{aligned}
D\left[\left(\xi-\frac{1}{2}\right)^{2}\right] & =E\left[\left(\xi-\frac{1}{2}\right)^{4}\right]-\left[E\left(\xi-\frac{1}{2}\right)^{2}\right]^{2} \\
& =\int_{0}^{1}\left(\xi-\frac{1}{2}\right)^{4} d \xi-\left[\int_{0}^{1}\left(\xi-\frac{1}{2}\right)^{2}\right]^{2} \\
& =\frac{1}{80}-\frac{1}{144}=\frac{1}{180}
\end{aligned}
$$

thus

$$
\begin{equation*}
D\left(\overline{s^{2}}\right)=\frac{1}{180 N} \tag{20}
\end{equation*}
$$

Substituting equation 13 and equation 17 -- 20 into equation 16, the test statistics of the mean, 2nd power sample moment, and variance are:

$$
\begin{gather*}
U_{1}=\sqrt{12 N}\left(\bar{x}-\frac{1}{2}\right) \\
U_{2}=\frac{1}{2} \sqrt{45 N}\left(\overline{x^{2}}-\frac{1}{3}\right)  \tag{21}\\
U_{3}=\sqrt{180 N}\left(\overline{S^{2}}-\frac{1}{12}\right)
\end{gather*}
$$

According to equation 21, the values of the test statistics $U_{1}, U_{2}, U_{3}$ were found to be $0.063324,-0.260758$, -1.288283 respectively ( See Table I ). The critical values $U_{\alpha}$ of size $\alpha^{\star 4}$ were then determined, $U_{\alpha}=1.645$. These results showed that $\left|U_{1}\right|,\left|U_{2}\right|,\left|U_{3}\right|<U_{\alpha}$. Therefore, the null hypothesis is accepted.

[^1]
## Table I

Lambda=44441 0
$x_{0}=32413 \quad 0$
$C_{0}=15683 \quad 0$
$\bar{X}=0500409$
$\overline{X^{2}}=0 \quad 331595$
$\overline{S^{2}}=0 \quad 081186$
$U 1=0 \quad 063324 \quad U 2=-0260758 \quad U B=-1288283$
$x^{2}=5 \quad 73$
J
$P(J)$
$U(J)$
1
$3224710 e-03$
0144177
2
1.419969e-02
0634712
3
$2927258 e-03$
0130813
4
2 618280e-02
1169759
5
$-1747989 e-04 \quad-0 \quad 007807$
$6 \quad-3 \quad 061413 e-02 \quad-1367050$
7
$2185708 \mathrm{e}-02$
0975766
8
$-2260654 e-02$
-1 008971
$9 \quad-3442464 e-02 \quad-1536049$
10
7 923329e-03
0353455

## 332 Test of unıformuty

The test of the uniformity of the pseudorandom numbers is also known as the goodness_of_fit test [48,49,46] The common chi_square goodness_of_fit test was used for the purposes of this study

The goodness of_fit test is based on the difference between observed and expected frequencies of the random numbers as follows

$$
\begin{equation*}
x^{2}=\sum_{1=1}^{k} \frac{\left(O_{i}-N p_{i}\right)^{2}}{N p_{i}} \tag{22}
\end{equation*}
$$

where $O_{1}(1=1,2,3, \quad 10)$ and $N p_{1}$ represent the observed and expected frequencies respectively, for the 1 th cell Hence $N$ is the capacity of the random samples and $p_{1}$ is the probability of the value of the random variable $\xi$ in the 1th cell

The test procedures employ the following forms Each element of a given random sample $x_{1}, x_{2}, x_{3}$, $x_{N}$ falls into one of the $k$ cells $c_{1}, c_{2}, c_{3}, \quad c_{k}$ This test will determine at the $\alpha$ level of significance, whether or not it is reasonable to suppose the observed distribution of the $N$ sample values is consistent with the null hypothesis

Step 1 Count the number $O_{2}$ of observed elements in cell $c_{1}$, for $2=1,2,10$

Step 2 On the basis of the null hypothesis, calculate $N p_{1} \quad\left(p_{1}=p_{2}=p_{10}=01\right.$, for this project $)$, the expected number of elements in cell $c_{1}$, for $1=1$ , $2, k(k=10)$

Step 3 Calculate the chi_square statistic $x^{2}\left(x^{2}=573\right)$

Step 4 Calculate the number of degrees of freedom $m$ of the underlying chi_square distribution Set $m=$ $k-1=9$ in this study

Step 5 Find the critical value $x_{\alpha}{ }^{2}\left(x_{\alpha}{ }^{2}=1692\right)$ such that the probabılıty of a chı_square random varıable with $m$ degrees of freedom will exceed $x_{\alpha}{ }^{2}$ is $\alpha$ (see APPENDIX B [8])

Step 6 Since $x^{2}<x_{\alpha}^{2}$ the null hypothesis wall accept that the random numbers generated by the random number generator are unıform (See Table II)

Table II

| SUBINTERVAL | OI | EI | $\left(O_{1}-E_{1}\right)^{2}$ |
| :---: | :---: | :---: | :---: |
| , |  |  |  |
| [0-0-0 1) | 198 | 200 | 4 |
| [0 1-0 2 ) | 183 | 200 | 289 |
| [0 2-0 3) | 199 | 200 | 1 |
| [0 3-04) | 211 | 200 | 121 |
| $\left[\begin{array}{lll}0 & -0 & \text { ] }\end{array}\right.$ | 225 | 200 | 625 |
| $[05-06]$ | 198 | 200 | 4 |
| [06-07) | 191 | 200 | 81 |
| [07-0 8) | 196 | 200 | 16 |
| [0 8-0 9) | 201 | 200 | 1 |
| [09-10) | 198 | 200 | 4 |
| Total | 2000 | 2000 | 1146 |

## 333 Test of independence

The main objective in testing the independence of pseudorandom numbers is to determine whether a linear relationship exists between the pseudorandom numbers $A$ number of methods of testing independence are currently in use In this project, independence is examıned using a test of the correlation coefficient

The correlation coefficient between two varıables is a measure of their linear relationship and is denoted by $r_{x y}[47,49,51]$, which is defined as

$$
\begin{equation*}
I_{x y}=\frac{s_{x y}}{s_{x} * s_{y}} \tag{23}
\end{equation*}
$$

$s_{x y}$ represents the covariance between $x$ and $y$
$s_{x}, s_{y} \quad$ represent the standard deviation of $x$ and $y$
respectively

The equation above may be expressed by the following form

$$
\begin{equation*}
r_{x y}=\frac{\frac{1}{N} \sum_{i=1}^{N} x_{1} y_{1}-\frac{1}{N^{2}}\left(\sum_{i=1}^{N} x_{1}\right)\left(\sum_{1=1}^{N} y_{1}\right)}{\sqrt{\left[\frac{1}{N} \sum_{i=1}^{N} x_{1}^{2}-\left(\frac{1}{N} \sum_{i=1}^{N} x_{1}\right)^{2}\right] \sqrt{\left[\frac{1}{N} \sum_{i=1}^{N} y_{i}^{2}-\left(\frac{1}{N} \sum_{i=1}^{N} y_{i}\right)^{2}\right]}}} \tag{24}
\end{equation*}
$$

To compute this equation for a data sample $\{(x 1, y 1)$, $\left.(x 2, y 2), \quad\left(x_{N}, y_{N}\right)\right\}$, rank the $x_{1}$ in order, and likewise rank the $y_{1}$ As $x_{1}$ and $y_{1}$ are from a same population, the maximum distance between $x_{1}$ and $y_{1}$ is defined as $j$ ( $j=1,2,3, \quad, \quad J=(1-10)$ ) Therefore , $y_{1}=x_{1+\jmath,} x=y$,
and $s_{x}=s_{y}$ when these formulas are replaced into the equation 24, it can be written as follows

$$
\begin{equation*}
I_{x_{1} x_{1}+j}=\frac{\frac{1}{N-\jmath} \sum_{i=1}^{N-\jmath} x_{2} x_{1+j}-\bar{x}^{2}}{s^{2}} \tag{25}
\end{equation*}
$$

So that, $x_{x_{1} x_{i+j}}$ is a number between -1 and +1 If
$I_{x_{1} x_{1+1}}$ equals zero then $x_{1}$ and $x_{1+\jmath}$ are not correlated $A$
positive correlation means that if a particular $x_{1}$ happens to be larger than the mean $x$, then $x_{1+y}$ will also $($ on
average ) be larger than the mean $x$ For a negative $r_{x_{1} x_{1+j}}$, a larger $x_{1}$ will imply a smaller $x_{1+3}$, where $I_{x_{1} x_{1+j}}$ equals 1 (or -1 ) then $x_{1}$ and $x_{1+j}$ will have a perfect correlation

The null hypothesis states, $r_{12+3}=0$ For a large
sample size(N-J>50), according to the central limit theorem, the test statistic $U$ has approxımately a standard normal distribution Therefore, the expression[8] of the $U$ 15

$$
\begin{equation*}
U=r_{12+j} \sqrt{N-j} \tag{26}
\end{equation*}
$$

Suppose the significance level is $\alpha=005$, the critical values of $U_{\alpha}$ are determined ( see APPENDIX A ) Since $|U|<U_{\alpha}$, the null hypothesis was accepted

# Chapter 4 Simulation of ATM multiplexer 

## for burst sources

### 4.1 Introduction


#### Abstract

The ATM technique allows digital communications of any type to share a common transmission channel and switching devices on a statıstical multiplexing basis Information is transmitted in the form of fixed length cells Chapter 2 has outlined three kinds of sources in the ATM network, e g ,


(a) ON/OFF sources emıt cells perıodically during activity periods, or "bursts" of variable length alternating with silences, also of variable length,
(b) Precewise constant bit rate sources emit cells perıodically at a frequency determined by their bit rate,
(c) Continuous varying sources The cell emission rate might vary continuously, in the sense that the interval between successive cells varies gradually or discontinuously, with the rate

```
changing at random instants between different
constant values[47] ( See Fig 4 1 )
```


(a) $\mathrm{ON} / \mathrm{OFF}$ source

(b) Piecewise constant rate source

(c) Contunuously varying rate source

Fig 41 Variable bit rate sources

The previously proposed analytical approaches[61] do not adequately cover the large varıety of real situations and a complete analysis of the effects of the various source parameters on the performance of an ATM multiplexer is not available yet Therefore, the simulated modelling of an ATM multiplexer loaded by the superposition of homogeneous bursty sources is studied in this Chapter, 1 e, all the superımposed sources are characterızed by the same parameter values The services of the different QOS requirements wall be discussed in Chapter 5

Many of the traffic sources that an ATM network supports, display bursty characterıstics Bursty sources
such as voice sources consist of arrivals occurring cells periodically ( at a peak rate ) during talkspurts and no arrivals at all during silences In [61], the superposition of a multiplicity of bursty sources modeled by Markov Modulated Poisson Process ( MMPP ) It $1 s$ assumed that the bursts ( or silences ) are characterızed by the geometric and uniform distribution respectively in this chapter $A$ comparison of results for the geometric distribution and uniform distribution is shown in Fig 42 for the mean offered load $\rho=09,092,094,096,098,10$ Thus Fig 42 it can be seen that there is no obviously difference for the cell loss values between the geometric distribution and uniform distribution $T O$ save simulation time ( Because, the simulation time using geometric distribution is very long ), the uniform distribution is employed in all simulation experıments that follow


Fig 42 Cell loss probabilıties versus mean offered load for the buffer sıze $=100$ cells and for both geometric and uniform distribution

The multiplyıng of a large number of bursty sources on a high capacity ATM channel gives rise to the queuing system of single server and deterministic service tame Queues of cells may arıse because avaılable capacıty is "overallocated," using statistical multiplexing to gain efficiency in a superposition of bursty sources In general, the total bit rate of active sources is small enough to be handled by an ATM multıplexer, but, at tımes, a large number of sources will emıt bursts simultaneously Even if the cell mean arrıval rate 1 s less than the output capacıty, a queue will still occur due to the colncidence of cell arrivals from different sources If there $1 s$ excessive use of the bandwidth, then this may cause cell loss at the buffer

To ensure network transparency with respect to offered services, the QOS parameters ( the cell loss probabilıty and the cell delay , will occur within specified limıts, which are for further study and are dependent on connection type[6,48] The cell delay consists of the cell packetization delays, the propagatıon delays, and the delays of the output queue The cell packetızation delays and propagation delays over transmıssion lınes are fixed and unchangeable regardless of traffic In addition, the cell loss and masdelivery due to the ATM header field error during transmıssion are also independent and not considered further. So that, the key parameters that cause ATM network
performance deterioration are the cell loss and the cell delay in the buffer queue to the output channel in the ATM multiplexer Therefore, the performance parameters of an ATM multiplexer are specıfically focused on the cell loss probabılıty and the cell delay in this study[49]

Delay control methods Two delay control methods have been developed expounded in [50] 1) The method of determining the upper limit of the queue length and delay can not exceed this upper limit, 2) To use larger queues and "clıpped" cells, which exceed the delay bound, are counted in the lost cells[53] Method 1) is selected in this study ( See section 43 )

Loss rates Loss rates of the order of $10^{-10}$ have been quoted in other papers[51,52] As the operating speed of the UNIX workstation is limıted, it is impossible to perform a simulation for a long enough time Thus, loss rates of the order of $10^{-6}$ are only obtained in this Chapter

Assuming a finite buffer size of five hundred cells ( the maxımum delay is 500 cells ), the cell_buffer overflow probabllity is well under $10^{-6}$ at $90 \%$ mean offered load in order that the ATM multiplexer can be sized to satisfy such qualıty of service objectıves, besides showing the cell loss probabılıty for dıfferent $K($ buffer sıze ) and $\rho$ ( mean offered load), the distribution of queuing length (or

```
buffer occupancy ) is also shown in section 4 5
```

An ATM multiplexer is composed of three parts, 1 e, input sources, multiplexing modules, and an output channel In this study it is modelled to be of the following basic form


Fig 43 ATM multiplexer system

### 4.2 Simulation Traffic Source Models

The traffic processes of the bursty sources have already been discussed in Chapter 2 In summary, A channel is shared by $N$ statistically identical and independent sources, alternating between bursts and silence periods In the following simulations these will be uniformly distrıbuted with mean value $\lambda($ cells per burst ) and $\mu$ ( slots per silence period ) Inıtially when the simulation
is commented the burst state is generated at random for each source using a predetermıned probabılıty dıstribution $\zeta[53]$ It is assumed that $\zeta$ equals $04[14]$ in this Chapter

The parameters $\lambda$ and $\mu$ can then be chosen according to the equation

$$
\zeta=\frac{\lambda}{\lambda+\mu}
$$

The cell arrıval process from a single bursty source consists of arrivals occurring at fixed intervals of $T \mathrm{~ms}$ during bursts and no arrivals at all during silences Therefore, the successive burst and silence perıods form an alternating renewal process All these tıme intervals are andependent, with each burst being of random length $X T$ and each silence period of random length $Y S T$ is the time between two successive cells arrıvals during a volce burst This is a small unit of information with a 4 octet header and 60 octet payload ( a cell equals 512 bits ) in this study ( see Fig 44 )[54]

The interarrival times of the cells are usually one packetization period $T$, but occasionally are expanded to encompass a packetızation period plus a sılence period ( Z $=Y S+T$ ) Thus, each cell interarrıval time from one bursty source equals length $T=1365 \mathrm{~ms}$ ( The peak offered load of each source $1 \mathrm{~s} 375 \mathrm{~kb} / \mathrm{sec}$, the mean offered load of
each source $15150 \mathrm{~kb} / \mathrm{sec}$, and a cell length is 512 bits ), with probability $p=219 / 220$ and of length $Y S+T$ with probability $(1-p)=1 / 220$, as shown in Fig 44 In general the packetization perıod $T$ depends on the cell length and the coding scheme used If we are to consider 64 kbs/sec ADPCM and a cell length of 512 bıts then the value of $T$ would be 8 ms The higher data rate which is used in this study would arıse from high qualıty speech lınks


$$
\begin{aligned}
* \mathrm{~T} & =400^{*} \mathrm{~S}, \text { it is a fixed packetzation penod } \\
\mathrm{mm} \mathrm{~S} & =3413 \times 10^{6} \mathrm{~s} \text {, it is a slot time }
\end{aligned}
$$

Fig 44 Packet arrival process for a burst source

### 4.3 Service Model and Flowcharts

The ATM multiplexer is assumed to be a standard single-server queue with limited buffer and a first-in-
first-out (FIFO) service discipline The traffic entering the FIFO queue is a superposition of $N$ independent and ıdentically distributed cell streams A cell service time equals a fuxed slot time of ( 512 bıts)/(150 Mb/sec) $\approx 3413$ $10^{-6}$ second In standard queuing parlance, this system can be simulated to become a discrete_time $\Sigma G / D / 1 / K$ (general statistics/constant service time/single server/finite buffer ) queuing model[44,55] The cells of each source arrive at the multiplexer with an average rate, $I=293$ cells/sec ( $150 \mathrm{~kb} / \mathrm{sec}$ ) An arriving cell 1 s transmitted immediately if the buffer is empty and the output channel is idle, otherwise this cell is queued in the ATM multiplexer buffer When the buffer content reaches the threshold $Q_{\max }\left(\right.$ or delay time $\left.T_{\max }\right)$, the newly arruving cells are discarded without generating retrials The server models a slotted channel with a fixed capacity of $C=150$ $\mathrm{Mb} / \mathrm{sec}$, and a fixed cell size of $D=512$ bıts/cell The service rate is denoted by $U=C / D \approx 293000$ cells/sec The flow diagrams illustrating this process are shown in Figs $45-46$ The priority service discipline will be discussed further in chapter 5


Move to next source Take a random number x from generatoro()


This source is in the burst state Take a random number x1 from generatorl() to generate the burst length with geometric distribution.
(cell)

This source is in the silence state. Take a random numbef $x 2$ from generator2( )to generate silence length with geometric distribution.
(slot)

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### 4.4 Simulation Assumptions and Conditions

Several assumptions and conditions associated with the source parameters and the system parameters of an ATM multiplexer must be defined before it's sımulation is attempted

The Source Parameters

1 The number of sources $N$ 1s 900, 920, 940, 960, 980, and 1000, ( that means the average offered load $\zeta$ is from 09 to 101

2 All sources are independent and identically distributed

3 The average burst length of each source XT is 300 ms This average value 15 derived from a uniformly distributed burst length which is a multiple of $T$

4 The average silence length of each source YS is 450 ms Again a uniform distribution of an integer number of slots describes this random varıable

5 The activity factor of the burst $\zeta$ is' 04

7 The average but rate of each source $A_{0}$ 1s 150 $\mathrm{kb} / \mathrm{s}$ ( the peak bit rate $A$ is equal to $375 \mathrm{~kb} / \mathrm{s}$, the mean offered load of $N$ sources $\rho$ equals $N A_{0}$ )

The System Parameters

1 The buffer size $K$ was chosen $100,200,300,400$, and 500

2 The service discipline is FIFO

3 There is only one output channel

4 The bit rate of output channel $C$ is $150 \mathrm{Mb} / \mathrm{sec}$ and $M=C / A$ indicates the maximum number of sources that can be accommodated in the ATM multıplexer

For the values chosen this gives an absolute maximum number of channels $\mathrm{N}=1000$, program using the C language at workstation $T o$ obtain the performance measures ( Cell loss probabilıty and delay distribution etc ), each sımulation was run for 60 sec

### 4.5 Performance Results


#### Abstract

Using the above values of the source parameters and the ATM system parameters, the simulation results are presented in Figs $47-415$


The distribution of the queue length (or buffer occupancy), for Buffer sıze $=100,200,300,400$ and 500, and for different values of the mean offered load $\rho(0)$, $092,094,096,098,10$, 15 shown in Figs 47 411 For each buffer size, the probabılıty distribution of queue length follows a bımodal behavıour, 1 e, the queue is alternatively almost full or almost empty[44] Such a phenomenon is inherent in the statıstıcal multiplexing, and which is more pronounced when the value of $\rho$ is higher Moreover, the curves of Figs 47-411 show that a buffer slze of about 30 cells ls the threshold beyond which the effect of the correlations cannot be neglected The region to the left of that threshold is called " sensitive region " The bımodal behavıour has been obtaıned using analytical and simulation methods for $K=50$ and for different values of $\rho(09,05$, and 02$)$ in Ref [56]

In Figs $412-413$, the cell loss probabilıty is plotted against the buffer sıze, for different values of $\rho$ In principle, a valuable reduction of the cell loss probability can only be achıeved by reducing $\rho$ or increasing $K$ The former, with low values of $\rho$ imply that
the efficlency of the dynamic bandwidth assignment will be low With the latter, the obtained curves ( See Fig 412 ) point out that an increase of the buffer size $K$ is practically 1 neffective for the cell loss probabılıty Such a phenomenon 15 more remarkable when increasing $\rho$ Only if $K$ is increased up to extremely high values can the cell loss values be evıdently reduced, but it is also to be taken into account that a maxımum delay $T_{\max }$ constraint implies an upper bound of $K$, for the hypothessized values of $C$ As a consequence, the matching between the desired quality of service and the performance of the ATM multiplexer can be obtained only by limıting the value of $\rho$ under the higher mean offered load $\rho($ See Fig 412 ) Oppositely, because the probability distribution of queue length is hıgher in the " sensitive region " when $09 \leq \rho$ $\geq 10$ Therefore, by increasing the buffer size and reducing the mean offered load, the cell loss probability is evidently decreased in the region, especially when $\rho$ is lower (See Fig 413 )

Fig $414-415$ shows the effect of buffer length and a range of different load values To satısfy the cell loss probabılıty of less than $10^{-5}, \rho$ has to be less than approximately 09 and $K$ greater than 200 cells


Fig 47 Probability distribution of queue length for various values of $\rho$ and a buffer size equal to 100 cells


Fig 48 Probability distribution of queue length for various values of $\rho$ and a buffer size equal to 200 cells


Fig 49 Probability distribution of queue length for various values of $\rho$ and a buffer size equal to 300 cells


Fig 410 Probability distribution of queue length for various values of $\rho$ and a buffer size equal to 400 cells


Fig 411 Probability distribution of queue length for various values of $\rho$ and a buffer sıze equal to 500 cells


Fig 412 Cell loss probabılıty versus buffer size for varıous values $\rho$


Fig 413 Cell loss Probabılıty versus buffer size for varıous values $\rho$


Fig 414 Cell loss Probabilıty versus $\rho$ for varıous values of the buffer sıze


# Chapter 5 Simulation of ATM Multiplexer 

## With Multiple QOS Classes

### 5.1 Introduction


#### Abstract

It has been discussed in Chapter 4 that bursty sources of the same characteristics are statistically multıplexed to efficiently utilize the network resources in an ATM multiplexer In general, The ATM networks will provide a wide range of multimedıa services with dıverse traffic flow characterıstics ( e 9 , bit rate and burstiness ) and quality of service ( QOS ) requirements Therefore, bandwidth management and traffic control are required to meet the QOS requirements of the various types of traffic $[57,58,59,60]$ In studyıng the QOS, it has to be recognized that there will be varıous required values for cell delay time $T_{\max }\left(\right.$ or $\left.T_{\text {average }}\right)$ and cell loss rate $\Gamma$ in a multimedia environment Thus, two QOS control methods are possible to define a single QOS class and control the QOS of all the media information equitably, or to define multiple qOS classes and control each different classified medıum individually In the first case, efficient use of the network resource is difficult since the most stringent QOS requirement should be selected as the network standard QOS In the second case, it wall be shown in this chapter


that the multiplexer gain can be improved by QOS control In addition, the users can select one of the classes appropriate to thelr requirements

In this Chapter, in order to design an economic and effective ATM multiplexer, the relationship between the traffic balance of classes and buffer size of each class 1 s studied The cell loss probability and delay time of each class ( same numerical distribution sources and different numerical distribution sources between the classes ) are evaluated

### 5.2 The Architecture of an ATM Multiplexer with Priority Classes

The $N$ sources are divided into three priority classes according to QOS requirements The sources of each class retain their bursty nature Traffic flow is a superposition of $N_{1}, N_{2}$, and $N_{3}\left(N_{1}+N_{2}+N_{3}=N\right)$ statıstically 1 dentical and independent sources, alternating between burst and silence perıods These are assumed to be uniformly distributed with mean values $\lambda_{1}\left(\lambda_{2}, \lambda_{3}\right)$ and $\mu_{1}\left(\mu_{2}, \mu_{3}\right)$, respectively Inıtıally burst / silence state distribution is generated at random, from a predetermined probability distribution $\rho_{1}\left(\rho_{2}, \rho_{3}\right)$ The offered load to each class is denoted by $A_{1}, A_{2}$, and $A_{3}$, respectively The offered load on each input source of these three Classes therefore becomes
$A_{1}{ }^{\prime}=A_{1} / N_{1}, \quad A_{2}{ }^{\prime}=A_{2} / N_{2}$, and $A_{3}{ }^{\prime}=A_{3} / N_{3}$, respectively Under this assumption, the buffer configuration is shown in Fig 51 The buffer length distribution of each class is mutually independent The buffer size of each class is selected according to the QOS requirements of each class In this study, only three FIFO buffers share a single server, in that there are only three $Q O S$ classes in this ATM multiplexer The cells of each class arrıve independently from the $N_{1}, \quad N_{2}$, and $N_{3}$ input sources and are distributed to each of the corresponding class buffers At each buffer, the cells are transmitted according to the FIFO discipline In one cell slot time of the output channel, only a single cell from among the three classes can be transmitted according to the priority assignment control ( see Section 53 ) The server models a slotted output channel with a fixed capacity of $C=150 \mathrm{Mbits} / \mathrm{s}$ and a fixed cell size of $D=512$ bıts/cell The service rate is denoted by $u=C / D$ $\approx 293000 \mathrm{cells} / \mathrm{s}$


### 5.3 Priority Assignment Control Method

In a multımedıa envıronment, the multıplexer gain can be improved by defining multiple QOS classes and using a QOS control which manages the required QOS of each class indlvidually Priority assignment control is presented as a QOS control method in an ATM multiplexer This method has been discussed in[1] It has been confirmed in [1] by simulation that this control method is more effective when the interclass quality difference is bigger and the burstiness of the traffic is stronger in [1] Moreover, the control scheme to enlarge the actual admissible offered load region by adaptively changing the priority assignment ratıo has also been presented In this control method, the transmıssion bandwidth ( output cell slots ) through which cells are transmitted with the highest priority is assigned to each class in a priorıty assignment perıod $P$ Each class can be given varıous QOS values by changing the priority assignment ratio $W_{n}$, which determines the minımum output bandwidth of each class

1) Prıorıty assignment ratıo ( $W_{1} W_{2} \quad W_{n}$ ) This parameter is the most predominant parameter in controlling the QOS of each class and should be determined according to the required QOS of each class and the traffic balance of the classes The minımum output bandwidth of each
class is guaranteed by the prıority assignment ratıo
2) Priority assignment perıod $P$ (cell slots ) The priority slots of each class will be distrıbuted in the period $P$ To efficlently assign the priority slot to each class, the value of $P$ should be a multiple of sum of the priority assignment ratıo of each class $\left(W_{1}+W_{2}+\quad+\right.$ $W_{n}$ ) The priority slots of each class should be distributed as periodically as possible in the period $P$ in order to reduce the output burstiness of each class for the next switching node
3) Priority scheduling in each cell slot When more than two QOS classes are multiplexed, if there are no waiting cells of the class that has the highest priority at the slot, a cell of one of the other classes can be transmitted This allows improvements in bandwidth efficiency compared to a segregation of bandwidth among the separate queues The priority scheduling is shown in Fig 52


Fig 52 Priority assignment control method

In this control method, the maximum delay time of each class is not equal to the upper limit value of queue length It not only relates to the upper limit of queue length, but also relates to the priority assignment ratio In other words, the maximum delay time of each class $1 s$ guaranteed by the priority assignment ratio and the upper limit of the queue length it is assumed that corresponding to the priority assignment ratio $W_{1} \quad W_{2} \quad W_{n}$, the upper limit of the queue length of each class $Q_{1}, Q_{2}, \quad Q_{n}$ will be determined so that the maximum delay time in each class $D_{1}, D_{2}, \quad D_{n}($ cell slot $)$ will meet the required value as follows[1]

$$
\begin{aligned}
& Q_{1}=D_{1} * W_{1} /\left(W_{1}+W_{2}+\right. \\
& Q_{2}=D_{2} * W_{2} /\left(W_{1}+W_{2}+\right. \\
& \\
& Q_{n}=D_{n} * W_{n} /\left(W_{1}+W_{2}+\right. \\
& \left.+W_{n}\right)
\end{aligned}
$$

When the queue length exceeds the upper limit value, arriving cells are discarded If the priority assignment ratio is changed, the upper limıt value of the queue length must also be changed

[^2]

Move to next source, distingush the class of the source.


Take a random number $x$ from generator00


This source ts in the burst state. According to the source perameters of the class i and $x 1$ wich is from generator 10 to generate the burst leagth with uniform distriburion. ( coll )

This source is in the silence state. According to the source parameters of the class 1 and $x 2$ which is from generator 20 to generate the sileace length with unifform destribution. ( slot)


### 5.4 Performance Results


#### Abstract

The results of the performance parameters simulated are specıfıcally focused on the cell loss probabılıty and cell delay time at the buffer of each class in this study All of the simulations reported in the Chapter are based on the assumptions of a fixed cell size of $D=512$ bıts/cell , the average bit rate of each source $A_{0}=150 \mathrm{~kb} / \mathrm{s}$, and an output capacity of $C=150 \mathrm{mb} / \mathrm{s}$ In addition, The priority assignment perıod $P$ is equal to 6 cell slots and the priority assignment ratio of each class $1 s W_{1}=3, W_{2}=2$, and $W_{3}=1$ The simulations were run for 100 seconds Two different input categories are considered in this priority multiplexing scheme


## Type 1 input category

The reference sources of each class have the same parameter values, and the average offered loads of each class $A_{1}, A_{2}$, and $A_{3}$ have the same values, 1 e , $A_{1}=A_{2}=A_{3}$ These values are
a The peak bit rate of each source $F_{p}=375 \mathrm{~kb} / \mathrm{s}$
b Average bıt rate of each source $F_{a}=150 \mathrm{~kb} / \mathrm{s}$
c The burst activity factor $\rho=F_{a} / F_{p}=04$
d Average burst length $L_{b}=300 \mathrm{~ms}$
e Average silence length $L_{s}=450 \mathrm{~ms}$
f The buffer sizes of each class have the same values, 1 e , 10 cells ( or 15 cells )

Using these parameter values simulation, of the ATM multiplexer with priorıty classes has been carrıed out The simulation results are presented in Fig 55-56



Mean Traffic Intensity of Each Class
Fig 56 Delay times at each buffer versus $A\left(A=A_{1}+A_{2}+A_{3}\right)$ where $A_{1}=A_{2}=A_{3}$

The cell loss probabılıty versus the buffer sıze ( 10 cells and 15 cells ), and with different values of $A=A_{1}+$ $A_{2}+A_{3}\left(A_{1}=A_{2}=A_{3}\right)$ is shown in Fig 55 This figure shows that when the buffer size of each class changes between 10 and 15 cells, then the cell loss probabılıty of each class changes accordingly With hıgher priorıty classes, the change becomes more obvious Usually, the cell loss probabılıty of each class steadıly became higher with the increase of the average offered load of these three classes, but, after the total average offered load $A$ reaches about 0 9, the cell loss probabılıty $\Gamma_{1}$ remains approximately constant the change of the cell loss probability is very little ) The point of 09 is called "the critical point", and the rıght of the crıtical point is called "the steady region" In the region, Only by increasing $K_{1}$ can the cell loss probabilıty $\Gamma_{1}$ be evidently decreased This is because class 1 has the highest prıorıty of being served on the output channel When $A$ is less than $09\left(A_{1}<03\right)$, the bandwidth allocation of class 1 is not enough the After 0 9, despite the fact that the increasing $A_{1}, A_{2}$ and $A_{3}, \Gamma_{1}$ will remain approximately constant at a cell loss probabılıty of 3 119600e-05 for a buffer sıze of 1s 10 cells ( it is zero when the buffer size is reduced to 15 cells ) Of course, if $A_{1}$ is too big, the cell loss probability $\Gamma_{1}$ will be increased apparently

As is shown in Fig 56 , the average delay time varies significantly with the buffer size at the lower priority
class, whıle the varıations of the average delay tımes for the different buffer sızes at higher priorıty classes are not apparent These phenomena can be explaned by the fact that the probability distribution of longer queue lengths is generally higher for the lowest priority class, especially under higher average offered loads for the highest priority classes the probabılıty distrıbution of smaller queuing length is usually hıgher, particularly under lower average offered load (See Fig 57 )

It has been shown in Chapter 4 that the probabilıty distribution of queue length follows a bimodal behaviour in the statistical multiplexing without priority class Such a phenomenon also happens when the prıorıty classes are introduced as shown in Fig 57


Fig 57 Probability distribution of queuing length for $A=09,099\left(A=A_{1}+A_{2}+A_{3}\right.$, and $A_{1}=A_{2}=A_{3}$, the buffer size $K 1=K 2=K 3=10$ cells


#### Abstract

The reference sources of each class are the same as in Type 1, but the average offered load ( $A_{1}$, $A_{2}$, and $A_{3}$ ) of one of these three classes is a constant.


It is assumed that $A_{1}=0.4\left(\right.$ or $\left.A_{2}=0.4, A_{3}=0.4\right)$, and then the average offered loads of other two classes are increased gradually. The results are shown in Fig. 5.85.13. The increasing average offered loads of any two classes of these three classes will lead to an increase in the total average offered load $A$. Generally speaking, the cell loss probabilities of each class is increased, and the delay times of each class is also increased ( See Fig. 5.85.13). In Fig. 5.8, the average offered load of class 1 is a constant, i.e., $A_{1}=0.4$. The cell loss probability of class $1\left(\Gamma_{1}\right)$ steadily became higher with the increase of the average offered load of the other two classes, $A_{2}$ and $A_{3}$. But, after the total average offered load $A$ reaches about 0.92 ( i.e., "the critical point" is 0.92.), $\Gamma_{1}$ will remain approximately constant at a cell loss probability of $8.332914 \mathrm{e}-05$ for a buffer size of is 15 cells ( it is about $1.269284 \mathrm{e}-03$ when the buffer size is reduced to 10 cells ). However, The value of the constant depends to a large extent on The priority assignment period $P$, the priority assignment ratio of each class, and the value of $A_{1}$ when the

```
total average offered load A reaches "the crıtical point"
(See Fig 5 10, 5 12)
    In Fig 5 9, 5 11, 5 13, it is also shown that the
variations of the average delay times for the different
buffer slzes at hlgher priority classes( or at lowest
priority class when }\mp@subsup{A}{3}{}\mathrm{ is smaller ) are not apparent
```

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Mean Traffic Intensity of Each Class
Fig 58 Cell loss probabılıtıes of each class versus $A\left(A=A_{1}+A_{2}+A_{3}\right.$ ) where $A_{1}$ is a constant


Mean Traffic Intensity of Each Class
Fig 59 Delay tames at each buffer versus $A\left(A=A_{1}+A_{2}+A_{3}\right)$ where $A_{1}$ ls a constant


Mean Traffic Intensity of Each Class
Fig 510 Cell loss probabilities of each class versus $A\left(A=A_{1}+A_{2}+A_{3}\right)$ where $A_{2}$ is a constant


Mean Traffic Intensity of Each Class
Fig 511 Delay times at each buffer versus $A\left(A=A_{1}+A_{2}+A_{3}\right)$ where $A_{2}$ is a constant


Fig 512 cell loss probabılıtıes of each class versus $A\left(A=A_{2}+A_{2}+A_{3}\right)$ where $A_{3}$ is a constant


Fig 513 Delay times at each buffer versus $A\left(A=A_{1}+A_{2}+A_{3}\right)$ where $A_{3}$ is a constant

## Chapter 6 Conclusions


#### Abstract

The specific focus of this thesis has been on the performance of an ATM multiplexer for bursty sources There are two themes in the thesis 1) simulating an ATM multiplexer without priority class for bursty sources 2) simulating an ATM multiplexer with three priority classes for bursty sources All of the simulations reported are based on the assumptions of a fixed cell size of $D=512$ bits/cell, an average bit rate of each source of $A_{0}=150$ $\mathrm{kb} / \mathrm{s}$, a multiplexer output capacity of $C=150 \mathrm{Mb} / \mathrm{s}$

In the first theme, The distribution of the queue length, for different Buffer sizes and values of the average offered load $\rho$ has been analyzed Thus, a inherent phenomenon of the distributions of the queue length has been brought to light in statistical multiplexing ------ a bımodal behavıour However, a threshold value of the buffer size is found through observing the bimodal behaviour When the buffer size $K$ is less than the threshold, the cell loss probability is apparently decreased by increasing $K$ and reducing $\rho$, especially when $\rho$ is lower But, changing $K$ is practically ineffective for the cell loss probabılıty when $K$ is bigger than the threshold Such the effect is more pronounced under increasing $\rho$ Only if $K$ is increased up to extremely high values can the cell loss values be


significantly reduced it should also be taken into account that a maximum delay $T_{\max }$ constraint implies an upper bound on $K$, for the chosen value of $C$ As a consequence, the matching between the desired $Q O S$ and the performance parameters of the ATM multiplexer can be obtained only by limiting the value of $\rho$ when $K$ is bigger than the threshold these results are very useful in the design of an economıc and effective ATM multiplexer

In the second theme, two different input categories, which share an ATM multiplexer with three priority classes respectively are considered using the priority assignment control method of [15] The relationship between the traffic balance of the three classes and buffer size of each class is studied The cell loss probabılıty and delay time of each class are evaluated

In the first input category, the reference sources of each class have the same parameter values, and the average offered loads of each class $A_{1}, A_{2}$, and $A_{3}$ have the same values, 1 e , $A_{1}=A_{2}=A_{3}$ In the second input category, the reference sources of each class are the same as 1), but the average offered load ( $A_{1}, A_{2}$, and $A_{3}$ ) of one of these three classes is a constant It is found out that these two different input categories have some generalities in the QOS parameters respect ( the cell loss probabılıty and delay tıme of each class )

For the cell loss probability, when the buffer size of each class is increased, then the cell loss probability of each class must also be raised accordingly. With higher priority classes, the rate of increase becomes more obvious. Usually, the cell loss probability of each class steadily became higher with the increase of the average offered load of these three classes. But, after the total average offered load $A$ reaches a certain value, which is called "the critical point", despite the increasing $A$, the cell loss probability $\Gamma_{1}$ remains approximately constant. The value of the constant depends to a large extent on the priority assignment period $P$, the priority assignment ratio of each class, and the value of $A_{1}$ when the total average offered load A reaches "the critical point". The right of the critical point is called "the steady region". In this region, only by increasing $K_{1}$ can the cell loss probability $\Gamma_{1}$ be evidently decreased. To satisfy the QOS requirements of each class and to allocate the bandwidth of each class effectively, the bandwidth of the highest priority class must first be allocated in the "steady region", then the cell loss probability $\Gamma_{1}$ is satisfied by changing only the buffer size, because the effect of changing $A_{1}$ is not evident in the "steady region". But, for the other two classes the cell loss probability can be satisfied by changing either of the buffer size and the average offered load.
with the buffer size at the lowest priority class when the average offered load of this priority class $1 s$ very large, while the variations of the average delay times for the different buffer sizes at higher priority classes( or at lowest priority class when $A_{\text {lowest }}$ is very small ) are not apparent These phenomena can be explained by the fact that the probability distribution of longer queue lengths is generally higher for the lowest priority class, especially under higher average offered loads for the highest priority classes the probability distribution of smaller queuing length is usually higher, particularly under lower average offered load

The above results are very useful to allocating bandwidth of each class effectively in ATM multıplexer with the priority class

## References

2 T S Rzeszewskı, "A Two layer Fibre Network for Broadband Integrated Services," IEEE Transactions on Consumer Electronics, Vol 35, No 2, May 1989

3 Ralner Handel, "Evolution of ISDN Towards Broadband ISDN," IEEE Network, January 1989

4 T1S1 1/89-395, "T1S1 Technical Sub-committee Broadband Aspects of ISDN Baselıne Draft Document", Sept 1989

5 CCITT Rec I 121, "Broadband aspects of ISDN", Geneva, June 1988

6 CCITT Rec I 221, "B-ISDN service aspects", Geneva Meetıng, 23-25 May 1990

7 CCITT Rec I 151, "B-ISDN ATM Functional Characteristıcs", June 1990

8 CCITT Rec I 361, "B-ISDN ATM Layer Specıfication", June 1990

9 CCITT Rec I 150, and I 361 - I 363, "Broadband aspects of ISDN-B-ISDN ATM functional characteristics, ATM layer specification for $B-$ ISDN, and B-ISDN ATM adaptation layer functional descrıption/specıfıcatıon", June 1990

10 CCITT Draft Revision of Rec I 121, "Broadband Aspects of ISDN", June 1990

11 C Anthony Cooper, "Toward a Broadband Congestion Control Strategy," IEEE Network Mag, May 1990

12 Simon Kayking, Digital communications, John Wiley \& Sons, Inc New York, 1988

13 Joseph Y Hul, "Network, Transport, and Switching Integration for Broadband Communication", IEEE Network, March 1989

14 Joseph $Y$ Hul, Switching and Traffic Theory for Integrated Broadband Network, New York, SpringerVerlag, 1989

15 Dogan A Tugal, Data Transmission Analysis, Design, Applications, McGraw-Hıll Book Company, New York, 1982

16 Elbert, Bruce R, Private Telecommunications Networks, Artech House. Inc 1989

17 Roy D Rosner, Distributed Telecommunications Networks, Wadsworth, Inc 1982

18 Mischa Schwartz, Telecommunication Networks Protocols, Modelling and Analysis,

19 Peter Newman, "A Fast Packet Switch for the Integrated Services Backbone Network", IEEE J Select Areas Commun , Vol 6, No 9, Dec 1988

20 Pıerre-Girard Fontollıet, Telecommunication Systems, Artech House, Inc 1986

21 David R Smith, Digital Transmission Systems, Wadsworth, Inc New York, 1985
$22 J Y$ Huı, "Resource Allocation for Broadband Networks," IEEE $J$ Select Areas Common , Vol 6, no 9, Dec 1988

23 Rainer Hondel, "Evolution of ISDN Towards Broadband ISDN", IEEE Network, Jan 1989

24 Mıchael J Rıder, "Protocols for ATM Access Networks", IEEE Network, Jan 1989

25 Steven E Minzer, Broadband ISDN and Asynchronous Transfer Modode (ATM), IEEE Commun Magazine, Sep 1989
$26 \mathrm{P} K$ Prasanna, $R$ Zoccolıllo, "Discussion of Emerging Broadband ISDN Standards", IEEE T C E, Vol 35, No 2, May 1989

27 Susumu Yoneda, "Broadband ISDN ATM Layer Management Operations, Administration, and Maintenance Considerations," IEEE Network, May 1990

28 Marek R Wernık, "Broadband Publıc Network and Swıtch Archltecture," IEEE Commun Mag Jan 1991

CCITT COM XVIII-288-E, Mar 1989
30 Wıllıanm $R$ Byrne, "Broadband ISDN Technology and Archıtecture, IEEE Network, Jan 1989

31 Marıo Gerla, "Toplogy Design and Bandwidth Allocation in ATM Nets," IEEE $J$ Select Areas Commun, Vol 7, No 8, Oct 1989

James $F$ Mollenauer, "Standards for Metropolitan Area Networks," IEEE Commun Mag, Vol 26, No 4, Aprıl 1988

William $R$ Byrne, "Evolution of Metropolitan Area Networks to Broadband ISDN," Commun Mag, Jan 1991

34 Janusz Fılıpıak, "Structured Systems Analysis Methodology for Design of an ATM Network Architecture" IEEE $J$ Select Areas Commun, Vol 7, No 8, Oct 1989

35 Kotıkalapudı Srıram, Ward Whıtt, "Characterızıng Superposition Arrıval Processes in Packet Multiplexers for Volce and data," IEEE $J$ Select Areas Commun, Sep 1986

36 Gıllıan $M$ Woodruff, "Multımedıa Traffic Management Principles for Guaranteed ATM Network Performance," IEEE $J$ Select Areas Commun , Vol 8, No 3, April 1990

37 James $W$ Roberts, "The Superposition of Periodic Cell Arrival Streams in an ATM Multıolexer," IEEE Transaction on Commun, Vol 39, No 2, Feb 1991

38 Jerry Gechter, "Conceptual Issues for ATM," IEEE Network, Jan 1989

39 M G Hartley(ed), Digital Simulation Methods, Peter peregrinus England, 1975

40 John R Clymer, Systems Analysis Using Simulation and Markov Models, Prentice_Hall, Englewood Clıffs, NJ, 1990

41 Fu Zhang, Telecommunication Traffic Engineering, The People's Post and Telecommunlcation Publishing House, Beljung, 1986

42 Ricardo $F$ Garzia(ed), Network Modelling, Simulation, and Analysis, Bell Telephone Laboratories, 1990

43 John $E$ Freund, Ronald $E$ Walpole, Mathematical Statistics, Prentice-Hall, Englewood Clıffs, N J, 1989

44 R L Barlow, Statistics, John Wiley \& Sons, England, 1989

45 Ronald E Walpole, Introduction to Statics, Macmillan Publishing Co. New York, 1982

46 Arnold O Allen, Probabılıty, Statıstics, and Queuing Theory, New York, 1978
47. Ilkka Norros, "The Superposition of Variable Bit Rate Sources in an ATM Multiplexer," IEEE J. Select. Areas Commun., Vol. 9, No. 3 April 1991.
48. Hiroshi Saito, "An Analysis of Statical Multiplexing in an ATM Transport Network," IEEE J. Select. Areas Common., Vol. 9, no. 3,April 1991.
49. Lisa G. Dron, "Delay Analysis of Continuous Bit Rate Traffic Over an ATM Network," IEEE J. Select. Areas Commun., Vol. 9, No. 3, April 1991.
50. A.A. Lazar, A. Temple, and R.Gidron, "An architecture for integrated network that guarantees quality of service," Int. J.Digit. and Analog Commun. Syst., Vol. 3, No. 2,Apr. -June 1990.
51. Hirokazu Ohnishi, Tadanobu Okada, "Flow Control Schemes and Delay/Loss Tradeoff in ATM Networks," IEEE J. Select. Areas Common. Vol. 6, no. 9, Dec. 1988.
52. C. Anthony Cooper, "Toward a Broadband Congestion Control Strategy," IEEE Network Mag., May 1991.
53. Nanying Yin, "Congestion Control for Packet Voice by Selective Packet Discarding," IEEE Transactions on Commun., Vol. 38, No. 5, May 1990.
54. Roger C. F. Tucker, "Accurate Method for Analysis of a Packet-speech Multiplexer with Limited Delay," IEEE Transactions on Commun., vol. 36, No. 4, April 1988.
55. Yoshihiro Ohba, Masayuki Murata, "Analysis of Interdeparture Processes for Bursty Traffic in ATM Network," IEEE J. Select. Areas Commn. Vol. 9, no. 3, April 1991.
56. Andrea Baiocchi, "Loss Performance Analysis of an ATM Multiplexer Loaded with High-Speed ON-OFF Sources", IEEE J. Select. Areas Common., Vol. 9, No. 3, April 1991.
57. Yasushi Takagi, "Priority Assignment control of ATM Line Buffers with Multiple QOS Classes," IEEE J. Select. Com. 5, Vol. 9, No. 7, Sep. 1991.
58. Jay M. Hyman, "Real- time Scheduling with Quality of Service Constraints," IEEE, J. Select. Areas Commun., Vol. 9, No, 7, Sep. 1991.
59. Arthur Y.-M. "Priority Queuing Strategies and Buffer Allocation Protocols for Traffic control at an ATM Integrated Broadband Switching System," IEEE J.

Select Areas Commun , Vol 9, Des 1991
Hans Kroner, "Priority Management in ATM Switching Nodes," IEEE $J$ Select Areas Commun , Vol 9, No 3, April 1991

## APPENDIX

## APPENDIX A

## Critical Values of the $t$ Distribution

| n |  | 10 | 0 | 05 | 0 | $\begin{aligned} & \alpha \\ & 025 \end{aligned}$ | 0 | 01 | 0 | 005 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 3 | 078 | 6 | 314 | 12 | 706 | 31 | 821 | 63 | 657 |
| 2 | 1 | 886 | 2 | 920 | 4 | 303 | 6 | 965 | 9 | 925 |
| 3 | 1 | 638 | 2 | 353 | 3 | 182 | 4 | 541 | 5 | 841 |
| 4 | 1 | 533 | 2 | 132 | 2 | 776 | 3 | 747 | 4 | 604 |
| 5 | 1 | 476 | 2 | 015 | 2 | 571 | 3 | 365 | 4 | 032 |
| 6 | 1 | 440 | 1 | 943 | 2 | 447 | 3 | 143 | 3 | 707 |
| 7 | 1 | 415 | 1 | 895 | 2 | 365 | 2 | 998 | 3 | 499 |
| 8 | 1 | 397 | 1 | 860 | 2 | 306 | 2 | 896 | 3 | 355 |
| 9 | 1 | 383 | 1 | 833 | 2 | 262 | 2 | 821 |  | 250 |
| 10 | 1 | 372 | 1 | 812 | 2 | 228 | 2 | 764 |  | 169 |
| 11 |  | 363 | 1 | 796 | 2 | 201 | 2 | 718 | 3 | 106 |
| 12 |  | 356 | 1 | 782 | 2 | 179 | 2 | 681 | 3 | 055 |
| 13 |  | 350 | 1 | 771 | 2 | 160 | 2 | 650 | 3 | 012 |
| 14 |  | 345 | 1 | 761 | 2 | 145 | 2 | 624 | 2 | 977 |
| 15 | 1 | 341 | 1 | 753 | 2 | 131 | 2 | 602 |  | 947 |
| 16 |  | 337 | 1 | 746 | 2 | 120 | 2 | 583 | 2 | 921 |
| 17 | 1 | 333 | 1 | 740 | 2 | 110 | 2 | 567 | 2 | 898 |
| 18 | 1 | 330 | 1 | 734 | 2 | 101 | 2 | 552 |  | 878 |
| 19 | 1 | 328 | 1 | 729 | 2 | 093 | 2 | 539 |  | 861 |
| 20 | 1 | 325 | 1 | 725 | 2 | 086 | 2 | 528 |  | 845 |
| 21 |  | 323 | 1 | 721 | 2 | 080 | 2 | 518 | 2 | 831 |
| 22 | 1 | 321 | 1 | 717 | 2 | 074 | 2 | 508 | 2 | 819 |
| 23 | 1 | 319 | 1 | 714 | 2 | 069 | 2 | 500 | 2 | 807 |
| 24 | 1 | 318 | 1 | 711 | 2 | 064 | 2 | 492 | 2 | 797 |
| 25 | 1 | 316 | 1 | 708 | 2 | 060 | 2 | 485 |  | 787 |
| 26 |  | 315 | 1 | 706 | 2 | 056 | 2 | 479 |  | 779 |
| 27 | 1 | 314 | 1 | 703 | 2 | 052 | 2 | 473 |  | 771 |
| 28 | 1 | 313 | 1 | 701 | 2 | 048 | 2 | 467 |  | 763 |
| 29 | 1 | 311 | 1 | 699 | 2 | 045 | 2 | 462 |  | 756 |
| inf | 1 | 282 | 1 | 645 | 1 | 960 | 2 | 326 |  | 576 |

Extract this table from [5].

## APPENDIX B

Critical Values of the Chi-Square Distribution


Extract this table from [5].


[^0]:    3 Recent publications include Space Division Multiplexing among multiplexing techniques it is accomplished by bounding the metallic wires or coaxial pairs together to form a single cable It is a useful and economical technıque when relatively few channels are to be transmitted in a short distance within a building or in an exchange area for local customer connections

[^1]:    * The level of significance of the test $\alpha$ is usually chosen to be 0.05 .

[^2]:    The flow diagrams illustrating this priority assignment control method are shown in Figs $53-54$

