Modeling and Simulation of Traffic Control Mechanisms in ATM Networks

A Thesis

Submitted in fulfillment of the
requirements for the award of the degree of

Doctor of Philosophy

Submitted by

Sakshi Kaushal
(Registration No. 9030353)

Under the supervision of

Dr. R. K. Sharma
Professor
School of Mathematics and Computer Applications
Thapar University, Patiala.

Department of Computer Science and Engineering
Thapar University,
Patiala–147 004 (Punjab) India.
August 2008

CERTIFICATE

I hereby certify that the work which is being submitted in this thesis entitled **"MODELING AND SIMULATION OF TRAFFIC CONTROL MECHANISMS IN ATM NETWORKS"**, in fulfillment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY** submitted in Department of Computer Science and Engineering, Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of Dr. R. K. Sharma and refers work of other researchers which are duly listed in the reference section.

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

Sakshi Kaushal

(Sakshi Kaushal)
Reg. No. 9030353

This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge and belief.

RK Sharma
27/8/08

(R. K. Sharma)
Professor, SMCA and Dean of Academic Affairs,
Thapar University,
Patiala–147 004 (INDIA).
Supervisor

ABSTRACT

Broadband Integrated Services Digital Network (B-ISDN) represents the most important development in the evolution of telecommunication systems. The aim of B-ISDN is to provide an all-purpose, flexible, efficient and cost effective environment for all new emerging services based on voice, video and data in an integrated fashion. High speed networks provide real-time variable bit rate service with diversified traffic flow characteristics and quality requirements. The main challenge here is the efficient use of network resources and mechanisms in order to achieve a satisfactory quality performance. In order to achieve the aggressive goal, which B-ISDN aims at, a promising transfer and switching technique called Asynchronous Transfer Mode (ATM) has been adopted. The Quality of Service (QoS) measures, such as, cell loss and delay in ATM nodes are the parameters that significantly contribute to the degradation of network performance. It is worth noting that the control of each of these parameters has a special impact on the other parameter, for example, voice traffic can tolerate some cell loss but is very sensitive to cell delay, while video and/or data transfer applications can allow for some delay but not the cell losses. For video applications, the loss of consecutive cells becomes even more critical when reproducing the original data.

Buffer management in queueing systems plays important role towards effective control of QoS for various types of applications. Traffic can be shaped by placing cells into buffers to compensate for a difference in rate of flow of data or time of occurrence of events. With larger buffers, the probability of losing cell decreases but the overall delay increases. Hence, it becomes necessary to utilise buffering and scheduling algorithms to regulate QoS attributes in a high speed network. In this thesis, the focus is given on two important design factors, namely, buffer management and scheduling algorithms. We assume that one can always improve performance by increasing speed, selecting a more efficient operating system, or even building specialised hardware to replace inefficient software components. However, for a pre-determined set of available resources, we examine the impact of buffer management algorithms on most important QoS attribute, *i.e.*, cell loss. The network is prone to cell loss in the situation of congestion, when multiple cells blasting away simultaneously at peak rate through different incoming links attempt to reach the same outgoing link during the same cell slot time. In this case, only

one cell is allowed to go through the network while the others must be stored in buffers. At this time, a switch buffering strategy as well as the buffer size becomes important since buffers are required to achieve low cell loss rate by providing a place to guard against cell loss when the switch is overloaded with bursty traffic.

The control schemes usually categorise and manage the cells based on the cell loss priorities assigned to them, which determines the cells to be dropped in case of congestion. The main function of cell discarding mechanisms in congested network is to control the relative cell loss probabilities of different cell discarding algorithms. It has been shown in the literature that priority-based cell discarding improves the system performance for voice and video traffic. The present thesis considers the space priority mechanisms for optimising the network utilisation in broadband networks and evaluates the impact of controlling traffic and improvement of network’s throughput; when priorities are used. Two buffer management schemes, namely, Pushout scheme and Partial Buffer Sharing (PBS) scheme, use selective cell discarding of cells in buffer. It has been shown that the PBS scheme not only performs well to meet the QoS requirements for multiple priority classes but is also easy to implement. As such, this scheme has been proposed as a candidate for overload control mechanism. In a number of research works, the PBS scheme is analysed with different types of Poisson arrival processes. The challenge in designing a PBS scheme is to select optimal threshold value to obtain desired relative cell loss ratio among the different classes of traffic.

The objective of present work is to seek optimal solution of PBS mechanism for reducing cell loss and hence improving QoS when the threshold is able to adapt based on input traffic. In order to accomplish these objectives, a comprehensive study of various priority-based methods used for controlling cell loss in high speed networks has been carried out. The analysis of PBS scheme revealed that due to fixed threshold in buffer, the cell loss control is effective only for single priority class, irrespective of the input traffic model and its characteristics. To make the buffer adaptive for adjusting relative cell loss ratios according to input traffic conditions, the dynamically controlled threshold method has been designed to be called as ADaptive Partial Buffer Sharing (ADPBS) scheme. In this scheme, the threshold is dynamically varied in run-time based on consecutive cell loss behavior for two priority classes. Its queueing performance is analysed using two different traffic models, namely, Poisson input traffic model and Autoregressive process based video model. Also, different traffic load values, input traffic mix, threshold control parameter combinations and different buffer sizes are used for analysing the performance of the proposed method. All the simulation experiments are conducted using MATLAB 7.0 and the results for dynamic threshold are compared with First In First Out (FIFO) queue and PBS queue having Static (or fixed) threshold (SPBS).

This thesis is divided into six chapters. A brief outline of each chapter is given in the following paragraphs.

First chapter introduces the B-ISDN and ATM networks. It gives an overview of the role of traffic control and management functions of the ATM layer. The QoS parameters are discussed in relation to different ATM service classes. The main focus in the presentation is on various priority mechanisms under Usage Parameter Control (UPC) that have been devised so far and are used in this thesis.

In second chapter, review of the literature relating to the traffic and network resource management has been done. A detailed survey on algorithms and input traffic models for buffer management under PBS scheme in ATM switch has also been carried out.

Third chapter is divided into two parts. In the first part, PBS priority mechanism has been implemented using a fixed-size buffer being serviced by a single server for traffic streams of high priority (real-time) and low priority (non-real-time) cells. A recursive algorithm is implemented in MATLAB to calculate loss probabilities for block of consecutive cells. The effect of different threshold values on cell loss probabilities is also examined. The second part discusses the proposed model with adaptive threshold for PBS queue. The algorithm for adaptive partial buffer sharing scheme is implemented in MATLAB that assumes a finite queue of fixed-size with the initial value of threshold set at 70% of buffer size. The source traffic with two classes of priorities; class 1 with high priority and class 2 with low priority are considered. The threshold in ADPBS scheme is not fixed and is varied dynamically according to the type and burstiness of incoming traffic. The cell loss ratio is controlled by adaptive threshold that depends on a set of control parameters.

Chapter four provides the analysis of adaptive threshold controlled partial buffer management scheme in which the threshold is dynamically varied in runtime based on consecutive cell loss behavior for two priority classes. The performance of ADPBS queue is analysed with Cell Loss Ratio as a major QoS parameter using Poisson traffic model as input source to the FIFO, Static threshold PBS and ADPBS queues. In the source model, the inter-arrival time of the cells is distributed exponentially. The source traffic module and the queueing system are simulated using MATLAB. The cell loss data of each queue is captured by a common module and this is used for performance analysis of all the three queues. This chapter is structured in a manner to present results of each traffic condition in a separate section. It is commonly observed for various combinations of threshold control parameters that the ADPBS queue manages to adapt the threshold to allocate sufficient buffer space for the kind of traffic class which forms majority in the incoming traffic; as such, high and low priority cell loss is reduced upto 93% and 28%, respectively, in comparison with other two types of queues.

In fifth chapter, the performance of ADPBS queue is analysed with Variable Bit Rate (VBR) based video traffic model for frame sizes of MPEG encoded video sequence based on second order nested autoregressive processes. With the nested autoregressive processes in traffic model, the empirical video sequences can be captured at both small and larger lags. The implementation of complete model along with the three queues is done using MATLAB. The simulations are carried out under different traffic conditions, such as, various combinations of threshold control parameters, varying traffic load, input traffic mix variation and different buffer sizes. For performance analysis, the simulation is carried out by taking 30 samples under each category and the results of simulations are captured, compiled and compared for all three queues. The relative cell loss ratio of high priority cells and low priority cells, when compared for different input traffic mix ratios, is 14 times and 2.2 times higher in SPBS queue than that in ADPBS queue, respectively. The overall consecutive cell loss in ADPBS scheme is 83% less than the consecutive cell loss in SPBS queue for high priority traffic and 54% less for low priority traffic.

Finally, Chapter six presents the inferences drawn as a result of the various simulations conducted in this thesis. Also, some pointers to the future research on the topic under consideration in this thesis are discussed briefly in this chapter.

ACKNOWLEDGEMENTS

At the outset, I am highly indebted to my revered supervisor, Dr. R. K. Sharma for his untiring support, encouragement and able guidance at each and every step throughout this research endeavor. I find no words to express my heartfelt thanks to Professor Sharma for supervising this work so diligently and delightfully.

I wish to thank Department of Computer Science and Engineering, Thapar University for providing the research facilities and various other resources which were extremely valuable in the completion of this thesis. I am also grateful to UIET department, Panjab University, Chandigarh for giving me permission to attend International Conference WMSCI'2005, USA during my Ph.D. program and thus helped me to gain valuable international research experience.

I express my gratitude to the Doctoral Committee Dr. Seema Bawa, Dr. Rajesh Kumar and Dr. Mahesh Kumar Sharma for monitoring the progress and providing valuable suggestions for improvement of my Ph.D. research work.

I appreciate the cooperation received from all my friends and colleagues especially Dr. B. S. Sohi, Director, U.I.E.T, Panjab University, Ms. Damandeep Kaur, Thapar University, Mr. Sarbjeet Singh, U.I.E.T, Panjab University.

I extend my unending thanks and utmost appreciation to my parents for their undying love, support, encouragement and to afford me all the opportunities I've ever asked for.

I am extremely beholden to my husband who has taken lot of efforts in shaping my research work and stood as a pillar of strength for me with unending faith and empathy. I am not able to find words to express my feelings for my little daughter Savi who was really deprived of her mother's attention and care for a considerable period but whose love never wavered.

FINALLY, I GENUFLECT TO THE ALMIGHTY FOR THE INNATE IMPETUS.

Sakshi Kaushal

(Sakshi Kaushal)

LIST OF FIGURES AND GRAPHS

ABBREVIATIONS

ABR	Available Bit Rate
ADPBS	ADaptive Partial Buffer Sharing
AR	Autoregressive
ATM	Asynchronous Transfer Mode
BBP	Bulk Bernoulli Process
B-ISDN	Broadband Integrated Services Digital Network
BT	Burst Tolerance
CAC	Connection Admission Control
CBR	Constant Bit Rate
CDV	Cell Delay Variation
CDVT	Cell Delay Variation Tolerance
CER	Cell Error Ratio
CLP	Cell Loss Priority
CLR	Cell Loss Ratio
CMR	Cell Mis-insertion Ratio
CSLB	Continuous-State Leaky Bucket
CTD	Cell Transfer Delay
DADT	Different Algorithm with Different thresholds
DAR	Discrete autoregressive
DAR(1)	Discrete autoregressive process of order 1
DSL	Digital Subscriber Line
FIFO	First In First Out
GCRA	Generic Cell Rate Algorithm
GFR	Guaranteed Frame rate
GOP	Group of Pictures
HOL	Head-Of-Line
HOL/PBS	Head-Of-Line/Partial Buffer Sharing
HOL-PJ	Head-Of-Line with Priority Jump
IP	Internet Protocol
ITU-T	International Telecommunication Unit-Telecommunication

LRD	Long Range Dependence
MBS	Maximum Burst Size
MCR	Minimum Cell Rate
MLT	Minimum Length Threshold
MMFF	Markov Modulated Fluid Flow
MMPP	Markov Modulated Poisson Process
MPCS	Multiclass Personal Communication Service
N-ISDN	Narrowband Integrated Services Digital Network
nrt-VBR	Non-real-time Variable Bit Rate
NTCD/MB	Nested Threshold Cell Discarding scheme with Multiple Buffers
OPS	Optical Packet Switch
PBS	Partial Buffer Sharing
PCR	Peak Cell Rate
PR	Preemptive-Resume
QLT	Queue Length Threshold
QoS	Quality of Service
rt-VBR	real-time Variable Bit Rate
SCR	Sustainable Cell Rate
SECBR	Severely Errored Cell Block Ratio
SPBS	Static Partial Buffer Sharing
SRD	Short Range Dependence
SVC	Switched Virtual Circuit
UBR	Unspecified Bit Rate
UNI	User-Network Interface
UPC	Usage Parameter Control
VBR	Variable Bit Rate
VC	Virtual Channel
VCC	Virtual Channel Connection
VHDL	Verilog Hardware Description Language
VoIP	Voice over Internet Protocol
VP	Virtual Path
VPC	Virtual Path Connection
WFQ	Weighted Fair Queueing
WWW	World Wide Web

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 PREAMBLE

Network infrastructure of telecommunication service providers is driven by the need for cost-effective deployment and management of new and existing services, such as, public and private telephony, leased lines, and data transfer applications. The transfer of information consisting of data, video and voice has transitioned from a large collection of different equipments including narrowband and broadband switches to a single network of Asynchronous Transfer Mode (ATM) multi-service switches. With this convergence, service providers are able to reduce total operating costs attributed to lower network management and overall equipment requirements. ATM is a high performance, connection oriented network architecture. ATM has been designed to carry traffic for Broadband Integrated Services Digital Networks (B-ISDNs) (ITU, 1995a and Prycker, 1995). As such, ATM supports a multitude of different digital communication, such as, voice and video telephony, broadcast video, data file transfers and World Wide Web (WWW) applications *etc*. Traditionally, these services have been provided by physically and logically separate networks, namely, the telephony networks, the cable-TV networks and the Internet. Each network has been tailored to support the Quality of Service (QoS) needed by its applications (Vuskovic, 1999b). However, in an integrated service network we need to accommodate applications with very different QoS requirements, such as, minimum end-to-end delay, maximum available bandwidth, and minimum cell loss probability.

ATM is connection oriented and when a connection is set up resources are reserved along a path from the source to the destination. Over each ATM connection a stream of fixed-size packets, called cells, are transmitted (ITU, 1991a). Each cell is 53 bytes long and it consists of 5 byte cell-header and 48 byte payload (user data). Long messages are segmented and sent in consecutive cells in the stream. The ATM network guarantees that cells within a stream are delivered in the same order as they are transmitted (Dravida and Nanda, 1997). Typically, an ATM network consists of a set of source nodes, ATM switches and destination nodes as shown in Fig. 1.1. A source node segments the messages into cells and apply traffic shaping using a cell spacer (*e.g.*, a leaky bucket algorithm given by Partridge (1992)) to the cell stream. Cells from multiple applications are sent to the output queue. A port controller dequeues cells from the output queue and sends them on the outgoing link. Each switch routes cells from a set of incoming lines to a set of output queues based on stream identifiers in the cell-headers. Eventually, the cells reach their destination node where messages are reassembled and delivered to the destination application. Any given implementation may, for instance, have a single output queue for all outgoing links, or may have multiple logical queues for different traffic classes for each outgoing link (Meyer *et al.*, 1993).

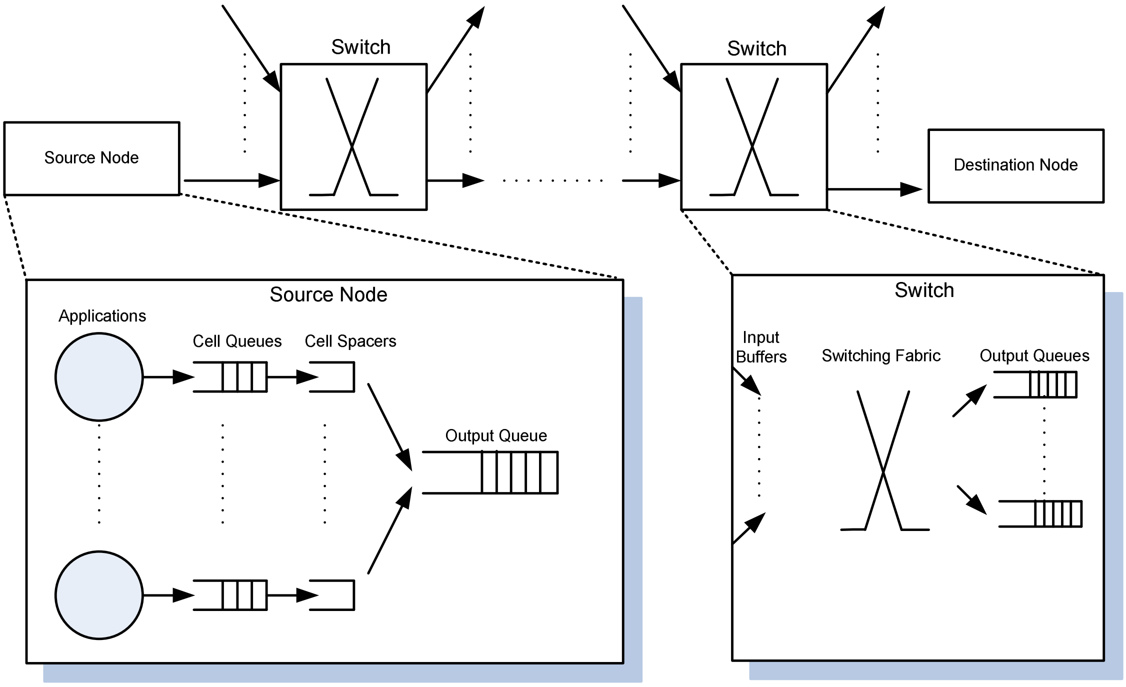


Fig. 1.1: Structure of a typical ATM network.

ATM has been designed to support the high bandwidth optical signaling of present and future information super highways (Vuskovic, 1999a). The cell concept has been designed to allow efficient hardware implementations. ATM is proposed as a carrier of the next generation global telecom network. This network should support a number of communication services, including phone calls, video conferencing and computer communication. ATM is widely deployed and is used as a multiplexing service in Digital

Subscriber Loop (DSL) networks, where it compromises to fit DSL's low data rate needs well. In turn, DSL networks support Internet Protocol (IP) (and IP services, such as, Voice over Internet Protocol (VoIP)) via Point to Point Protocol over ATM (Perez *et al.*, 1996) and Ethernet over ATM (Grossman and Heinanen, 1999). In third generation (3G) Mobile Networks, ATM is used as the technology to ensure high speed data transfer in core network switching elements. In these environments, low latency and very high QoS is required to handle linear audio and video streams.

1.2 ATM TRAFFIC MANAGEMENT

ATM network shares several services and connections each with a different characterisation. The required bit rate may vary from a few kbps to several Mbps range (Berger *et al.*, 1998). Some services have stronger real-time constraints than others; some services tolerate a few cell losses, others do not. Within such a network all connections may impact on each other. It is the task of traffic control to bound these effects and to achieve the following two main goals:

- to provide specified and guaranteed level of QoS.
- to use available network resources efficiently.

1.2.1 Traffic control parameters

Traffic contract in ATM network specifies the negotiated characteristics of a connection (ITU, 1995b). The traffic contract at the public User-Network Interface (UNI) consists of connection traffic descriptors and a set of QoS parameters. These parameters are discussed in this section.

1.2.1.1 Connection traffic descriptors

Traffic parameters describe the inherent traffic characteristics of a traffic source. It may be quantitative or qualitative (Reibman and Berger, 1995; Kasera and Sethi, 2003). The connection traffic descriptors consist of all parameters and the conformance definition used to specify the conforming cells of the connection unambiguously. The connection traffic descriptor includes the following.

- the source traffic descriptors,
- the cell delay variation tolerance (CDVT), and
- the conformance definition.

The source traffic descriptors are characterised by the following parameters.

i) Peak Cell Rate (PCR) - It is the maximum rate at which a user is allowed to inject data into the network. A PCR can also be used to earmark the cells arriving in excess at an end point. The inverse of PCR gives the minimum inter-arrival time of cells for a given connection. As such, for a particular connection, if the minimum spacing between cells is T, then the PCR is $1/T$.

ii) Sustainable Cell Rate (SCR) - SCR is a measure of long-term average of user traffic. It is an upper-bound on the long-term average of conforming cells for an ATM connection.

iii) Maximum Burst Size (MBS) - MBS is the amount of data that an ATM source can send at a rate equal to PCR while still complying to PCR. If MBS and PCR are known, then the maximum burst duration is determined using the relation $T_{MBS} = MBS / PCR$.

iv) Minimum Cell Rate (MCR) - MCR is the minimum cell rate that is guaranteed for a connection and we can avail more cells if there is no congestion.

v) Burst Tolerance (BT) - BT is the measure of the interval between consecutive bursts during which cells are sent at PCR. As such, it is the time interval after which an ATM source can again send data at PCR without violating the long-term average of SCR.

CDVT is the permissible delay variation or jitter tolerance, which allows the cells to reach at the destination before their theoretical arrival time. This parameter may allow cells to appear on a connection back to back even at line rate but still complying with PCR.

Conformance definition is used to specify the conforming cells and it discards or tags the non-conforming cells.

1.2.1.2 QoS parameters

The definition of QoS given by International Telecommunication Unit-Telecommunication (ITU-T) in its recommendation I.350 (ITU, 1988 and 1993) says that, “QoS is the collective effect of service performances that determine the degree of satisfaction of a user of the specific service”. In general, QoS is the capability of a network to provide better service to selected network traffic over various technologies, including frame relay, ATM *etc*. The primary goal of QoS is to provide priority, dedicated bandwidth, controlled jitter and latency (required by some real-time and interactive traffic), and improved loss characteristics. As such, QoS enables the network to provide better service to certain flows by either raising the priority of a flow or limiting the priority of another flow. When using congestion-management tools, the priority of a flow is raised by queueing and servicing queues in different ways. The queue management tool used for congestion avoidance raises priority of higher-priority flows by dropping lower-priority flows. Some of the parameters that are used to quantify the connections' QoS are end-to-end delay, cell loss probability and bit error rate. The traffic related measures for QoS in ATM networks can be divided into two classes as shown in Fig. 1.2.

Connection set-up delay represents the time that it takes for a call set-up message transfer to be acknowledged, excluding the user's response time. Connection release delay is the time that it takes for a call release message transfer to be acknowledged. Connection acceptance probability is defined as the ratio of accepted calls to total number of calls calculated over a long period of time. Out of the six cell level QoS parameters given in Fig. 1.2, the first three are negotiable, while last three are not.

Connection Level Parameters

- Connection set-up delay
- Connection release delay
- Connection acceptance probability

Cell Level Parameters

- Cell Loss Ratio
- Maximum Cell Transfer Delay
- Peak-to-Peak Cell Delay Variation
- Cell Error Ratio
- Cell Mis-insertion Ratio
- Severely Errored Cell Block Ratio

Fig. 1.2: QoS parameters in ATM networks.

Negotiability implies that the value of that particular QoS parameter can be decided by user or not. For example, the value of Cell Loss Ratio (CLR) can be specified by a user in the signaling message. The network can then decide whether the specified value is acceptable or not. The provision for specifying desirable value exists only for those parameters that are negotiable. There are following three broad categories for assessment of all six cell level QoS parameters.

i) Speed: ATM network has to specify how fast cells can be delivered at the destination. Cell Transfer Delay (CTD) and Cell Delay Variation (CDV) measure the speed of ATM networks in delivering cells, CTD measures the transit delay and CDV measures the variation in these delays.

ii) Accuracy: Cell Error Ratio (CER), Cell Mis-insertion Ratio (CMR) and Severely Errored Cell Block Ratio (SECBR) parameters specify the accuracy with which cells are delivered. CER is the ratio of the total number of cells delivered with error to the total number of cells delivered. CMR is the number of cells, meant for some other destination, inserted per second. SECBR is the ratio of severely errored cell blocks to the total transmitted cell blocks.

iii) Dependability: Accuracy can be measured only when cells are delivered. For this, CLR is specified and it measures whether a cell is actually delivered or not. CLR is the fraction of cells (cell lost/total cells transmitted) that are either not delivered to the destination or delivered after a pre-specified time.

Depending upon various combinations of traffic attributes discussed above, ATM service offerings are classified into six categories, namely, Constant Bit Rate (CBR), real-time Variable Bit Rate (rt-VBR), non-real-time Variable Bit Rate (nrt-VBR), Unspecified Bit Rate (UBR), Available Bit Rate (ABR) and Guaranteed Frame Rate (GFR) (ATM Forum, 1999). Real-time services require strict constraints on delay and variation in delay. These services need continuous flow of cells and if any cell is lost or continuity is disrupted it declines the QoS. For example, in case of voice services, lost leads to clipped voice at the destination. Where as in case of low priority services, there is flexibility in its delay constraints. Thus, such services have greater degree of statistical multiplexing and hence improved utilisation of network resources. In Table I, all ATM service categories are compared for their related traffic characteristics including traffic descriptors and service descriptors. The nature of service category is also shown in terms of traffic type and its sensitivity to time, along with respective applications.

Table I

ATM SERVICE CATEGORIES

Service Category	Traffic Descriptors	Nature of Traffic	Negotiable Service Descriptors	Time Sensitive	Applications
CBR	PCR, CDVT	Stable	maxCTD, P2P CDV, CLR	Yes	Uncompressed Video, Voice, Circuit Emulation
rt-VBR	PCR, CDVT, SCR, MBS	Bursty	maxCTD, P2P CDV, CLR	Yes	Compressed Video and Voice
nrt-VBR	PCR, CDVT, SCR, MBS	Bursty	CLR	No	Data-transfers, Banking Transactions, multimedia e-mail
UBR	PCR, CDVT, SCR, MBS	Bursty	-	No	E-mail and FTP
ABR	PCR, CDVT, MCR	Bursty	CLR is low (not quantifiable)	No	E-mail and FTP
GFR	PCR, CDVT, MCR, MBS, MFS	Bursty	CLR is low (not quantifiable)	No	E-mail and FTP

According to Saito (1994), cell loss and cell delay in ATM nodes are the parameters that significantly contribute in the degradation of ATM network performance at cell level. It is worth noting that the control of each of these parameters has a special impact on the other parameter; for example, voice traffic can tolerate cell loss to certain extent but is very sensitive to cell delay, while the file transfer applications can allow for some cell delay but not the cell loss.

1.3 TRAFFIC CONTROL

Setting-up a connection in an ATM network implies the declaration of specifications of cell stream's traffic characteristics. After this declaration, the connection will only be accepted if the network has enough available resources to accommodate both the new connection and the already established connections, without compromising the QoS of all connections. During the life time of a connection, monitoring is performed to ensure that the traffic characteristics of the cell stream agree with the ones declared at the connection set-up phase; if there are any discrepancies, penalties are imposed to the user. This global process is called traffic control, while the decision of accepting a connection and allocating network resources to it is called Connection Admission Control (CAC) and monitoring mechanism is called Usage Parameter Control (UPC). CAC and UPC are two important traffic control mechanisms.

CAC consists of a set of actions taken by the network at the call establishment phase in order to establish whether a Virtual Channel Connection (VCC) or Virtual Path Connection (VPC) can be accepted or rejected. This decision of acceptance or rejection for each Virtual Path (VP) and Virtual Channel (VC) along the connection route is based upon the estimated traffic characteristics of the VC – the QoS requirements of the virtual channel and the current network load.

During traffic contracting, CAC procedures determine if sufficient resources are available in the network to support the requested call. It also ensures that the performance of existing connections is not degraded by accepting the new one. If sufficient resources are not present or the acceptance of connection may endanger the QoS guarantees of the existing connections, the network rejects the call. Several approaches have been suggested in literature by ATM Forum (1994), Jain (1998), and Shiomoto *et al.* (1999) for CAC algorithms. These algorithms differ mainly in the methods that characterise the traffic and predict future traffic.

After a connection is accepted by the network using a CAC procedure, it must be ensured that the network resources are protected from malicious or unintentional misbehavior of the source producing the call, which can affect the QoS of other already established calls in the network. This job of UPC function in network, also known as traffic policing, is to take certain set of actions to monitor and ensure that the traffic contract is respected in terms of traffic offered, at the user access and the network access, respectively. Typical locations for the UPC function include the entrances to a local switching node and a cross-connect. UPC is performed on each traffic parameter of a source traffic descriptor. It checks the validity of each VP/VC identifier; counts the number of cells that are arriving and that belong to certain connection.

Several algorithms have been proposed to monitor traffic and to enforce traffic contract (ATM Forum, 1999). The most commonly used algorithm is the Generic Cell Rate Algorithm (GCRA) (McDysan and Spohn, 1998). Once it is determined using the GCRA algorithm that a particular cell is non-conforming, appropriate actions, such as, Cell Passing, Cell Tagging and Cell Discarding are taken are taken against the offending cells.

1.3.1 ATM priority mechanisms

In order to optimise the network utilisation, and to manage the traffic as per traffic contract negotiated at the time of connection admission, priority mechanisms, which are part of UPC, are used in order to maintain QoS. Priorities are important in communication networks as the importance of cells differs from cell to cell. For example, suppose a router needs to process two cells, one an ordinary datagram and the other, a routing update cell. It is possible that if the datagram is forwarded before the routing cell is processed; the datagram will be forwarded to an incorrect or outdated route. Under such circumstances, it is important that the routing table update cell be processed immediately, *i.e.*, it should be given a higher priority. In order to fulfill different performance requirements of ATM cells transfer, several priority control mechanisms have been proposed in literature. First, within each virtual connection a cell loss priority can be assigned on a per cell basis. Second, different cell delay priorities can be used for different ATM transfer capabilities. Third, individual connection priority control mechanisms are also possible. Presently, ATM switch architecture supports a sophisticated combination of all three priority control mechanisms. These mechanisms use algorithms to control the traffic as per defined priority levels.

Each ATM cell has an explicit Cell Loss Priority (CLP) bit in its header (Handel and Huber, 1999). As such, in cell loss priority mechanism, there are two different priority classes. A single ATM connection (on virtual path or channel level) may consist of both priority classes when the information to be transmitted is classified by the user into more and less important parts. For example, a layered video encoder produces two types of data streams, an essential layer and an enhancement layer. The essential layer is sufficient to produce an average quality picture, while the enhancement layer improves the picture quality. The layered encoder is an example where cells belonging to the same application have different priority. In this case the two priority classes are treated separately by CAC and UPC. For such applications during overload conditions, the cells of the enhancement layer can be selectively discarded. Selective cell discard**,** that is, discarding cells with low priority (CLP = 1), either assigned by the user or tagged by the network UPC, is a priority control function. The applicability of selective cell discard depends on the ATM transfer capability. For cells with CLP equal to 1, no guarantee is given for a maximum cell loss ratio.

In delay priority mechanism, during connection establishment each virtual connection is assigned to a specific ATM transfer capability. Among the different transfer capabilities, different delay priorities can be used. For real-time and non-real time connections, for example, nrt-VBR, ABR and UBR, different queues can be provided within switch. Whenever a free cell transmission slot is available, one cell out of these three queues can be transmitted. nrt-VBR connections are given priority over ABR connections which in turn might have a higher priority than UBR connections. In this scenario, UBR cells would be transmitted only if the other two cells queues are empty. In this case of high network load more and more cells would be queued. However, with this mechanism it is not possible to guarantee a MCR per connection as it might be required for ABR.

In individual connection priority control scheme, each individual connection is handled by a separate cell buffer queue. Such scheme allows misbehaving connections to be isolated so that they do not affect others and it can provide fairness among all connections competing for the available transmission capacity. This buffering scheme is also known as per-VC queueing. The connections are selected for transmission according to round robin scheduling. Another, more complex scheduling is strategy is known as Weighted Fair Queueing (WFQ). With WFQ, different weights are assigned for each connection. The available transmission capacity is shared among all connections in proportion to the connections' weights. WFQ makes this possible to guarantee an MCR and to shape the traffic (Moorman and Lockwood, 1999).

The use of priority mechanisms affects mainly two traffic performance measures: the cell loss probability due to buffer overflow and the waiting time translated into delay. So, when compared with no-priorities case, cell loss probability and waiting time of high priority traffic is decreased. Priority disciplines in queueing theory can be categorised into two major types: service or delay priority which governs the time at which cells in the buffer are transmitted, are also known as Time priorities; and Space priority disciplines governs the input access of cells into the buffer.

1.3.1.1 Time priority mechanisms

These priority mechanisms take into account that some services may tolerate longer delays than others (*e.g.*, specific data services versus voice). Head-Of-Line (HOL) is the most well known mechanism applicable to time priorities that serves multiple classes with different delay requirements, by classifying the traffic into *n* fixed priorities. The input buffer is divided into *n* queues and an arriving cell is placed in its corresponding queue. When the cells from *class 1* queue are served and it becomes empty, then only cells from *class 2* queue can be served. When both the *class 1* and *class 2* queues become empty, cells from *class 3* can be served and so forth. This method is useful only for CBR traffic, since it will always have service priority. However, performance is poor for lower priority classes. The delay for these classes can become too large if there is a volume of high priority traffic.

HOL with Priority Jump (HOL-PJ) has been proposed and implemented by Eckberg (1992) and is a variation of HOL that tries to solve this problem. Some bound on maximum delay can be put on low priority cells, so that these cells may also have chance to transmit even if there are higher priority cells in the queue.

1.3.1.2 Space priority mechanisms

Space priority mechanisms play an important role in controlling ATM traffic. These help to reduce buffer size by sharing it completely or partially and thus decrease the cell loss probability. Each source marks every cell with a priority level indicator: low priority or high priority. High priority cells (Class 1 cells or vital cells), are cells that should have a very low loss rate and low priority cells (Class 2 cells or ordinary cells) are cells that may be lost in case of congestion. The schemes investigated in the literature by Kroner *et al.* (1991) for space priorities are Pushout and Partial Buffer Sharing (PBS). We discuss these two schemes, in brief, in the following sub-sections.

1.3.1.2.1 Pushout scheme

In Pushout scheme, the cells waiting for transmission are stored in finite-size buffer and proper cell sequencing is guaranteed by a First In First Out (FIFO) service discipline. Low priority cells in the buffer are replaced or overwritten by newly arrived high priority cells; when buffer is full. Therefore no high priority cells are discarded until the buffer is full. In Fig. 1.3, the flowchart for complete operation of Pushout scheme is presented.

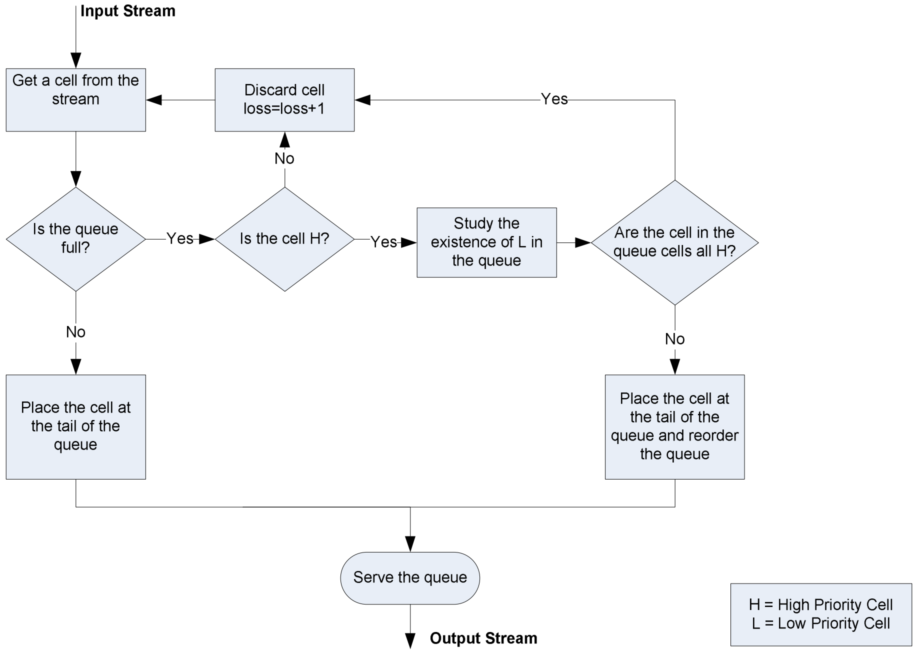


Fig. 1.3: Flowchart for Pushout scheme.

This mechanism assures a very low cell loss for high priority traffic. The disadvantage of this scheme is its complex implementation. While high priority cells are replacing low priority cells, it is still necessary to ensure that sequence of cells is preserved. Hence, the buffer may no longer have a FIFO discipline, which means that it will be necessary to keep track of where the low priority cells are stored, as well as the sequence of both high and low priority cells and overall sequence of cells.

1.3.1.2.2 Partial buffer sharing scheme

A threshold T is fixed in the PBS scheme and low priority cells are accepted in the buffer only when the current buffer occupancy is not more than T. The buffer size N is partitioned into two parts: the first one of size T for accommodating all incoming cells and the second one of size $N-T$ for only high priority cells. The special case when $T=N$ corresponds to the typical complete buffer sharing scheme, *i.e.*, with no space priority control. In Fig. 1.4, the flowchart for complete operation of PBS scheme is presented.

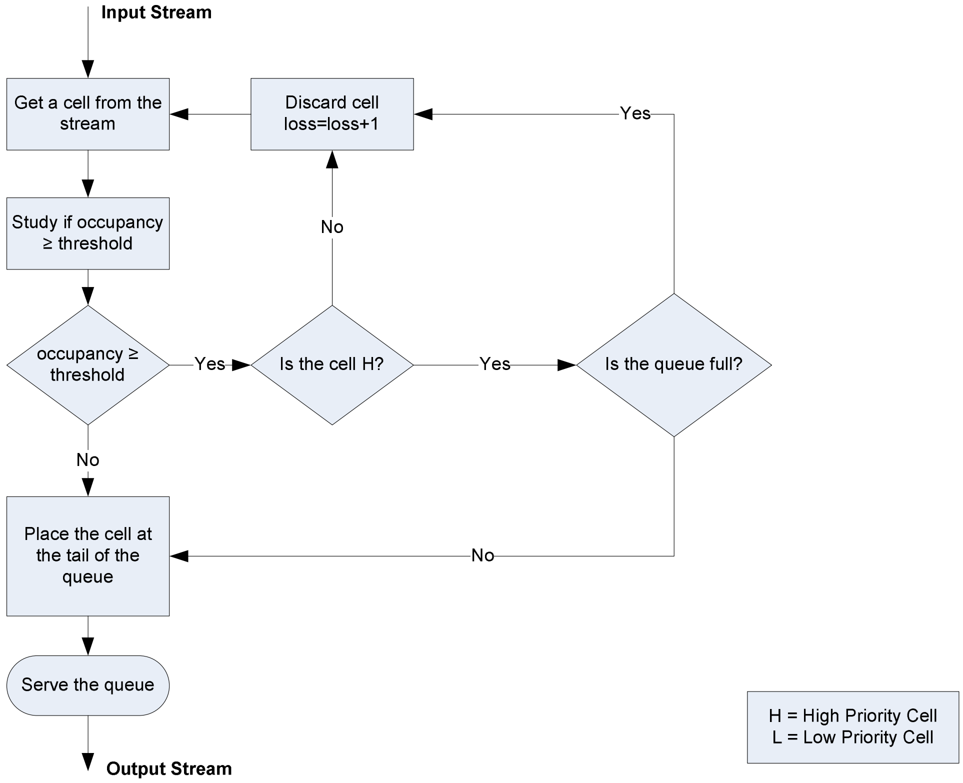


Fig. 1.4: Flowchart for Partial Buffer Sharing scheme.

The implementation of PBS scheme is simpler than the implementation of Pushout scheme (Fonseca *et al.*, 1994), but its efficiency is not that good, since high priority cells do not have priority over low priority cells at all times. For example, when the queue is full and there are ordinary cells waiting for service, arriving vital cells will be lost. The specific problem with this approach lies in the determination of the threshold value. If it is set to a very low value, low priority cells at the buffer may unnecessarily be discarded, thus restricting the effectiveness of marking cells. On the other hand, if the threshold is set to a large value, the performance of high priority cells may deteriorate, since there may not be enough space left to accommodate them. Therefore, it becomes necessary to adjust the value of the threshold when a change occurs in the characteristics of the traffic at the buffer.

1.4 MOTIVATION

As the nature of multiplexed data, voice and video traffic on cell switched networks changes dynamically, the performance analysis of these networks have three major concerns, namely, switching times, queueing delays and cell losses. These parameters impact the ability of network to maintain QoS, resource allocation and specially the buffer management.

Buffer management in ATM switching systems plays an important role in addressing the trade-off between efficiency measured in terms of overall cell loss and betterment in terms of individual source cell loss. Traffic can be shaped by placing it into buffers and delaying its entry into network thereby ensuring a more constant flow of traffic in the network. Therefore, it is desirable to utilise buffering and scheduling algorithms to regulate QoS attributes in a high speed network. Priority based cell discarding has been shown to have the potential of improving system performance for voice and video traffic (Huang and Wu, 1994). The schemes for buffer management based on priority mechanisms are Push-out scheme and PBS scheme (Kang and Tan, 1994). Both of these schemes use selective discarding of cells in buffer. It has been shown that the partial buffer sharing scheme not only performs well to meet the QoS requirements for multiple priority classes but is also easy to implement. As such, this scheme has been proposed as a candidate for overload control mechanism.

In a number of research works, the partial buffer sharing scheme is analysed with different types of Poisson arrival processes. The challenge in designing a PBS scheme is to adjust its threshold optimally to obtain desired relative cell loss ratio among the two classes of traffic. Out of the few papers, which were found in literature dealing with this problem, one is by Ahn and Lee (1999). They have proposed an algorithm to find optimal threshold and buffer size in PBS. Their work shows that, when high priority traffic is equal to or more than 70% of the total input traffic, optimal threshold equals the optimal buffer size. Under this situation, PBS becomes equivalent to FIFO, which is practically infeasible. Moreover, this work deals only with Poisson traffic model and the effect of varying traffic load is not examined. The other paper by Chuang *et al.* (2000) is an attempt to obtain desired cell loss ratios by varying threshold in PBS. They have analysed variation in packet loss with exponential, homogeneous and heterogeneous traffic sources.

Their simulation results have failed to show consistent performance of cell loss behavior for both priority classes. Moreover, they have focused on high priority traffic class only. The ratio of cell loss probability tend to be stable when the input traffic is varied, hence it lacks in adapting to dynamics of input traffic changes. Thus there is a good scope for improving fairness in congestion control for both priority classes. The objective of present work is to control the threshold optimally in PBS mechanism for reducing cell loss for traffic of both priority classes and hence improving QoS when the threshold is able to adapt based on bursty input traffic.

1.5 ORGANISATION OF THE THESIS

This Ph.D research work in undertaken to empirically investigate the buffer management techniques to optimise the network utilisation and evaluates the impact of controlling traffic. The organisation of thesis is briefly outlined as follows.

In Chapter 1, an introduction to the concepts and principles of B-ISDN and ATM networks is presented. It gives an overview of the QoS parameters and different service classes in ATM network. ATM traffic control mechanisms are also discussed. The main focus in the presentation is on various priority mechanisms under UPC that have been devised so far.

In Chapter 2, a comprehensive and exhaustive review of the literature for various methods and algorithms used for managing traffic under CAC and UPC in broadband networks has been carried out. Also, various methods used for analysing different time and space priority mechanisms based on cell losses, especially under PBS, have been discussed. Different methods that were used in literature for input traffic modeling like Markovian arrival process, Poisson process and variations of Poisson processes are also discussed. A detailed survey on algorithms for buffer management in ATM switch has also been carried out. We have also discussed the work done by various researchers for analysing VBR traffic on ATM network using autoregressive (AR) model.

Chapter 3 deals with two issues, namely, implementation of existing PBS model and proposition of a new model. The PBS priority mechanism has been implemented using a fixed-size buffer being serviced by a single server. A recursive algorithm has been implemented to calculate loss probabilities for these types of traffic using MATLAB. Further the effect of different threshold values on cell loss probabilities is also examined. We have also proposed and implemented a new and efficient algorithm to control and vary threshold in PBS queue.

In Chapter 4, the analysis of adaptive threshold controlled partial buffer management scheme in which the threshold is dynamically varied in runtime based on consecutive cell loss behavior for two priority classes is provided. The performance of proposed scheme is analysed with cell loss ratio as a major QoS parameter using Poisson traffic model. The source traffic model and the queueing system are simulated using MATLAB.

In Chapter 5, the performance of proposed scheme is further analysed with VBR based video traffic model for frame sizes of MPEG encoded video sequence based on second order nested autoregressive processes. The implementation of complete model along with the three queues is carried out in MATLAB environment.

Finally, the Chapter 6 concludes with the summary of work presented and the main goals achieved in this thesis. The benefits and limitations of the research work have also been discussed. Also, some directions for future work in the field of high speed networks and especially in the area of buffer management in VoIP networks are discussed briefly in this chapter.

CHAPTER 2

REVIEW OF THE LITERATURE

The literature review, in this thesis, has been divided into four parts. First part deals with the innovations in the field of design and development of ATM networks and traffic management in ATM networks. Second part elaborates network resource management techniques to control traffic effectively. Third part reviews the importance and role of priority mechanisms to control cell losses in ATM networks. In fourth part of the chapter, work done in literature on modeling of VBR traffic is presented.

2.1 ATM TRAFFIC MANAGEMENT

The efforts to provide a unified network for different applications started with the development of Narrowband Integrated Services Digital Network (N-ISDN). However, the inherent limitations of N-ISDN forced ITU-T to look for alternatives that could satisfy the increased bandwidth demand without sacrificing the efficiency. ATM technology was developed to fulfill the requirements of B-ISDN services. The step towards this objective was taken by ITU-T with its published recommendations I.321 (ITU, 1991b and 1997), which addressed the fundamental principles and initial specifications for ATM. It is recognised as the standard switching and multiplexing technique to support various types of existing and new multimedia services in a unified network with greater flexibility and efficiency (Saito, 1994; Mario *et al.*, 1999). ITU, 1991 had given ATM layer as the core layer of the ATM protocol stack. The entire functionality essential to ATM is performed at this layer. This layer implements the mechanisms for traffic control and management (Cuthbert and Sapanel, 1993; Onvural, 1994). As ATM networks transfer the user information in small fixed-size packets through a very high speed link, such characteristics make the congestion control and resource allocation in these networks complicated. It is an established fact that different applications have different QoS requirements (Fischer *et al.*, 1994). To cope with these, many novel traffic management strategies have been suggested in literature (Eckberg, 1992; Lee and Lee, 1992; Mitrou, 1994; ATM Forum, 1994; Roberts *et al.*, 1996; Alberti *et al.*, 2004; Kuhl and Thibodean, 2006). The work done in these areas is discussed in the following section.

2.1.1 Traffic management schemes based on ATM service attributes

Communication networks need to have some processes which can control the way in which the resources are allocated, as to prevent traffic congestion and packet loss. As such, the way in which bandwidth is allocated, inside the network, is crucial for it to obtain a good throughput and to operate at acceptable levels. Such control techniques employ a specific set of traffic parameters to admit or deny a connection using functions like CAC. A successful CAC strategy should achieve a good balance between user's desire for QoS guarantees and the network provider's desire for the maximum revenue (Gibbens *et al.*, 1995). Furthermore, it should be relatively simple to implement, suitable to a wide range of traffic types, and able to deal with time-varying traffic. Several approaches have been suggested for CAC algorithms (Fisal and Brewster, 1991; Mase and Shioda, 1991; Lee and Lee, 1992; Mitrou, 1994) which differ mainly in the method used to characterise the traffic and predict future traffic.

According to Fisal and Brewster (1991), there are many variants of CAC algorithms, but all of them fall under two basic categories, namely, non-statistical (or peak bandwidth allocation) and statistical CAC algorithms. With peak bandwidth allocation approach, the bandwidth given to each connection is its peak bit rate. But applying this allocation scheme to bursty connections will imply a great waste of bandwidth, especially if the connection is characterised by a large value of ratio of peak bit rate to average bit rate. In statistical approach, the bandwidth allocated to each source is less than its peak rate but greater than its average bit rate, whose value guarantees the source its required QoS. Statistical algorithms are performance efficient but difficult to implement and so requires accurate modeling of source traffic.

UPC is performed for each traffic parameter which is negotiated during connection set-up phase (ITU, 1994). Policing algorithms detect and quickly respond to any traffic violation in the network. Leaky bucket is probably the most well known algorithm that helps UPC judging a violation in the connection set-up phase (Goralski, 2001). Variants of this algorithm can be found in literature as proposed by Castelli *et al.* (1991) and Chao (1991). The simple leaky bucket algorithm has been used by Mitrou (1994) to police the parameter mean rate. He has considered a very large size of the bucket and the leak rate was set equal to the mean rate of the source being policed. This method has shown that when policing the mean rate, the time taken by the UPC mechanisms to detect traffic violations would be much longer than that for peak rate policing. Therefore, the use of mean rate policing had lead to an ineffective protection of the network against misbehaving traffic.

The other UPC algorithm that has been considered by Ramamurthy *et al.* (1994) and Mark and Ramamurthy (1995) is the dual leaky bucket algorithm. In this algorithm, two leaky buckets algorithms were executed in parallel and two concepts have been used – sustainable cell rate and the burst tolerance. The double leaky bucket mechanism was more efficient in terms of policing traffic sources than a simple leaky bucket algorithm. As such, the policing scheme, proposed in ITU (1994), considered a process with two leaky buckets (one for CLP = 0 stream, *i.e.*, the high priority traffic, and another for the CLP = 0+1 stream, *i.e.*, aggregated traffic).

The variants of leaky bucket mechanism that consider buffering before the traffic is analysed by the UPC, have also been proposed in literature (Wu and Mark, 1995). In buffered leaky bucket mechanism, the bursty input traffic is modeled as Markov Modulated Poisson Process (MMPP). Although this helped shaping the bursty traffic, it also introduced extra delay.

ATM Forum (1994) proposed GCRA, which was equivalent to Continuous-State Leaky Bucket (CSLB) policing algorithm as given by ITU (1994). The GCRA is defined with two parameters, namely, the Increment (I) and the limit (L) and is generally represented as GCRA(I, L). The algorithm assures that the cells of a connection entering the networks are spaced by a specific time interval I and that a maximum tolerance L is allowed. The PCR can be policed at public UNI using GCRA(T, τ) where T is inversely proportional to PCR, and τ is the CDVT$_{\text{PCR}}$. Similarly for SCR, it can be represented as GCRA(T_s, τ_s), where T_s is inverse of SCR and τ_s is the CDVT$_{\text{SCR}}$. For each cell arrival, GCRA determines whether the cell is conforming to the traffic contract of the connection, and thus GCRA provides the formal definition of traffic conformance to the traffic contract.

As discussed in Chapter 1, under section 1.2.1.1, ATM Forum has proposed several connection traffic parameters including PCR, SCR, MBS, MCR and CDVT in ATM networks. Out of these parameters, PCR and CDVT$_{\text{PCR}}$ are mandatory traffic descriptors to implement the traffic control mechanisms (ATM Forum, 1995). Guillemin *et al.* (1995) have demonstrated that traffic control mechanisms, based on the parameters SCR and CDVT_{SCR}, could effectively utilise the resources in a simple and efficient manner. The enforcement of these two parameters by UPC allowed the network to allocate sufficient resources but less than those based on PCR and hence ensured that desired performance objectives could be achieved.

Baiocchi and Cuomo (1996) have analysed impact of specific SCR and CDVT_{SCR} values on UPC performance and studied its dimensioning for the measured MPEG traffic. They have analysed the Star Wars sequence (Garrett and Willinger, 1994) and 21 MPEG sequences (Rose, 1995). Their experimental results showed that the efficiency can be improved at the expense of a large increase in the values of τ_s. For the higher values of τ_s, the SCR falls below half of PCR and the fraction of non-conforming cells reduces below the threshold of 10^{-4}.

Roberts *et al.* (1996) had given a CAC algorithm for CBR connection which was characterised by its PCR only. The connection was rejected if the PCR value exceeded a certain threshold value (a predefined percentage of link rate). This ensured that no connection occupied a significant portion of the link capacity. The connection request was rejected if the number of CBR connections exceeded a pre-specified maximum value and it also regularly checked if sufficient bandwidth was available for new connections. But this algorithm did not take into account the QoS parameter, *i.e.*, CLR and CDV of the request. For VBR connections, the effectiveness of CAC algorithm depends on the burstiness of the connections.

Alberti *et al.* (2004) has discussed modeling and simulation of ATM traffic management. They presented a survey of topics including modeling approach, requirements of trust-worthy performance, QoS analysis and choice of simulation environment where the network models could be implemented. They also presented a new ATM network model in SimNT 2.0 simulation environment, which covered Soft Virtual Connection (SVC) routing and management, per-VC queueing, weighted fair-share scheduling, traffic shaping, effective bandwidth, CAC, selective cell discarding, leaky bucket traffic policing, traffic contract configuration and negotiation.

2.2 NETWORK RESOURCE MANAGEMENT

Bandwidth and buffer are two important network resources that are statistically shared through statistical multiplexing in the data networks. Bandwidth in a network being finite (Hsu and Walrand, 1996), its allocation and use must be monitored. The mechanism used for bandwidth management is generally known as scheduling. Various authors have proposed scheduling algorithms to provide fair sharing of the total bandwidth and are briefly reviewed below.

2.2.1 Bandwidth management schemes

For managing real-time and non-real-time traffic, Misic and Chanson (1996) proposed the virtual effective bandwidth admission control algorithm. They considered that each type of traffic has its own separate capacity sub-region that was dependent upon the traffic descriptors of the source, QoS bound for a given traffic class, and the sum of average arrival rate of connections from other traffic classes. They concluded that the bandwidth of capacity sub-regions could be dynamically adjusted to satisfy the instantaneous needs of traffic sources, which were modeled as Poisson input traffic. The algorithm also derived the expression of virtual effective bandwidth for each specific capacity sub-region under different QoS limits like average queue length, delay, traffic losses and target connection losses.

Henaoui *et al.* (1996) and Teixeira *et al.* (1997) suggested dynamic multiplexing algorithms for user terminal equipment to maintain a minimum level of quality among all video sources by using the least possible bandwidth without violating the traffic contract for MPEG VBR video traffic. On the same basis, a burst-level priority scheme was used by Fernandez and Mutka (1997) to maintain QoS requirements to bursty connections that shared same resources by allocating bandwidth to bursts on-the-fly according to their priorities. This scheme used a two-level priority CAC scheme for the independent heterogeneous on-off sources.

For exploiting the feature of the multiplexing gains of packet switching, while still providing QoS guarantees in ATM network, multi-rate scheduling mechanisms that provided different rates of service at different times were proposed by Saha *et al.* (1998). The experiments were carried out by considering MPEG video sequences from a number of applications. These applications effectively represented a number of connections admitted while maintaining the same level of service guarantees.

Berger and Whitt (1998) studied the concept of effective bandwidth specifically for connection admission control and capacity planning. Every connection was assigned more than one effective bandwidth, one for its own priority level and the other for each lower priority level. The study demonstrated the advantage of using priorities when lower priority classes had substantially looser performance criteria.

Chiruvolu *et al.* (1998) have developed a dynamic bandwidth allocation scheme for VBR video traffic. In this study, authors have described that due to burstiness of the correlated VBR video traffic, adaptive resource management was highly desirable. The Least Mean Square adaptive filter has been used to predict the VBR traffic at regular intervals. The results of their study show that the frequency of the bandwidth changes and cell loss rate, both were reduced at the same time in buffer for VBR video traffic. In another study, Cho and Cho (2002) have proposed a dynamically adjusting per-flow buffer management scheme to ensure minimum QoS in routers, as such, there was less delay, reduced delay-jitter and more fairness. They proposed Buffer Management based on Rate Estimation (BARE) scheme that can be applied to TCP flows and to flows transferring data of real-time application. They introduced a virtual threshold function that divided router operation into three modes allowing the average queue size to fluctuate around the value and thus eliminated unnecessary delay.

Arora and Baras (2002) had proposed a QoS provisioning architecture that guarantees end-to-end QoS for real-time connections. In this work, a hierarchical scheduler has been used that provided bandwidth to connections, and also bounded the delay and jitter guarantees. The updated messages were sent to all nodes by monitoring devices to detect violation patterns. As such, the resources were better utilised with this scheme.

2.2.2 Buffer management schemes

For predictive service, a scheduling algorithm alone is not enough to provide different QoS required by individual traffic streams. Although a good scheduling algorithm can provide guaranteed bandwidth for each stream and thus provides separations in mean delay, but it does not control the order of cell losses. The cell loss rate for each stream depends on buffering mechanisms (Tobagi, 1990; Doshi *et al.*, 1992; Liu and Moylan, 1996; Yaprak and Psarris, 1998; Mokhtar and Pereira, 2001). In this section, the literature regarding different buffer management schemes has briefly been reviewed.

An ATM switch is a network element that provides cell transport connection control and network management. Therefore an ATM switch architecture, have considered several buffering options (Causey and Kim, 1994; Ranganathan *et al.*, 1998). The design of buffer management algorithm determines how the total buffer space is distributed among the various output queues. Therefore the design of buffer management algorithm needs to consider packet loss ratio and the hardware complexity. Lefelhoz *et al.* (1996) studied two most general schemes for buffer management, namely, shared pool and per-flow allocation. The shared buffer pool scheme was Complete Sharing scheme. The per-flow allocation scheme allocated certain buffer space to each stream. Depending on the percentage of the buffer reserved for each stream, it could be further divided into two sub-schemes – Complete Partitioning and Partial Sharing. Complete Sharing scheme maximised buffer utilisation efficiently but could not provide separation in cell loss rate. In contrast, complete partitioning could provide fairness in terms of separation in cell loss rate but resulted in low utilisation of buffer. The result of the study showed that main problem with partial sharing was the difficulty in calculating the buffer size to be reserved for each stream. The study further concluded that by using priority strategy, there was improvement in complete sharing scheme but at the loss of low priority stream. Yousefizadeh and Jonckheere (2005) have also proposed two dynamic partitioning buffer management techniques which addressed the trade-off between efficiency and fairness. They had applied adaptive learning power of perceptron neural networks to the arriving self-similar traffic patterns of queueing system and these schemes were proved to be efficient, fair and easy to implement.

2.3 PRIORITY BASED TRAFFIC CONTROL SCHEMES

The priority control mechanism, which is a part of UPC, is an effective method to support multiple classes of services having different QoS requirements. In this mechanism, various traffic types are classified and prioritised according to their cell loss and/or delay requirements. Priority mechanisms have been classified into two categories, namely, time priority and space priority. A number of studies reporting the advantages and applications of priority control mechanisms for managing cell losses have been conducted. A few of them are briefly reviewed below.

2.3.1 Time priority based methods

Schemes based on time priorities generally schedule the order of service for each packet according to its priority and buffer status. The simplest scheme is the HOL priority control which always schedules delay-sensitive (or real-time) cells before loss-sensitive (non-real-time) cells (Schormanns *et al.*, 1991). It significantly degrades the performance of loss sensitive cells when the load of delay sensitive cells is very high. Chipalkatti *et al.* (1989) and Gravey and Hebuterne (1991) have compared the performance of the HOL, Maximum Laxity Threshold (MLT) and Queue Length Thresholds (QLT) policies under mixed type of real-time and non-real-time cells. The study demonstrated that the FIFO policy causes relatively high losses for non-real-time traffic while providing relatively low delays for real-time traffic. Its converse was also true when priority was given to non-real-time traffic unconditionally.

In contrast to the no-priority and unconditional priority scheme, the MLT and QLT policies can control the performance of both traffic types by proper selection of the threshold parameter values. Chipalkatti *et al.* (1989) also observed little difference in the performance of the MLT and QLT policies and concluded that QLT was more practical than MLT due to its simpler implementation. Eckberg (1992) proposed another delay-priority control scheme, known as, Head-of-Line with Priority Jump to satisfy the delay constraints of each class of traffic and tried to solve the delay problem. The study revealed that if some bound on maximum delay could be put on low-priority cells, then these cells might also get chance to transmit even if there were higher priority cells in the queue. Lee and Sengupta (1993) proposed a threshold-based delay-priority control scheme, which provided adequate QoS to real-time traffic and improved service to the low priority traffic also.

2.3.2 Space priority based methods

Time priority based mechanisms lack in fulfilling the cell loss related QoS requirements of a connection. To address this, the space priority mechanisms for high speed integrated networks have been proposed and analysed in detail in the literature. Schormanns (1992) presented algorithms for calculating steady state waiting time probabilities for cells of any priority level in ATM queueing models. The algorithms included an arbitrary number of non-preemptive time priority levels in which a cell of the highest priority was set to the head of the queue on arrival but could not be serviced until the cell presently under service got finished, even though this cell might be of low priority.

Gravey and Hebuterne (1991) and Huang and Wu (1994) studied combined time and space priority mechanisms. They used traffic model in which the arrival of a cell was a Bernoulli process with a certain traffic load and an algorithm was developed using

Markov chain that guaranteed both the delay and packet loss requirements of each traffic class present in the system. But the algorithm proved to have higher time complexity even for small switch. In another study by Lee *et al.* (1999), hybrid Head Of Line/Partial Buffer Sharing (HOL/PBS) queueing scheme was proposed to reduce the block rate of Multiclass Personal Communication Service (MPCS). They have considered two dimensional Markov process that investigated the impact of major parameters including termination forced probability and mean waiting time, on the system performance. This study reported that hybrid scheme performed better than HOL scheme.

Kroner *et al.* (1991) and Lin and Silver (1991) have reported on the use of cell level priority mechanisms to fulfill different quality requirements of ATM traffic. They considered a case of congested network in which different types of cells competed for transmission and then the network might intentionally discard some cells to make room for other cells. Loss priority control was more concerned with reducing the cell loss probabilities of the loss-sensitive data. In a study conducted by Race (1992), a significant improvement of the admissible traffic load using cell loss priorities is reported. They illustrated that their proposed scheme allowed smaller buffer sizes to be chosen, therefore reducing the complexity of implementation.

Petr and Frost (1991) have studied a multiple loss-priority queueing system in which the discarding policy of arrival packets was controlled by a set of nested thresholds values. They developed efficient search techniques for determining the set of thresholds that maximised the offered load when constraints on cell loss probabilities of each class were specified. Results illustrated that nested threshold discarding systems could significantly support higher traffic load than systems without priorities. The study also showed the increase in performance with respect to traffic mix and cell loss constraints.

Garcia and Casals (1992), had applied matrix analytic methods to evaluate Pushout and PBS, in which the input traffic has been modeled by a Markov Arrival Process (MAP). Bae *et al.* (1992) have investigated the usefulness of threshold based priority packet discarding scheme as a method to control network congestion. They analysed a loss-priority queueing system with a finite buffer in which, two MMPP were admitted, and observed that individual packet loss probability is decreased. The results inferred potential effectiveness of threshold based priority packet discarding scheme and appeared to justify further the pursuit of this research.

Dagiukas and Ghanbari (1993) proposed an algorithm that combined the philosophy of both the Pushout and PBS mechanisms. The proposed mechanism was similar to PBS up to the full occupancy of the queue, *i.e.*, it accepted low priority traffic only up to the threshold of the queue and accepted high priority traffic, up to the full capacity of the queue. However, if a high priority cell arrived at the queue when the buffer is full, then that cell might take the last low priority cell stored out of the queue. This study showed that the proposed scheme degraded the QoS for low priority cells in particular.

Akyildiz and Cheng (1994) and Cheng *et al.* (1996) also analysed an output-queueing packet switch in which two loss-priority packets were admitted and different scheduling and push-out schemes were adopted. They considered Poisson arrival process and obtained individual packet loss probabilities and mean waiting time of each class with limited approximation error.

Cidon *et al.* (1993) examined the effect on consecutive cell loss probabilities of FIFO queue under a homogeneous traffic condition. In contrast to other works that computed the consecutive cell loss probabilities based on an independent assumption, they developed an efficient recursion for the computation of the distribution of the number of lost cells within a block of fixed or variable size. Their results showed that the consecutive cell loss probabilities with independent probability calculation were far less than that with recursive algorithm but this scheme underestimates the consecutive loss probabilities. The work described by Elwalid and Mitra (1994) considers the analysis of a stochastic fluid model with loss priorities for Markov Modulated fluid sources. The study considered both the cases – where only two levels of priority were present and where an arbitrary number of priority levels were present. One of the characteristics of this analysis is that it provided a complete delay distribution for each priority class.

Since ATM network carries aggregated traffic from different sources, it is important to model the traffic sources accurately. The Poisson and Bernoulli processes were considered for modeling a large number of independent traffic sources by Chipalkatti *et al.* (1989), Kroner *et al.* (1991) and Suri *et al.* (1994), but these processes are not suitable for voice traffic or video traffic having high correlation in their inter-arrival time for cells (Ezekiel *et al.*, 2003). For this reason the Bulk Bernoulli Process (BBP), MMPP or Markov Modulated Fluid Flow (MMFF) model were used by Kouvatsos and Tabet (1995) and Krunz *et al.* (1994a, 1994b).

Various strategies, such as, HOL, QLT schemes that are used for selective discarding or priority scheduling consider only one aspect of QoS requirements, either the cell loss rate or the delay requirement. Krunz *et al.* (1994a) have reported on the design and analysis of buffer management scheme for multimedia traffic with both loss and delay priorities. They proposed a Nested Threshold Cell Discarding scheme with Multiple Buffers (NTCD/MB) to implement loss and delay priority queueing strategies for satisfying a wide range of QoS requirements. They considered a heterogeneous mix of traffic with both high priority and low priority traffic types as input to two buffers interacting through a common server. The cell arrivals were modeled using fluid-flow approach. They calculated steady state probability distribution for the content of the buffers. The numerical results demonstrated that NTCD/MB scheme effectively enhanced the delay performance of real-time traffic while satisfying different cell loss requirements.

Many other studies have also been reported on the use of priority mechanisms for traffic control and improved QoS (Liao, 1994; Dailianas and Bovopoulos, 1994; Moon and Rexford, 2000; Petipong and Suvepon, 2003). Dailianas and Bovopoulos (1994) proposed a complete traffic management scheme for multimedia ATM networks. They studied four different classes of traffic, namely, loss-free service, burst-scale service, cell-scale service and unreliable service. Each traffic class had different performance requirements expressed in terms of delay and loss guarantees. Their work also provided a complete specification of switch operation as well as real-time CAC algorithms. Dailianas and Bovopoulos (1995) further extended the work and proposed two algorithms, one to assign priorities to adapt the current load at each switch and the second algorithm to decide whether a particular channel should be admitted for service or not. According to them, priorities were assigned by the network on a node by node basis and could dynamically be configured for every connection newly established or terminated.

Wu and Mark (1995) proposed Complete Sharing Virtual Partitioning (CSVP) strategy for buffer management at a multiplexer in ATM networks. In this study, the total buffer space was partitioned based on the relative traffic load and when a new cell belonging to an oversubscribed type arrived, it could occupy the spare space of an unsubscribed type and could be overwritten when necessary. Fluid flow approach was used to analyse the performance of CSVP scheme. The results showed that the state boundaries that were directly related to the cell loss probabilities were characterised by ordinary differential equations. The numerical results further illustrated that CSVP method exhibited a cell loss rate performance superior to complete partition and maintained a fair allocation to participating users.

Lee *et al.* (1997) investigated the usefulness of priority control mechanism to handle loss and delay requirements of ATM traffic. A common server for both real-time and non-real-time traffic was used and cell arrivals of input stream were modeled by MMPP. They employed two different buffers for real-time and non-real-time traffic in their scheme and compared the performance for cell loss and delay variations. Their results revealed that proposed scheme achieved outstanding cell loss rate for the non-real-time traffic of high priority by imposing priorities.

Moon and Rexford (2000) studied the priority queue architectures by focusing on its hardware implementation to efficiently handle a large number of packets on a high speed link. They explored the existing priority queue architectures and proposed two new architectures to scale to large number of packets and priority levels. They designed and simulated the architectures using Verilog Hardware Description Language (VHDL) and epoch silicon compiler in order to compare a range of priority queue sizes and performing metrics. They established that the proposed architecture performed well and could be used for guaranteeing QoS requirements in high speed networks. Petipong and Suvepon (2003) have also shown in their study that the QoS in ATM switch system can be increased by using PBS priority scheme, in which low priority cells get discarded when the buffer is full, under self-similar traffic environment.

Sharma and Virtamo (2002) have also investigated the usefulness of priorities in a finite buffer queue. They considered a Markov Modulated Poisson Process to model the Internet traffic more realistically. They obtained rates of convergence to the stationary distribution and functional limit theorems for this system. They also developed algorithms to compute stationary density of the workload process, the waiting times, and the probability of packet loss. They further studied the queue performance with two priority classes and showed its benefits over single class traffic.

Normal stochastic process for statistical multiplexing has been used by Zhipin and Chuangyin (2002) to predict the performance of ATM network with priority for heterogeneous and correlative bursty traffic sources. The analytical technique required mean arrival rate and auto-covariance function, which was less complex and independent of buffer size. The performance analysis revealed that the method is valid and useful. The proposed method had the merits that it could easily solve cell loss probability especially with larger buffer and avoid huge state space problem comparing with classical state transition matrix method.

Awan and Fretwell (2005) used space and service priorities for analysing performance of single server finite capacity G/G/1/N queues. They presented closed form of analytical solution based on principle of maximum entropy for queues with distinct priority classes under Preemptive-Resume (PR) or HOL service disciplines. They used a vector to represent a sequence of thresholds for each priority class jobs. The form of state probabilities, such as, the joint, aggregate and blocking probabilities were established analytically using intensive recursive relationships.

Avrachenkov *et al.* (2005) have also studied priority queueing with finite buffer size. They introduced a randomised pushout buffer management mechanism to control the loss probability of priority packets efficiently. The packet loss probabilities for priority and non-priority traffic were calculated using the generating function approach. They compared randomised pushout scheme with threshold based pushout scheme. With the analysis and results they concluded that proposed scheme was much easier to control than threshold based pushout and also it could be used to serve for Differentiated Services of the Internet.

2.3.2.1 Partial buffer sharing mechanism

The analysis of PBS scheme has been reported in several papers in the literature. Kroner *et al.* (1991) described three different space priority mechanisms: Pushout, Partial Buffer Sharing and Separate Routes. This study classified the input traffic into several classes and restricted the access to buffer use according to the traffic classes. In Separate route, different queues can accommodate the low and high priority traffic. Some authors have considered this situation (Alonso *et al.*, 1989; Gallassi *et al.*, 1990), but route separation does not use cell level buffer management. Kroner *et al.* (1991) have also shown that the system performance can be improved by using priorities and that the partial buffer sharing mechanism is a good compromise between performance and implementation.

Meyer *et al.* (1993) used a finite state Markov process based model to evaluate the loss and delay performance of an ATM switching element using PBS scheme. Analytical results were then used to dimension the buffer capacity and the threshold level of the queue, in order to obtain the cell loss probabilities required by each type of traffic. It was also shown that the loss performance and the utilisation of resources in switch improved in presence of a priority mechanism like PBS. Liao (1994) also studied a discrete-time queueing model for PBS with two MMPP inputs to analyse the effect of PBS on system performance for bursty traffic.

Ramesh *et al.* (1996) examined the efficacy of using CLP bit to carry traffic streams with differential QoS results. They used PBS and PBS-Pushout buffer priority schemes to obtain the trade-off curves of traffic with CLP bit set to 0 and 1 separately. In their study, a revenue optimisation problem was formulated by analysing the performance of an ATM multiplexer with two traffic classes, *i.e.*, one with CLR < 10^{-9} (high priority class) and other with CLR < 10^{-4} (low priority class).

A good number of ATM switches are of the shared memory type (Kumar and Aggarwal, 1994; Collier and Kim, 1996; Varma and Stiliadis, 1997). In shared memory type switches, all input and output ports have access to a shared memory space (Choudhury and Hahne, 1996 and 1997). Choudhury and Hahne (1998) proposed a scheme called Dynamic threshold scheme, which was proved to be simple to implement; and due to its adaptive nature, in case of uncertainties and changes in traffic conditions, this scheme was better than static threshold scheme. The key idea in the design algorithm was that the amount of buffer space in each queue was decided by a threshold placed on each queue. This was called as control threshold, which was proportional to the remaining space in the buffer. The dynamic threshold scheme used partly threshold scheme and partly pushout scheme. The results of the study revealed that PBS with pushout policy outperformed other schemes. The performance was further enhanced when the input cell, upon its arrival, was made to join the other buffer spaces with least queue length, if the parent buffer was full. If the current buffer was also full, the new cell from the current buffer was made to join its buffer by pushing out the last entered cell belonging to other queues.

Hahne and Choudhury (2002) extended the Dynamic threshold strategy to share the common buffer among traffic classes with different loss priorities. They discussed and analysed the buffer allocation among the competing ports and loss priority classes using different schemes.

Lee and Un (1997) described the application of priority control schemes in ATM switches to increase the resource utilisation and satisfy QoS of each traffic type. Each input queue of the ATM switch adopted one of the space priority mechanisms: partial-pushout or partial buffer sharing, which assigned priorities for buffer access to each traffic type according to its loss constraints. The distribution of input queue length and loss probabilities of each traffic class was obtained using matrix geometric solution method and their performances were compared. The simulation results show that switch utilisation with space priority mechanism was much higher than the one without any priority control; and the required buffer was reduced while satisfying the same QoS of each traffic class.

Yaprak and Psarris (1998) proposed an adaptive buffer allocation scheme based on virtual partitioning among different output ports in ATM switch. To detect congestion and for updating threshold, they used three attributes, namely, in-use bandwidth of distinct QoS, available buffer space on the corresponding logical queue and the latest updated cell arrival rate destined to the corresponding output port. This information was used as basis for heuristics measure of the traffic for near future. System behavior under varying on-off bursty traffic pattern was investigated via simulation on OPNET package. A Cell-Accommodation-Rule was applied whenever a cell arrived at the switch and threshold was updated after every fixed time slots. He also suggested that the adaptive buffer allocation strategy got benefit from the dynamically updated thresholds and was superior to the static complete partitioning scheme in the sense of low cell loss. They concluded that under heavy traffic load, the frequency of threshold updating played a critical role in gaining higher throughput and maintaining fair cell loss among all output ports.

Taggle and Sharma (1998) have studied the effect of using thresholds for buffer space management under bursty multicast traffic. They have evaluated the performance of a generic shared memory ATM switch in terms of cell loss rate and cell delay. The threshold scheme assigned priority to cells depending on whether the memory occupancy was above or below the threshold. Their study demonstrated that with the traffic load below 100%, there was improvement in average cell delay. At 100% output load, the threshold value greatly affected cell delay and above 100% load, there was minimal effect on cell delay.

While a number of studies on PBS were reported to reduce the cell loss probabilities, only a few considered the methods to find optimal threshold value by varying the threshold. Among these few studies, Ahn and Lee (1998, 1999) have proposed an algorithm to find optimal threshold and buffer size in PBS scheme. They investigated that major challenge in designing a PBS scheme was to adjust its threshold optimally to obtain desired relative cell loss ratio among the two classes of traffic. Their work shows that when high priority traffic was equal to or more than 70% of the total input traffic, optimal threshold was equal to the optimal buffer size. Under this situation, PBS became equivalent to FIFO, which was practically infeasible. Moreover, this work deals only with Poisson traffic model and the effect of varying traffic load was not examined.

Chuang *et al.* (2000) attempted to obtain desired packet loss ratios by varying threshold in PBS. They have analysed variation in packet loss with exponential, homogeneous and heterogeneous traffic sources. Their simulation results have failed to show consistent performance of packet loss behavior for both priority classes. Moreover, they have focused on controlling packet loss of high priority traffic class only. The ratio of packet loss probability tend to be stable when the input traffic was varied, hence it lacked in adapting to dynamics of input traffic changes. Thus there is a good scope for improving fairness in congestion control for both priority classes.

For loss free transmission of packets, WFQ algorithm assumes that a certain amount of buffer is allocated for each connection. This buffer allocation policy, however, requires much buffer space when many connections are sharing a link. As such, Matsufuru and Aibara (2000) evaluated the use of PBS policy combined with UPC for efficient buffer management and flexible QoS control using Markov model input process in ATM switches. The results showed that the cell loss ratio was reduced independently of delay and buffer size.

It has been comprehended in another study by Aweya *et al.* (2004) that the performance of buffer can be improved by employing dynamic thresholds. They emphasised that use of an efficient and fair buffer allocation scheme without appropriate queue management can not necessarily ensure the improved performance. They suggested active queue management algorithm which had a common queue threshold value, used to manage the size of each queue. At predetermined time intervals, the threshold value was re-computed and packet loss probabilities were calculated based upon common queue threshold value. The results obtained by them reveal that given buffer management scheme adapted to changing load conditions and dynamically allocated buffer space to all queues in a recursive fashion. Moreover, the proposed scheme was simple to implement as compared to the scheme given by Choudhury and Hahne (1998) and it required low processing overhead to compute the dynamic queue thresholds and packet loss probabilities.

In another study, the investigation of packet buffer management algorithms was described by Rajan and Chu (2005), for reducing packet loss effectively. The proposed algorithm, named as Different Algorithm with Different Threshold (DADT) was based on allocation of buffer space for each queue proportional to different packet size of each application. They inferred that the optimum value of threshold for the queue could be determined by observing packet size for a particular queue and hence, the packet loss could be reduced. The simulations used different sized packets to determine the optimum value of threshold for each queue as compared to a single control threshold value used by Choudhury and Hahne (1998) in their work. The results revealed that DADT algorithm improved the packet loss ratio by more than 10% over other algorithms.

Subasi and Koklukaya (2005) also studied the dynamic allocation of input buffer space in ATM switching elements as a function of traffic load without considering congestion control parameters. A shared buffer pool with threshold based virtual partitioning among input ports was used, which supplied the necessary input buffer space as required by each input port. The system behavior under varying traffic load has been investigated using a simulation program. As compared with static allocation scheme, under bursty traffic load conditions, this scheme had shown increased network throughput and a fair share of the buffer space.

Current literature on input buffer management reveals that, in representative ATM networks under highly bursty traffic conditions, fuzzy thresholding approach yields lower cell loss rate at the cost of lower throughput (Ghosh and Razouqi, 2003). Also, under less bursty traffic, the traditional fixed thresholding approach achieves higher throughput at the expense of higher cell loss rate (Wang *et al.*, 2007).

Citro *et al.* (2001) proposed an adaptive dynamic buffer management scheme in which the network control dynamically switched between two input buffer management techniques, *i.e.*, fuzzy thresholding approach and fixed thresholding approach. They modeled ATM networks in an asynchronous distributed simulator and on network realistic traffic stimuli workstations. After the analysis of adaptive buffer management queue, they inferred that input buffer management alternates at each individual ATM multiplexer between fixed and fuzzy schemes according to the type of traffic – less bursty or consistent bursty and so their proposed schemes integrated the best characteristics of both schemes. Lightner (2006) also developed a fuzzy buffer controller that minimised cell loss in ATM switch. The fuzzy controller arranged the cells in buffers in a sequence based upon corresponding priority class, end-to-end delay parameters *etc.*

Wang *et al.* (2007) also developed a queueing model based on fuzzy threshold controlled space buffer management scheme. They have studied its performance based on packet loss probabilities, under realistic condition for both high priority and low priority traffic.

At the time of the switch fabric design, the shared or separate output buffer form is determined. It can not be altered during actual operation. Performance studies by Ghosh (2006) have proved a significant improvement in performance by introducing a predictive dynamic output buffer reconfiguration scheme in which a floating buffer, of the same size, is appended, at runtime to any one of the output links buffers; augment its net buffer capacity and thus increased network throughput. The hardware complexity increases when we implement this scheme.

Suri *et al.* (2006) examined the performance improvement in ATM switch by modifying the switch fabric design and packet forwarding method. They proposed a scheme for picking and forwarding cells from input buffer to the output buffer using simulator in ATM switch. The algorithm used more than one processes for achieving the shortest queue length and minimum waiting time. The study demonstrated that with the use of proposed algorithm, the number of out-of-order and lost packets for high traffic loads were decreased, thus network throughput and performance were improved.

A Markovian model for Optical Packet Switch (OPS) employing PBS mechanism has successfully been used by Perati (2007) to study packet loss behavior and then analysed short term and long term performance. Results show that proposed model was useful in performing the optimal buffer control of OPS using PBS scheme to provide differentiated services under self-similar traffic input. They further concluded that this model reduced computational complexity by reducing dimension of Markovian arrival process for low priority traffic and could be used to find optimal threshold for obtaining better performance and utilisation simultaneously.

2.4 MODELING OF VBR TRAFFIC

To facilitate the performance analysis in ATM networks, accurate mathematical modeling of various types of traffic sources, such as, voice, data and video is required. In general, data traffic is modeled by the Poisson process while voice calls are modeled by either the Interrupted Poisson Process or MMPP (Ide, 1988). As discussed in previous section of this chapter, many researchers have studied the performance of ATM networks using these models. However, these models lack in modeling the video traffic accurately, which is bursty in nature due to the instant variability of the video content being encoded (Paxson and Floyd, 1995; Berger *et al.*, 1998; Frigon and Victor, 1998; Krunz and Makowski, 1998; Ho, 2003). In ATM networks, video traffic is a dominant traffic for broadband ATM networks and it provides separate service category for bit rate coding and transmission of video traffic. In this section, the literature regarding modeling of video traffic is briefly reviewed.

Several researchers have rigorously analysed the VBR traffic and its modeling in ATM networks (Maglaris *et al.*, 1988; Nomura *et al.*, 1989; Grunenfelder *et al.*, 1991; Shim *et al.*, 1994; Elwalid *et al.*, 1995; Blefari, 1996; Heyman *et al.*, 1996), as it is the basis of video traffic control. One of the important traffic models other than Poisson or its variants is the autoregressive (AR) model.

AR model is a typical model for VBR traffic as described in literature (Shugong, 1997). It allows to accurately study the behavior of a single or multiplexed VBR traffic source in an ATM multiplexer and is suitable for modeling correlated traffic, such as, VBR encoded video. In VBR video, the video frames are generated at deterministic time intervals. It can model correctly the occurrences of frames with a large number of cells; which are primary factor in determining cell-loss rates. In majority of works reported in the literature, the discrete autoregressive (DAR) model, in many forms, has been used to model broadcast-video traces in past (Heyman *et al.*, 1992; Frater *et al.*, 1994; Krunz and Tripathi, 1997; Hwang *et al.*, 2002; Hwang and Shoraby, 2003).

Heyman *et al.* (1992) studied source modeling and performance related issues of video teleconference services over ATM networks. They used a long sequence of real video data to study multiplexing performance issues and to develop good source models. This aspect distinguished this study among all the previous studies. They had two major observations from this study; one was that traffic periodicity played important role when multiple video traffic sources were multiplexed for transition; the other was that number of cells per frame for video teleconference data followed a gamma distribution. They had investigated that appropriate buffer scheduling policy with priority classes could be used to reduce source periodicity effects.

Huang and Xu (1998) have suggested that a first order AR gamma sequence could be used to model VBR video traffic. This model correctly represented the occurrence of frames with a large number of cells to determine cell loss rate and its analysis showed that this model was more suitable to emulate a single video source than discrete autoregressive process of order 1 (DAR (1)). Hwang *et al.* (2002) have studied the performance of queue with DAR(1) process. They analysed waiting time distribution of the GI/G/1 queue with the help of an algorithm. They investigated the effect of parameters of DAR(1) on waiting time distributions. They also derived a simple approximation of asymptotic decay rate of the tail probabilities for the virtual waiting time in heavy traffic case.

Hwang and Shoraby (2003) have given analysis of a discrete-time queueing system with a DAR(1) input model to obtain closed-form expressions for the probability generating function and mean queue length. The analysis revealed that queueing performance was sensitive to the correlation of the arrival process. They also considered a queue with two state Discrete-time Markov Modulated Batch Arrival (D-MMBA) model to compare its queueing performance with DAR(1) model based on two parameters, *viz.*, marginal batch size distribution and carried load. The results show that DAR(1) arrival process exhibited larger queue length than a D-MMBA process. They further examined the effect of correlation on the queueing performance with changing marginal batch size distribution. This study showed that correlation affected queueing performance less significantly when the variance of batch size distribution was small.

Hwang and Choi (2004) investigated the queueing delay performance of PBS scheme with DAR(1) arrivals. They analysed a multi-server priority queue with two priority classes and used DAR(1) process to obtain a good mathematical model for VBR coded teleconference video traffic. They emphasised that queueing delay was more important than loss probability for high priority traffic; which could be reduced at the expense of loss of low priority traffic. The results revealed that PBS policy significantly decreased the waiting time as the value of threshold was increased. Lazaris *et al.* (2008) also used DAR(1) model in their work, to capture the behavior of multiplexed MPEG-4 videoconference movies from VBR coders.

A large number of researchers have discussed PBS scheme for effectively controlling cell loss ratios among traffic of different priority classes, however, only a few of them have focused on finding optimal threshold to obtain better QoS and improved performance results. In their proposed schemes, they mainly aim at controlling loss of high priority traffic only, where as, the low priority traffic suffer losses. Also, these schemes lack in adapting to the dynamics of input traffic changes. It is evident from review of literature that there exists no technique which effectively controls the cell loss ratios for both priority classes by dynamically changing the threshold in PBS scheme. Hence, further investigations are needed in this direction.

Moreover, no study showing application of adaptive threshold control in PBS scheme for analysing consecutive cell loss behavior in VBR video traffic using AR model has been reported till now in the existing literature. Hence, there is strong need for exploring the potential and capabilities of ATM technology in combination with PBS scheme for effective QoS management. The proposed study aims to explore various existing potential buffer management schemes in ATM networks useful for improving QoS. Several methods for input traffic modeling; and buffer management using several schemes (PBS, Pushout, Partial-Pushout *etc.*) have been investigated in this research work. As a result, appropriate buffer management scheme is designed to control the threshold optimally in PBS scheme for reducing cell loss for traffic of both priority types and hence improving QoS when the threshold is able to adapt based on bursty input traffic. Thus, it further improves fairness in congestion control for both priority classes.

CHAPTER 3

MODELS FOR SHARING BUFFER SPACE

3.1 INTRODUCTION

In order to effectively utilise network resources while providing satisfactory QoS to all the network users, prioritising the users' traffic according to their service requirements becomes necessary in high speed broadband networks. The network oriented QoS of a traffic type as defined in section 1.2.1.2, includes end-to-end cell delay and cell loss. Buffer management is a fundamental technology to provide QoS control mechanism, which controls the assignment of buffer resources among different flows or flow aggregations according to certain policies. According to the degree of sensitivity to the transmission delay and other factors, the traffic that a broadband network supports can be divided into two classes: high priority (real-time) and low priority (non-real-time). Real-time traffic has very strict delay constraints and it may tolerate very less occasional cell losses while non-real-time traffic can be required to reach the destination correctly with some loss-oriented priority policy. As such, the two classes of traffic have different service requirements which are in a trade-off. Real-time traffic is thus given a high priority as compared to non-real-time traffic.

The cost involved in the implementation of network is greatly affected if the cells from all services are handled in the same manner; as the design and dimensioning of network would be carried out according to QoS requirement of most demanding services. In order to control the cost, priority classes of different services have been introduced using space priority mechanisms as described in section 2.3. Priority mechanisms are used to optimise the network utilisation, while meeting the requirements of each type of traffic. The user may generate different priority traffic flows by using the loss priority bit capability and when buffer overflow occurs, cells from the low priority are then selectively discarded by network elements. Kroner *et al.* (1991) and Lin *et al.* (1991) proposed a priority control method called as Partial Buffer Sharing (PBS) for mixed traffic consisting of high priority and low priority cells. PBS scheme is used to prioritise the traffic of users in the broadband networks. When the buffer level is low, PBS accepts both high priority and low priority cells and when the buffer level is over a predefined threshold, low priority cells can not access the buffer and are discarded. In other words, high priority cells continue to access the buffer unless it is full. Fig. 3.1 illustrates the two operation modes of PBS mechanism. In most of existing partial buffer sharing schemes, the threshold is considered to be fixed. These schemes are referred to as Static Partial Buffer Sharing (SPBS) schemes (Kang and Tan, 1993). The challenge in designing a SPBS scheme is to select optimal threshold value to obtain desired relative cell loss ratio among the two classes of traffic.

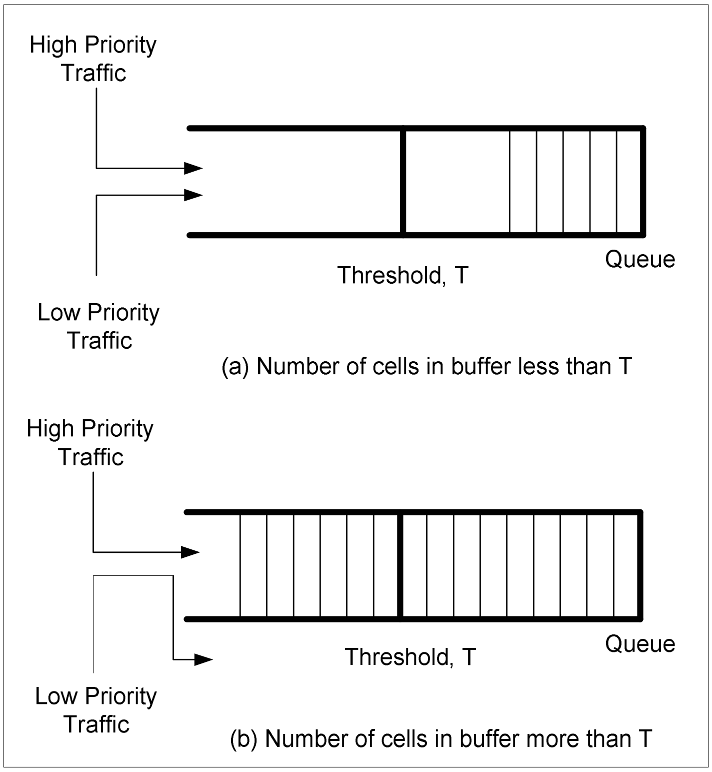


Fig. 3.1: Traffic model of PBS scheme.

In the present work, we have considered Cell Loss Probability as the performance measure of high priority traffic and low priority traffic and have also considered mathematical equations, given by Kwag *et al.* (1994). The quality of traffic including video, voice and other data signals is sensitive to consecutive cell losses rather than single cell loss (Jeong and Copeland, 1998 and Wang and Luan, 2001). Therefore, the performance measure for traffic in this thesis study is considered as consecutive cell loss probabilities.

This chapter deals with two issues, namely, implementation of existing PBS model and proposition of a new model. The PBS priority mechanism has been implemented using a fixed-size buffer being serviced by a single server. For the purpose of analysis, we have focused on low priority traffic as it can not share the buffer space beyond a threshold value. We have implemented a recursive algorithm to calculate loss probabilities for these types of traffic using MATLAB. Further the effect of different threshold values on cell loss probabilities is also examined. We have also proposed and implemented a new and efficient algorithm to control and vary threshold in PBS queue.

3.2 MODELING AND ANALYSIS OF PBS

This section illustrates recursive analysis of PBS model and the algorithm for this model, as given by Kwag *et al.* (1994).

3.2.1 Recursive analysis of traffic model

The traffic model has two input streams for different types of traffic, *i.e.,* high priority and low priority streams. The cells arrive at system according to Poisson process with arrival rates λ_r and λ_n for high priority and low priority traffic respectively. Both types of cells are stored at a common buffer which has a fixed service time with parameter μ for both traffic types. The capacity of buffer is M_2 and threshold level is M_1.

According to PBS mechanism, low priority cells are admitted to buffer only when buffer occupancy is less than $M_1 (< M_2)$ while the buffer access of high priority traffic is limited by its full capacity. Fig. 3.2 shows the state transition diagram of buffer under the PBS mechanism.

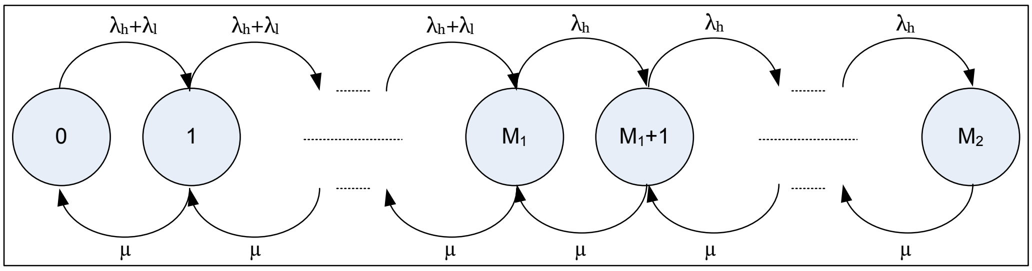


Fig. 3.2: State transition diagram of PBS scheme.

3.2.1.1 Notations

We have used following notations in the present work.

i) $\Pi(i)$, $i = 0, 1, ..., M_2$: The probabilities of having i cells in the system when a cell arrives.

ii) $Q_i(k),\ i = 0,\ 1,\ ...,\ M_2,\ 0 \le k \le i$: The probabilities that k cells out of i cells in the system leave the system during an inter-arrival period.

iii) $P^n(j,s),\ s \ge 1,\ 0 \le j \le s$: The probabilities of j losses in a block of s low priority cells.

iv) $P^r(j,s),\ s \ge 1,\ 0 \le j \le s$: The probabilities of j losses in a block of s high priority cells.

v) $P_i^n(j,s),\ i = 0,\ 1,\ ...,\ M_2,\ s \ge 1,\ 0 \le j \le s$: The probabilities of j losses in a block of s low priority cells given that there are i cells in the system just before the arrival of the first cell of the block.

vi) $P_i^{\bar{n}}(j,s),\ i = 0,\ 1,\ ...,\ M_2,\ s \ge 1,\ 0 \le j \le s$: The probabilities of j losses in a block of s low priority cells given that there are i cells in the system just before the arrival of a high priority cell.

vii) $P_i^r(j,s),\ i = 0,\ 1,\ ...,\ M_2,\ s \ge 1,\ 0 \le j \le s$: The probabilities of j losses in a block of s high priority cells given that there are i cells in the system just before the arrival of the first cell of the block.

viii) $P_i^{\bar{r}}(j,s),\ i = 0,\ 1,\ ...,\ M_2,\ s \ge 1,\ 0 \le j \le s$: The probabilities of j losses in a block of s high priority cells given that there are i cells in the system just before the arrival of a low priority cell.

ix) $P_{ind}^n(j,s),\ s \ge 1,\ 0 \le j \le s$: The probabilities of j losses in a block of s low priority cells under the independence assumption.

x) $P_{ind}^r(j,s),\ s \ge 1,\ 0 \le j \le s$: The probabilities of j losses in a block of s high priority cells under the independence assumption.

3.2.1.2 The governing equations

From the state transition diagram given in Fig. 3.2, we can derive the following balance equation.

$$(\lambda_i + \mu_i)\,\Pi(i) = \lambda_{i-1}\,\Pi(i-1) + \mu_{i+1}\,\Pi(i+1) \qquad \dots (3.1)$$

where

$$\lambda_i = \begin{cases} \lambda_n + \lambda_r, & 0 \le i < M_1 \\ \lambda_r, & M_1 \le i \le M_2 \end{cases}$$

$$\mu_i = \mu \qquad 0 \le i \le M_2$$

Here λ_i and μ_i are the arrival and service rates at state i, respectively. It can also be noted that total offered load ρ is given by $\left(\frac{\lambda_n + \lambda_r}{\mu}\right)$ and low priority cell load ρ_n is given by $\left(\frac{\lambda_n}{\mu}\right)$.

The solution of balance equation (3.1) gives the probabilities $\Pi(i),\ i = 0,\ 1,\ 2,\ \ldots,\ M_2$ as,

$$\Pi(i) = \begin{cases} \rho^i\, \Pi(0), & 0 \le i < M_1 \\ \rho^{M_1} (\rho_n)^{i-M_1}\, \Pi(0), & M_1 \le i \le M_2 \end{cases} \qquad \ldots (3.2)$$

and

$$\Pi(0) = \left[\sum_{i=0}^{M_1} \rho^i + \sum_{i=M_1+1}^{M_2} \rho^{M_1} (\rho_n)^{i-M_1} \right]^{-1}$$

In the present analysis, our focus is to calculate the probabilities, $P^r(j,s)$ and $P^n(j,\ s)$, of j losses in s cell block from each traffic. By conditioning on the number of cells seen in the system by the first cell in the block when it arrives, following equations can be framed:

$$P^r(j,s) = \sum_{i=0}^{M_2} \Pi(i)\ P_i^r(j,s) \qquad \ldots (3.3)$$

$$P^n(j,s) = \sum_{i=0}^{M_2} \Pi(i)\ P_i^n(j,s) \qquad \ldots (3.4)$$

Also, the matrix $Q_i(k)$ has been introduced to solve the above equations recursively as follows:

$$Q_i(k) = \begin{cases} \left(\frac{\mu}{\mu + \lambda_n + \lambda_r}\right)^k \left(\frac{\lambda_n + \lambda_r}{\mu + \lambda_n + \lambda_r}\right), & 0 \le k < i \\ \left(\frac{\mu}{\mu + \lambda_n + \lambda_r}\right)^i, & k = i \end{cases} \qquad \ldots (3.5)$$

The initial values of $P_i^n(j,s)$ can be obtained as:

$$P_i^n(j,1) = \begin{cases} 1, & j=0 \\ 0, & \text{otherwise} \end{cases} \qquad 0 \le i < M_1 \qquad \dots (3.6)$$

$$P_i^n(j,1) = \begin{cases} 1, & j=1 \\ 0, & \text{otherwise} \end{cases} \qquad M_1 \le i < M_2 \qquad \dots (3.7)$$

$$\mathrm{P}_i^n(0,\, k) = 0 \qquad 1 \le k \le s \qquad \dots (3.8)$$

For $s \ge 2$, as first cell arrives in the system, it sees i ($0 \le i < M_1$) cells present already in the system. If k ($0 \le k \le i+1$) cells are transmitted during the inter-arrival time between the first and second cells, the second cell sees $i+1-k$ cells in the system at its arrival. Hence, as first cell is not lost, j cells must be lost out of $s-1$ cells. The probability that a cell selected arbitrarily is a low priority is given as $p(n) = \left(\frac{\lambda_n}{\lambda_n + \lambda_r}\right)$. Therefore, $p(\bar{n}) = 1 - p(n)$ and we have following equation:

$$P_i^n(j,s) = \sum_{k=0}^{i+1} Q_{i+1}(k) \times \left[p(n)\ P_{i+1-k}^n(j,s-1) + p(\bar{n}) P_{i+1-k}^{\bar{n}}(j,s-1)\right], \quad 0 \le i < M_2 \qquad \dots (3.9)$$

If there are more than $M_1 - 1$ cells in the system, the first low priority cell will be lost and because of this $j-1$ cells must be lost out of $s-1$ cells. The second cell sees $i-k$ cells in the system, if k ($0 \le k \le i+1$) cells are being served during inter-arrival time of first and second cell. We thus obtain the following equation.

$$P_i^n(j,s) = \sum_{k=0}^{i} Q_i(k) \times \left[p(n)\ P_{i-k}^n(j-1,s-1) + p(\bar{n}) P_{i-k}^{\bar{n}}(j-1,s-1)\right], \quad M_1 < i \le M_2 \ \dots (3.10)$$

On the similar pattern, $p_i^{\bar{n}}(j,s)$ is obtained.

$$P_i^{\bar{n}}(j,s) = \sum_{k=0}^{i+1} Q_{i+1}(k) \times \left[p(n)\, P_{i+1-k}^n(j,s) + p(\bar{n}) P_{i+1-k}^{\bar{n}}(j,s)\right], \quad 0 \le i \le M_2 \qquad \dots (3.11)$$

$$P_{M_2}^{\bar{n}}(j,s) = P_{M_2-1}^{\bar{n}}(j,s) \qquad \dots (3.12)$$

In order to solve the equation (3.4), the probabilities $P_i^n(j,1)$ are computed from the initial conditions. Next, we calculate the probabilities $P_i^{\bar{n}}(j,k),\ 0 \le i \le M_2$ using equations (3.11) and (3.12). The probabilities $P_i^n(j,k),\ 0 \le i \le M_2$ are calculated recursively using equations (3.9) and (3.10).

For comparing the results with those obtained from independent assumptions, we have also computed $P_{ind}^{r}(j,s)$ and $P_{ind}^{n}(j,s)$. The blocking probabilities for high priority and low priority cells are $p_n = \sum_{i=M_1}^{M_2} \Pi(i)$ and $p_r = \Pi(M_2)$, respectively. Under independent assumption each cell arrival can be considered as an independent trail and given as

$$P_{ind}^{r}(j,s) = \binom{s}{j} p_r^j (1-p_r)^{s-j} \qquad \ldots (3.13)$$

$$P_{ind}^{n}(j,s) = \binom{s}{j} p_n^j (1-p_n)^{s-j} \qquad \ldots (3.14)$$

3.3 ALGORITHM

Algorithm 3.3 (Recursive Algorithm for PBS scheme) is proposed in this section for calculating loss probabilities. This algorithm is based on the recursive equations discussed in section 3.2.1.2 and this analyses cell loss probability for a number of lost cells within a fixed-size block under PBS scheme. We have implemented this algorithm in MATLAB 7.0.

Algorithm 3.3 (Recursive Algorithm for PBS scheme)

BEGIN

Step 1: Identify number of cells in system and denote it by *i*. The buffer capacity is denoted by *M2* and the threshold in queue is represented by *M1*. Determine the probability of *k* cells leaving the system out of *i* cells during an inter-arrival and it is denoted by *Q(i)(k)*.

Step 2: The probability of loss of *j* low priority cells in a block of *s* low priority cells, given that there are *i* cells in the system before the arrival of first cell of the block, is represented as *pn(j, s)*. For *i* = 0 to *M2*, compute initial conditions for loss probability with a block of one low priority cell and is given by *pn(j, 1)*.

```
Step 3: Using initial conditions, calculate the probability of $j$ cells lost in a block of $s$ low
        priority cells, given that there are $i$ cells in the system before arrival of high
        priority cell. This is denoted by pnbar(j, s). Initially, it is calculated with $s = 1$.
Step 4: For $s = 2$ to BLOCK_SIZE (where BLOCK_SIZE is number of cells in a given
        block), repeat the following steps:
        Step 4.1: For $j = 0$ to $s$, perform the following operations:
                  Step 4.1.1: Calculate pn(j, s) for all values of $i$ from 0 to M2.
                  Step 4.1.2: Find pnbar(j, s) for all values of $i$ from 0 to M2. Go to step
                              4.1.
        Step 4.2: Go to step 4.
Step 5: Calculate probability of having $i$ cells in the system when a new cell arrives and it
        is denoted by pie(i).
Step 6: To get final probability of $j$ losses in a block of BLOCK_SIZE for low priority
        traffic, multiply pie(i) by pn(j, s) for all values of $i$ between 0 to M2.
Step 7: Calculate independent loss probability for $j$ losses out of BLOCK_SIZE cells
        using Bernoulli's Law.
END
```

3.4 NUMERICAL RESULTS

In this section, distribution of lost cells in a fixed-size block is calculated using equations given in 3.2.1.2. We have assumed the buffer size $M_2 = 30$, threshold level $M_1 = 24$, and block size = 10. The distribution of consecutive cell loss probability by recursive method is compared that with independent assumption.

Fig. 3.3 shows that with recursive equations the loss probability for low priority cells increases as compared to that with independent assumption. But the independent assumption lacks in correlation between adjacent cell losses and may lead to incorrect consecutive cell loss probability.

The threshold value in PBS scheme can be changed to control buffer space allocated to different traffic sources. Fig. 3.4 depicts the effect of varying thresholds on loss probability of low priority traffic. The block loss probabilities for low priority traffic have been plotted as a function of the PBS threshold parameter.

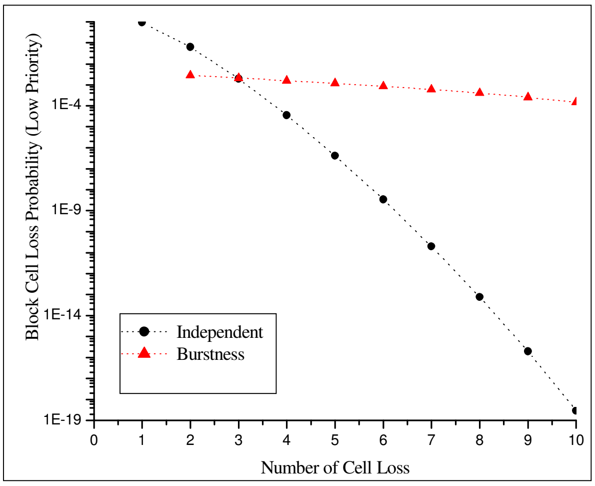


Fig. 3.3: Comparison of block cell loss probability for low priority cells with recursive equations and independent assumption.

An increase in the threshold parameter results in significant improvement of service quality for low priority traffic. Similar pattern was observed for different values of buffer size. At a threshold level equal to half of buffer size, the loss probability decreased by 67.75% and 96.60% for buffer size $M_2 = 30$, and 50 respectively when compared with the buffer size $M_2 = 20$. Hence a suitable value of PBS threshold chosen in accordance with traffic mix and service requirement helps to increase buffer space utilisation and gives high degree of flexibility. This has motivated us to propose the ADaptive Partial Buffer Sharing ADPBS (ADPBS) model as illustrated in section 3.5.

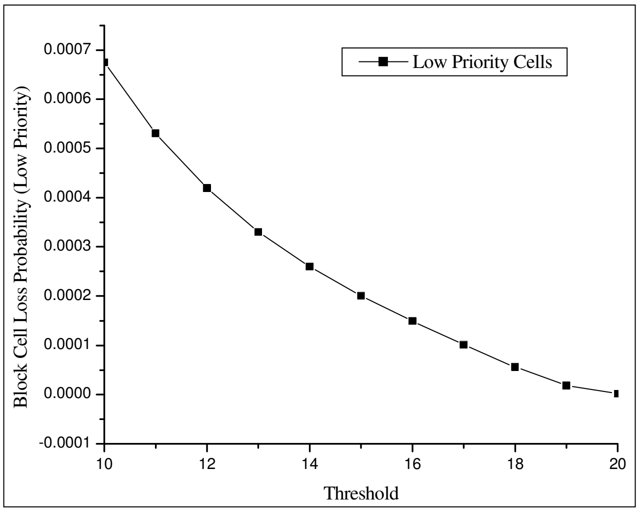


Fig. 3.4: Effect of threshold value on block cell loss probability for low priority cells in PBS scheme.

3.5 ADPBS MODEL

The challenge in designing a PBS scheme with fixed (or static) threshold is to select optimal threshold value to obtain desired cell loss ratio among different classes of traffic. The quality of traffic, including voice and video, is sensitive to consecutive cell losses rather than a single cell loss. The main goal is to accommodate more incoming cells from various sources and smooth out the burst arrival rate within a predefined buffer size. In a network, there can be situations in which the incoming traffic from various sources may have different proportions of high priority cells and low priority cells. But, with a fixed threshold, PBS queue can not adapt to such dynamically changing traffic conditions. For that reason, a novel scheme of adaptive threshold to fairly regulate the sharing of memory among queue for traffic of loss priorities is proposed. The adaptive threshold scheme, named as, Adaptive Partial Buffer Sharing (ADPBS) scheme, is an improvement of Static threshold PBS (SPBS) scheme. When the bursty traffic load changes, the system will go through a transient and improves the cell loss ratio performance between two classes (*i.e.,* high priority cells and low priority cells) and hence, improves the buffer utilisation also. The cell discarding decision is taken according to the certain parameters defining relationship between current queue occupancy and the threshold value.

We have assumed a finite queue of size M and source traffic with two classes of priorities, class 1 with high priority and class 2 with low priority. There is one threshold level T, as illustrated in Fig. 3.5. The arrival rate for high priority traffic is represented by λ_h and that for low priority by λ_l. The service rate of the queue is represented as μ. The traffic load for the queue is given by $\rho = (\lambda_h + \lambda_l) / \mu$. Any arriving cell can be admitted into the queue if the current queue occupancy is less than the threshold T, otherwise only high priority cells can be admitted if queue is not full. A counter is maintained to count the number of lost cells for each class (N_h for high priority and N_l for low priority) with initial value set to zero. We have also considered two parameters for high priority cells, namely, number of consecutive losses for these cells, also called as loss control limit (c_h) and modification step level (s_h). In case, c_h consecutive losses of high priority cells are there, the threshold T is decreased by modification step level s_h. Similarly, two parameters for low priority cells, namely, number of consecutive losses for these cells, also called as loss control limit (c_l) and modification step level (s_l) have also been used. The initial value of threshold T is set at some value between two levels – starvation level and overflow level. Starvation level is the minimum level below which threshold can not be further decreased. It denotes sum of a predefined threshold (considered here as 20% of buffer size) and s_h. Its minimum possible value is 1. Overflow level is the maximum level above which threshold value can not be further increased. It represents sum of a predefined threshold and s_l. Its maximum value can be equal to size of buffer.

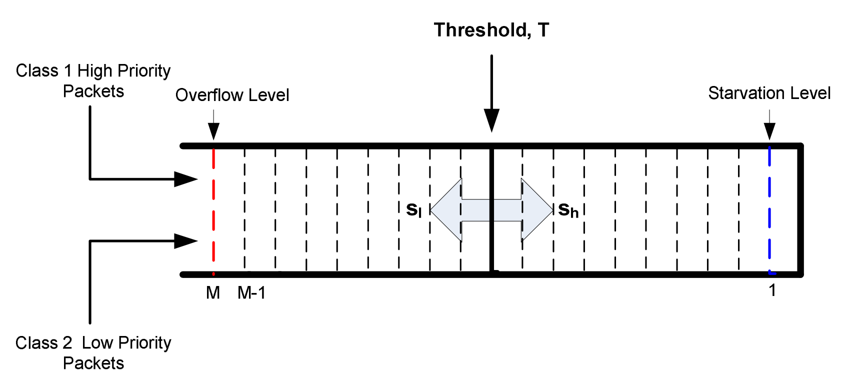


Fig. 3.5: ADPBS queueing model with two priority classes.

The amount of limit movement by parameters s_h and s_l are based on the bursting of the traffic, the more burst the traffic, the large the values should be set to reduce excessive fluctuations. The changes in level of threshold are determined by the size of c_h and c_l. When the values of c_h and c_l are set to be very large then the threshold will not be changed very often and ADPBS scheme becomes equivalent to the SPBS scheme. The ADPBS scheme implemented in MATLAB, is based on the assumption that if a number of consecutive low priority cells are lost, there is a probability that heavy low priority traffic will arrive in a short while and the discarding threshold should be increased to provide sufficient buffer space for them. In case, a number of consecutive high priority cells are lost, the discarding threshold should be decreased to provide sufficient queue space for high priority cells. If the threshold moves towards the right, it yields enough space only for high priority cells to be accommodated in buffer at the cost of loss of low priority cells due to reduced buffer space for those. Hence, loss probability of low priority cells increases. Similarly, the threshold movement towards left results in increased loss probability of high priority cells.

3.5.1 Proposed algorithm

Following notations have been used in the algorithm proposed for ADPBS scheme.

i) *CELL_PRIORITY*: The function *priority_decision()* decides the priority class of every cell upon its arrival. The priority class of cell can either be high priority (*HIGH*) or low priority (*LOW*).

ii) *CELLS_IN_SYSTEM*: It represents the number of cells simulated.

iii) *CONSEC_CELL_LOSS_HI*: It is counter for the total number of consecutive high priority cells lost during simulation.

iv) *CONSEC_CELL_LOSS_LO*: It is counter for the total number of consecutive low priority cells lost during simulation.

v) *DEC_HI*: It represents unit step change (decrement) in threshold value based on consecutive loss of high priority cells.

vi) *DYN_THRESH*: It represents the threshold value in the ADPBS queue.

vii) *EVENT_TYPE*: Two types of events are possible, namely, arrival of cell (*CELL_ARRIVAL*) and departure of cell (*CELL_DEPARTURE*). The cell arrival process is modeled with Poisson Process (discussed in section 4.1) and autoregressive process (discussed in Section 5.1).

viii) *INC_LO*: It is the unit change (increment) in threshold value based on loss of consecutive low priority cells.

ix) *LOSS_CONTROL_HI*: It represents the control limit for high priority cell loss, on reaching which the threshold change is triggered.

x) *LOSS_CONTROL_LO*: It represents the control limit for low priority cell loss, on reaching which the threshold change is triggered

xi) *OVERFLOW_LEVEL*: It is the maximum level above which threshold value can not be further increased. It represents the sum of a predefined threshold value and *INC_LO*; and its maximum value can be equal to buffer size.

xii) *PREV_COUNTER_HI*: It represents the counter to check consecutive high priority cell loss.

xiii) *PREV_COUNTER_LO*: It represents the counter to check consecutive low priority cell loss.

xiv) *QUEUE_LENGTH*: It represents the number of cells in queue.

xv) *QUEUE_LIMIT*: It represents the total buffer capacity in terms of number of cells.

xvi) *STARVATION _LEVEL*: It is the minimum level below which threshold value can not be further decreased. It represents the sum of a predefined threshold value (taken as 20% of buffer size) and *DEC_HI*; and its minimum possible value can be 1.

xvii) *TOTAL_CELL_LOSS_HI*: It represents total number of high priority cells lost during simulation.

xviii) *TOTAL_CELL_LOSS_LO*: It represents the total number of low priority cells lost during simulation.

xix) *SIM_CELLS*: It represents the total number of cells to be simulated.

Algorithm 3.5.1 (ADPBS Scheme)

```
BEGIN
Step 1: Recognise the number of cells to be simulated (SIM_CELLS)
Step 2: While CELLS_IN_SYSTEM < SIM_CELLS, repeat the following steps:
    Step 2.1: determine EVENT_TYPE
    Step 2.2: if EVENT_TYPE is CELL_ARRIVAL, go to step 2.3; else go to step 2.7.
    Step 2.3: increment the counter CELLS_IN_SYSTEM by 1.
    Step 2.4: determine CELL_PRIORITY
    Case 1: (high priority cell)
    Step 2.5: if CELL_PRIORITY is HIGH, go to step 2.5.1; else go to step 2.6.
        Step 2.5.1: if QUEUE_LENGTH ≥ QUEUE_LIMIT, go to step 2.5.2;
                    else go to step 2.5.7.
        Step 2.5.2: increment the counter TOTAL_CELL_LOSS_HI by 1.
        Step 2.5.3: if PREV_COUNTER_HI equals (CELLS_IN_SYSTEM - 1),
                    go to step 2.5.4; else go to step 2.5.6.
        Step 2.5.4: increment the counter CONSEC_CELL_LOSS_HI by 1.
        Step 2.5.5: if CONSEC_CELL_LOSS_HI equals LOSS_CONTROL_HI,
                    go to step 2.5.5.1; else go to step 2. //for next cell
                    Step 2.5.5.1: reset CONSEC_CELL_LOSS_HI.
```

```
                Step 2.5.5.2: if DYN_THRESH > STARVATION_LEVEL, go to step 2.5.5.3; else go to step 2.
                Step 2.5.5.3: decrease DYN_THRESH by DEC_HI. Go to step 2. //for next cell
        Step 2.5.6: set PREV_COUNTER_HI equal to CELLS_IN_SYSTEM, CONSEC_CELL_LOSS_HI to 1 and CONSEC_CELL_LOSS_LO to 0. Go to step 2. // for next cell
        Step 2.5.7: increment QUEUE_LENGTH by 1 and reset CONSEC_CELL_LOSS_HI, CONSEC_CELL_LOSS_LO. Go to step 2. // for next cell
Case 2: (low priority cell)
Step 2.6: if QUEUE_LENGTH < DYN_THRESH, go to step 2.6.1; else go to step 2.6.3.
        Step 2.6.1: increment QUEUE_LENGTH by 1.
        Step 2.6.2: reset CONSEC_CELL_LOSS_HI, CONSEC_CELL_LOSS_LO. Go to step 2. //for next cell
        Step 2.6.3: increment TOTAL_CELL_LOSS_LO by 1.
        Step 2.6.4: if PREV_COUNTER_LO equals (CELLS_IN_SYSTEM - 1), go to step 2.6.5; else go to step 2.6.7.
        Step 2.6.5: increment the counter CONSEC_CELL_LOSS_LO by 1.
        Step 2.6.6: if CONSEC_CELL_LOSS_LO equals LOSS_CONTROL_LO, go to step 2.6.6.1; else go to step 2. //for next cell.
                Step 2.6.6.1: reset CONSEC_CELL_LOSS_LO.
                Step 2.6.6.2: if DYN_THRESH < OVERFLOW_LEVEL, go to step 2.6.6.3; else go to step 2.
                Step 2.6.6.3: increase DYN_THRESH by INC_LO. Go to step 2. //for next cell
        Step 2.6.7: set PREV_COUNTER_HI equal to CELLS_IN_SYSTEM, CONSEC_CELL_LOSS_HI to 0 and CONSEC_CELL_LOSS_LO to 1. Go to step 2. // for next cell.
Step 2.7: if QUEUE_LENGTH > 0, go to step 2.7.1; else go to step 2.7.2.
```

```
            Step 2.7.1: QUEUE_LENGTH gets decremented by 1. Go to step 2. //
                        for next cell.
            Step 2.7.2: Since no cell in the system, no cell departure is possible.
Step 3: Go to step 2. //for next cell.
END
```

3.6 CONCLUSION

In the first part of this chapter, we described modeling and analysis of the PBS mechanisms in detail and a recursive algorithm has been implemented using MATLAB, to calculate cell loss probabilities using a fixed-size block under PBS mechanism. The analysis has been done considering traffic streams of high priority and low priority cells. When compared with independent probability distribution, it was observed that consecutive cell loss of low priority is significantly different and the independent assumption underestimates the consecutive cell loss probabilities, thus leading to erroneous conclusion. There is trade-off between the cell loss probability of high priority and low priority traffic due to PBS. The effect of varying threshold on loss probabilities for low priority cells provides flexibility and improves performance of network. As such, the cell loss probability for low priority traffic decreases by increasing threshold value. The main objective of the second part of this chapter was to discuss a solution for fixed threshold PBS queue. We have presented an analytical model, namely, ADPBS, for discrete time finite queue which incorporates adaptive threshold to adapt for network traffic changes. This model is discussed in detail in the next chapters for different input traffic models.

CHAPTER 4

PERFORMANCE ANALYSIS OF ADPBS QUEUE FOR POISSON INPUT TRAFFIC

The ADPBS scheme as proposed in section 3.5 attempts to yield better QoS by adapting its threshold to the dynamic input traffic changes. In order to study the performance of ADPBS scheme, a simulation model, as given in Fig. 4.1, has been designed. This model comprises of three sections, namely, input section, simulation section and output section. The input section represents the input traffic source to be used for simulation and analysis. In the present work, the behavior of ADPBS scheme has been studied using two types of input traffic sources, one based on Poisson process and other based on AR process. The simulation results and performance analysis with Poisson process based traffic source are discussed in this chapter while the analysis of ADPBS queue with AR input process is given in Chapter 5. The simulation section consists of three queues, namely, ADPBS queue, SPBS queue, and FIFO queue. Each queue gets the same input at a particular instance. The cell loss behavior of all the queues is captured in last section of the simulation model, *i.e.*, output section. In this chapter performance comparison of all the queues is done under various input traffic conditions. The following sections deal with detailed analysis of ADPBS queue performance with respect to SPBS and FIFO queues.

4.1 POISSON PROCESS BASED INPUT TRAFFIC MODEL

The input section of simulation model consists of a Poisson process based source traffic generator that derives the input traffic module. This module deals with event management of cell arrival or departure. The relative cell loss behavior is studied by deploying exponential model to generate traffic common for the three different queue mechanisms. This distribution has been applied to model data traffic because of its simplicity (Ross, 1997; Sadiku and Tofighi, 1999; Chukwuemeka; Sadiku, 2001; Taha, 2004). Random inter-arrival times are described quantitatively in queueing models by the exponential distribution, which is defined as

$$f(t) = \lambda\, e^{-\lambda t},\ t > 0 \qquad \dots\ (4.1)$$

where $\lambda > 0$ is the parameter associated with the distribution.

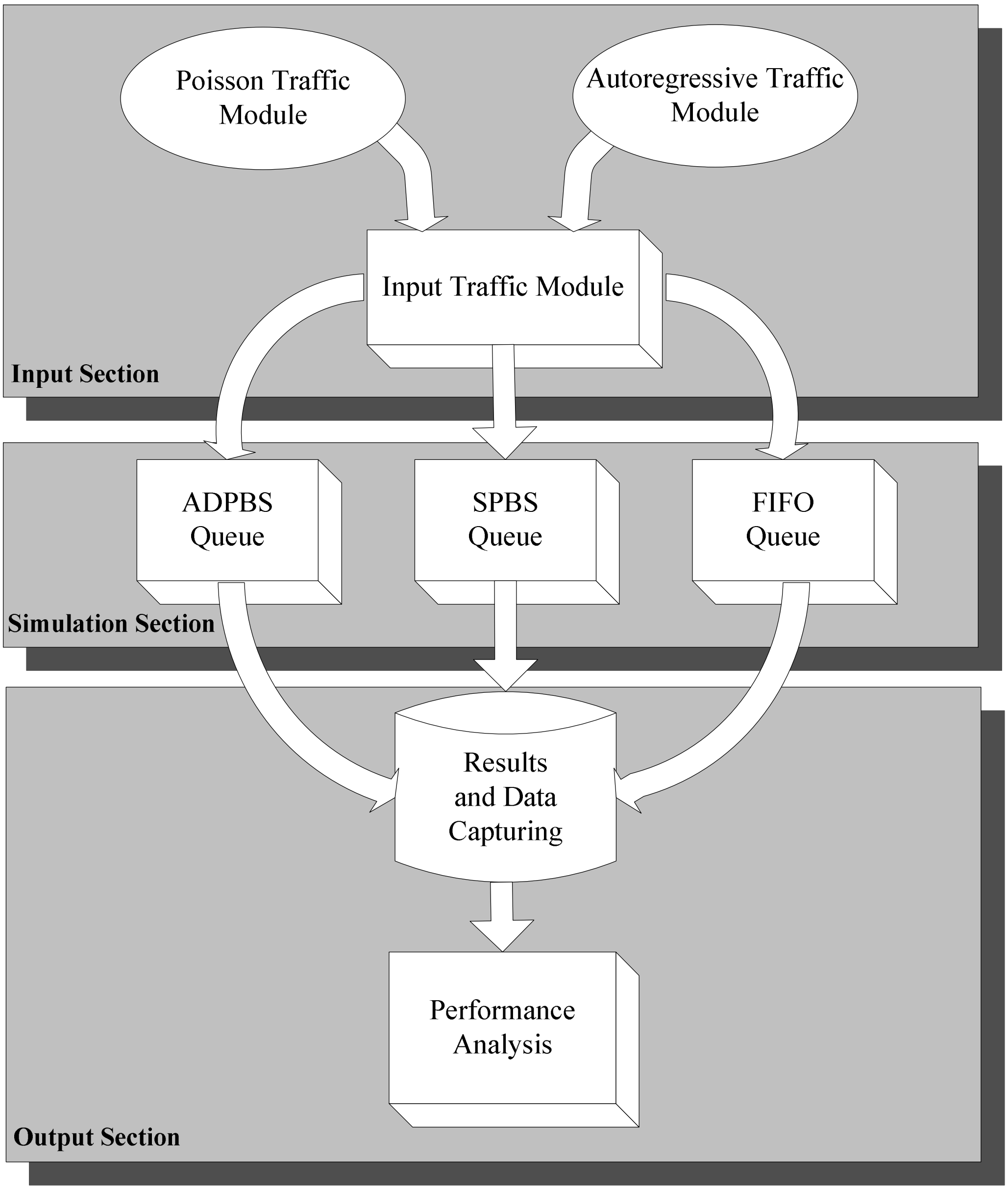


Fig. 4.1: Simulation model.

In this simulation study, we have considered the buffer size M at the level 30 and the service rate μ also at the level 30. The same values of buffer size and service rate are assigned to each queue. The performance of each queue is compared under different traffic conditions, which can be broadly classified under two categories; one based on threshold control parameters and other based on input traffic characteristics of the queue. For the purpose of analysis, simulation is carried out using different combinations of c_h, c_l, s_h and s_l, the parameters controlling the adaptive behavior of the model. Under the category of input traffic characteristics, effect of variation of traffic load and traffic mix is also studied and is given in following sections.

4.2 ANALYSIS OF ADPBS QUEUE USING DIFFERENT COMBINATIONS OF THRESHOLD CONTROL PARAMETERS

The threshold in ADPBS queue is controlled by four parameters, namely, c_h, c_l, s_h and s_l. During simulation, these parameters are used in a combination represented by c_h-c_l-s_h-s_l. The value of each parameter depends on the buffer size and preference given to a priority class. Performance comparison among the given schemes is carried out with cell loss ratio as QoS function. The combinations, which show better results in terms of less number of consecutive cell losses in ADPBS queue when compared to SPBS and FIFO queues, are identified. These selected combinations are then used for further simulations in order to study traffic load variation, input traffic mix variation etc. For the purpose of analysing ADPBS queue, different combinations of loss control limits c_h and c_l, which decide the threshold control limit for high or low priority cells, are used. We have considered the following three cases:

Case (i) : loss control limit of high priority cells < loss control limit of low priority cells
Case (ii) : loss control limit of high priority cells > loss control limit of low priority cells
Case (iii): loss control limit of high priority cells = loss control limit of low priority cells

Each of the above cases is simulated under traffic conditions with different proportions of high and low priority cells as input to the queue, *i.e.*, high priority cells in majority, low priority cells in majority and both types of cells in equal proportion. For each combination as mentioned above, 30 samples are captured by running simulation and plotted accordingly. Performance of the proposed ADPBS scheme is compared with SPBS and FIFO schemes, for different combinations of threshold control parameters in the subsequent sub-sections.

4.2.1 Results of combinations with loss control limit of high priority cells less than loss control limit of low priority cells

Under this category, when $c_h < c_l$, simulations are carried out for $c_h = 2$, $c_l = 4$ and

6 with $s_h = s_l = 1$ and 2. For the sake of clarity, we represent these combinations by 2-4-1-1, 2-4-2-2, 2-6-1-1 and 2-6-2-2. We have, in the present study, considered the smaller values of these control parameters. It however, has been noticed that the larger values of these control parameters lead to similar results. First, the traffic condition of high priority cells in majority is studied for 2-4-1-1 combination. The results of this simulation are summarised in Fig. 4.2 and Fig. 4.3 for consecutive cell loss of high priority cells and low priority cells, respectively. Since this particular combination of threshold control parameter has lower loss control limit for high priority cells than for low priority cells, the results of this simulation revealed that the loss is controlled for high priority cells and ADPBS queue performs relatively better than other queues. For a set of simulations, the average cell loss in ADPBS queue for high priority cells is 4300 and for low priority cells it is approximately 4100. It has been observed that there is not any significant deviation from this value, over a number of simulations.

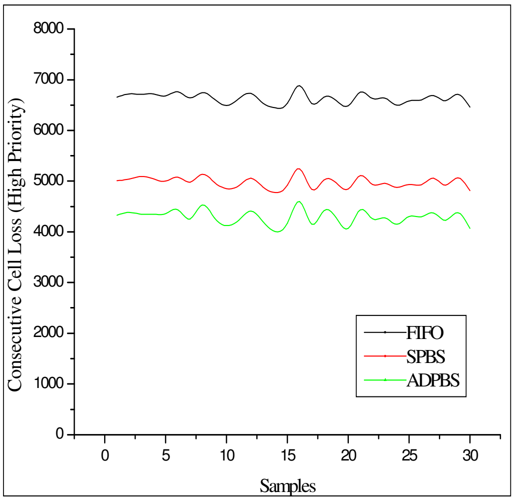


Fig. 4.2: High priority cell loss for 2-4-1-1.

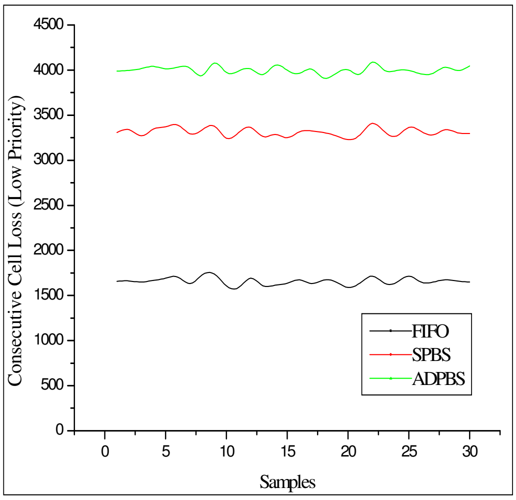


Fig. 4.3: Low priority cell loss for 2-4-1-1.

The performance of the ADPBS queue for traffic cases with other combinations, namely, 2-4-2-2, 2-6-1-1 and 2-6-2-2 is similar to the performance of this queue for combination 2-4-1-1. The results for the same are illustrated in Fig. 4.4, Fig. 4.6 and Fig. 4.8 for high priority cells and Fig. 4.5, Fig. 4.7 and Fig. 4.9 for low priority cells.

The comparison between ADPBS, FIFO and SPBS queues using different combinations of threshold control parameters, when input traffic to all these queues contains majority of low priority cells, is shown graphically in Fig. 4.10 to Fig. 4.17. According to the proposed scheme, preference would be given specifically to low priority cells because they are large in number.

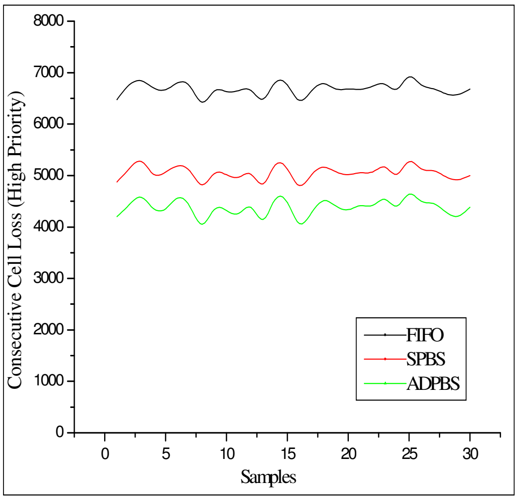


Fig. 4.4: High priority cell loss for 2-4-2-2.

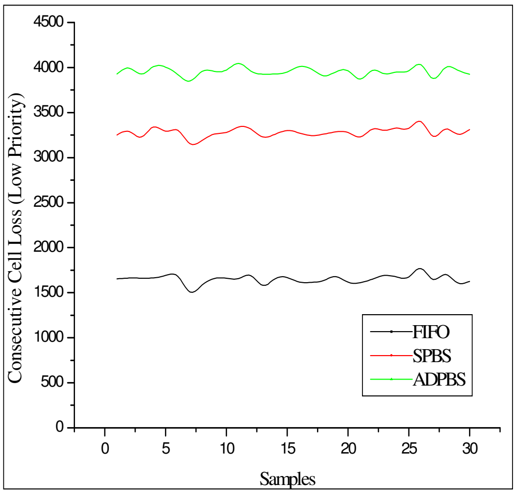


Fig. 4.5: Low priority cell loss for 2-4-2-2.

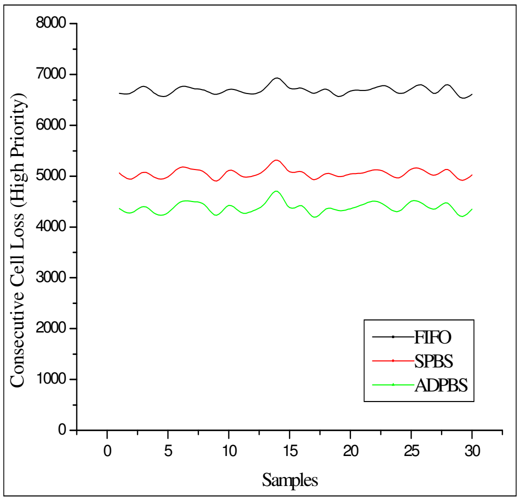


Fig. 4.6: High priority cell loss for 2-6-1-1.

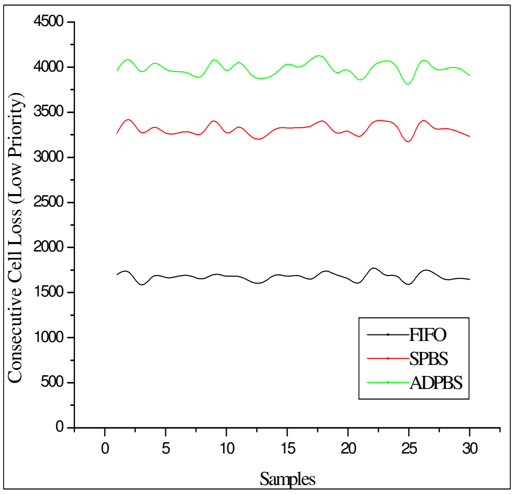


Fig. 4.7: Low priority cell loss for 2-6-1-1.

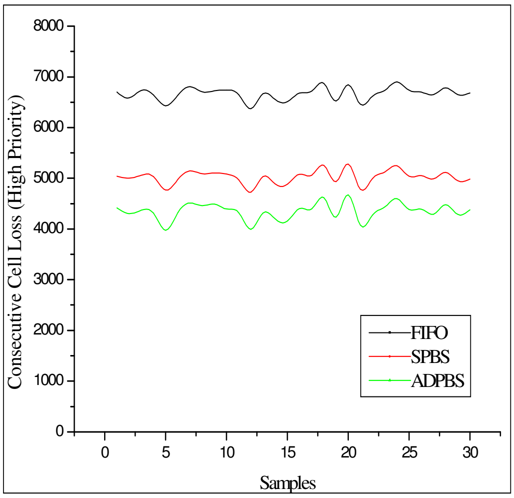


Fig. 4.8: High priority cell loss for 2-6-2-2.

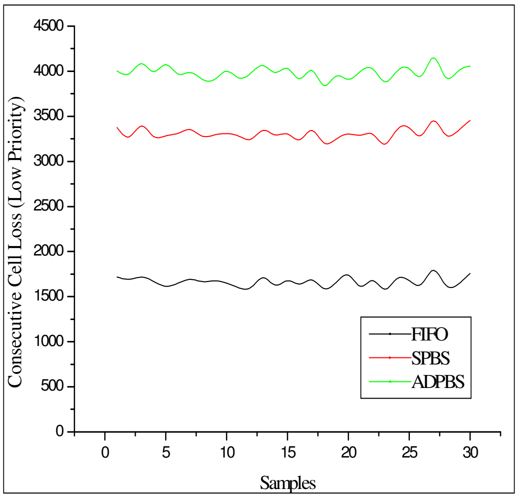
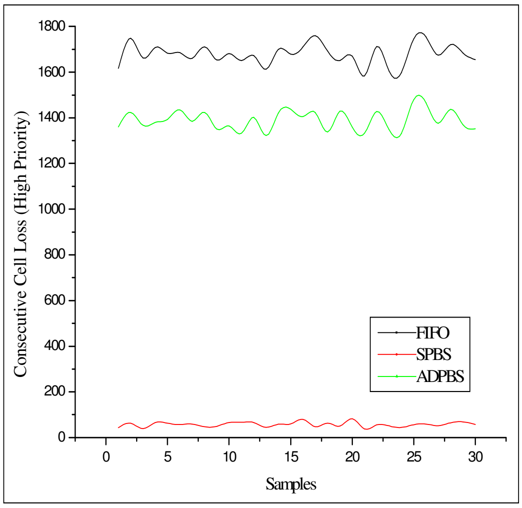


Fig. 4.9: Low priority cell loss for 2-6-2-2.



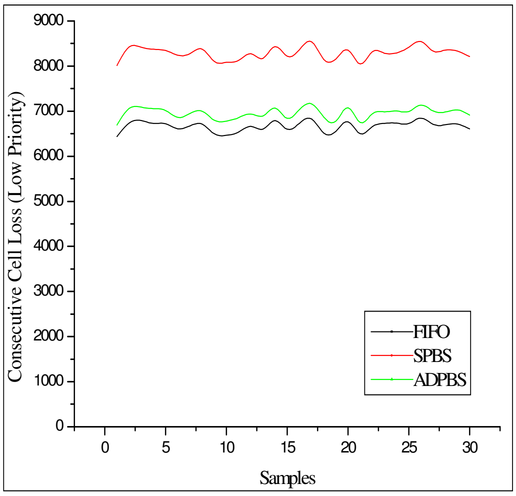
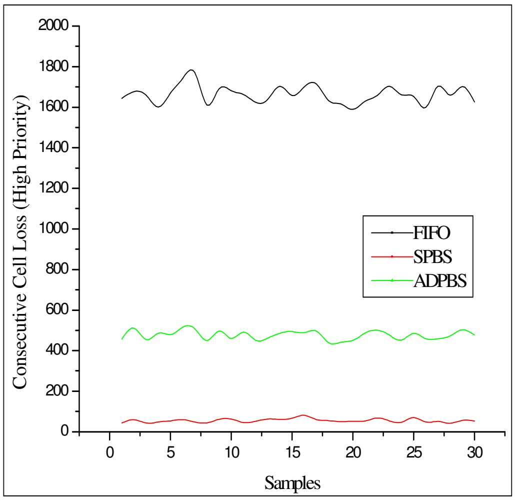


Fig. 4.10: High priority cell loss for 2-4-1-1.

Fig. 4.11: Low priority cell loss for 2-4-1-1.



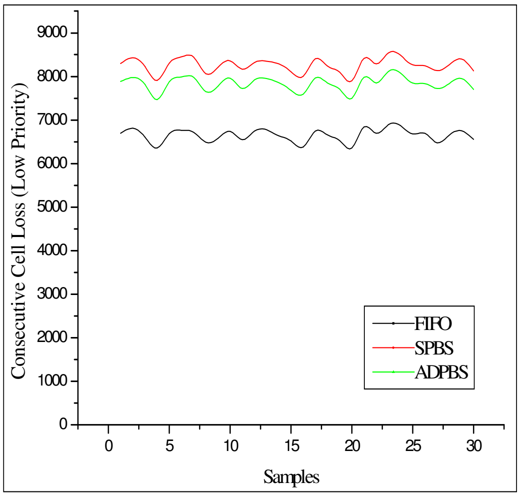
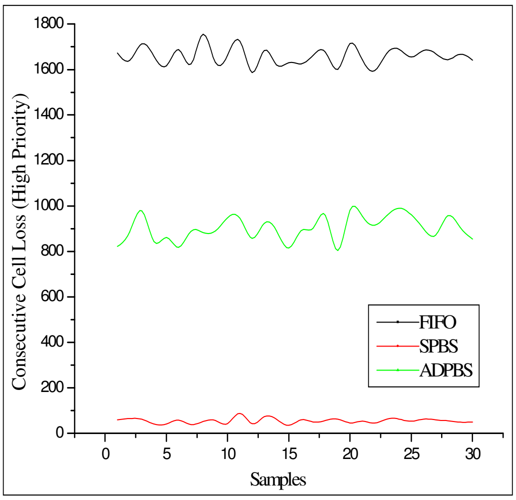


Fig. 4.12: High priority cell loss for 2-4-2-2.

Fig. 4.13: Low priority cell loss for 2-4-2-2.



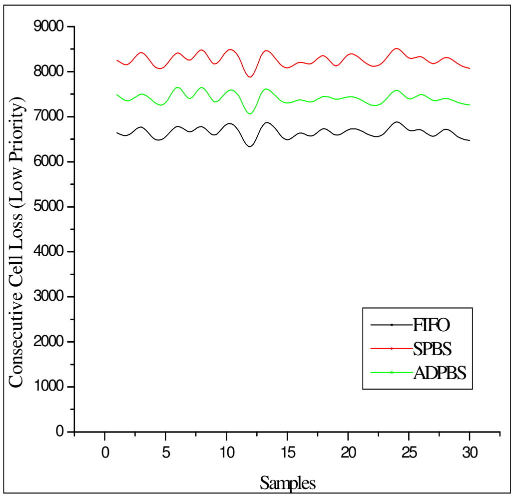


Fig. 4.14: High priority cell loss for 2-6-1-1.

Fig. 4.15: Low priority cell loss for 2-6-1-1.

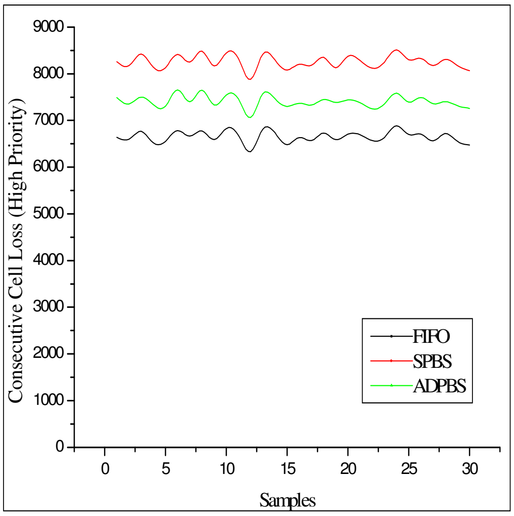


Fig. 4.16: High priority cell loss for 2-6-2-2.

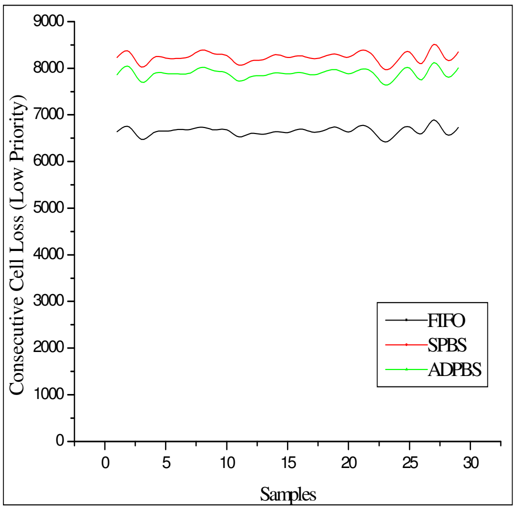


Fig. 4.17: Low priority cell loss for 2-6-2-2.

For input data stream with equal proportion of high and low priority cells, the consecutive cell loss behavior is illustrated in Fig. 4.18 to Fig. 4.25. From this set of simulations, it can be observed that ADPBS scheme will save more high priority cells because for these combinations, *i.e.*, 2-4-1-1, 2-4-2-2, 2-6-1-1 and 2-6-2-2, loss control limit of high priority cells (c_h) is less than loss control limit of low priority cells (c_l).

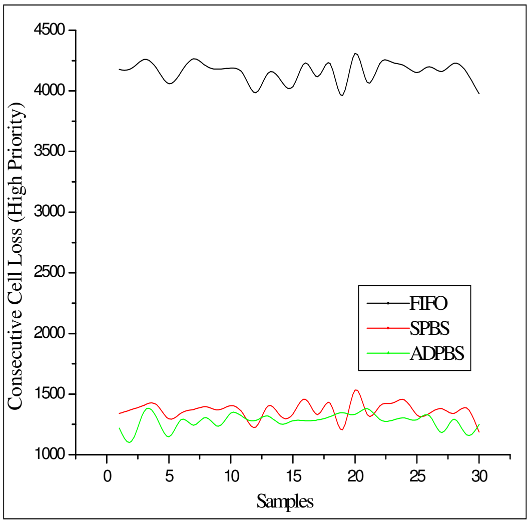


Fig. 4.18: High priority cell loss for 2-4-1-1.

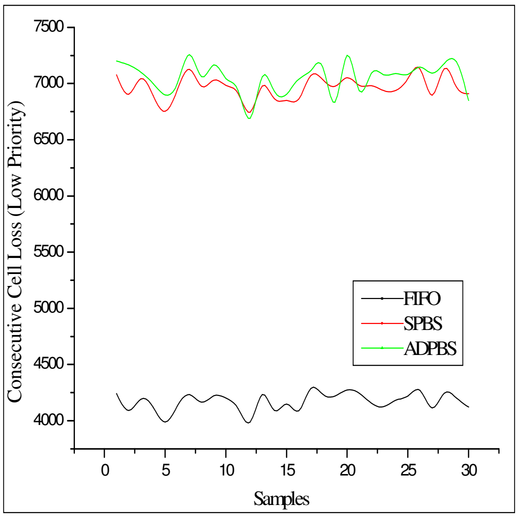
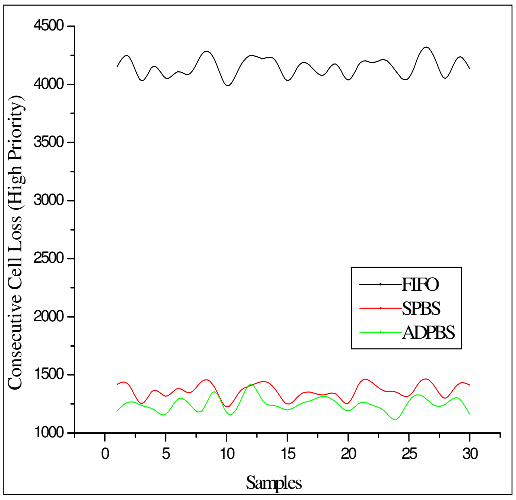


Fig. 4.19: Low priority cell loss for 2-4-1-1.



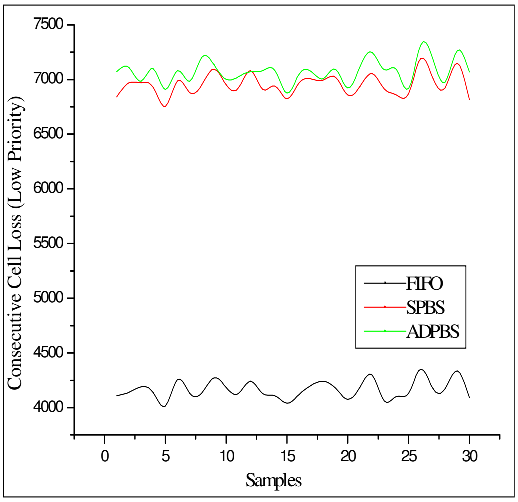
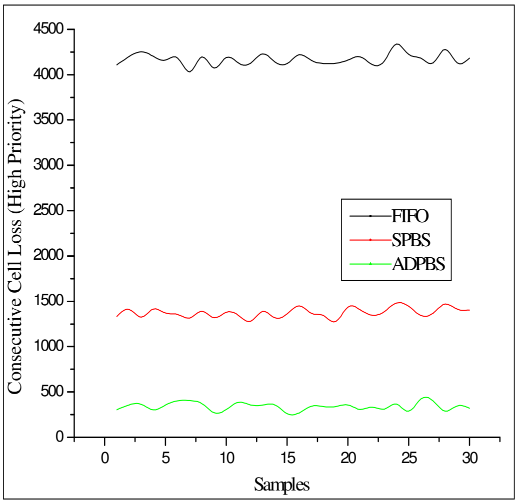


Fig. 4.20: High priority cell loss for 2-4-2-2.

Fig. 4.21: Low priority cell loss for 2-4-2-2.



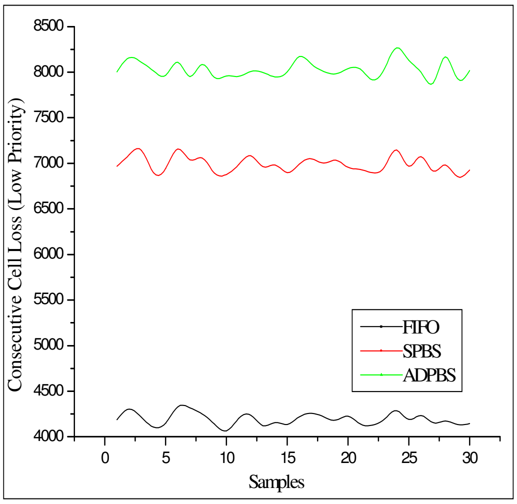
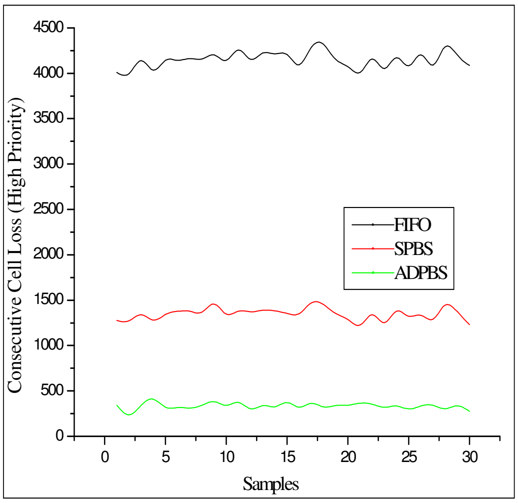


Fig. 4.22: High priority cell loss for 2-6-1-1.

Fig. 4.23: Low priority cell loss for 2-6-1-1.



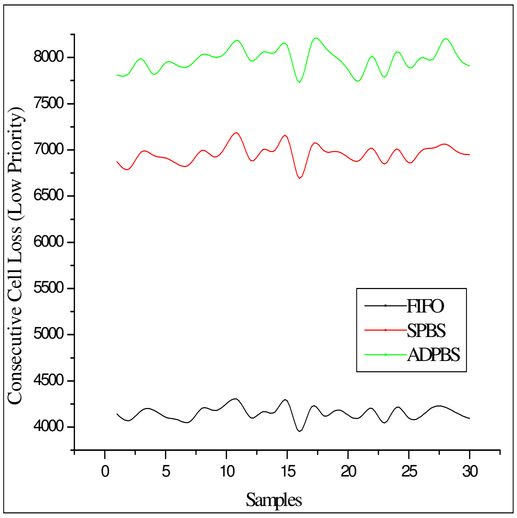


Fig. 4.24: High priority cell loss for 2-6-2-2.

Fig. 4.25: Low priority cell loss for 2-6-2-2.

In the subsequent sections, we have considered two combinations of threshold control parameters out of the combinations discussed above for analysing the performance of proposed scheme. Based on the minimum consecutive cell losses during simulation under $c_h < c_l$ category, combinations 2-4-2-2 and 2-6-2-2 are selected for further simulations in sections 4.3 and 4.4.

4.2.2 Results of combinations with loss control limit of high priority cells greater than loss control limit of low priority cells

The basic nature of this combination helps to control loss of low priority cells because loss control limit of low priority cells is less than loss control limit of high priority cells. The combinations 6-2-2-2, 4-2-1-1, 4-2-2-2 and 6-2-1-1 have been used for performance analysis under this case. The results are compiled graphically in Fig. 4.26**,** Fig. 4.28**,** Fig. 4.30 and Fig. 4.32 for high priority cells and in Fig. 4.27**,** Fig. 4.29**,** Fig. 4.31 and Fig. 4.33 for low priority cells for all three queues, when there is majority of high priority cells in the incoming traffic. It is observed that average loss of consecutive high priority cells in ADPBS queue is 5700, which is greater than SPBS queue. However, the loss of low priority cells in ADPBS queue is less than SPBS queue. This is inline to the inherent nature of this particular combination of threshold control parameters and the scheme adapts to reduce loss of low priority cells only.

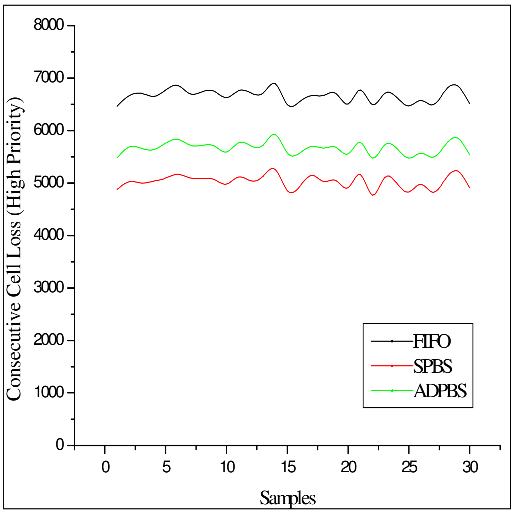


Fig. 4.26: High priority cell loss for 6-2-2-2.

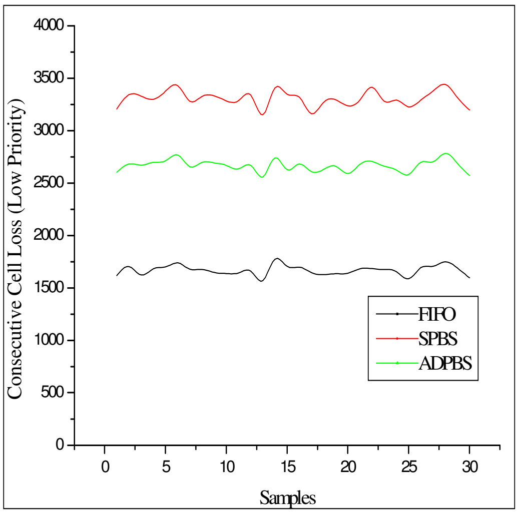
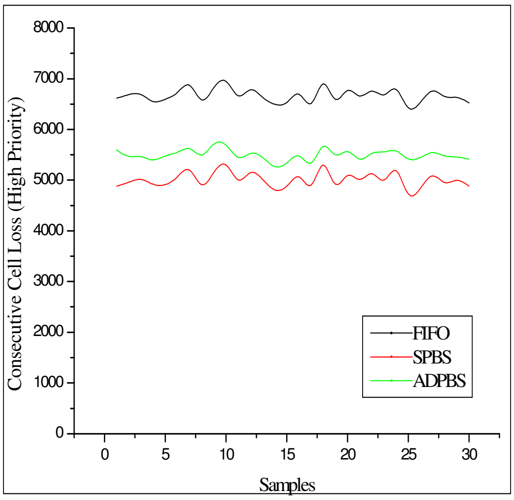


Fig. 4.27: Low priority cell loss for 6-2-2-2.



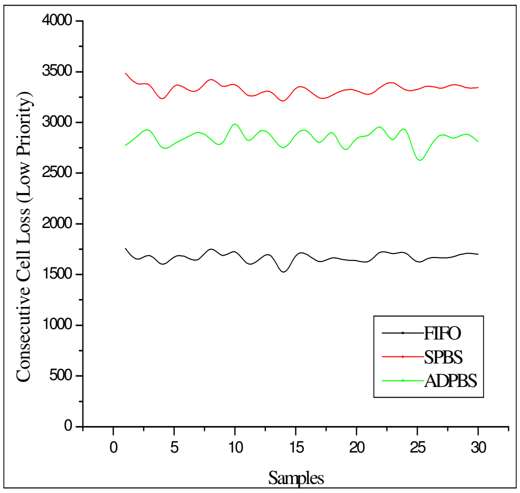
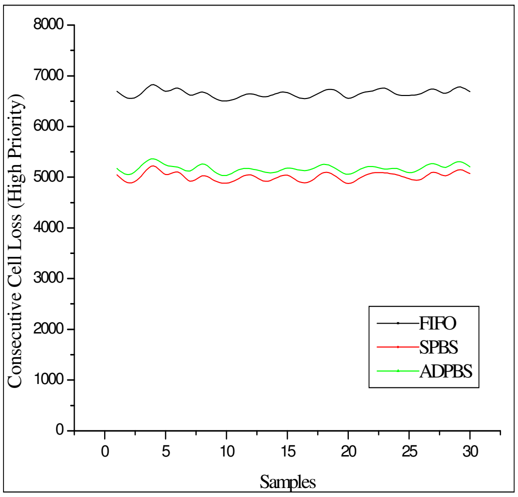


Fig. 4.28: High priority cell loss for 4-2-1-1.

Fig. 4.29: Low priority cell loss for 4-2-1-1.



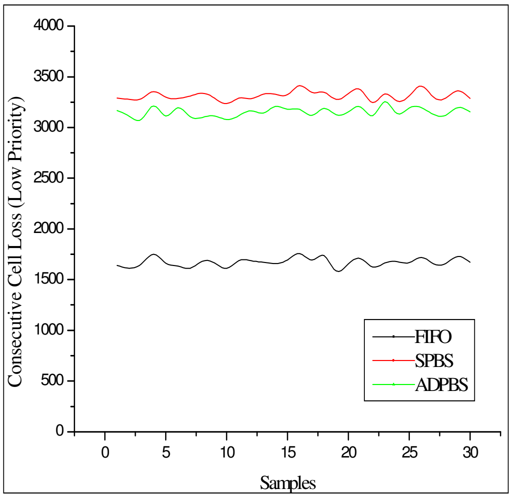
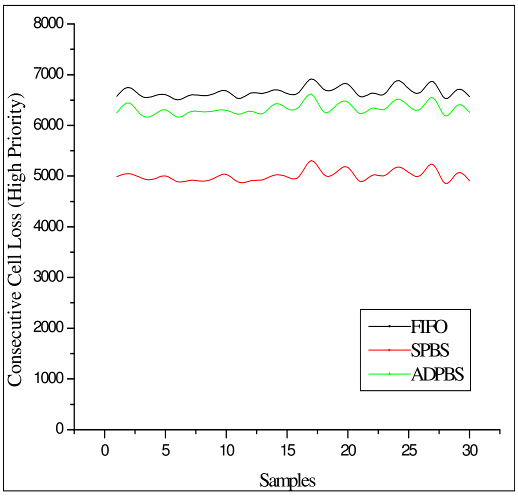


Fig. 4.30: High priority cell loss for 4-2-2-2.

Fig. 4.31: Low priority cell loss for 4-2-2-2.



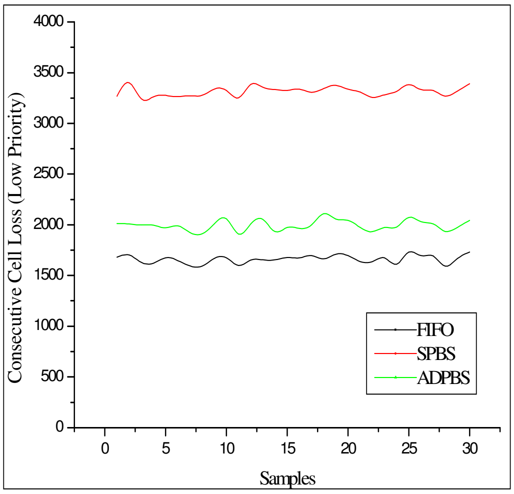


Fig. 4.32: High priority cell loss for 6-2-1-1.

Fig. 4.33: Low priority cell loss for 6-2-1-1.

During the simulation analysis, we have observed that c_h is set equal to 3, *i.e.*, with combinations 3-2-1-1 and 3-2-2-2, the trend for high priority cell loss is changed as shown in Fig. 4.34 and Fig. 4.36. It is observed that the high priority cell losses are least in ADPBS queue because value of c_h is less as compared to previous combinations discussed under this case. As such, ADPBS queue manages to adapt threshold more frequently and the loss is controlled in a better way.

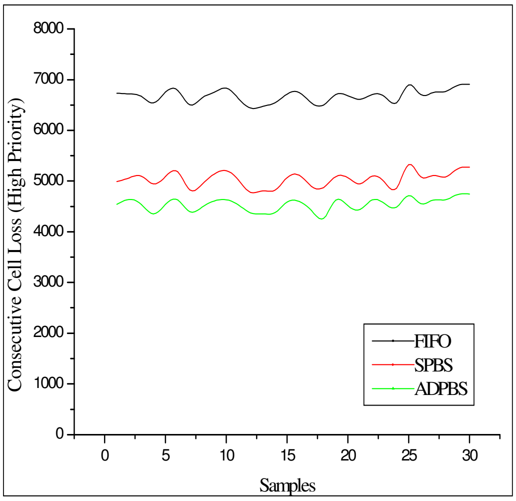


Fig. 4.34: High priority cell loss for 3-2-1-1.

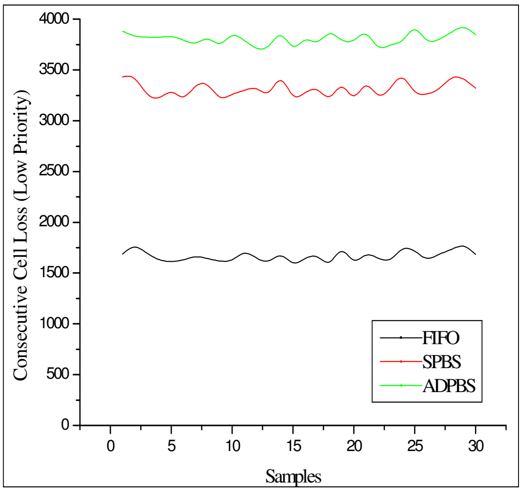


Fig. 4.35: Low priority cell loss for 3-2-1-1.

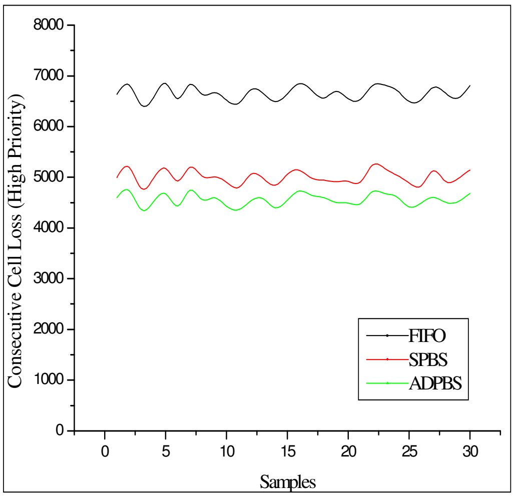


Fig. 4.36: High priority cell loss for 3-2-2-2.

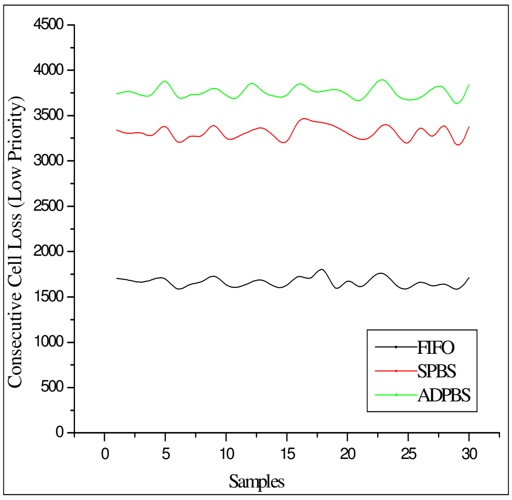


Fig. 4.37: Low priority cell loss for 3-2-2-2.

The results of the simulation study for high priority cell loss in ADPBS, SPBS and FIFO queues is depicted in Fig. 4.38, Fig. 4.40, Fig. 4.42 and Fig. 4.44 for 6-2-2-2, 4-2-1-

1, 4-2-2-2 and 6-2-1-1 combinations, respectively; when low priority cells are in majority. It can be inferred from Fig. 4.39, Fig. 4.41, Fig. 4.43 and Fig. 4.45 that the loss of low priority cells is 60%-70% more in SPBS queue as compared to ADPBS queue. FIFO queue is having the least losses for low priority traffic as this traffic is in majority in input and as such, FIFO queue will have maximum number of low priority cells in its buffer.

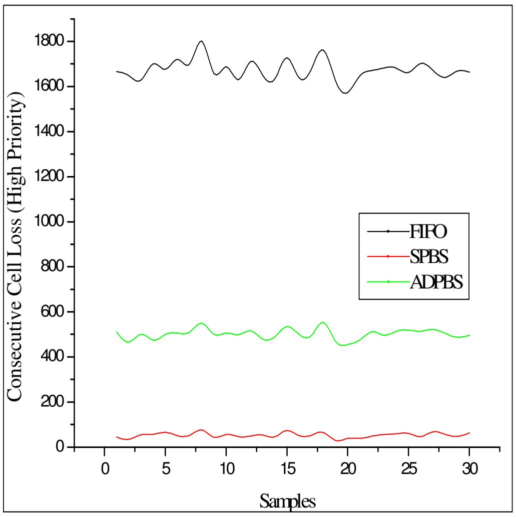


Fig. 4.38: High priority cell loss for 6-2-2-2.

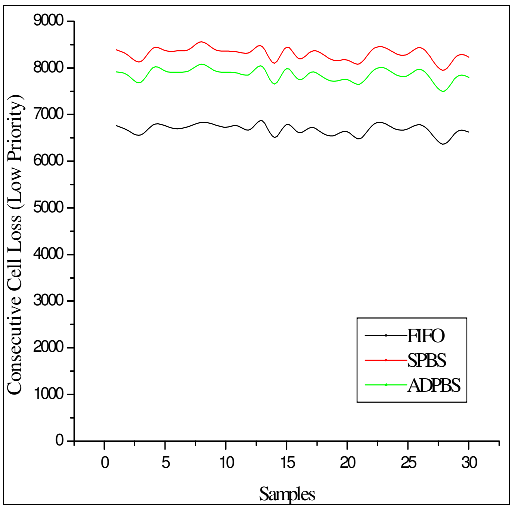


Fig. 4.39: Low priority cell loss for 6-2-2-2.

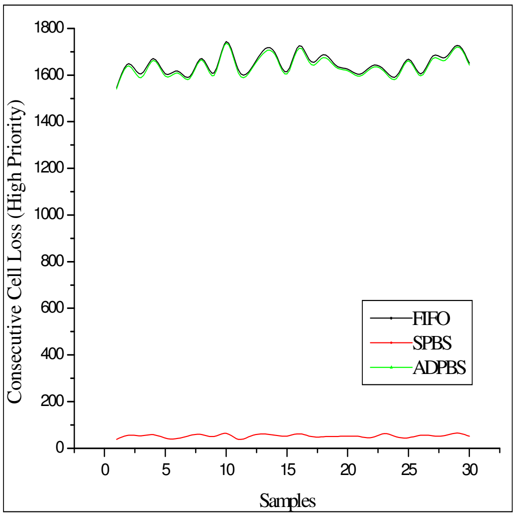


Fig. 4.40: High priority cell loss for 4-2-1-1.

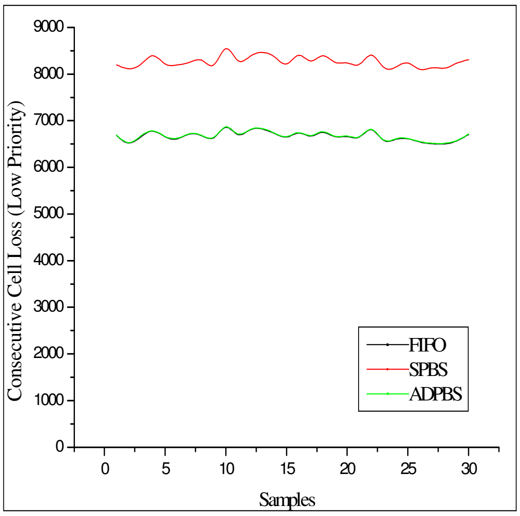


Fig. 4.41: Low priority cell loss for 4-2-1-1.

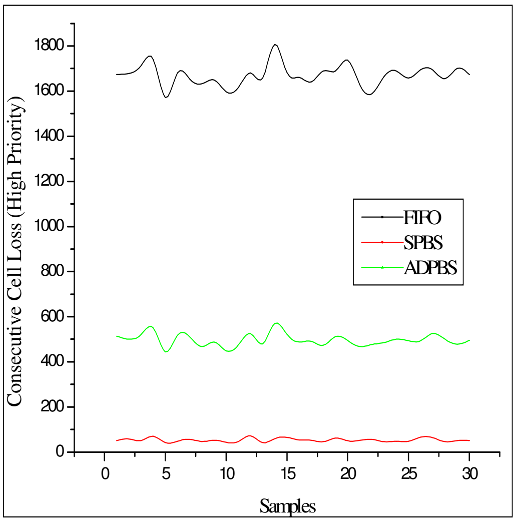


Fig. 4.42: High priority cell loss for 4-2-2-2.

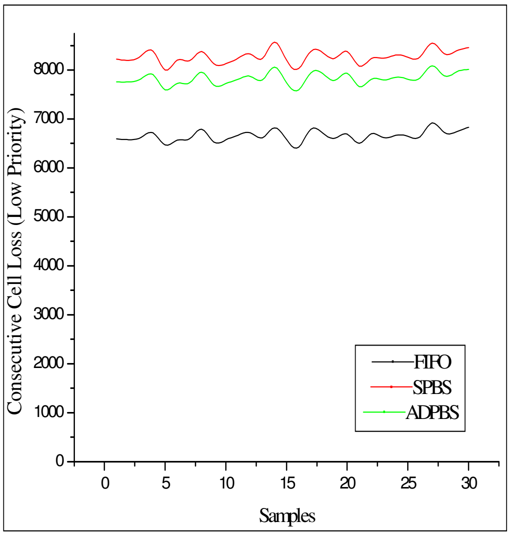


Fig. 4.43: Low priority cell loss for 4-2-2-2.

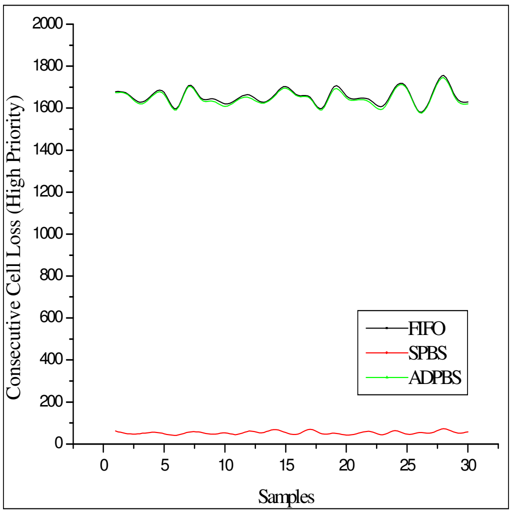


Fig. 4.44: High priority cell loss for 6-2-1-1.

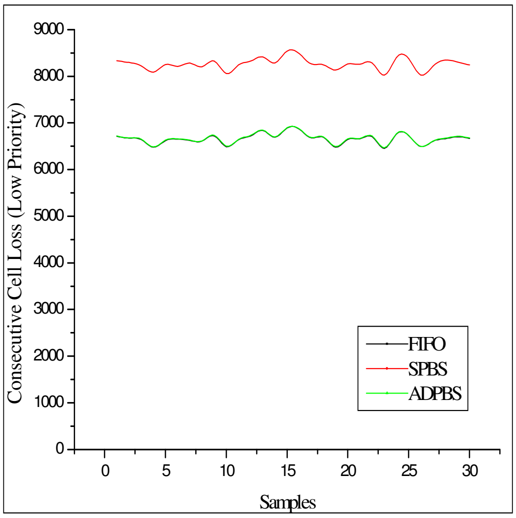
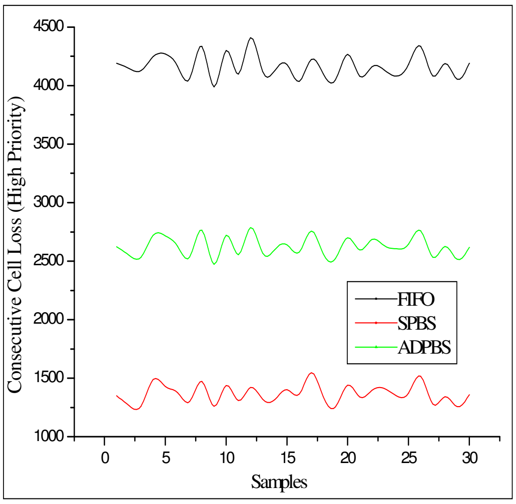


Fig. 4.45: Low priority cell loss for 6-2-1-1.

The consecutive cell losses are illustrated in Fig. 4.46 to Fig. 4.53 for equal proportion of high priority and low priority cells in input traffic. From the set of simulations, it can be inferred that low priority cells are given more preference for combinations 6-2-2-2, 4-2-1-1, 4-2-2-2 and 6-2-1-1 as loss control limit of low priority cells (c_l) is less than loss control limit of high priority cells (c_h).



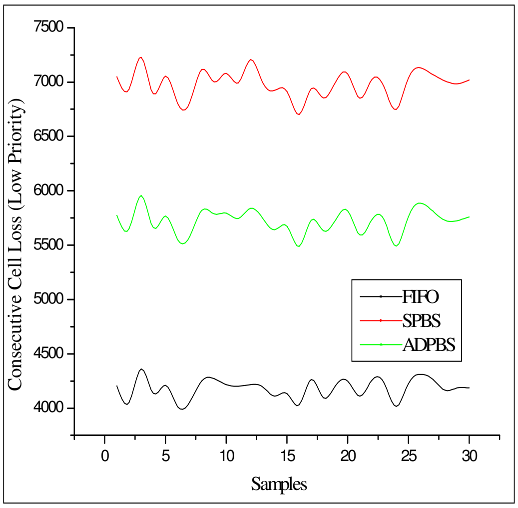
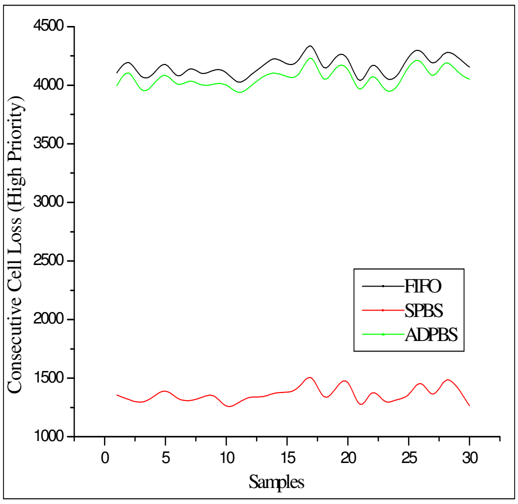


Fig. 4.46: High priority cell loss for 6-2-2-2.

Fig. 4.47: Low priority cell loss for 6-2-2-2.



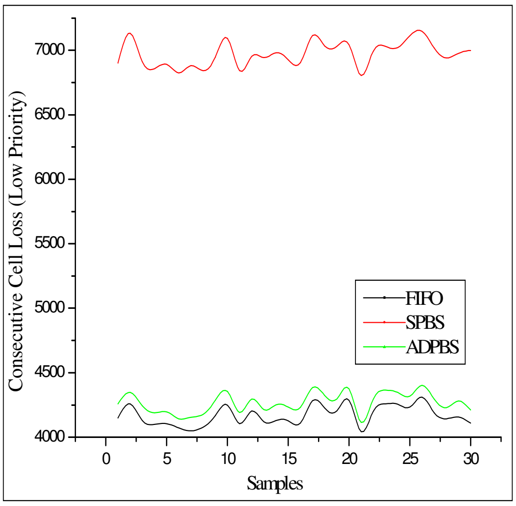
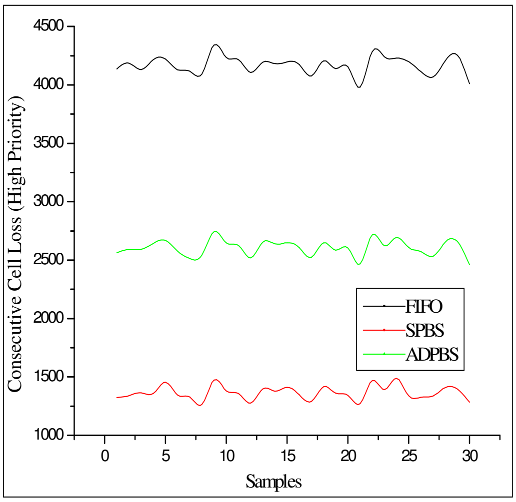


Fig. 4.48: High priority cell loss for 4-2-1-1.

Fig. 4.49: Low priority cell loss for 4-2-1-1.



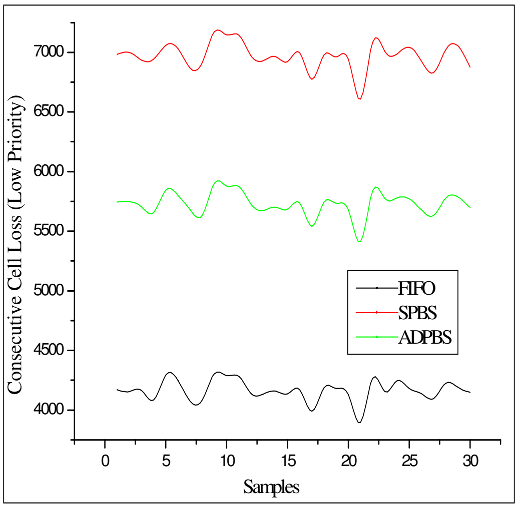


Fig. 4.50: High priority cell loss for 4-2-2-2.

Fig. 4.51: Low priority cell loss for 4-2-2-2.

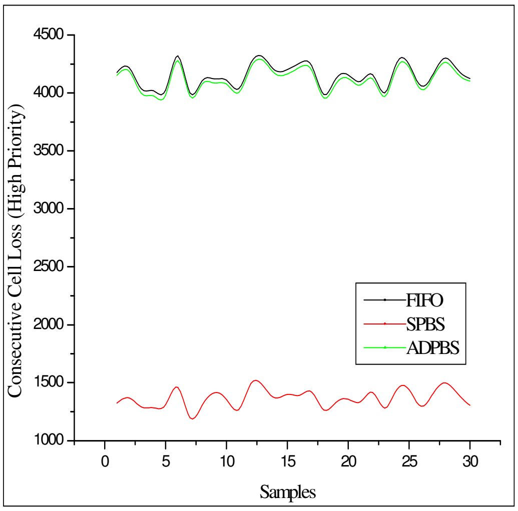


Fig. 4.52: High priority cell loss for 6-2-1-1.

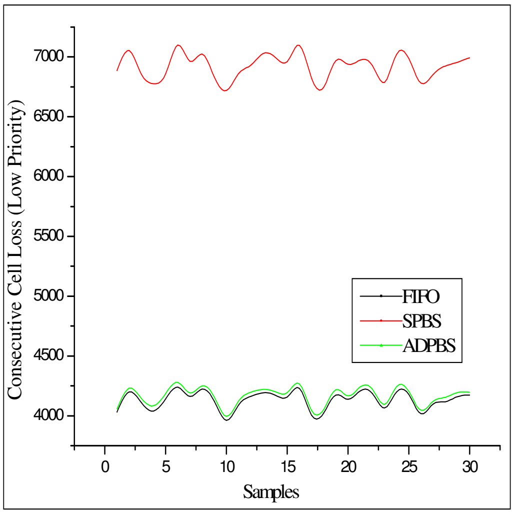


Fig. 4.53: Low priority cell loss for 6-2-1-1.

It can be inferred from these figures that loss of low priority cells in ADPBS queue is less and hence, shows the effectiveness of a particular threshold parameters' combination in controlling cell loss. On comparing the overall performance of different combinations, it has been noted that combinations 4-2-2-2 and 6-2-2-2 have minimum losses and are selected for further simulations.

4.2.3 Results of combinations with loss control limit of high priority cells equal to loss control limit of low priority cells

The simulation is carried out for combinations 2-2-1-1, 2-2-2-2, 4-4-1-1, 4-4-2-2 and 6-6-2-2. Fig. 4.54 to Fig. 4.63 illustrate the results of thirty different simulations run for all combinations; when high priority cells are in majority in the input traffic.

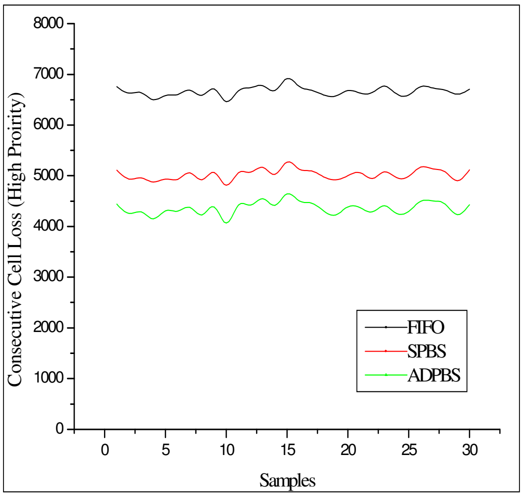


Fig. 4.54: High priority cell loss for 2-2-1-1.

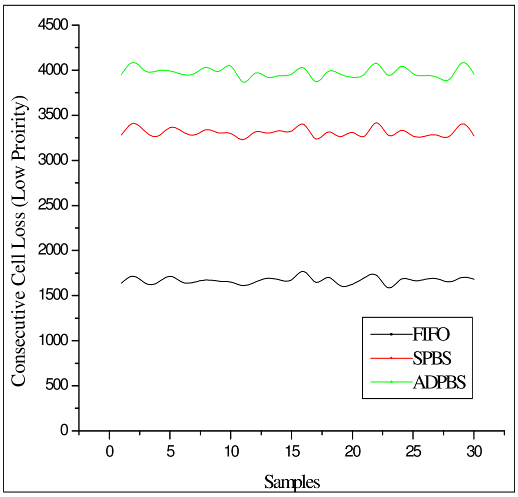
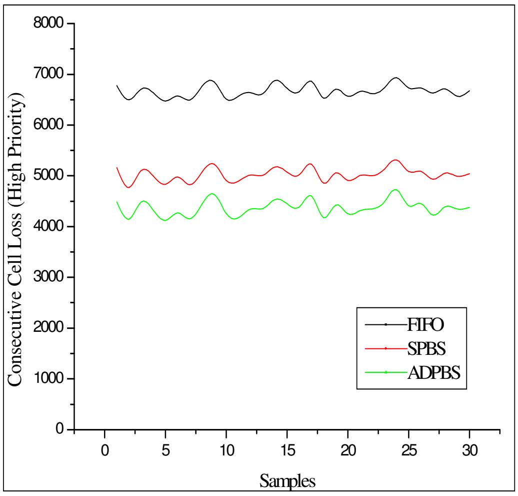


Fig. 4.55: Low priority cell loss for 2-2-1-1.



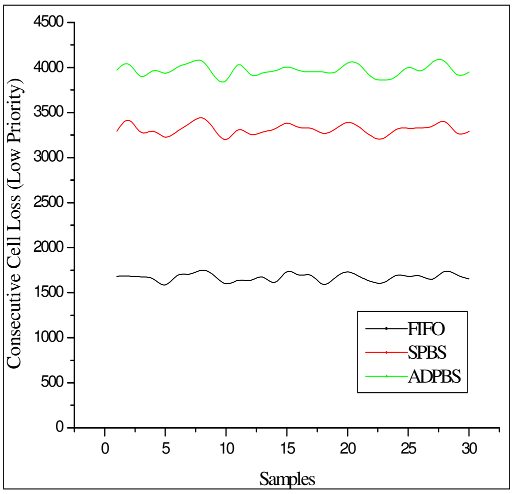
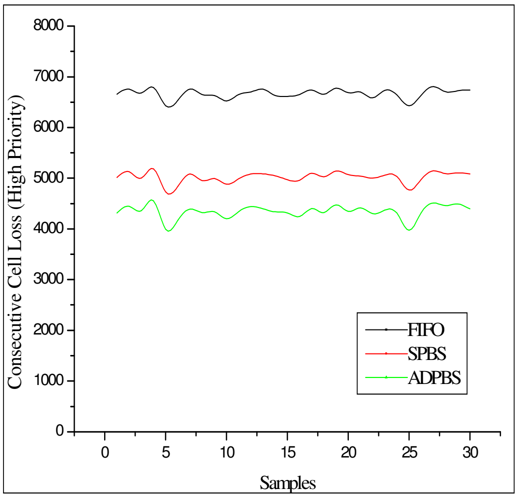


Fig. 4.56: High priority cell loss for 2-2-2-2.

Fig. 4.57: Low priority cell loss for 2-2-2-2.



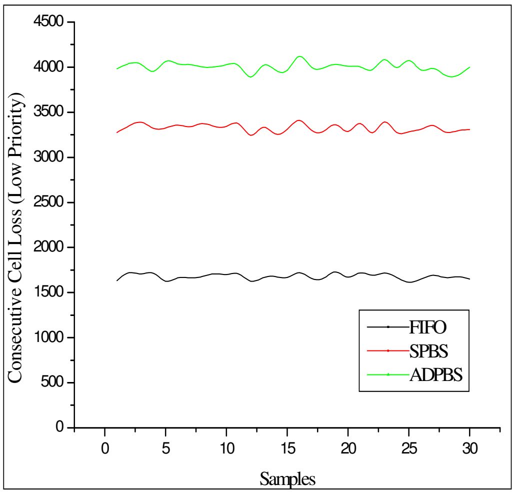
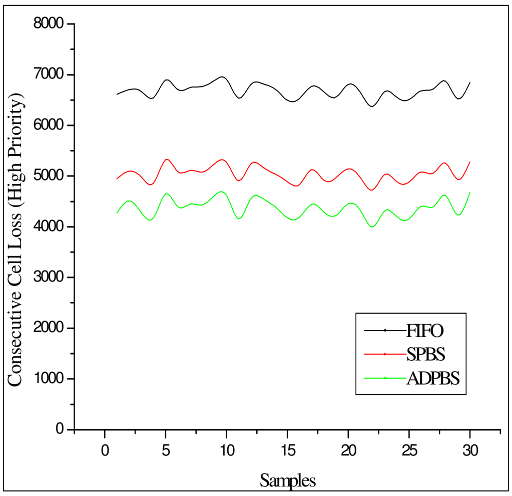


Fig. 4.58: High priority cell loss for 4-4-1-1.

Fig. 4.59: Low priority cell loss for 4-4-1-1.



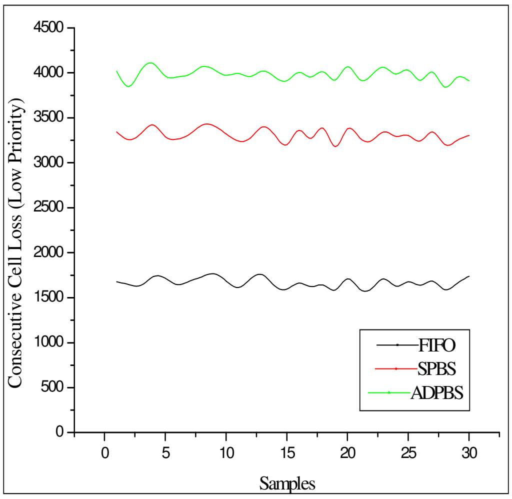
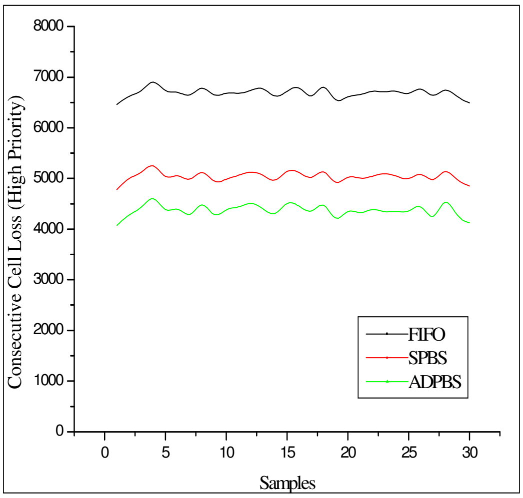


Fig. 4.60: High priority cell loss for 4-4-2-2.

Fig. 4.61: Low priority cell loss for 4-4-2-2.



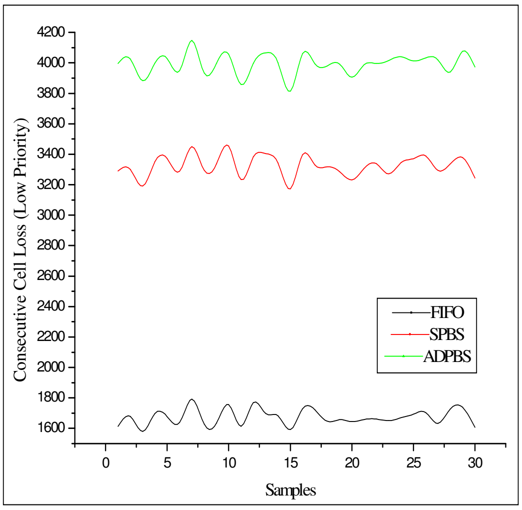
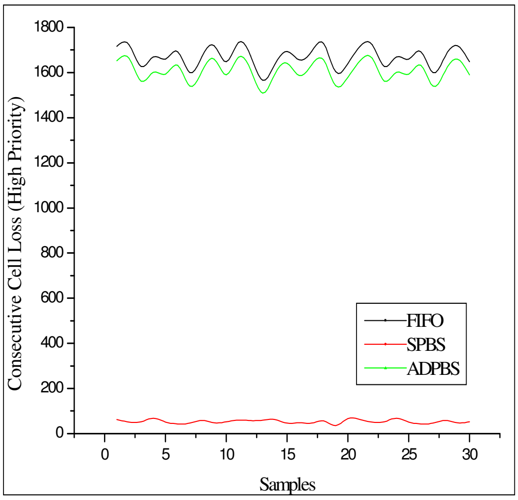


Fig. 4.62: High priority cell loss for 6-6-2-2.

Fig. 4.63: Low priority cell loss for 6-6-2-2.

The high priority cells, being in majority, experience the least loss in ADPBS queue among the three queues. This shows that when c_h is set equal to c_l, ADPBS queue gives best performance with its adaptive threshold mechanism. It has also been noted that high priority cell loss in SPBS queue is 15% higher than ADPBS queue.

Fig. 4.64 to Fig. 4.73 illustrate the results when low priority cells are in majority in input traffic. As the loss control limits are equal, low priority cells, being in majority, are retained.



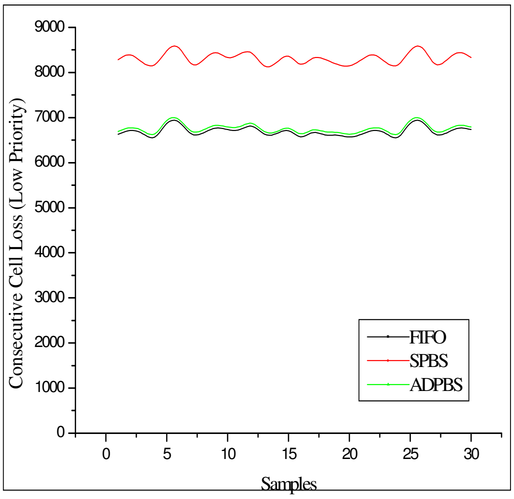
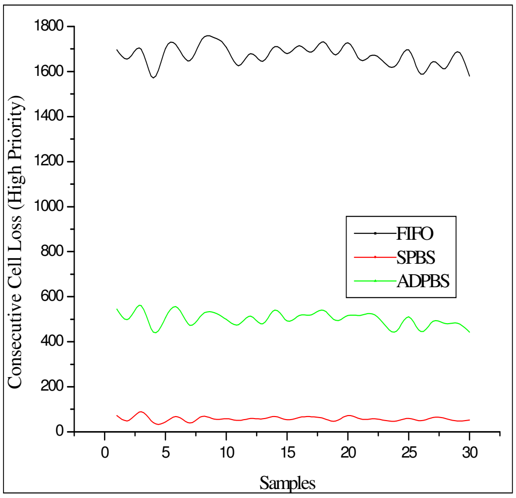


Fig. 4.64: High priority cell loss for 2-2-1-1.

Fig. 4.65: Low priority cell loss for 2-2-1-1.



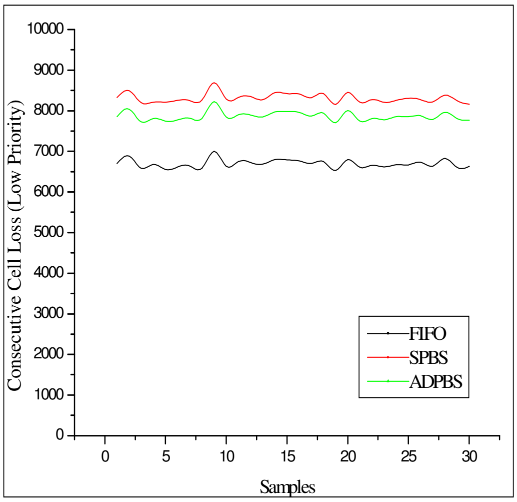
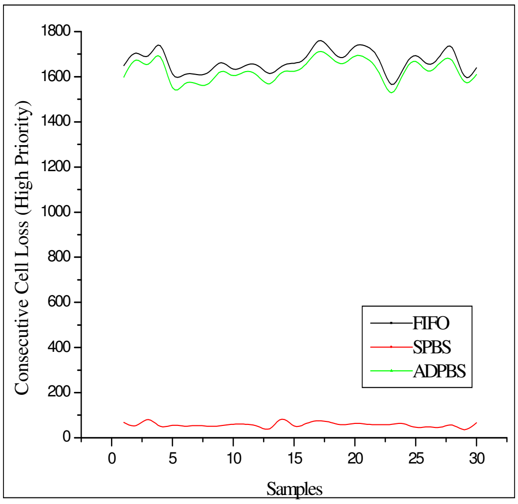


Fig. 4.66: High priority cell loss for 2-2-2-2.

Fig. 4.67: Low priority cell loss for 2-2-2-2.



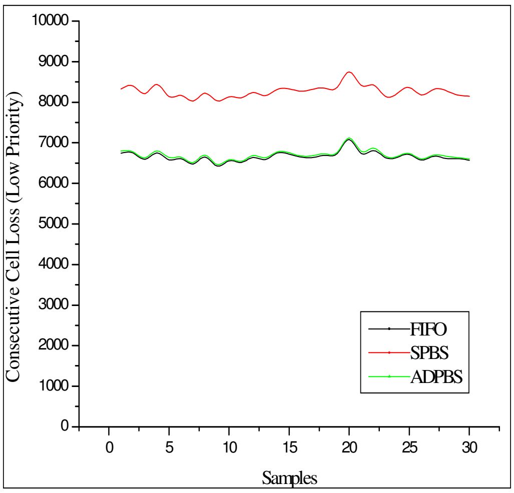
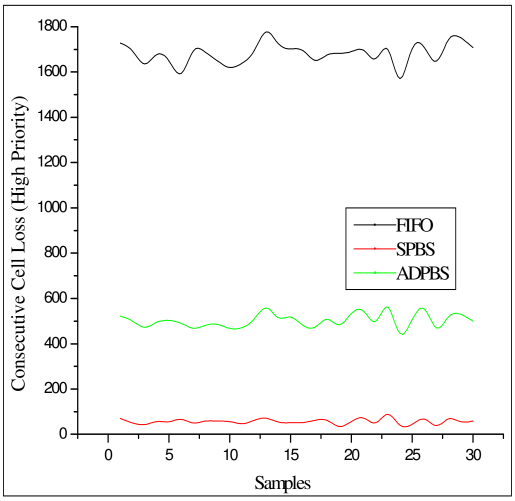


Fig. 4.68: High priority cell loss for 4-4-1-1.

Fig. 4.69: Low priority cell loss for 4-4-1-1.



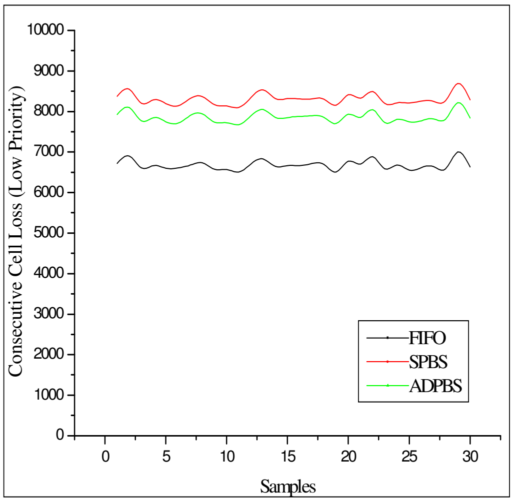


Fig. 4.70: High priority cell loss for 4-4-2-2.

Fig. 4.71: Low priority cell loss for 4-4-2-2.

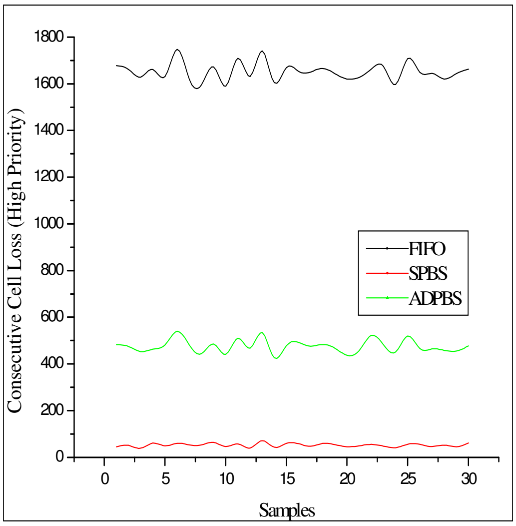


Fig. 4.72: High priority cell loss for 6-6-2-2.

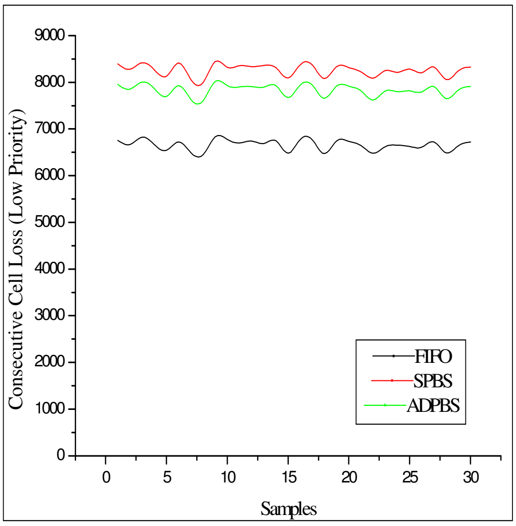


Fig. 4.73: Low priority cell loss for 6-6-2-2.

When the high priority and low priority cells are in equal proportion in the traffic stream input to the all three queues, the low priority cells are retained by ADPBS scheme. Fig. 4.74 to Fig. 4.83 present and compare the results of simulations carried out under this traffic condition.

Based on these results, combinations 2-2-2-2 and 6-6-2-2 have been selected for further simulations since these combinations give least losses as compared to other two queues.

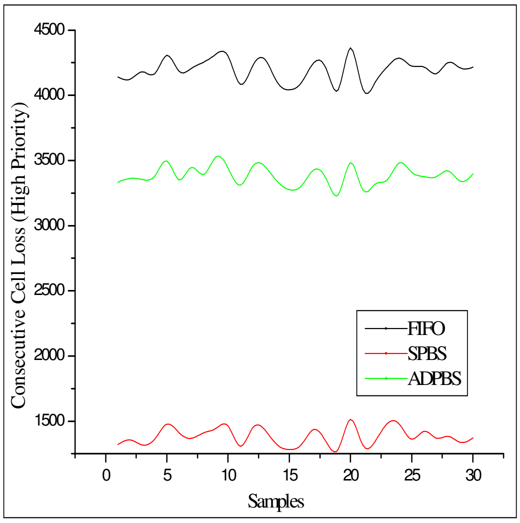


Fig. 4.74: High priority cell loss for 2-2-1-1.

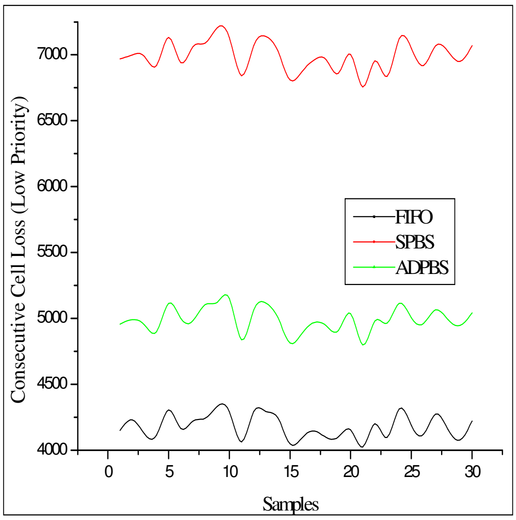


Fig. 4.75: Low priority cell loss for 2-2-1-1.

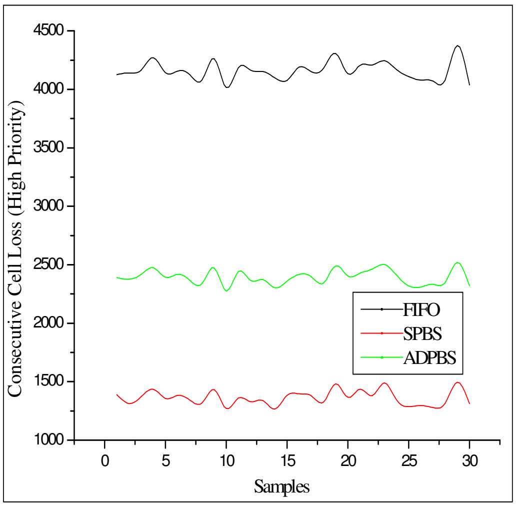


Fig. 4.76: High priority cell loss for 2-2-2-2.

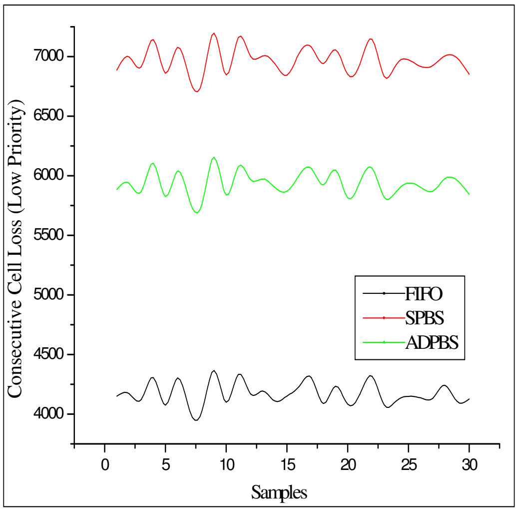


Fig. 4.77: Low priority cell loss for 2-2-2-2.

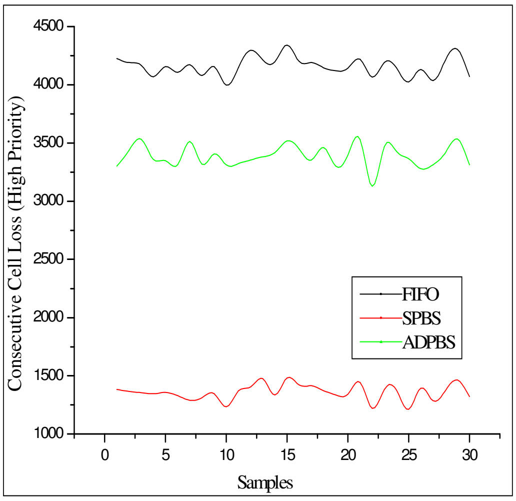


Fig. 4.78: High priority cell loss for 4-4-1-1.

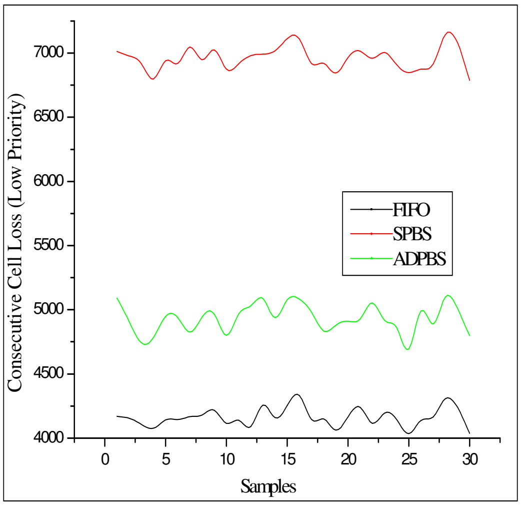


Fig. 4.79: Low priority cell loss for 4-4-1-1.

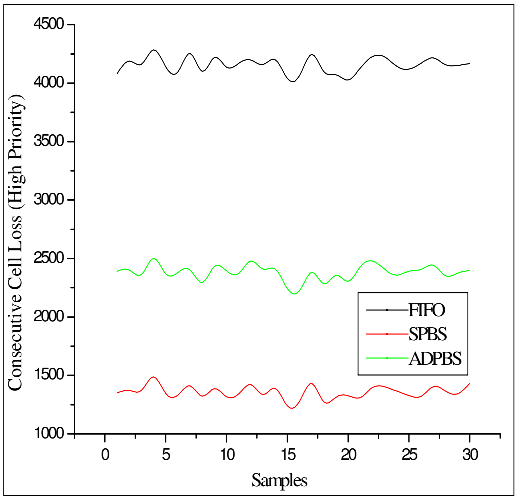


Fig. 4.80: High priority cell loss for 4-4-2-2.

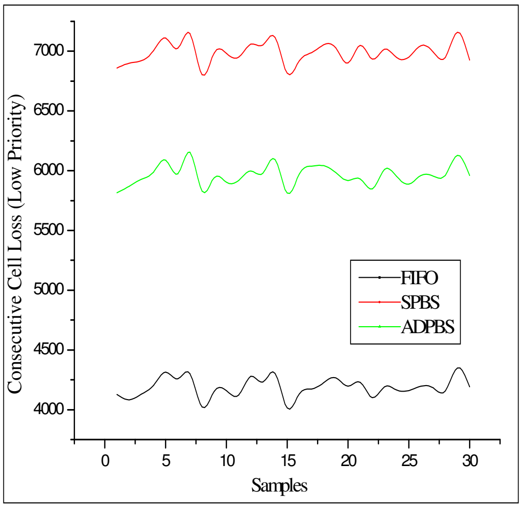


Fig. 4.81: Low priority cell loss for 4-4-2-2.

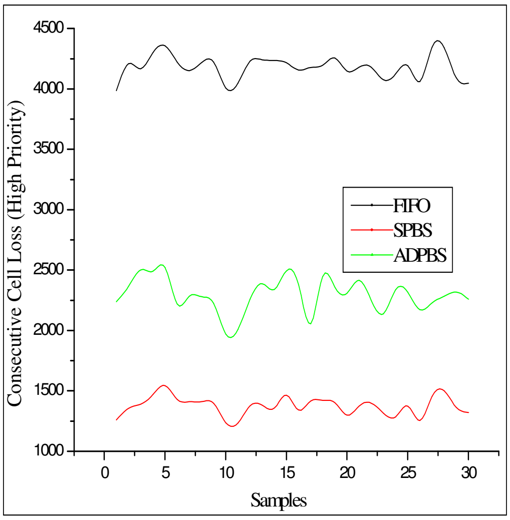


Fig. 4.82: High priority cell loss for 6-6-2-2.

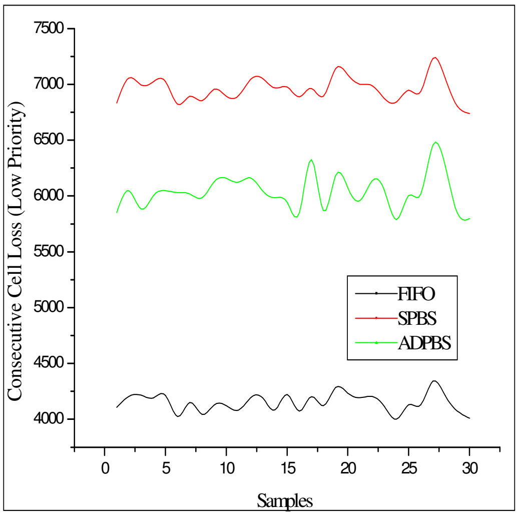


Fig. 4.83: Low priority cell loss for 6-6-2-2.

4.3 ANALYSIS OF ADPBS QUEUE WITH TRAFFIC LOAD VARIATION

Analysis of traffic load (ratio of cell arrival rate to service rate of queue, λ / μ) includes the study of buffer occupancy and cell loss behavior. In this section, the performance of adaptive threshold queue is discussed and compared with static threshold and FIFO queues for different traffic load values. For the performance analysis, three different traffic categories are considered: traffic with high priority cells in majority, traffic with low priority cells in majority, and traffic when both types of cells in equal proportion. For each traffic category, simulation study is carried out using different combinations of threshold control parameters, as selected in previous section.

4.3.1 High priority cells in majority

When high priority cells are in majority in the input data stream to FIFO, SPBS and ADPBS queues, the simulation is carried out for three different conditions – **(i)** when loss control limit of high priority cells is less than loss control limit of low priority cells, *i.e.*, combinations, such as, 2-4-2-2 and 2-6-2-2; **(ii)** when loss control limit of high priority cells is greater than loss control limit of low priority cells, *i.e.*, combinations, such as, 4-2-2-2 and 6-2-2-2; and **(iii)** when loss control limit of high priority cells is equal to loss control limit of low priority cells, *i.e.*, combinations, such as, 6-6-2-2 and 2-2-2-2.

4.3.1.1 Results of combinations with loss control limit of high priority cells less than loss control limit of low priority cells

For combination 2-4-2-2, the loss of consecutive high priority cells in ADPBS queue is compared with SPBS and FIFO queues in Fig. 4.84. From the graph, one can observe that up to load value 0.66, there is not any loss of cells in all queues. The loss starts increasing beyond this ratio and ADPBS queue has least loss among other queues. At the load value equal to 0.8, ADPBS queue performs 93% better than SPBS queue

Fig. 4.85 gives trend of low priority cells' loss for different load values. This again illustrates that for lower load values the difference in performance is insignificant, however, when the load value is higher, the FIFO queue performs better. The major reason behind this trend is that for higher value of load, most of the buffer space is used for accommodating the high priority cells, so low priority cells suffer more losses. At load value of 0.9, the loss in ADPBS queue reaches its peak and remains constant beyond that.

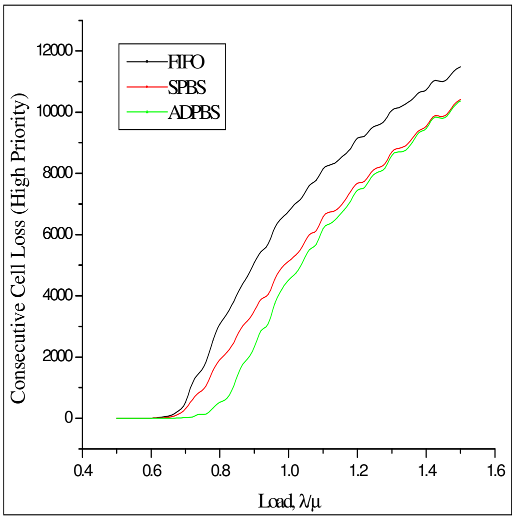


Fig. 4.84: High priority cell loss for different traffic load values (2-4-2-2).

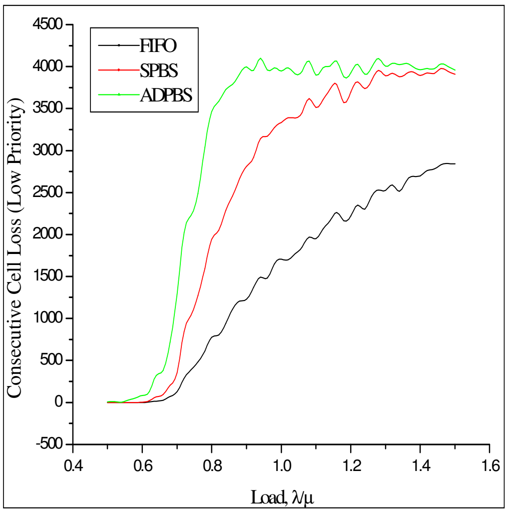


Fig. 4.85: Low priority cell loss for different traffic load values (2-4-2-2).

It has been observed that the simulation results follow the similar pattern for combination 2-6-2-2 as depicted in Fig. 4.84 for high priority cells. It can be inferred from Fig. 4.86 that for load values up to 0.68, there is no significant loss of high priority cells in any of the queues. However, it starts increasing beyond this point as load increases. The results shown in Fig. 4.87 for low priority cells, has the same pattern as illustrated in Fig. 4.85. At load value of 0.9, the loss in ADPBS queue reaches its peak and tends to be constant beyond that.

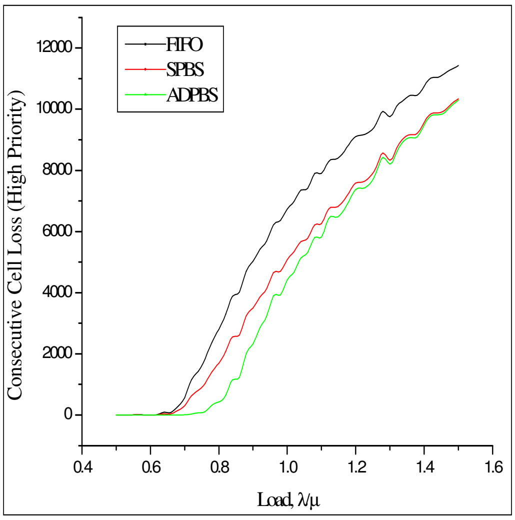


Fig. 4.86: High priority cell loss for different traffic load values (2-6-2-2).

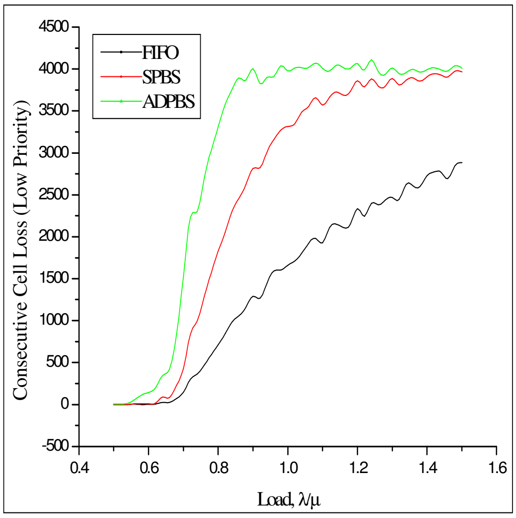


Fig. 4.87: Low priority cell loss for different traffic load values (2-6-2-2).

4.3.1.2 Results of combinations with loss control limit of high priority cells greater than loss control limit of low priority cells

The consecutive cell loss of high priority and low priority cells, for combination 6-2-2-2, is shown in Fig. 4.88 and Fig. 4.89, respectively, for different traffic load values. In this case, it is observed that **(a)** major content in input traffic is of high priority cells; **(b)** combination of threshold control parameters intends to save low priority cells. Since preference is given to save low priority cells, the ADPBS model performs in close vicinity of the SPBS model and the high priority cell losses are higher than the cell losses in SPBS queue as shown in Fig. 4.88. For low priority cells, ADPBS scheme works well to reduce their loss while SPBS queue experiences the highest loss pattern as given in Fig. 4.89. The percentage difference in cell loss of ADPBS and SPBS queues is upto 57% for higher load values, which decreases further as the load is increased. At 100% traffic load, the low priority cell loss in ADPBS queue is 23% less than SPBS queue. Thus ADPBS scheme manages to perform well even when the network experiences congestion.

The simulation study for combination 4-2-2-2 reveals similar result pattern (as with combination 6-2-2-2) for high priority and low priority cells. Fig. 4.90 and Fig. 4.91 contain the results of this study.

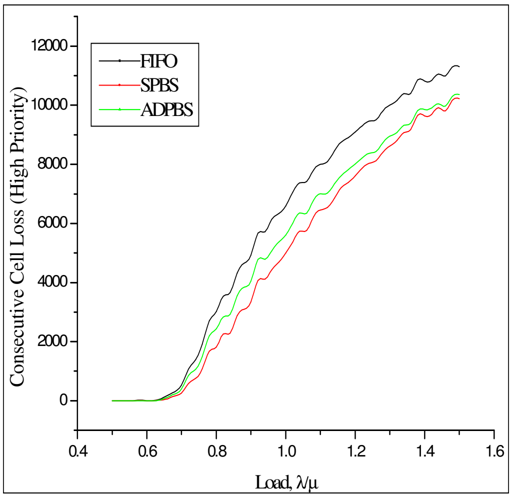


Fig. 4.88: High priority cell loss for different traffic load values (6-2-2-2).

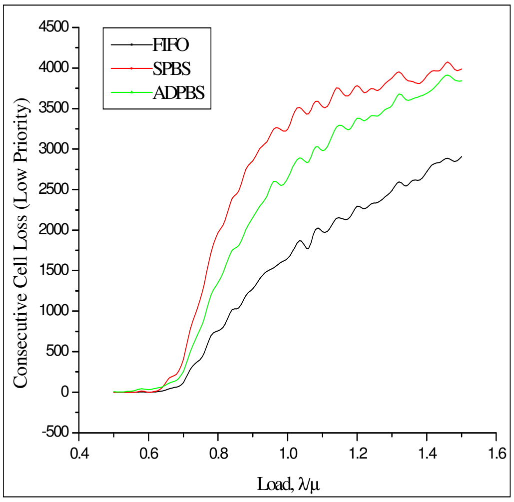


Fig. 4.89: Low priority cell loss for different traffic load values (6-2-2-2).

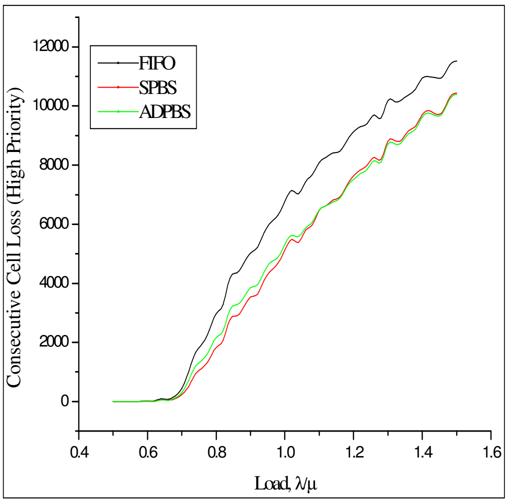


Fig. 4.90: High priority cell loss for different traffic load values (4-2-2-2).

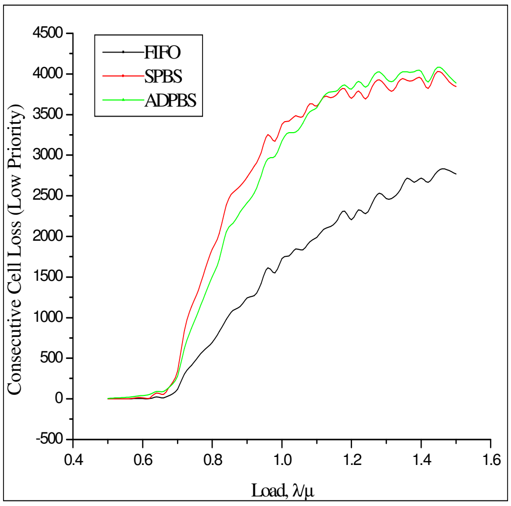
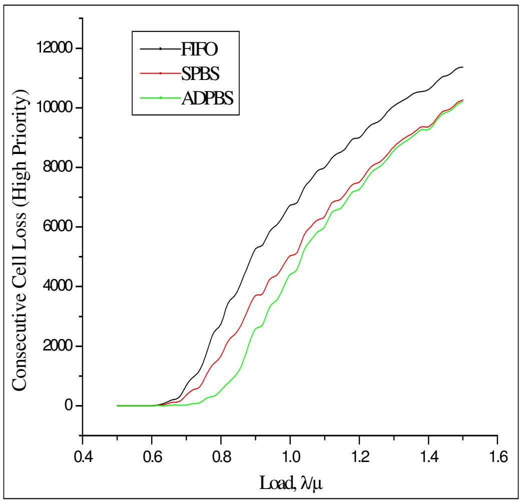


Fig. 4.91: Low priority cell loss for different traffic load values (4-2-2-2).

4.3.1.3 Results of combinations with loss control limit of high priority cells equal to loss control limit of low priority cells

Fig. 4.92 and Fig. 4.93 show the simulation results for high priority and low priority cell loss, respectively, with combination 6-6-2-2. Upto the load value of 0.66, the high priority cell loss in all the queues is very negligible. This loss of high priority cells tends to increase at a high rate with the increase in load value. One can, however, note that this rate is highest for FIFO queue and lowest for ADPBS queue. For extreme overload condition, loss of high priority cells is almost equal to the loss in SPBS queue. For higher traffic load values, the service rate of the queue is lower than the cell arrival



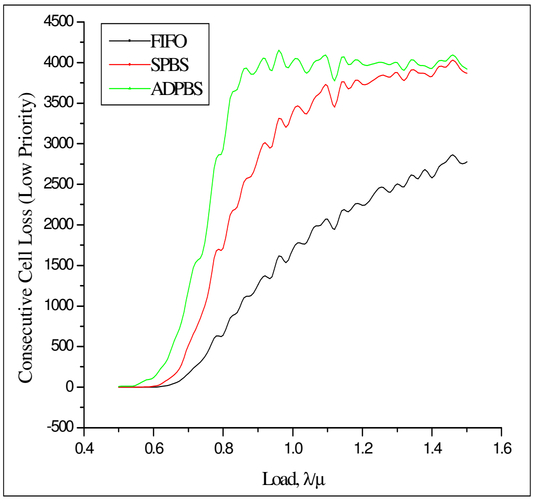
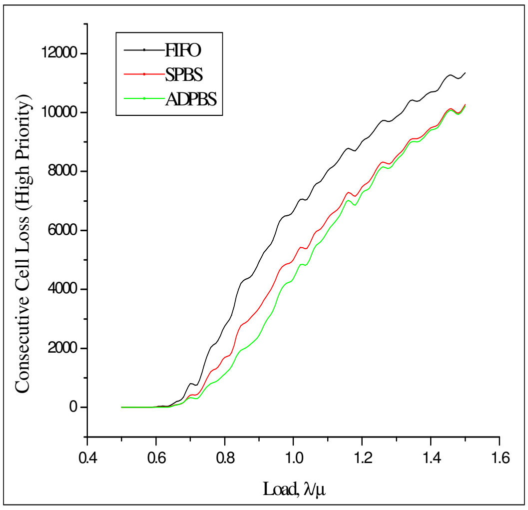


Fig. 4.92: High priority cell loss for different traffic load values (6-6-2-2).

Fig. 4.93: Low priority cell loss for different traffic load values (6-6-2-2).

rate, thus the buffer gets almost completely filled and the cell loss tends to increase even after changing the threshold due to limited buffer space. The trend of low priority cell loss in ADPBS queue is opposite to the trend of high priority cell loss. It can be inferred from Fig. 4.93 that ADPBS queue has the highest loss of low priority cells. Since the major part of the incoming traffic is high priority cells, the threshold adapts to accommodate these cells. As both high priority and low priority cells share the same limited buffer space, there is a trade-off situation. Due to this trade-off, the low-priority cells suffer loss when major part of buffer is occupied by high priority cells. This loss tends to increase with the increasing load values. But beyond the load value of 0.9, loss becomes almost constant and does not increase further.



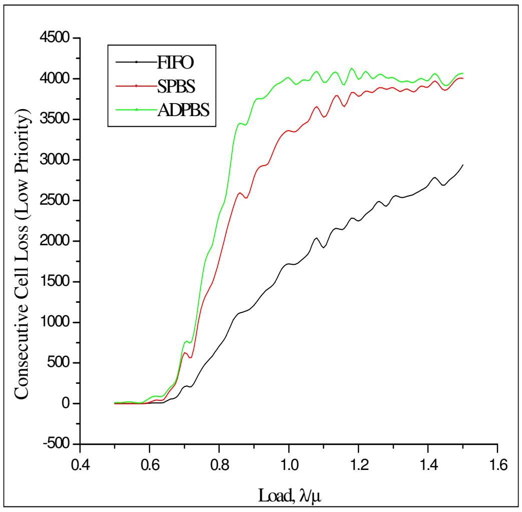


Fig. 4.94: High priority cell loss for different traffic load values (2-2-2-2).

Fig. 4.95: Low priority cell loss for different traffic load values (2-2-2-2).

For 2-2-2-2 combination, the results follow the similar pattern. In Fig. 4.94, it is shown that the loss in ADPBS queue is least for high priority cells among all three queues as high priority cells have complete access to the buffer. As more of the buffer space is allocated to high priority cells, the available space for low priority cells gets reduced and hence losses increase as shown in Fig. 4.95. As load is increased, the ADPBS queue tends to perform better with respect to SPBS queue. For higher load values, the cell loss trend in ADPBS queue tends to be same as FIFO queue.

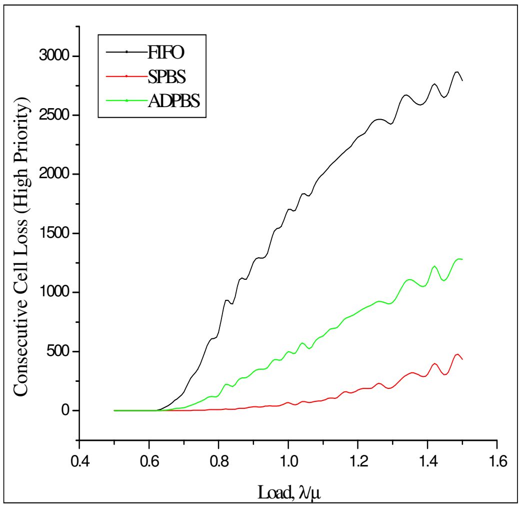
4.3.2 Low priority cells in majority

When low priority cells are in majority in the input data stream, the simulation is carried out for three cases – **(i)** when loss control limit of high priority cells is less than loss control limit of low priority cells, *i.e.*, combinations 2-4-2-2 and 2-6-2-2; **(ii)** when loss control limit of high priority cells is greater than loss control limit of low priority cells, *i.e.*, combinations 4-2-2-2 and 6-2-2-2; and **(iii)** when loss control limit of high priority cells is equal to loss control limit of low priority cells, *i.e.*, combinations 6-6-2-2 and 2-2-2-2.

4.3.2.1 Results of combinations with loss control limit of high priority cells less than loss control limit of low priority cells

When loss control limit of high priority cells is set lower than loss control limit of low priority cells, the scheme prefers to save high priority cells. However, in this particular traffic simulation case, the low priority cells are in majority, so the results are different than expected. The cell loss for high and low priority cells is shown in Fig. 4.96 and Fig. 4.97, respectively. The loss of high priority cells is higher in ADPBS queue in comparison with SPBS queue. Although the preference for reducing loss is given to high priority cells (combination 2-4-2-2), its loss in ADPBS queue is less than the loss in FIFO queue and more than the loss in SPBS queue because high priority cells are in minority in the incoming data stream.

The low priority cell loss in ADPBS queue, as shown in Fig. 4.97, is less than SPBS queue since it constitutes majority in the incoming data stream; hence the adaptive threshold control scheme manages to reduce its cell loss. The cell loss is 5% less in ADPBS queue in comparison with SPBS queue for different load variations.



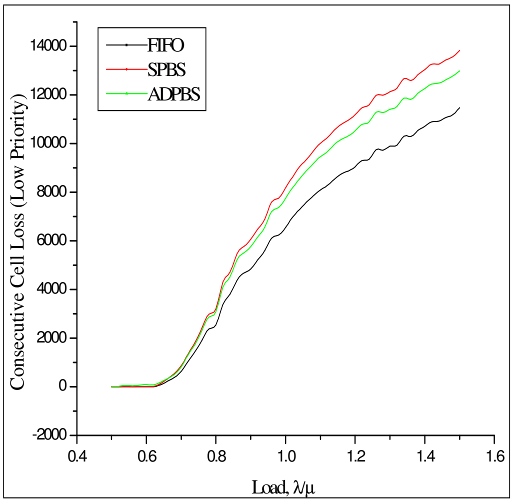
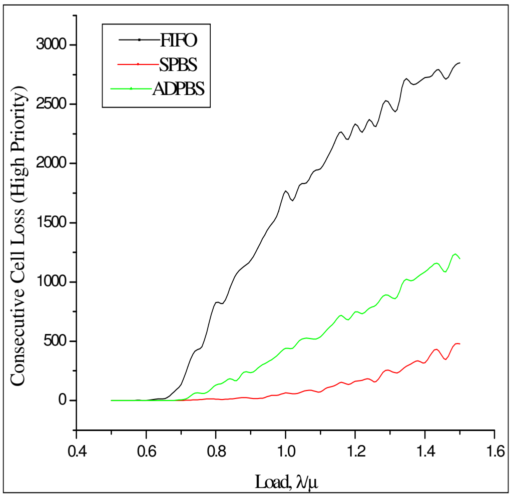


Fig. 4.96: High priority cell loss for different traffic load values (2-4-2-2).

Fig. 4.97: Low priority cell loss for different traffic load values (2-4-2-2).

If c_l is increased further to 6, *i.e.*, combination 2-6-2-2, the cell loss trend remains almost the same as in combination 2-4-2-2. The loss curve of high priority cells follows a path between the loss curves of FIFO and SPBS queues as shown in Fig. 4.98 and the loss of low priority cells in SPBS queue is 6% greater than ADPBS queue for different combinations of load values as shown in Fig. 4.99.



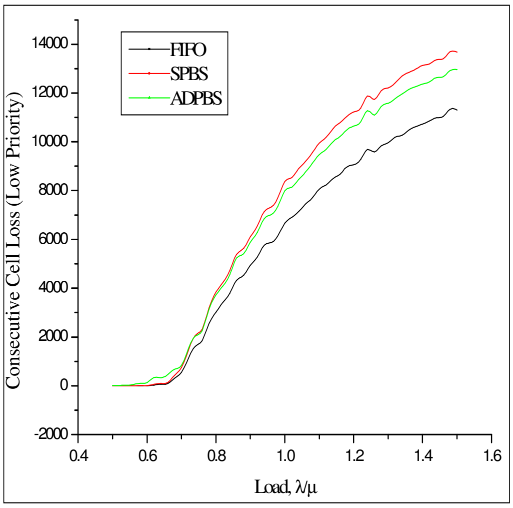


Fig. 4.98: High priority cell loss for different traffic load values (2-6-2-2).

Fig. 4.99: Low priority cell loss for different traffic load values (2-6-2-2).

4.3.2.2 Results of combinations with loss control limit of high priority cells greater than loss control limit of low priority cells

In combination 4-2-2-2, the preference is given to save low priority cells, which has very high share in the incoming traffic. The simulation results for high priority cells with this combination are given in Fig. 4.100. Initially, the performance of all the three queues is the same. The loss in FIFO queue tends to increase at a high rate when the load value is more than 0.66 where as cell losses in ADPBS queue do not increase significantly. Even for overload conditions, the performance of the queues follows the same pattern. In Fig. 4.101**,** the performance results of ADPBS queue for low priority cells are compared with SPBS and FIFO queues. The results show that the performance of ADPBS queue is better than SPBS queue since low priority cells are protected from being lost with this combination.

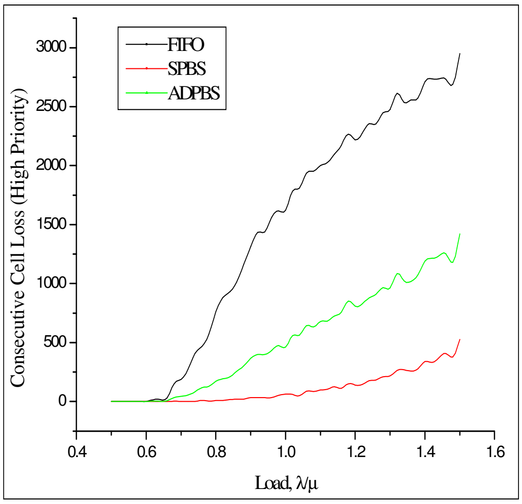


Fig. 4.100: High priority cell loss for different traffic load values (4-2-2-2).

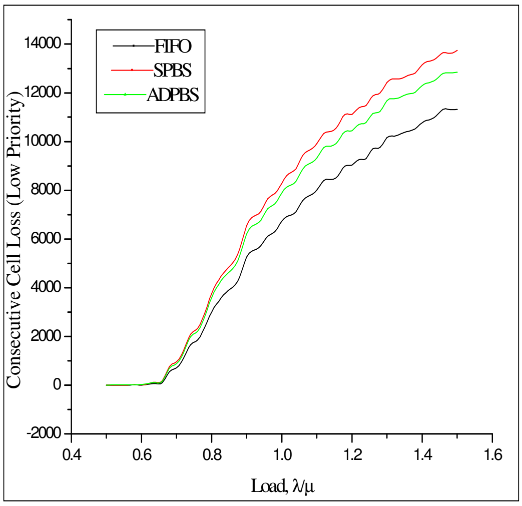


Fig. 4.101: Low priority cell loss for different traffic load values (4-2-2-2).

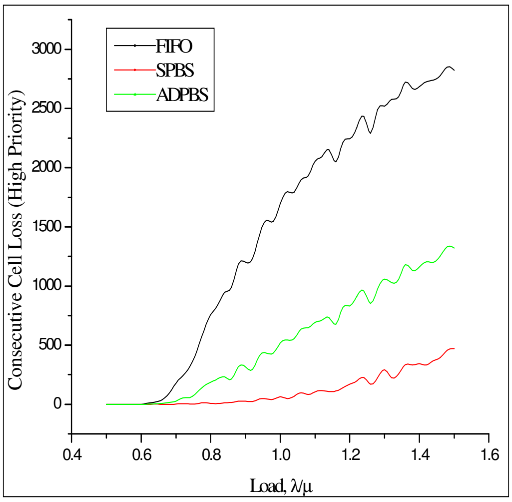


Fig. 4.102: High priority cell loss for different traffic load values (6-2-2-2).

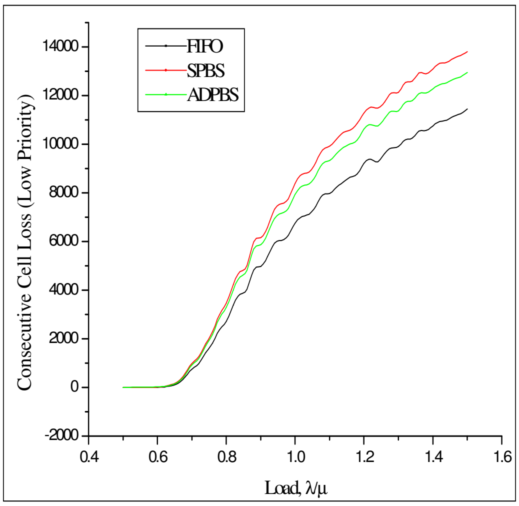


Fig. 4.103: Low priority cell loss for different traffic load values (6-2-2-2).

It is further observed that with combination 6-2-2-2, the simulation results follow similar pattern as given in Fig. 4.102 and Fig. 4.103 for high priority and low priority cells, respectively.

4.3.2.3 Results of combinations with loss control limit of high priority cells equal to loss control limit of low priority cells

With equal loss control limits of high and low priority cells, *i.e.*, combination 2-2-2-2, there is same preference set for controlling loss of cells of both priority classes through adaptive threshold method. The ADPBS scheme controls the loss of traffic which happens to be in majority in the input traffic stream. In this threshold control parameters combination, loss control limits of high and low priority cells are set to 2 and the high priority traffic is in minority. The cell loss curve of high priority cells in ADPBS queue follows an intermediate path between the cell loss curves of high priority cells in SPBS and FIFO queues, as shown in Fig. 4.104. As input traffic contains majority of low priority cells, ADPBS scheme allocates major part of the buffer space to low priority cells by adjusting the threshold. As such, the loss of low priority cells is less by 6% in ADPBS queue with respect to SPBS queue (Fig. 4.105).

Similar pattern has been observed for combination 6-6-2-2, where ADPBS scheme manages to reduce losses of low priority cells by 6% as compared with SPBS scheme. This depicts that ADPBS scheme controls loss of the priority class that is in majority in the incoming stream.

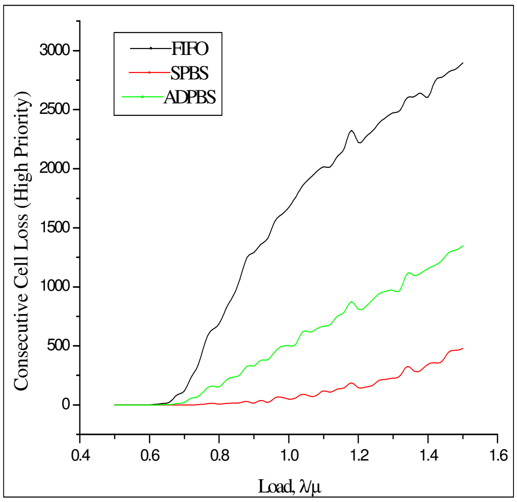


Fig. 4.104: High priority cell loss for different traffic load values (2-2-2-2).

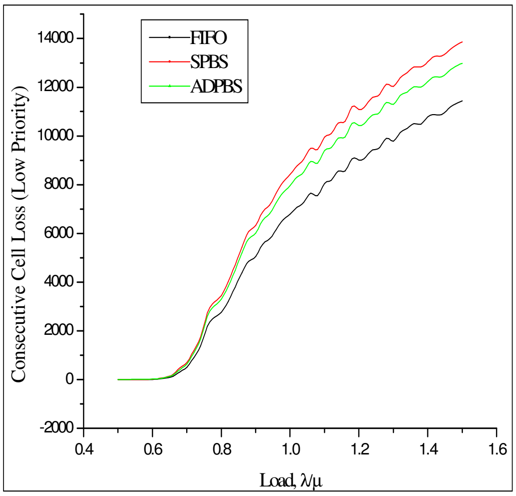


Fig. 4.105: Low priority cell loss for different traffic load values (2-2-2-2).

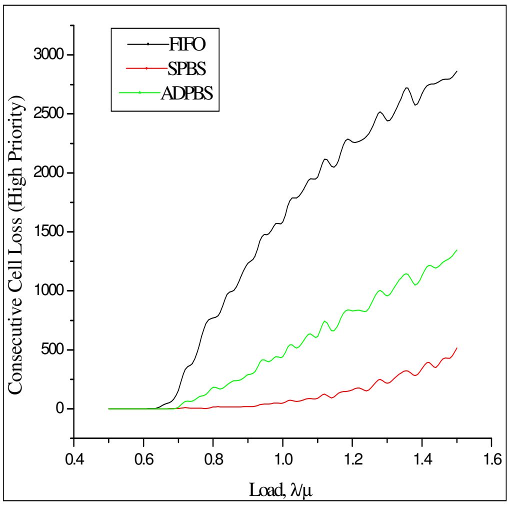


Fig. 4.106: High priority cell loss for different traffic load values (6-6-2-2).

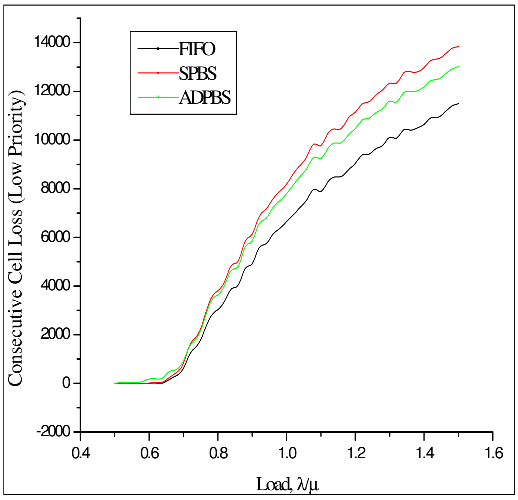


Fig. 4.107: Low priority cell loss for different traffic load values (6-6-2-2).

Fig. 4.106 and Fig. 4.107 illustrate the comparison among three queues using 6-6-2-2 combination for high priority and low priority cells, respectively.

4.3.3 High and low priority cells in equal proportion

When both high and low priority cells are in equal proportion in the input data stream, the simulation is carried out for three cases – **(i)** when loss control limit of high priority cells is less than loss control limit of low priority cells, *i.e.*, combinations 2-4-2-2 and 2-6-2-2; **(ii)** when loss control limit of high priority cells is greater than loss control limit of low priority cells, *i.e.*, combinations 4-2-2-2 and 6-2-2-2; and **(iii)** when loss control limit of high priority cells is equal to loss control limit of low priority cells, *i.e.*, combinations 6-6-2-2 and 2-2-2-2.

4.3.3.1 Results of combinations with loss control limit of high priority cells less than loss control limit of low priority cells

We have analysed the behavior of three queues under consider action for the combinations 2-4-2-2 and 2-6-2-2 in this sub-section. With combination 2-4-2-2, it is observed that the performance of SPBS and ADPBS queues is almost same for both high and low priority traffic classes when the load value is between 0.5 and 1.0. Under overload conditions, the ADPBS scheme tends to perform better than SPBS scheme and reduces high priority cell loss as shown in Fig. 4.108. As this particular combination of threshold control parameters give preference to reduce high priority cell loss, the low priority cells suffer from loss as shown in Fig. 4.109.

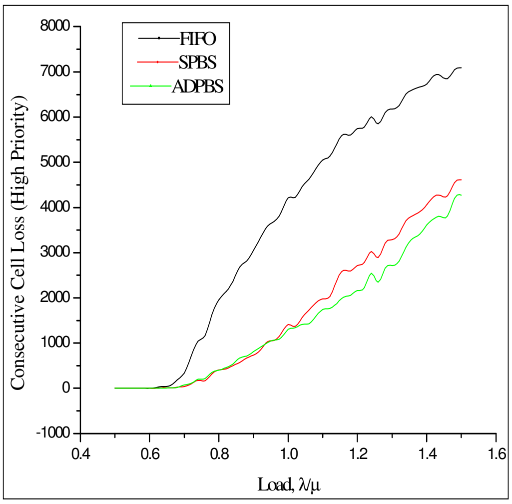


Fig. 4.108: High priority cell loss for different traffic load values (2-4-2-2).

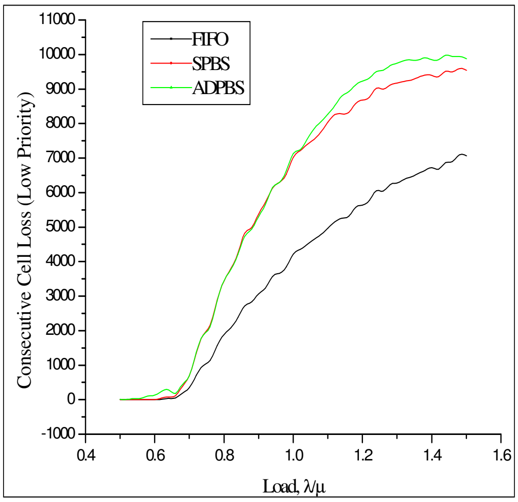


Fig. 4.109: Low priority cell loss for different traffic load values (2-4-2-2).

When the loss control limit of low priority cells is increased to 6, *i.e.*, with combination 2-6-2-2, the threshold adapts less frequently to accommodate low priority cells in buffer (Fig. 4.111). This further helps to reduce loss of high priority cells when load value is more than 0.7, as shown in Fig. 4.110. The high priority cell loss in ADPBS queue is less than high priority cell loss in SPBS queue by 73% to 93% when load value is varied from 0.64 to 1.00.

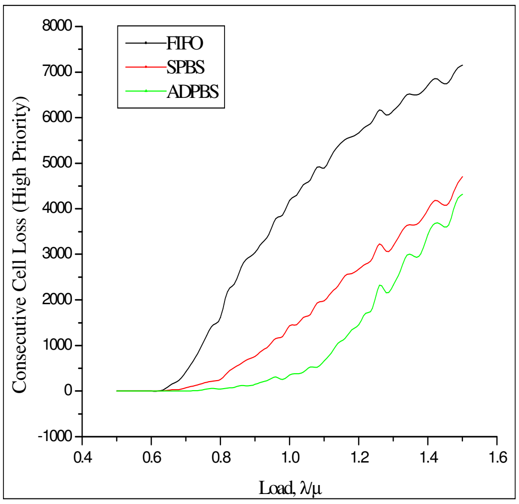


Fig. 4.110: High priority cell loss for different traffic load values (2-6-2-2).

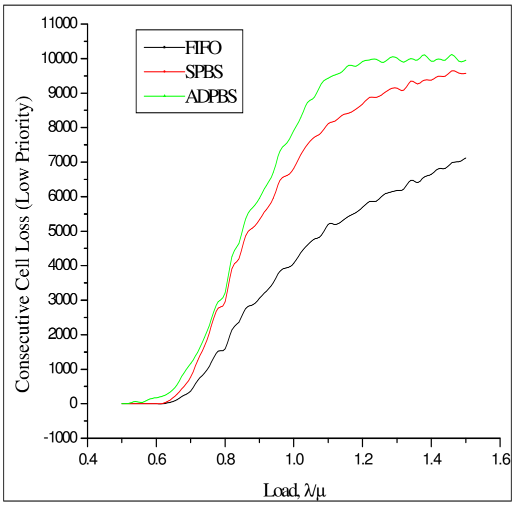


Fig. 4.111: Low priority cell loss for different traffic load values (2-6-2-2).

4.3.3.2 Results of combinations with loss control limit of high priority cells greater than loss control limit of low priority cells

With combination 4-2-2-2, preference is given to save low priority cells in comparison with high priority cells. The results given in Fig. 4.112 show that the loss of high priority cells in ADPBS queue is higher than the loss of high priority cells in SPBS queue. For load values upto 0.96, the loss of high priority cells in ADPBS queue is almost double than loss of high priority cells in SPBS queue. However, for overload conditions, this difference tends to reduce. It can be observed in Fig. 4.113 that loss of low priority cells is less in ADPBS queue in comparison with SPBS queue. For the traffic load values from 0.64 to 1.0, the difference in low priority cell loss of ADPBS queue and SPBS queue varies from 21% to 27%. Hence, it can be inferred that the threshold control parameters effectively control the loss of low priority cells.

When loss control limit of high priority cells (c_h) is increased to 6 (6-2-2-2 combination), the loss of high priority cells in ADPBS queue increases when compared with SPBS queue as shown in Fig. 4.114. If the load value is varied from 0.6 to 1.0, the cell loss in SPBS queue is 50% to 70% less than ADPBS queue. This difference reduces to approximately 20% when the load is further increased. As the loss control limit of low priority cells is less than that for high priority cells, low priority cell loss is less in ADPBS queue as shown in Fig. 4.115. A difference of about 20% is maintained in low priority cell loss of ADPBS and SPBS queues upto load value of 1.0. This difference reduces to about 10% as the load is increased.

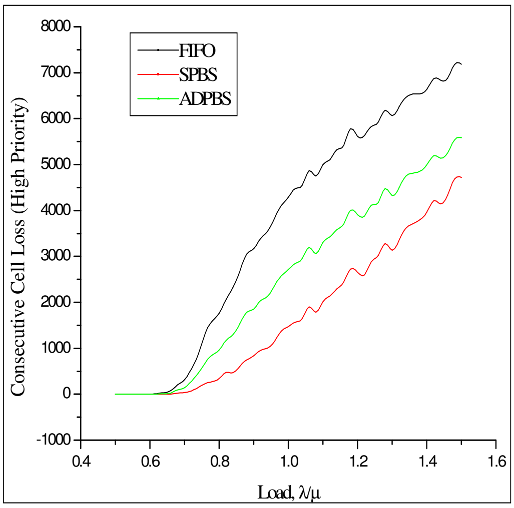


Fig. 4.112: High priority cell loss for different traffic load values (4-2-2-2).

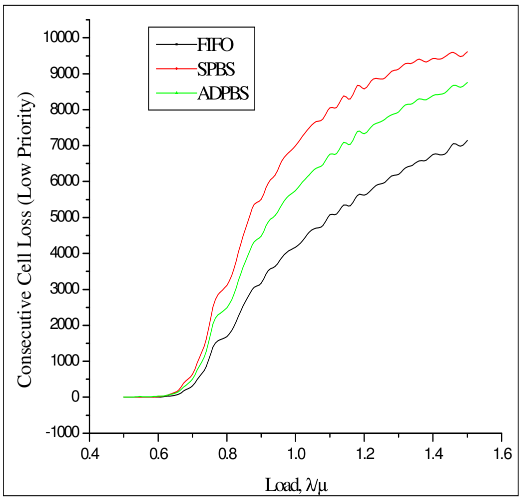


Fig. 4.113: Low priority cell loss for different traffic load values (4-2-2-2).

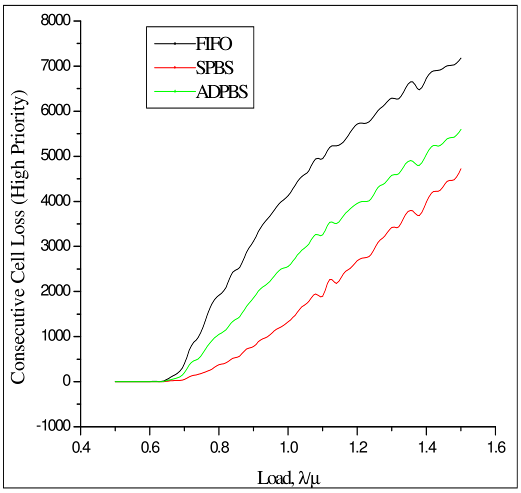


Fig. 4.114: High priority cell loss for different traffic load values (6-2-2-2).

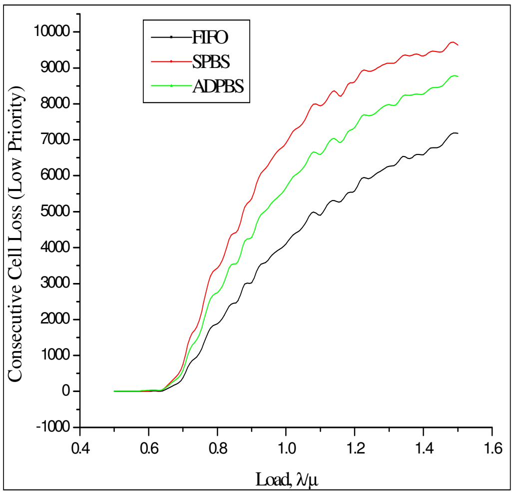


Fig. 4.115: Low priority cell loss for different traffic load values (6-2-2-2).

4.3.3.3 Results of combinations with loss control limit of high priority cells equal to loss control limit of low priority cells

For the case with combination 2-2-2-2 and input traffic with equal proportion of high priority and low priority cells, it can be inferred from Fig. 4.116 that the FIFO queue exhibits losses more than the losses in ADPBS queue. This ratio tends to decrease as load increases because buffer occupancy level becomes high. For SPBS queue, the high priority cell loss ratio is very negligible as the high priority cells have complete access to buffer space. Thus the loss of high priority cells is more in ADPBS queue as

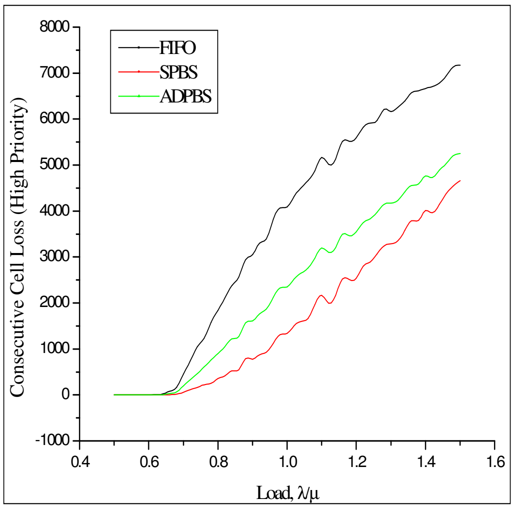


Fig. 4.116: High priority cell loss for different traffic load values (2-2-2-2).

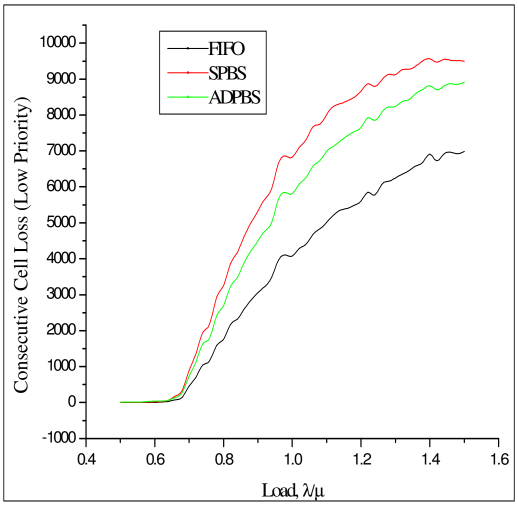


Fig. 4.117: Low priority cell loss for different traffic load values (2-2-2-2).

compared with SPBS queue and varies from 70% to 45% for a load variation of 0.7 to 1.0. As the load is increased further, this difference gets reduced to about 15%.

With combination 6-6-2-2, the high priority cell loss in SPBS queue is less than the high priority cell loss in ADPBS queue by 35% to 50% upto load value 1.0 (Fig. 4.118). This difference reduces to 10% as load value is increased to 1.5. Loss of low priority cells in ADPBS queue is less than SPBS by 8% to 14% for a load variation from 0.8 to 1.5 (Fig. 4.119).

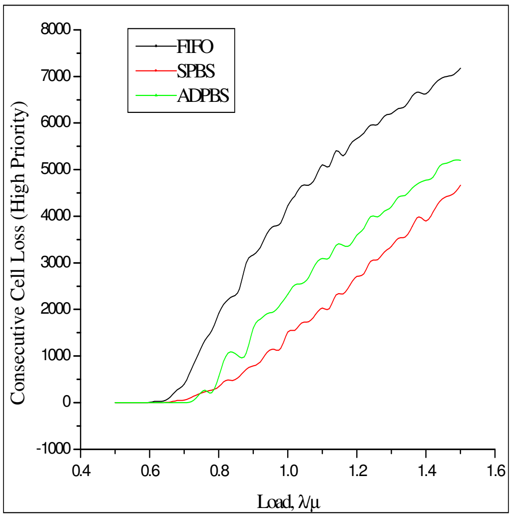


Fig. 4.118: High priority cell loss for different traffic load values (6-6-2-2).

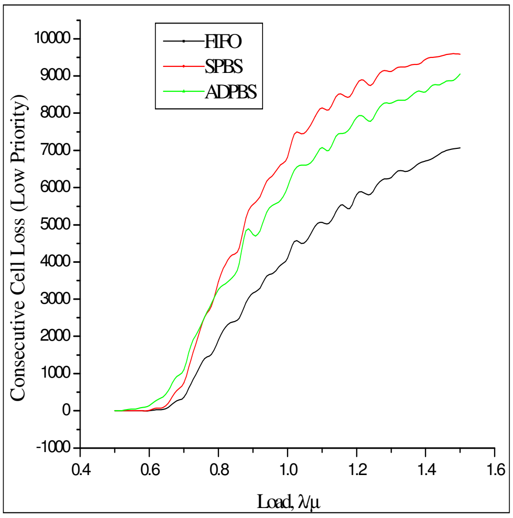


Fig. 4.119: Low priority cell loss for different traffic load values (6-6-2-2).

4.4 ANALYSIS OF ADPBS QUEUE WITH INPUT TRAFFIC MIX VARIATION

The cells of the incoming data stream belong either to class 1, *i.e.*, high priority or class 2, *i.e.*, low priority. Since the change of threshold in ADPBS queue depends on consecutive cell loss of high or low priority cells, its proportion in incoming traffic plays an important role in analysing the cell loss behavior of the queue. The ratio of arrival of high priority cells to low priority cells, *i.e.*, λ_h / λ_l, is the input traffic mix ratio, that has been used to analyse the performance of the ADPBS queue in this section. This ratio is varied from 0.1 to 6.0 to study its effect on cell loss behavior of ADPBS queue with respect to SPBS and FIFO queues. The study is carried out for selected combinations of threshold control parameters, under different traffic conditions.

4.4.1 Results of combinations with loss control limit of high priority cells less than loss control limit of low priority cells

For combination 2-6-2-2, the consecutive cell loss behavior of high priority cells for ADPBS, SPBS and FIFO queues is shown in Fig. 4.120. In this combination, one can observe that the high priority cells are having less loss in comparison with low priority cells. In the simulation study, the similar pattern has been observed (Fig. 4.120) and the loss of high priority cells in ADPBS queue is least among FIFO and SPBS queues. Below the input traffic mix ratio of 0.6, the SPBS queue shows good results with minimum loss of consecutive high priority cells, since the major content is low priority traffic ($\lambda_h / \lambda_l < 1$). However, ADPBS queue starts performing better beyond input traffic mix ratio of 0.6 and loss in proposed ADPBS scheme is upto 80% less than SPBS scheme. At input traffic mix ratio of 0.2, the cell loss ratio of high priority cells in FIFO and ADPBS queue is 4.52; for SPBS and ADPBS queues this ratio is 0.09. At input traffic mix ratio of 1.2, these ratios become 10.43 and 4.22, respectively.

The results for loss of consecutive low priority cells are shown in Fig. 4.121 for various input traffic mix ratios. It has been seen that below input traffic mix ratio of 0.6, the ADPBS queue performs better since the low priority traffic dominates till this ratio is equal to 1.0. However, its performance deteriorates significantly beyond this point. At input traffic ratio of 0.2, the consecutive cell loss ratio of low priority cells for FIFO and ADPBS queue is 0.86 where as for SPBS and ADPBS queues this ratio is 1.03. At input traffic mix ratio of 1.2, these ratios become 0.48 and 0.82, respectively.

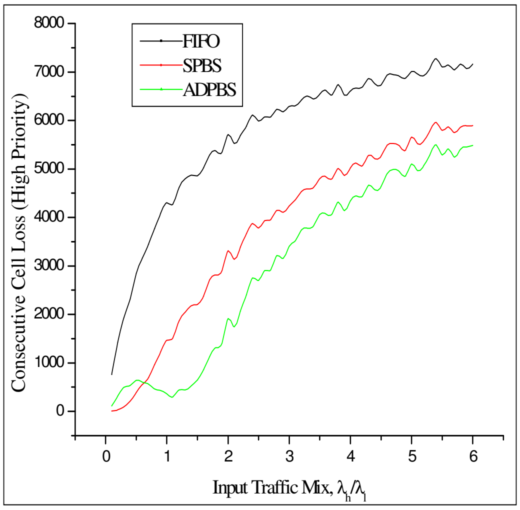


Fig. 4.120: High priority cell loss for different traffic mix ratios (2-6-2-2).

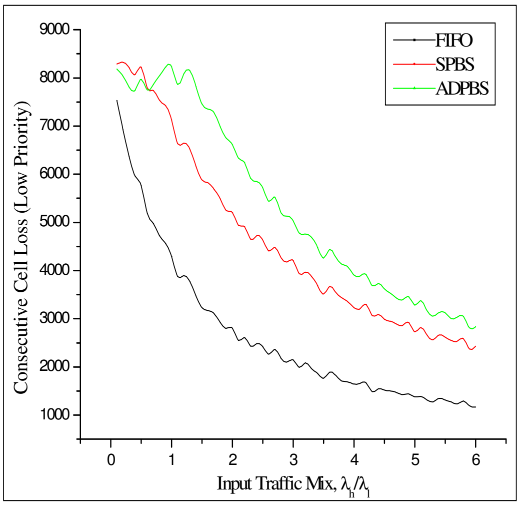


Fig. 4.121: Low priority cell loss for different traffic mix ratios (2-6-2-2).

For combination 2-4-2-2 of threshold control parameters, the simulation results follow the similar pattern as for combination 2-6-2-2, given in Fig. 4.122 and Fig. 4.123. One can infer from Fig. 4.122 that the performance of ADPBS queue is better than the performance of FIFO and SPBS queues when input traffic mix ratio is more than 1.0. The performance of ADPBS queue for low priority cells is better then the performance of SPBS queue when input traffic mix ratio is less than 1.0, as depicted in Fig. 4.123. It has been observed that the ADPBS queue performs better for the kind of traffic which has higher proportion in the input traffic mix. For example, when the input traffic mix has major content of high priority cells, the consecutive cell loss of high priority cells significantly decreases as compared to low priority cells.

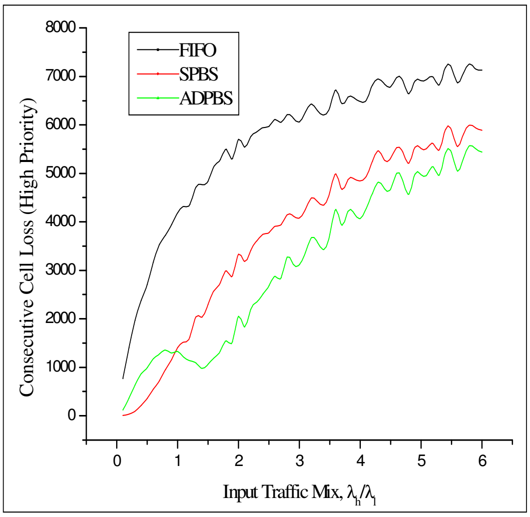


Fig. 4.122: High priority cell loss for different traffic mix ratios (2-4-2-2).

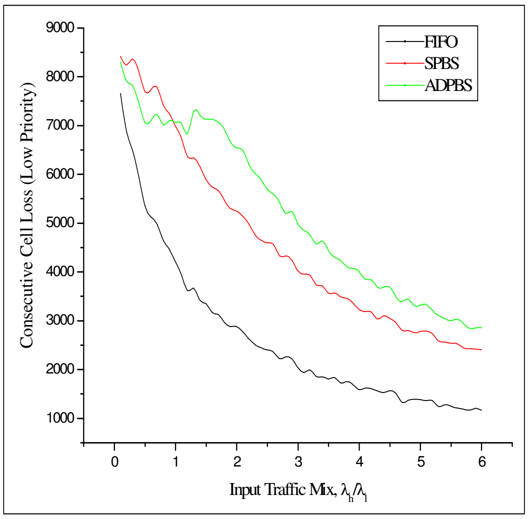


Fig. 4.123: Low priority cell loss for different traffic mix ratios (2-4-2-2).

4.4.2 Results of combinations with loss control limit of high priority cells greater than loss control limit of low priority cells

For combination 6-2-2-2, the threshold change in ADPBS queue will be triggered more frequently on the consecutive loss of low priority cells than the consecutive loss of high priority cells. As shown in Fig. 4.125, the consecutive cell loss for low priority cells in ADPBS queue is less than the loss of high priority cells in SPBS queue and the percentage variation ranges from 11% to 28%. From Fig. 4.124, the loss in ADPBS queue for high priority cells is higher than the loss in SPBS queue since this threshold control parameters combination favors the low priority cells.

It has also been observed that the results follow a similar pattern for combination

4-2-2-2. The results are illustrated in Fig. 4.126 for high priority cells and in Fig. 4.127 for low priority cells.

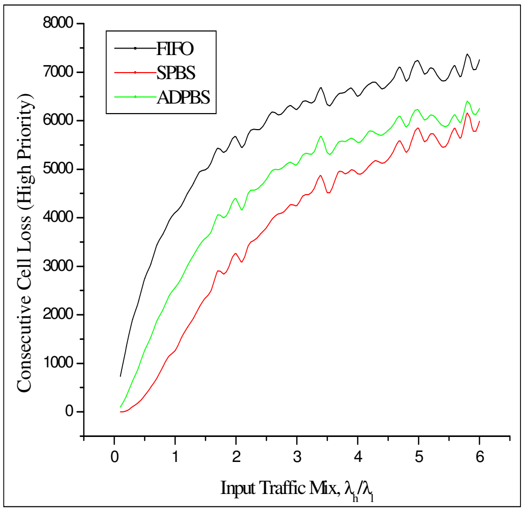


Fig. 4.124: High priority cell loss for different traffic mix ratios (6-2-2-2).

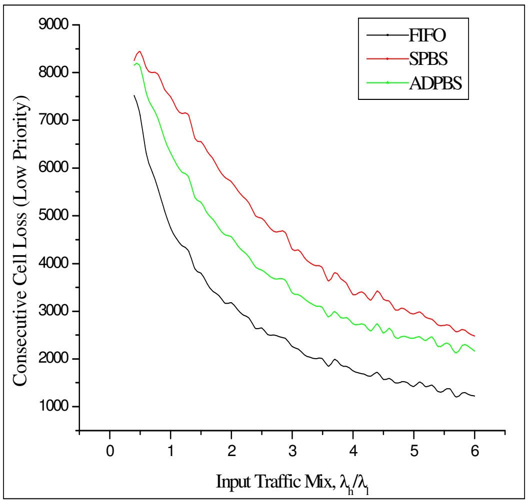


Fig. 4.125: Low priority cell loss for different traffic mix ratios (6-2-2-2).

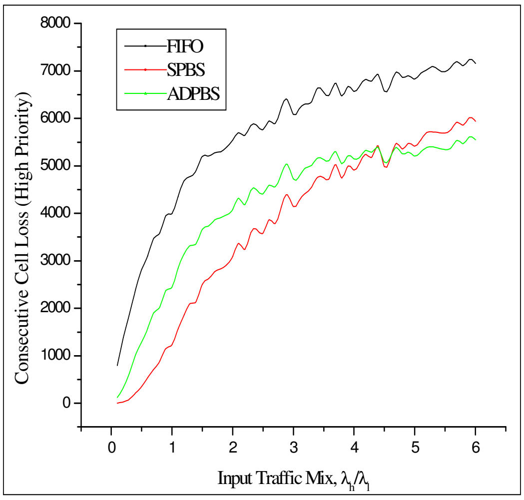


Fig. 4.126: High priority cell loss for different traffic mix ratios (4-2-2-2).

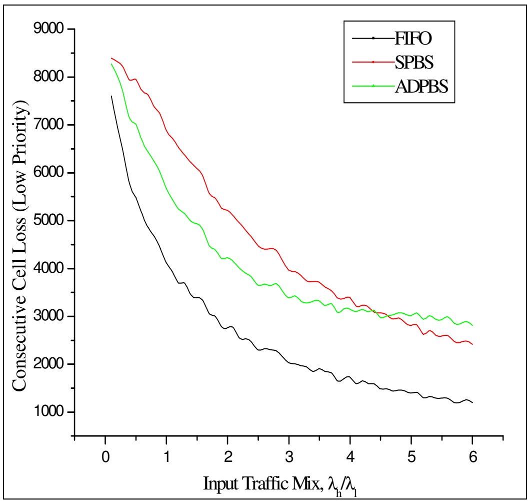


Fig. 4.127: Low priority cell loss for different traffic mix ratios (4-2-2-2).

4.4.3 Results of combinations with loss control limit of high priority cells equal to loss control limit of low priority cells

The simulation results of combination 6-6-2-2, as given in Fig. 4.128, show that ADPBS queue has the least consecutive cell loss of high priority cells beyond the traffic mix ratio of 1.4. As observed earlier, when loss control limit of high priority cells is equal to that of low priority cells, ADPBS queue attempts to reduce cell loss for the traffic type which is in majority in the input traffic stream. Fig. 4.129 shows that when low priority cells are in majority, the ADPBS queue again experiences less loss as compared to cell losses in SPBS scheme. Thus, the scheme has an adaptive queue mechanism using which it saves the cells that are in majority in input traffic.

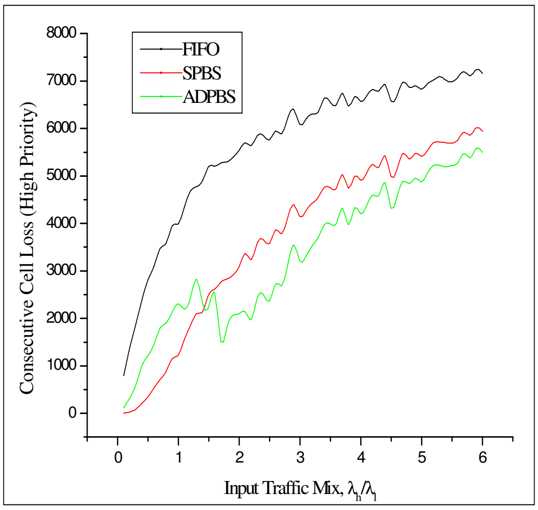


Fig. 4.128: High priority cell loss for different traffic mix ratios (6-6-2-2).

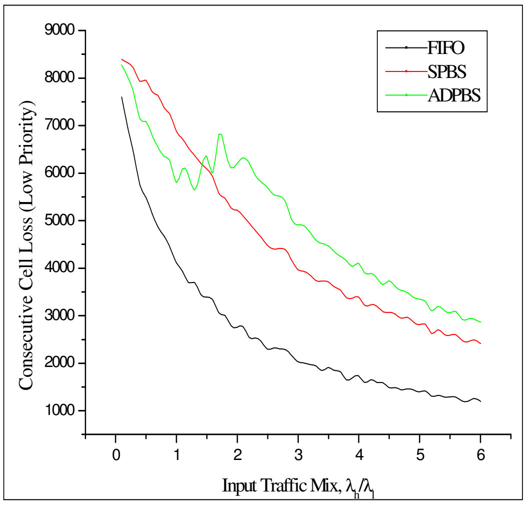


Fig. 4.129: Low priority cell loss for different traffic mix ratios (6-6-2-2).

The similar trend is seen in traffic case with combination 2-2-2-2 but with a difference that transition of loss curve starts at input traffic mix ratio value of 2.1 as compared to input traffic mix value of 1.4 with combination 6-6-2-2. Fig. 4.130 and Fig. 4.131 show losses for high and low priority cells, respectively, for combination 2-2-2-2.

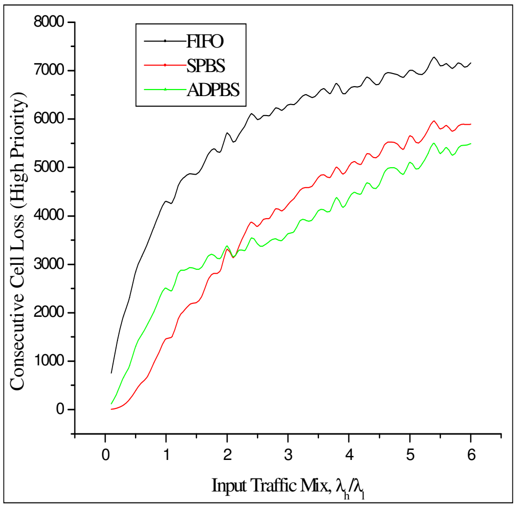


Fig. 4.130: High priority cell loss for different traffic mix ratios (2-2-2-2).

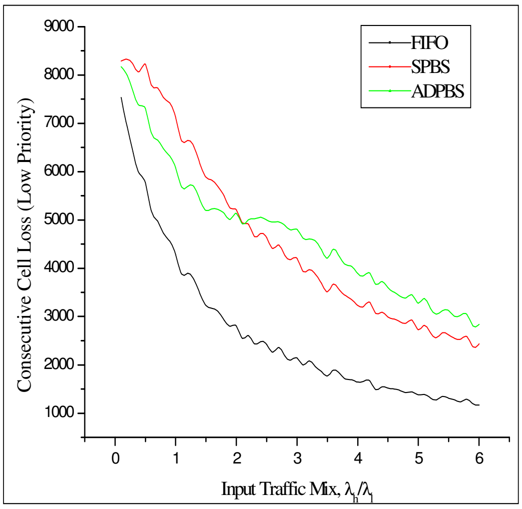


Fig. 4.131: Low priority cell loss for different traffic mix ratios (2-2-2-2).

4.5 CONCLUSION

Analysis of ADPBS queue with Poisson process based input traffic model is presented, described and discussed in this chapter. The simulation model used in this study compares the performance of ADPBS queue with SPBS and FIFO queues. The input to the three queues is Poisson process based traffic source in which, the inter-arrival times of cells are exponentially distributed and the complete simulation model is implemented in MATLAB. The critical parameter of QoS, that is, cell loss behavior of the queues is analysed under different traffic conditions, namely, various combinations of threshold control parameters; traffic load value variation; and input traffic mix variation.

The results reveal that ADPBS scheme outperforms SPBS and FIFO schemes due to its adaptive threshold control mechanism. It is observed that ADPBS queue manages to adapt the threshold to allocate sufficient buffer space for the kind of traffic class which is in majority in the incoming traffic stream; hence its cell loss is reduced upto 80% in comparison to SPBS and FIFO queues. The consecutive loss of high priority cells in ADPBS queue is upto 93% less than the consecutive loss of high priority cells in SPBS queue, when we consider the threshold control parameter combination favoring high priority cells. This performance of ADPBS queue is achieved for the case when high priority cells are in majority. The consecutive loss of low priority cells in ADPBS queue is upto 28% less than the consecutive loss of low priority cells in SPBS queue, when this type of cells are in majority and the threshold control parameter combination also favors low priority cells. When combinations of threshold control parameters are used in which equal preference is given to both types of priority classes, *i.e.*, combinations 2-2-2-2 and 6-6-2-2, the consecutive loss of high priority cells in ADPBS queue is upto 83% less than the consecutive loss of high priority cells in SPBS queue, for the case when high priority cells are in majority in input and the consecutive loss of low priority cells in ADPBS queue is upto 18% less than the consecutive loss of low priority cells in SPBS queue, for the case when low priority cells are in majority in input.

CHAPTER 5

PERFORMANCE ANALYSIS OF ADPBS QUEUE FOR AUTOREGRESSIVE TRAFFIC

Video traffic generated from different multimedia applications is a major source of traffic in B-ISDN. The video traffic streams are bursty in nature due to instant variability of video content being encoded. ATM networks offer promising advantages of VBR coding and transmission. VBR video transmission allows consistent image quality in contrast to CBR. Real-time traffic that includes voice and video, when transported over network, demands stringent QoS requirements. To better understand video transmission on high speed and integrated networks, an understanding of characteristics of VBR video traffic is also required. Modeling of VBR video traffic is one of the important subjects of research in ATM networks (Maglaris *et al.*, 1988; Sen *et al.*, 1989; Nomura *et al.*, 1989; Grunenfelder *et al.*, 1991; Heyman *et al.*, 1992; Shim *et al.*, 1994; Elwalid *et al.*, 1995).

Due to extremely high bandwidth requirements of uncompressed video streams, many coding algorithms have been developed for video compression. The MPEG standards for video coding have gained world-wide acceptance. The MPEG coding utilises both the spatial and temporal redundancy of video stream (Haskell *et al.*, 1997; Vuskovic and Du, 2004). Three frame types are defined in the MPEG algorithm: intra (I) frames, predicted (P) frames and interpolated (B) frames. A Group of Pictures (GOP) is composed of a regular pattern of frame types headed with an I-frame succeeded by B and P-frames, *e.g.*, a GOP with 12 frames can be described by IBBPBBPBBPBB. In the coding process, I and P-frames may be used as references. I-frames are coded with no reference to other frames, P-frames are coded with reference to the previous reference frame and B-frames are coded with reference to both the previous and the succeeding reference frame. Hence B-frames contain the least information, P-frames contain a bit more information than B-frames, and I-frames contain large amount of information in comparison with both B and P-frame. The MPEG standards allow arbitrary length for GOPs and flexible arrangements of frame types in a GOP. In the present study fixed-size GOP with deterministic and regular patterns has been considered. Using MPEG standards, the size of video frames vary drastically as the sequence is being generated, and this results in VBR traffic (Rose and Frater, 1995).

Autoregressive model is a typical model for VBR traffic as described in literature (Shugong, 1997). It enables to study the behavior of a single or multiplexed VBR traffic source in an ATM multiplexer with high accuracy and is suitable for modeling correlated traffic, such as, VBR encoded video traffic. In VBR video traffic, the video frames are generated at deterministic time intervals. It can model the occurrences of frames with a large number of cells correctly; which is a primary factor in determining cell loss rate. The discrete autoregressive (DAR) model in many forms has been used to model video sequences in past (Frater *et al.*, 1994; Heyman and Lakshman, 1996; Krunz and Tripathi, 1997; Hwang *et al.*, 2002 and Hwang and Shoraby, 2003).

In this chapter, ADPBS scheme has been analysed in which the threshold is dynamically varied in runtime based on consecutive cell loss behavior for two priority classes. Its queueing performance is studied with a video traffic model for frame sizes of MPEG-encoded video sequences based on two second order AR processes. The frame-size distribution has been studied using the traffic model that captures the empirical video sequences at both small and large lags. The section 5.1 provides a brief introduction of how an AR model is designed and used for simulation with SPBS, ADPBS and FIFO queues. The simulation results are analysed for different traffic load conditions, buffer sizes and other traffic parameter combinations.

5.1 AUTOREGRESSIVE VIDEO TRAFFIC MODEL

Liu *et al.* (2001) proposed model for simulating a video traffic efficiently. It can be noted that we have to use two second-order AR processes in order to model Short Range Dependence (SRD) and Long Range Dependence (LRD). SRD and LRD are two important characteristics of a video traffic. They have proposed that we can use a second-order AR process nested with another second-order AR process for modeling the video traffic. In the present work, we have used the video data sequences generated through experiment by Liu *et al.* (2001). They have encoded these video sequences using a MPEG-2 encoder. The sequences are broken into three separate parts containing three types of frame sizes, namely, I, P and B. They incorporated the scene changes of I-frame only, in their model. We briefly illustrate the scheme given by them.

Let us consider a linear system with input $\{s(t)\}$ and output $\{y(t)\}$, where t is the discrete time. The finite AR process for $\{s(t)\}$ and $\{y(t)\}$is given by (cf. Porat, 1994)

$$y(t) = \sum_{k-1}^{p} a_k \, y(t-k) + s(t) \qquad \ldots \; (5.1)$$

where $\{s(t)\}$ is an uncorrelated process with zero mean and variance σ^2, and $\{a_k, 1 \le k \le p\}$ is a finite sequence with $a_k \neq 0$. Such a process is denoted by $AR(p)$ and p is called the order of the AR process.

Let $X_I(n)$ be the size (*i.e.*, the number of bits or cells) of the n^{th} I-frame in an MPEG video sequence. $X_I(n)$ can be modeled as the sum of two independent random variables as,

$$X_I(n) = M_I(n) + \delta_I(n) \qquad \ldots \; (5.2)$$

where $M_I(n)$ is the mean frame size of the scene to which the n^{th} I-frame belongs and $\delta_I(n)$ represents the fluctuation of the n^{th} I-frame about the mean frame size of the scene.

For the j^{th} scene with length N_j that starts at the k^{th} I-frame, $M_I(n)$ will take the same value for every frame within the scene, which will be determined by another random variable $\overline{X}_I(j)$, *i.e.*,

$$M_I(k) = M_I(k+1) = \ldots = M_I(k + N_j - 1) \cong \overline{X}_I(j) \qquad \ldots \; (5.3)$$

The second random variable $\delta_I(n)$ in equation (5.1) is used to fit the sequence obtained from the original data by subtracting the mean frame size of the scene (*i.e.*, $M_I(n)$) from each frame within the scene. As a result, $\delta_I(n)$ have zero mean and it models a sceneless sequence with a variance σ_δ^2 very close, or equal to, the variance of the video traffic scenes.

In order to model SRD, a second-order AR process is used by Liu *et al.* (2001) for the sceneless sequence $\{\delta_I(n)\}$, as

$$\delta_I(n) = a_1 \delta_I(n-1) + a_2 \delta_I(n-2) + \varepsilon(n) \qquad \ldots \; (5.4)$$

where $\{\varepsilon(n)\}$ is a sequence of independent and identically distributed random variables. The mean of $\varepsilon(n)$ is zero since the mean of $\delta_I(n)$ is zero by definition, and the variance of $\{\varepsilon(n)\}$ is given by

$$\sigma_\varepsilon^2 = \frac{(1+a_2)\left[(1-a_2)^2 - a_1^2\right]}{1-a_2}\sigma_\delta^2 \qquad \ldots (5.5)$$

where σ_δ^2 is the variance of $\delta_I(n)$.

The LRD is modeled using another second-order AR process for the mean sequence $M_I(n)$, or equivalently $\overline{X}_I(j)$

$$\overline{X}_I(j) = b_1\overline{X}_I(j-1) + b_2\overline{X}_I(j-2) + \theta(j) \qquad \ldots (5.6)$$

where $\{\theta(j)\}$ is a sequence of independent and identically distributed random variables. The mean and variance of $\theta(j)$ are determined by

$$\mu_\theta = (1-b_1-b_2)\overline{\mu}_I \qquad \ldots (5.7)$$

and

$$\sigma_\theta^2 = \frac{(1+b_2)\left[(1-b_2)^2 - b_1^2\right]}{1-b_2}\overline{\sigma}_I^{\,2} \qquad \ldots (5.8)$$

where $\overline{\mu}_I$ and $\overline{\sigma}_I^2$ are the mean and the variance of $\overline{X}_I(j)$, respectively.

We have considered the empirical values of different parameters as given by Liu *et al.* (2001) for the case when GOP is one.

5.2 SIMULATION MODEL

The simulation model used for analysis of ADPBS scheme with AR process is given in Fig. 5.1. A second-order AR model is used to generate the traffic input for three queues, namely, FIFO, SPBS and ADPBS. The simulation is carried out for a set of frames. In every frame, a number of cells are generated by using AR process implemented in MATLAB with the help of *arsim* module that effectively simulates the realizations of AR processes (Scheneider and Neumaier, 2001). From the model explained in section 5.1 and data given by Liu *et al.* (2001), a set of values with GOP = 1 pattern have been used for carrying out simulation. The values of different parameters for this case are: $a_1 = 0.8707$, $a_2 = 0.1126$, $b_1 = 0.3365$, $b_2 = 0.2424$, $\overline{\mu}_i = 553$, $\overline{\sigma}_i = 112$, $\mu_\delta = 0$ and $\sigma_\delta = 121$.

Fig. 5.2 consists of frame-wise cell distribution, for a specific sample, generated

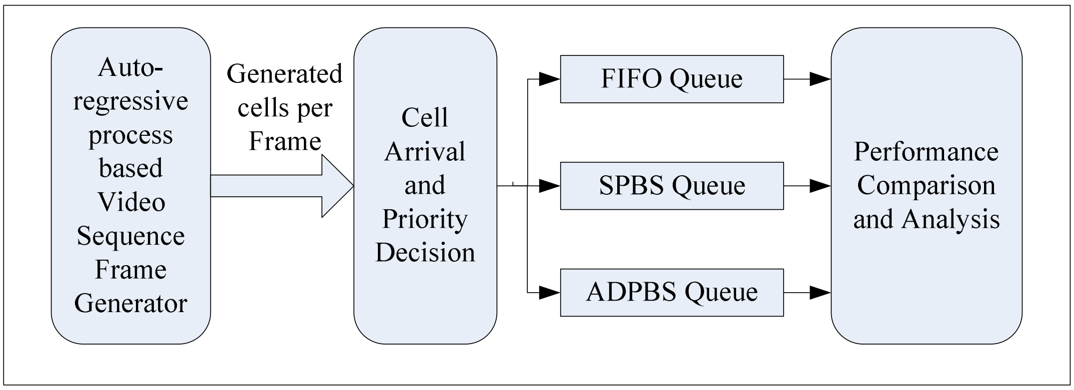


Fig. 5.1: Simulation model with AR process based input.

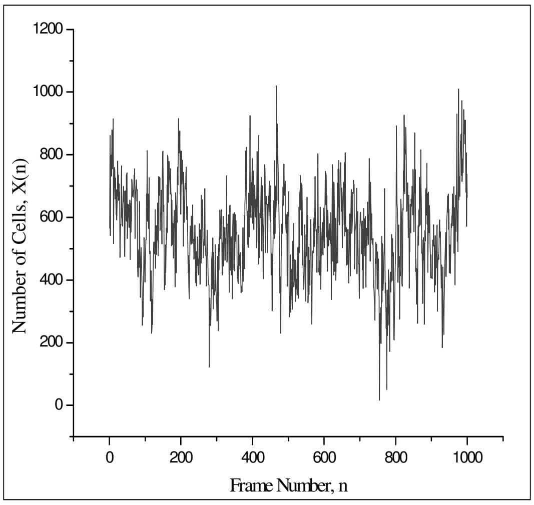


Fig. 5.2: Frame-wise distribution of cells.

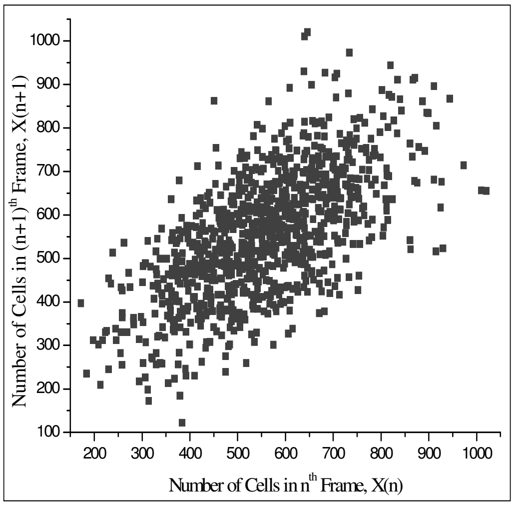


Fig. 5.3: Scatter diagram of correlation between frames with one lag.

with AR model that has been implemented in the present study. One lag scatter diagram of the frames for this sample is shown in Fig. 5.3. A positive correlation with a single cluster can be observed in this figure and the slope of linear regression line through the cluster has a value of nearly unity. This implies that frames remain close in amplitude at one lag. The values of other parameters used in the simulation have been taken as buffer size at the level 100, service rate at the level 600, number of frames are 1000 and frame rate is 25 frames per second. The performance of ADPBS queue is analysed with respect to other queues by considering the relative cell loss ratios, *i.e.*, ratio of consecutive cell loss in SPBS queue to that in ADPBS queue and the ratio of consecutive cell loss in FIFO queue to that in ADPBS queue. The performance evaluation based on its behavior is carried out under different traffic conditions, such as, different threshold control parameters, various traffic load conditions, different input traffic mix combinations, and different buffer sizes. The detailed results with these traffic conditions are discussed in the following sections.

5.3 ANALYSIS OF ADPBS QUEUE USING VARIOUS COMBINATIONS OF THRESHOLD CONTROL PARAMETERS

To study the cell loss behavior in ADPBS queue, the simulation study is carried out for different combinations of the threshold control parameters, namely, c_h, c_l, s_h and s_l. We have, in the present study, considered the smaller values of these control parameters. It however, has been noticed that the larger values of these control parameters lead to similar results. The combinations, that show better results in terms of less number of consecutive cell losses in ADPBS queue when compared with SPBS and FIFO queues, are identified. These selected combinations have been used for further simulations in order to study traffic load variation, input traffic mix variation, *etc*., in next sections. For the purpose of analysing ADPBS queue, we considered different combinations of loss control limit c_h and c_l, as discussed in section 4.2. The following three cases are considered.

Case (i) : loss control limit of high priority cells < loss control limit of low priority cells
Case (ii) : loss control limit of high priority cells > loss control limit of low priority cells
Case (iii): loss control limit of high priority cells = loss control limit of low priority cells

Each of the above cases is simulated under traffic conditions with different proportions of high priority and low priority cells as input to the queue, *i.e.*, high priority cells in majority, low priority cells in majority and both types of cells in equal proportion. For each combination as mentioned above, 30 samples of cell losses for different queues are captured by carrying out simulation experiments. Performance of the proposed ADPBS scheme is compared with SPBS and FIFO schemes with different combinations of threshold control parameters in the following sub-sections. In the graphs that are being presented in this chapter, we have abbreviated high priority cells by HPC and low priority cells by LPC.

5.3.1 Results of combinations with loss control limit of high priority cells less than loss control limit of low priority cells

The simulation is carried out for combinations 2-4-1-1, 2-6-2-2 and 2-6-1-1, when high priority cells are more than low priority cells in the traffic that has been inputted to all the queues. Under this category, loss control limit of high priority cells, c_h, is less than loss control limit of low priority cells, c_l, the preference is given to retain high priority cells. Fig. 5.4 to Fig. 5.7 graphically illustrate the simulation results for comparison of ADPBS queue, using these combinations, with SPBS and FIFO queues, when high priority cells are in majority in input traffic stream.

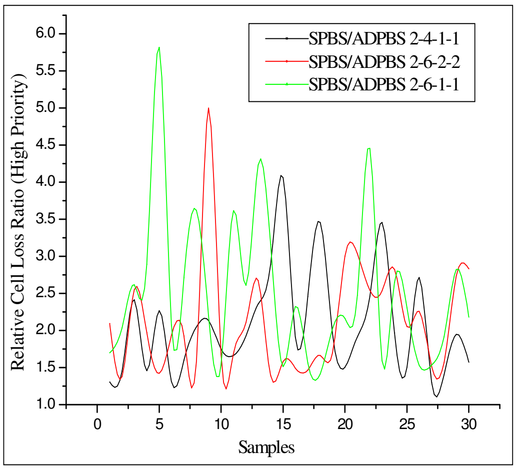


Fig. 5.4: Relative cell loss ratio for HPC (2-4-1-1, 2-6-2-2 and 2-6-1-1).

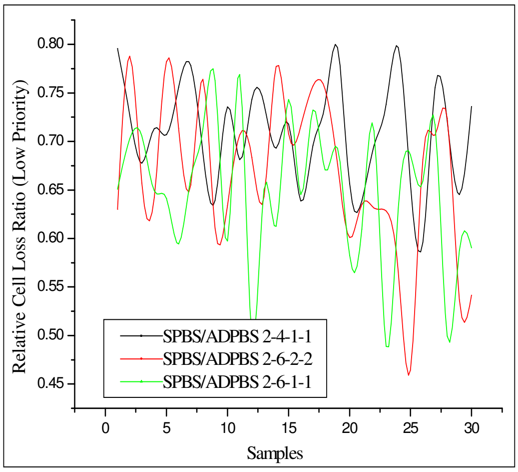


Fig. 5.5: Relative cell loss ratio for LPC (2-4-1-1, 2-6-2-2 and 2-6-1-1).

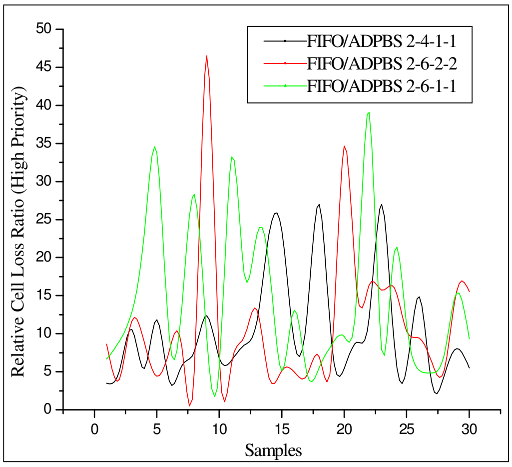


Fig. 5.6: Relative cell loss ratio for HPC (2-4-1-1, 2-6-2-2 and 2-6-1-1).

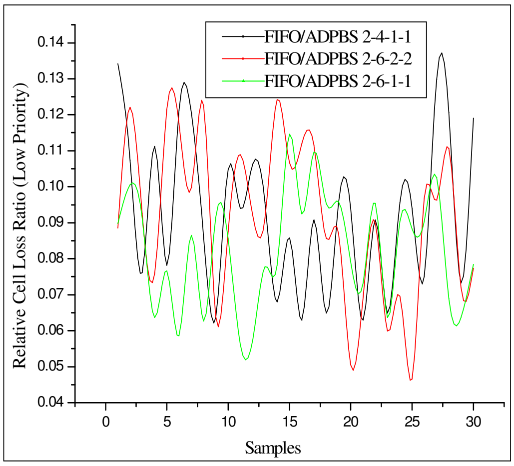


Fig. 5.7: Relative cell loss ratio for LPC (2-4-1-1, 2-6-2-2 and 2-6-1-1).

A similar comparison of relative cell loss ratios is represented in Fig. 5.8 and Fig. 5.10 for high priority cells and in Fig. 5.9 and Fig. 5.11, for low priority cells; when there are low priority cells in majority in input traffic stream. From Fig. 5.8, one can observe that high priority cell loss in SPBS and ADPBS queues is zero due to the reason that traffic input to the queue has very less high priority cells and cells of this priority class can access the complete buffer space.

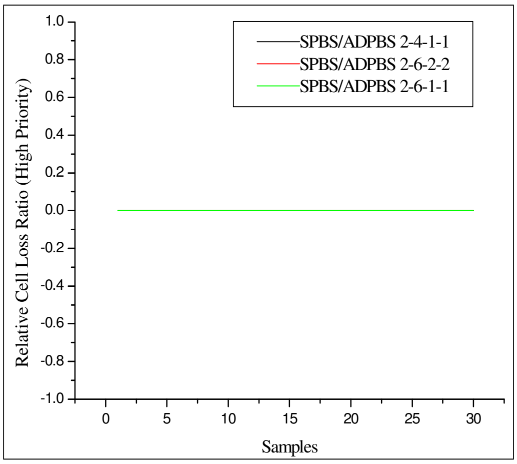


Fig. 5.8: Relative cell loss ratio for HPC (2-4-1-1, 2-6-2-2 and 2-6-1-1).

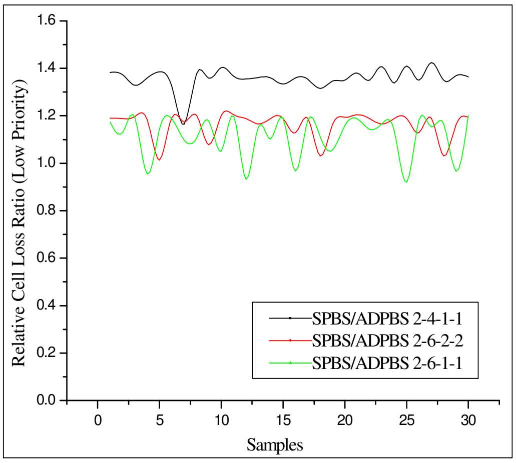


Fig. 5.9: Relative cell loss ratio for LPC (2-4-1-1, 2-6-2-2 and 2-6-1-1).

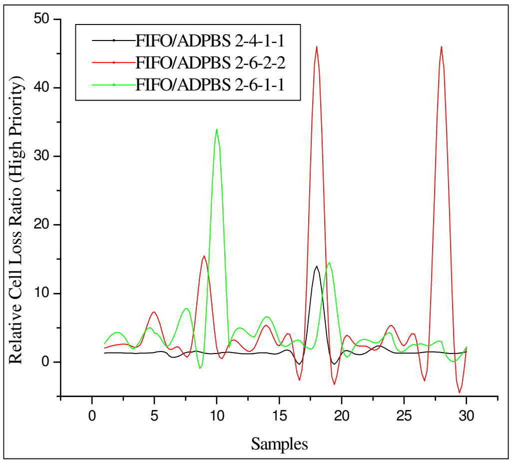


Fig. 5.10: Relative cell loss ratio for HPC (2-4-1-1, 2-6-2-2 and 2-6-1-1).

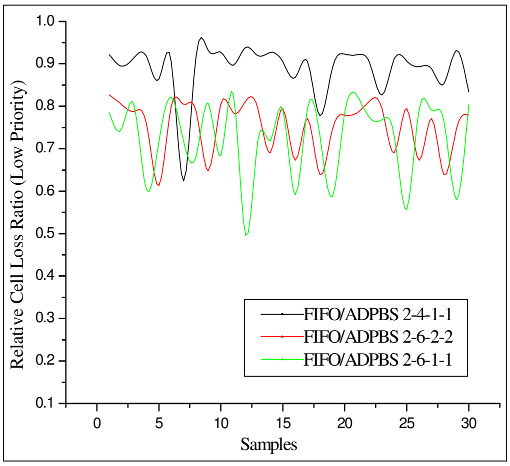


Fig. 5.11: Relative cell loss ratio for LPC (2-4-1-1, 2-6-2-2 and 2-6-1-1).

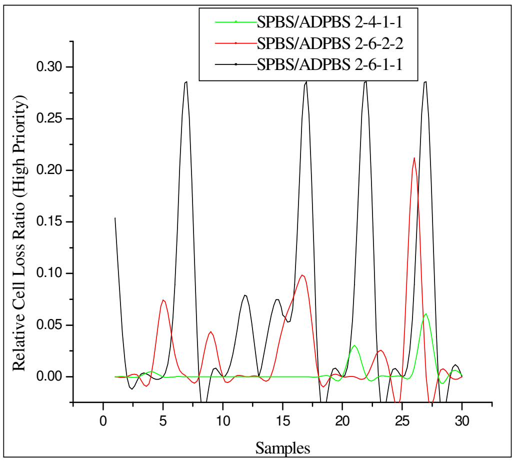


Fig. 5.12: Relative cell loss ratio for HPC (2-4-1-1, 2-6-1-1 and 2-6-2-2).

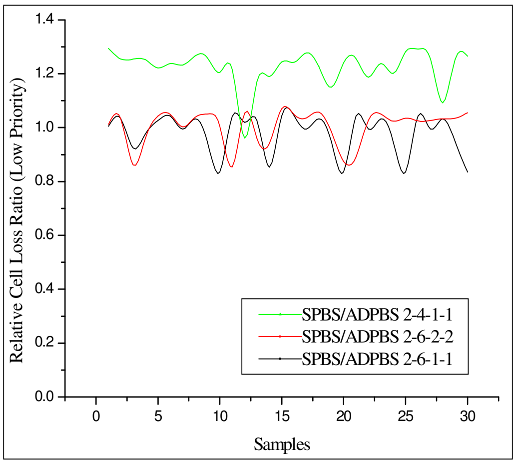


Fig. 5.13: Relative cell loss ratio for LPC (2-4-1-1, 2-6-1-1 and 2-6-2-2).

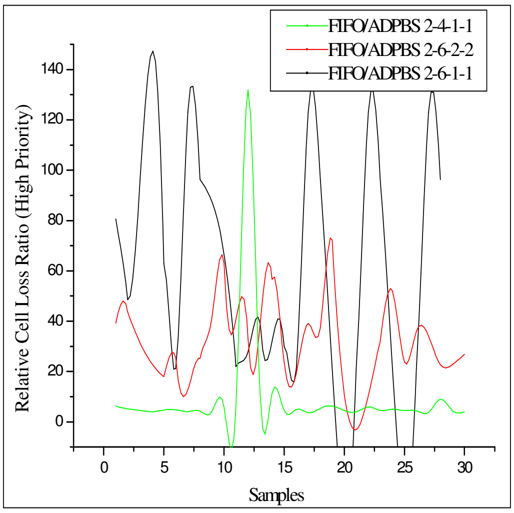


Fig. 5.14: Relative cell loss ratio for HPC (2-4-1-1, 2-6-2-2 and 2-6-1-1).

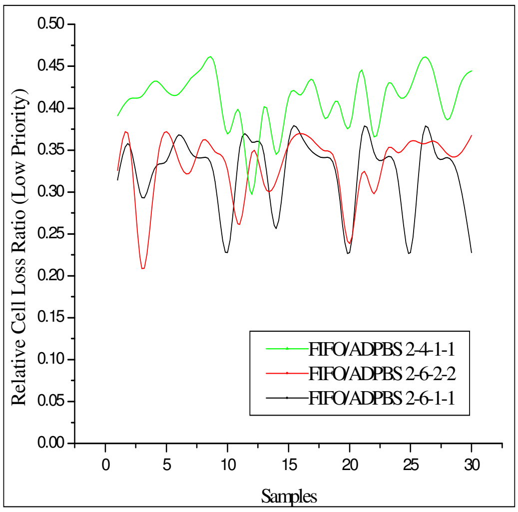


Fig. 5.15: Relative cell loss ratio for LPC (2-4-1-1, 2-6-2-2 and 2-6-1-1).

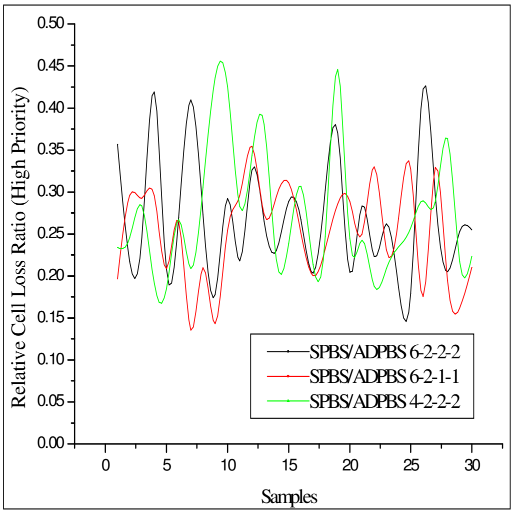
For equal proportion of high priority and low priority cells in input traffic data, the comparison of the relative cell loss ratio of high priority cells is illustrated in Fig. 5.12 for SPBS and ADPBS queues and in Fig. 5.14 for FIFO and ADPBS queues. The relative cell loss ratio of low priority cells is presented in Fig. 5.13 for SPBS and ADPBS queues and in Fig. 5.15 for FIFO and ADPBS queues.

Overall comparison of consecutive cell losses, during simulation experiments under $c_h < c_l$ case, reveals that combinations 2-4-1-1 and 2-6-2-2 have least losses and these are selected for further simulations in section 5.4 and 5.5.

5.3.2 Results of combinations with loss control limit of high priority cells greater than loss control limit of low priority cells

This combination of threshold control parameters reduces the cell losses in ADPBS queue for low priority cells since its loss control limit of low priority cells is less than the loss control limit of high priority cells. The combinations 6-2-2-2, 6-2-1-1 and 4-2-2-2 have been used for performance analysis under this case. The results of this simulation are presented in Fig. 5.16 to Fig. 5.19, when there are majority of high priority cells in the incoming traffic stream.

Fig. 5.20 to Fig. 5.23 present the results of simulations under this case for FIFO, SPBS and ADPBS queues, when low priority cells are in majority in input traffic. Further, relative cell loss ratio for different combinations is compared among three queues for equal proportion of high and low priority cells in the input traffic, and results for relative cell loss ratio of SPBS and FIFO queues to ADPBS queue is presented in Fig. 5.24 and Fig. 5.26 for high priority traffic. The relative cell loss ratio of low priority cells is presented in Fig. 5.25 for SPBS and ADPBS queues; and in Fig. 5.27 for FIFO and ADPBS queues.



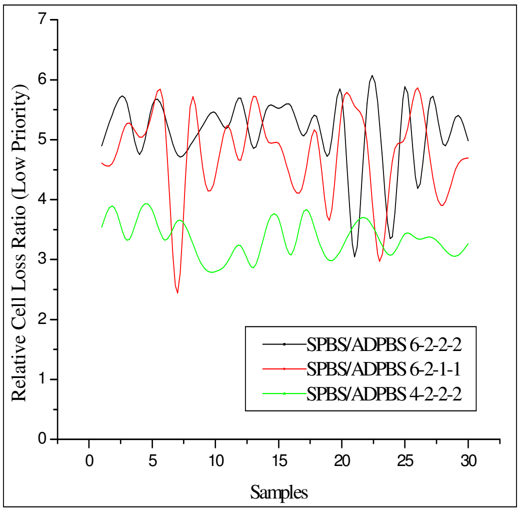
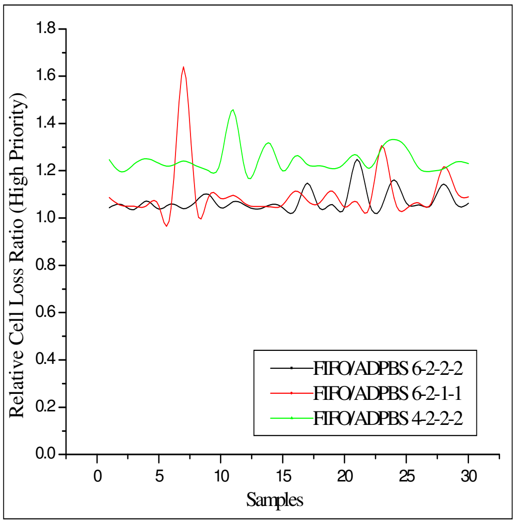


Fig. 5.16: Relative cell loss ratio for HPC (6-2-2-2, 6-2-1-1 and 4-2-2-2).

Fig. 5.17: Relative cell loss ratio for LPC (6-2-2-2, 6-2-1-1 and 4-2-2-2).



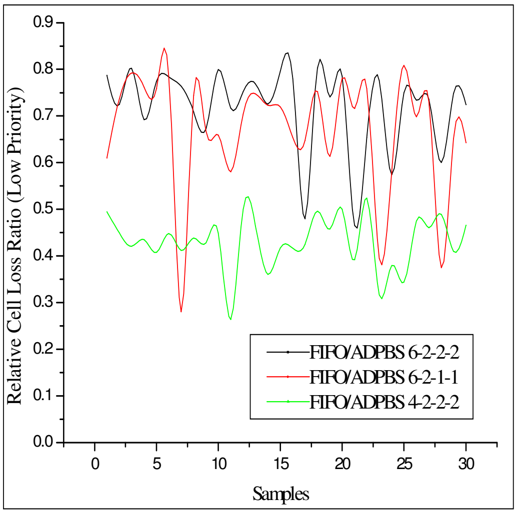
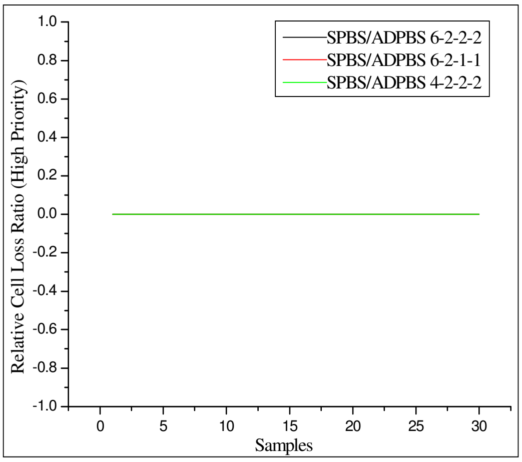


Fig. 5.18: Relative cell loss ratio for HPC (6-2-2-2, 6-2-1-1 and 4-2-2-2).

Fig. 5.19: Relative cell loss ratio for LPC (6-2-2-2, 6-2-1-1 and 4-2-2-2).



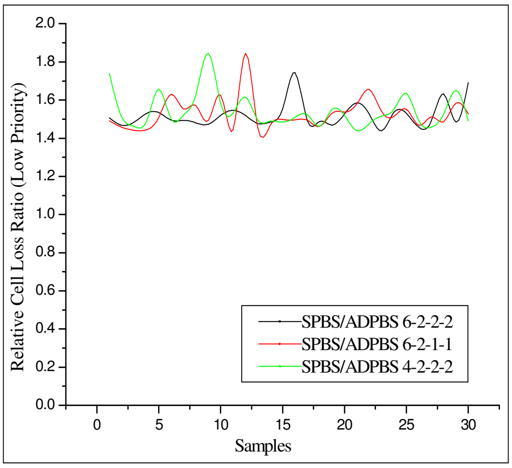
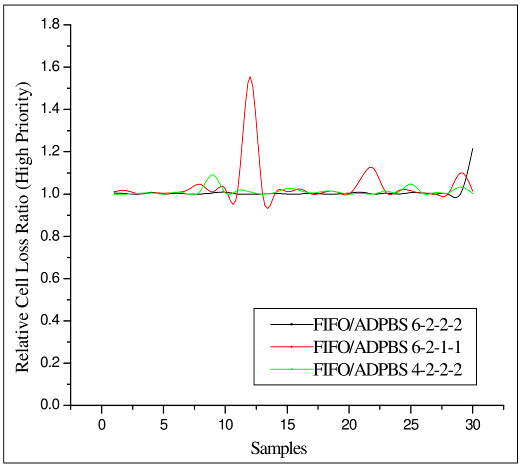


Fig. 5.20: Relative cell loss ratio for HPC (6-2-2-2, 6-2-1-1 and 4-2-2-2).

Fig. 5.21: Relative cell loss ratio for LPC (6-2-2-2, 6-2-1-1 and 4-2-2-2).



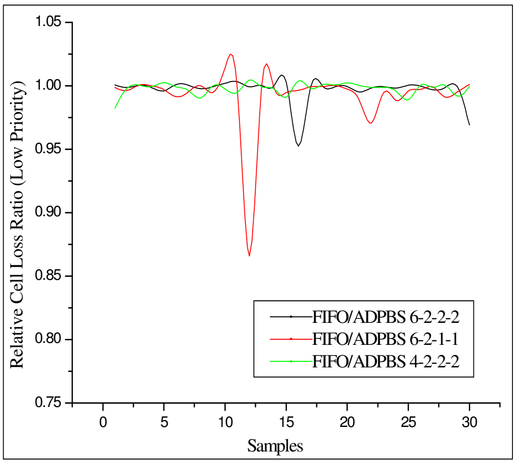
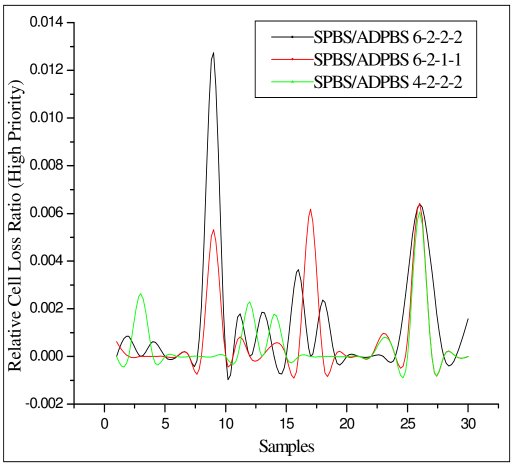


Fig. 5.22: Relative cell loss ratio for HPC (6-2-2-2, 6-2-1-1 and 4-2-2-2).

Fig. 5.23: Relative cell loss ratio for LPC (6-2-2-2, 6-2-1-1 and 4-2-2-2).



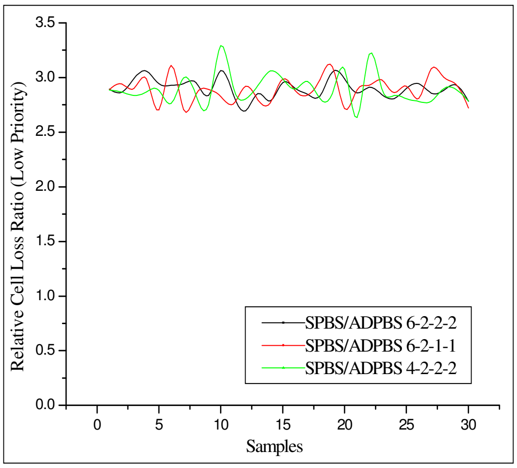
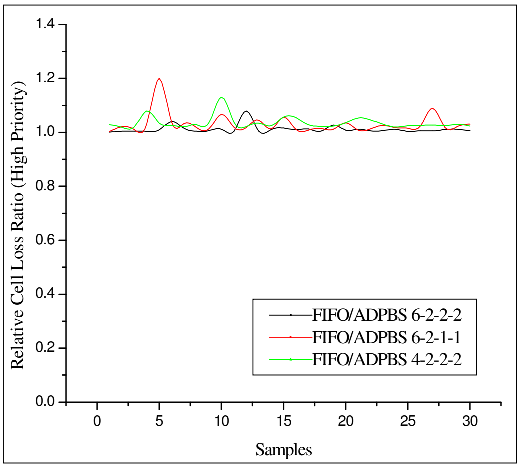


Fig. 5.24: Relative cell loss ratio for HPC (6-2-2-2, 6-2-1-1 and 4-2-2-2).

Fig. 5.25: Relative cell loss ratio for LPC (6-2-2-2, 6-2-1-1 and 4-2-2-2).



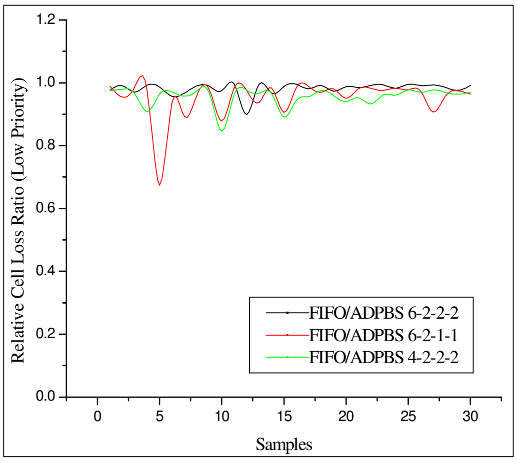


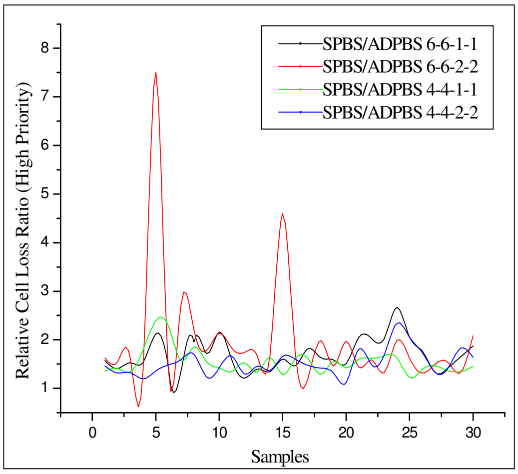
Fig. 5.26: Relative cell loss ratio for HPC (6-2-2-2, 6-2-1-1 and 4-2-2-2).

Fig. 5.27: Relative cell loss ratio for LPC (6-2-2-2, 6-2-1-1 and 4-2-2-2).

Comparison of cell loss performance of different combinations reveals that combinations 6-2-1-1 and 6-2-2-2 have minimum losses and are thus selected for further performance analysis under other traffic conditions in section 5.4 and 5.5.

5.3.3 Results of combinations with loss control limit of high priority cells equal to loss control limit of low priority cells

For equal loss control limit of both high priority and low priority cells, *i.e.*, $c_h = c_l$, the simulation study is carried out for combinations 6-6-1-1, 6-6-2-2, 4-4-1-1 and 4-4-2-2. Fig. 5.28 to Fig. 5.31 illustrate the results when high priority cells are in majority; Fig. 5.32 to Fig. 5.35 present the results when low priority cells are in majority and Fig. 5.36 to Fig. 5.39 when both priority types of cells are in equal proportion in input traffic.



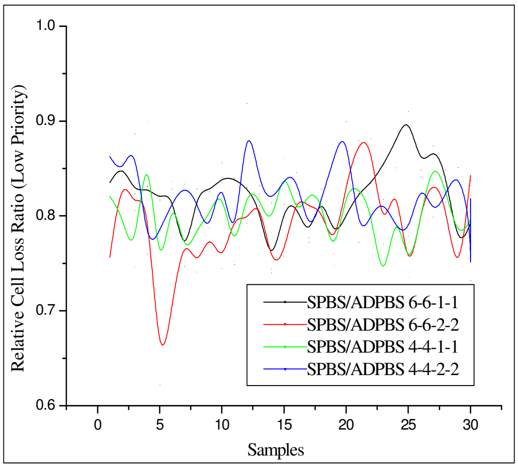
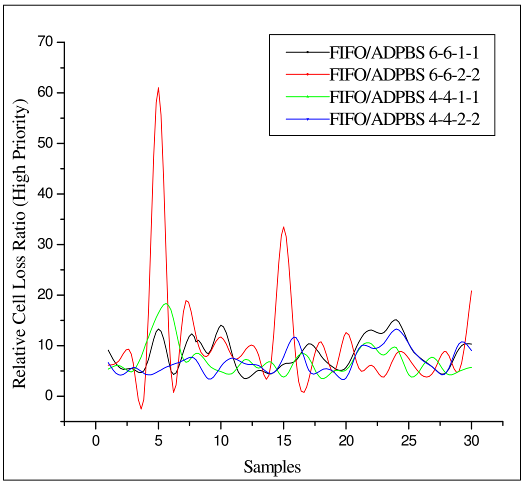


Fig. 5.28: Relative cell loss ratio for HPC (6-6-1-1, 6-6-2-2, 4-4-1-1 and 4-4-2-2).

Fig. 5.29: Relative cell loss ratio for LPC (6-6-1-1, 6-6-2-2, 4-4-1-1 and 4-4-2-2).



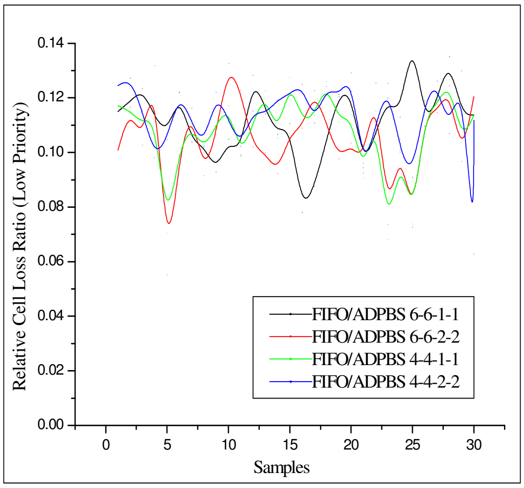
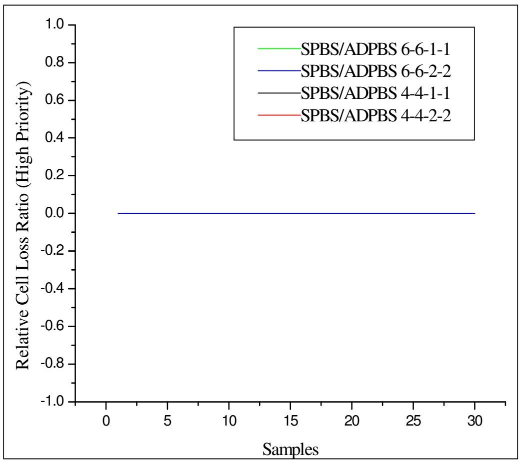


Fig. 5.30: Relative cell loss ratio for HPC (6-6-1-1, 6-6-2-2, 4-4-1-1 and 4-4-2-2).

Fig. 5.31: Relative cell loss ratio for LPC (6-6-1-1, 6-6-2-2, 4-4-1-1 and 4-4-2-2).



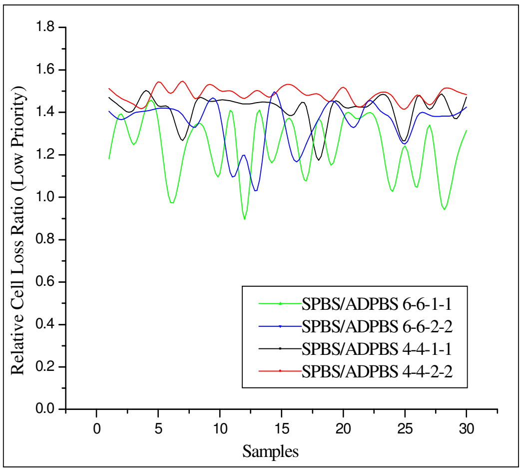
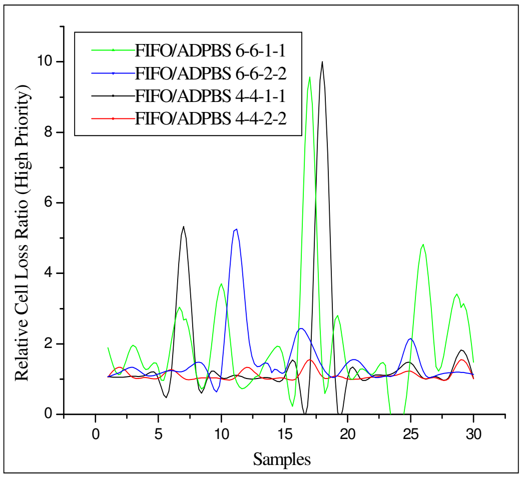


Fig. 5.32: Relative cell loss ratio for HPC (6-6-1-1, 6-6-2-2, 4-4-1-1 and 4-4-2-2).

Fig. 5.33: Relative cell loss ratio for LPC (6-6-1-1, 6-6-2-2, 4-4-1-1 and 4-4-2-2).



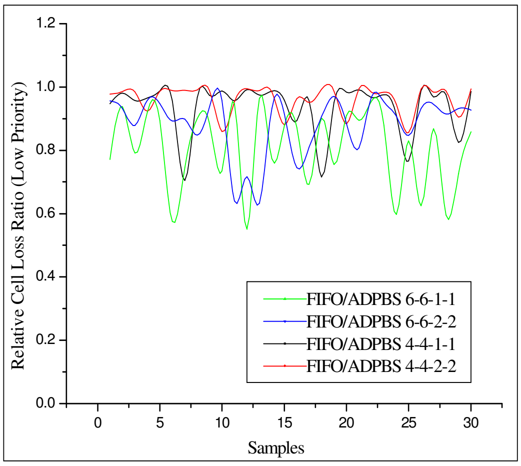


Fig. 5.34: Relative cell loss ratio for HPC (6-6-1-1, 6-6-2-2, 4-4-1-1 and 4-4-2-2).

Fig. 5.35: Relative cell loss ratio for LPC (6-6-1-1, 6-6-2-2, 4-4-1-1 and 4-4-2-2).

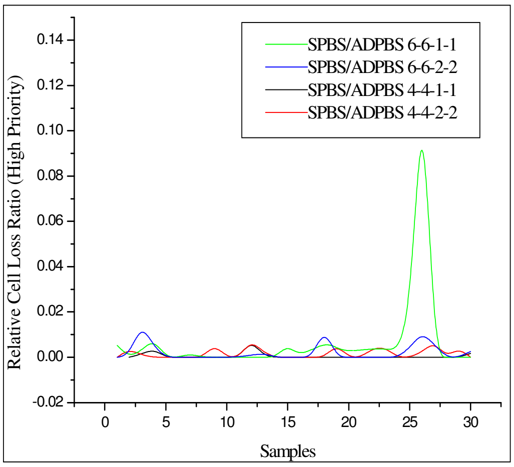


Fig. 5.36: Relative cell loss ratio for HPC (6-6-1-1, 6-6-2-2, 4-4-1-1 and 4-4-2-2).

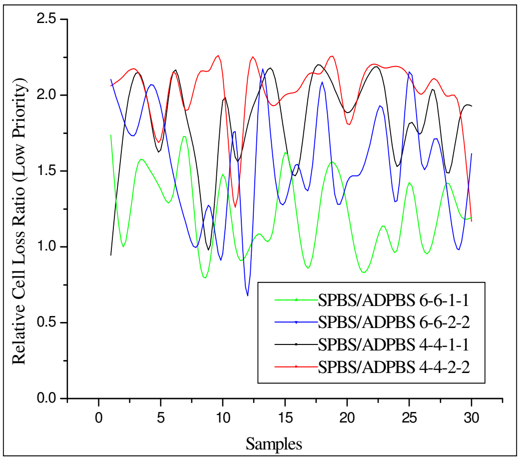


Fig. 5.37: Relative cell loss ratio for LPC (6-6-1-1, 6-6-2-2, 4-4-1-1 and 4-4-2-2).

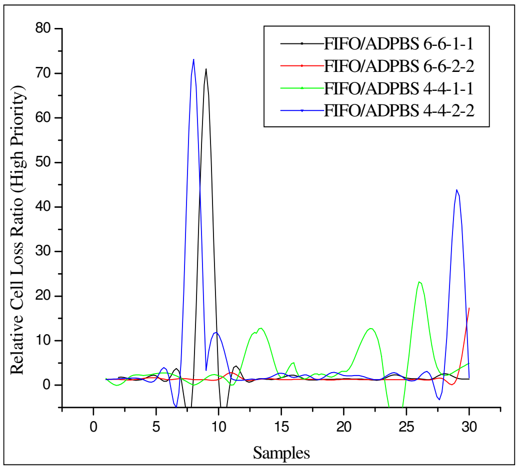


Fig. 5.38: Relative cell loss ratio for HPC (6-6-1-1, 6-6-2-2, 4-4-1-1 and 4-4-2-2).

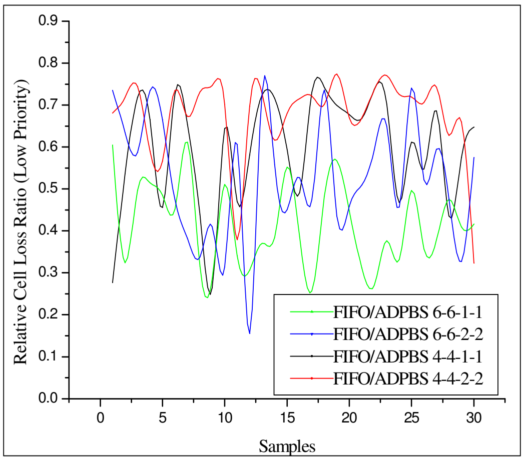


Fig. 5.39: Relative cell loss ratio for LPC (6-6-1-1, 6-6-2-2, 4-4-1-1 and 4-4-2-2).

For this traffic case, it is observed that loss of cells is controlled mainly for the kind of traffic that is in majority in input data stream. From the results, it can be inferred that combinations 4-4-1-1 and 6-6-2-2 are having least cell losses. These two combinations are used for further simulations in section 5.4 and 5.5.

5.4 ANALYSIS OF ADPBS QUEUE WITH TRAFFIC LOAD VARIATION

In this section, the performance of ADPBS queue is discussed and compared with SPBS queue and FIFO queue for different traffic load values. The performance analysis is organised under three different input traffic categories – traffic with high priority cells in majority, traffic with low priority cells in majority, and when both type of cells in equal proportion. For each traffic category, the traffic case with different combinations of threshold control parameters, as selected in section 5.3, are used for simulation study.

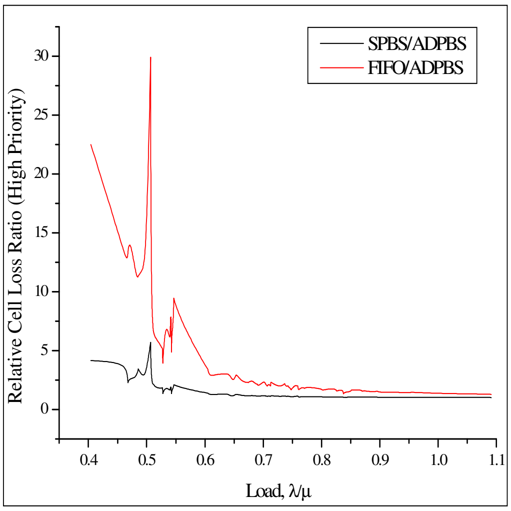
5.4.1 High priority cells in majority

When high priority cells are in majority in the input data stream, the simulation is carried out for three cases – **(i)** when loss control limit of high priority cells is less than loss control limit of low priority cells, *i.e.*, combinations 2-6-2-2 and 2-4-1-1; **(ii)** when loss control limit of high priority cells is greater than loss control limit of low priority cells, *i.e.*, combinations 6-2-1-1 and 6-2-2-2; and **(iii)** when loss control limit of high priority cells is equal to loss control limit of low priority cells, *i.e.*, combinations 6-6-2-2 and 4-4-1-1. The performance of the proposed ADPBS scheme is compared with SPBS and FIFO schemes, based on different load values and traffic cases, in the following sub-sections.

5.4.1.1 Results of combinations with loss control limit of high priority cells less than loss control limit of low priority cells

The loss of consecutive high priority cells in ADPBS queue for variation of traffic load is compared with SPBS and FIFO queues in Fig. 5.40 for combination 2-6-2-2. As the high priority cells are in majority, threshold adapts to accommodate those cells and the relative cell loss ratio of SPBS queue to ADPBS queue goes up to 5.89. For FIFO and ADPBS queues this ratio is as high as 30. This ratio decreases as the load increases since the service rate tends to become equal to cell arrival rate. With this change, the buffer occupancy level will be higher and hence ADPBS scheme becomes almost similar to SPBS scheme. The relative cell loss ratio of low priority cells is shown in Fig. 5.41. For low priority cells, the consecutive cell loss ratio increases as load value increases. It reflects the trade-off between cell loss ratio of two priority classes due to sharing of the limited buffer space.

It has also been observed that results follow similar pattern for combination 2-4-1-1. The cell loss behavior for high priority cells is illustrated in Fig. 5.42. There are large variations in cell loss ratios of FIFO queue till the load value of 0.53. When load value is increased, the relative cell loss ratio for high priority cells becomes stable.



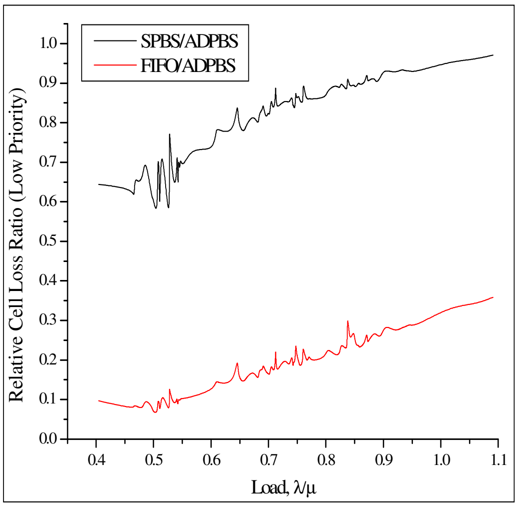
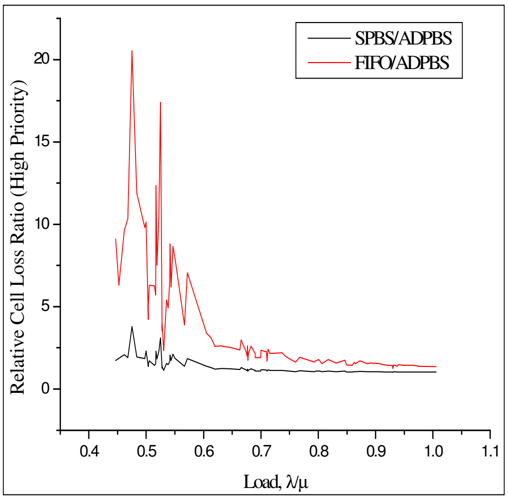


Fig. 5.40: High priority cell loss for different traffic load values (2-6-2-2).

Fig. 5.41: Low priority cell loss for different traffic load values (2-6-2-2).



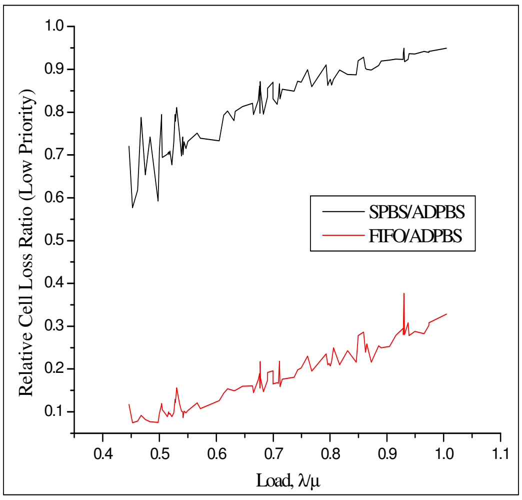


Fig. 5.42: High priority cell loss for different traffic load values (2-4-1-1).

Fig. 5.43: Low priority cell loss for different traffic load values (2-4-1-1).

Similarly, the relative high priority cell loss ratio of SPBS and ADPBS queue is 3.79 and it decreases as the load value increases. For higher load values, the relative consecutive cell loss in SPBS queue becomes almost constant. Since the low priority cells are very less in the incoming data stream, its losses are also very less. The cell loss ratios of SPBS and FIFO queues with respect to ADPBS queue are less than 1 as shown in Fig. 5.43. The relative cell loss ratios of SPBS and ADPBS queues tend to unity as the traffic load increases. This results due to the trade-off effect of high priority and low priority cells sharing the limited buffer space.

5.4.1.2 Results of combinations with loss control limit of high priority cells greater than loss control limit of low priority cells

The relative cell loss ratio of high priority and low priority cells, for combination 6-2-1-1, is shown in Fig. 5.44 and Fig. 5.45, respectively, for different traffic load values. In this traffic case, it can be observed that **(a)** major content in input traffic is high priority cells; **(b)** the combination of threshold control parameters tends to retain low priority cells. From the simulation results captured in Fig. 5.44, it can be inferred that high priority cell loss ratio of FIFO scheme over ADPBS scheme tends to unity when the traffic load is increased. The relative cell loss ratio of SPBS and ADPBS scheme is less than 1 and increases as the load increases. The low priority cell loss in SPBS queue is approximately 6 times higher in comparison with low priority cell loss in ADPBS queue. From Fig. 5.45, one can infer that this ratio tends to decrease as load increases because the access of buffer space for low priority cells is controlled by threshold control limits. For FIFO queue, the relative cell loss ratio of FIFO queue is less than 1. If we increase the load value, this ratio stabilises at a value of 0.7.

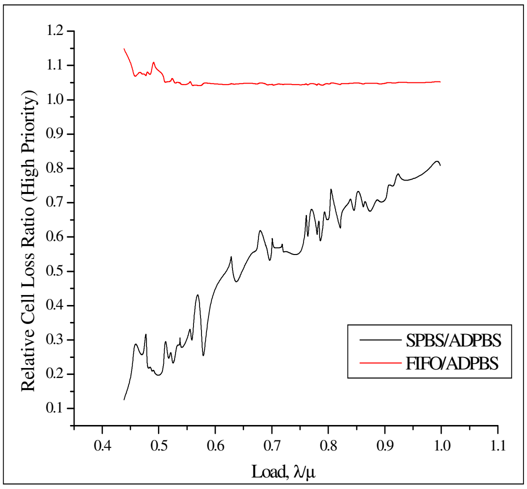


Fig. 5.44: High priority cell loss for different traffic load values (6-2-1-1).

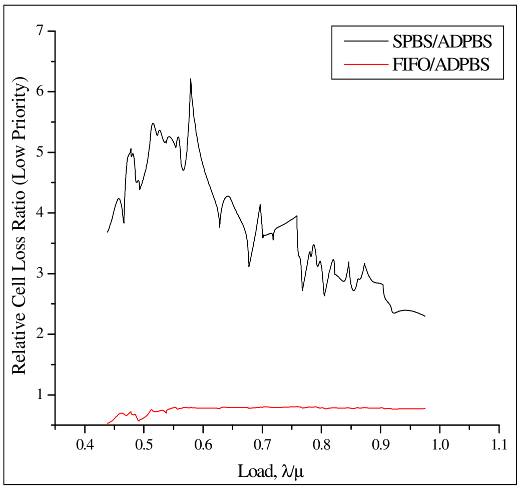
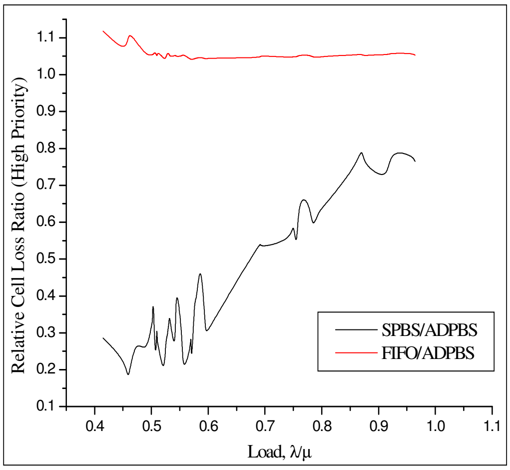


Fig. 5.45: Low priority cell loss for different traffic load values (6-2-1-1).

It is further observed that results follow similar pattern for combination 6-2-2-2 as shown in Fig. 5.46 and Fig. 5.47 because loss control limit parameter remains the same, only modification step level parameters, *i.e.*, s_h and s_l, are different. As the major part of the incoming traffic is high priority cells, ADPBS queue starts performing better as the load increases. When we compare the cell loss ratio of low priority cells, it has been observed that cell loss in ADPBS queue is less than the cell loss in SPBS queue, but the loss of low priority cells will be more at higher load as the number of high priority cells is more than the number of low priority cells.



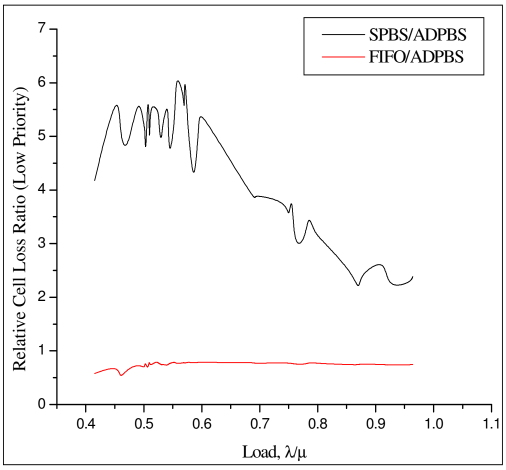


Fig. 5.46: High priority cell loss for different traffic load values (6-2-2-2).

Fig. 5.47: Low priority cell loss for different traffic load values (6-2-2-2).

5.4.1.3 Results of combinations with loss control limit of high priority cells equal to loss control limit of low priority cells

For the case with combination 6-6-2-2, it can be inferred from Fig. 5.48 that the high priority cell loss in SPBS queue is relatively 1.8 times higher than the cell loss in ADPBS queue. For FIFO queue the relative high priority cell loss is 10.7 times higher than the high priority cell loss in ADPBS queue. This is due to that incoming traffic consists of high priority cells in majority and these cells can access the entire buffer space. As traffic load value increases, this ratio tends to decrease. Fig. 5.49 depicts that loss of low priority cells in ADPBS queue is higher than other two queues since the low priority traffic is low in concentration in the incoming data stream; as such, the major part of the buffer space gets allocated to accommodate high priority traffic.

The simulation results for combination 4-4-1-1 are shown in Fig. 5.50 and Fig. 5.51. The SPBS queue has high priority cell loss which is approximately 150% more in comparison with the loss of high priority cell loss in ADPBS queue. It can be observed that as load value increases, the cell loss ratio of SPBS queue over ADPBS queue tends to follow the same pattern that is followed by the cell loss ratio of FIFO queue over ADPBS queue. For higher load values, the service rate of the queue is lower than the cell arrival rate, thus the queue gets almost completely filled and the loss tends to be higher even after changing the threshold due to limited buffer space. The FIFO queue also experiences decrease in cell loss ratio with respect to ADPBS queue as the load value increases. This relative cell loss ratio varies from 1.28 to 30.4 and this large variation attributes to the burstiness of the incoming traffic. Fig. 5.51 shows that the low priority cell loss in ADPBS queue is higher than other two queues since major part of the incoming traffic is high priority cells. As load value increases, the ADPBS scheme tends to perform better with respect to SPBS scheme as well as FIFO scheme.

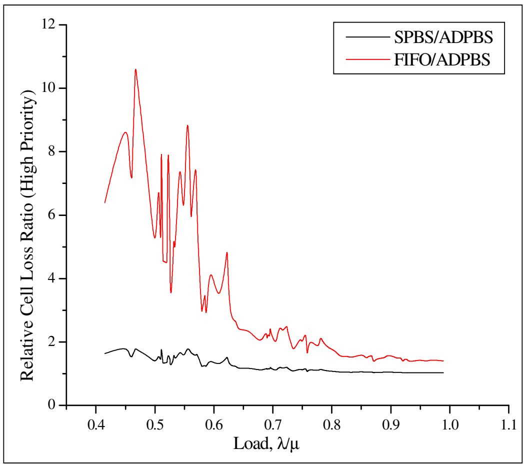


Fig. 5.48: High priority cell loss for different traffic load values (6-6-2-2).

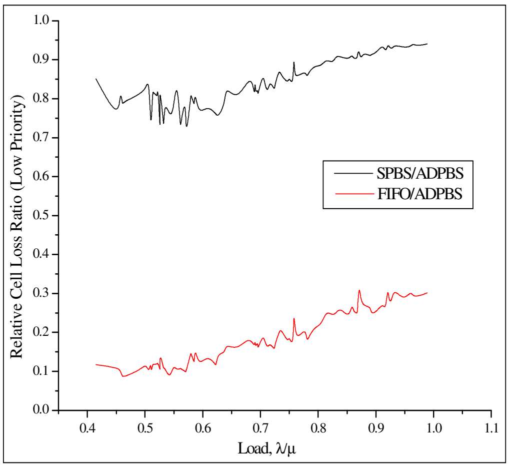


Fig. 5.49: Low priority cell loss for different traffic load values (6-6-2-2)

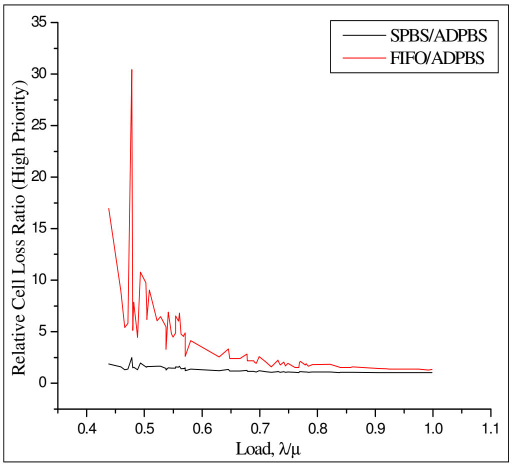


Fig. 5.50: High priority cell loss for different traffic load values (4-4-1-1).

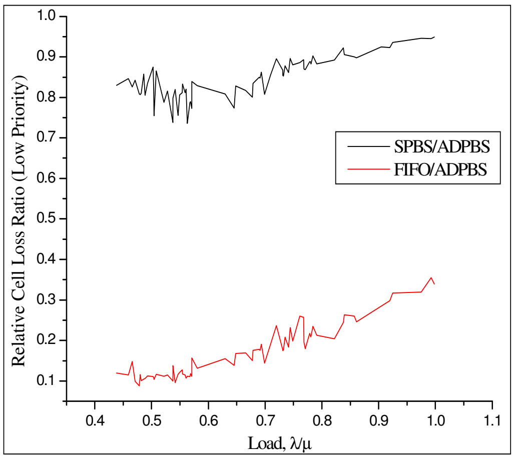


Fig. 5.51: Low priority cell loss for different traffic load values (4-4-1-1).

5.4.2 Low priority cells in majority

When low priority cells are in majority in the input data stream, again the simulation is carried out for three different cases – **(i)** when loss control limit of high priority cells is less than loss control limit of low priority cells, *i.e.*, combinations 2-6-2-2 and 2-4-1-1; **(ii)** when loss control limit of high priority cells is greater than loss control limit of low priority cells, *i.e.*, combinations 6-2-1-1 and 6-2-2-2; and **(iii)** when loss control limit of high priority cells is equal to loss control limit of low priority cells, *i.e.*, combinations 6-6-2-2 and 4-4-1-1. The performance of the proposed ADPBS scheme is compared with SPBS and FIFO schemes, based on different load values and traffic cases, in the following sub-sections.

5.4.2.1 Results of combinations with loss control limit of high priority cells less than loss control limit of low priority cells

When the loss control limit for high priority cell is 2 and loss control limit for low priority cells is 6, preference is given to retain high priority cells, although it has very small percentage in the incoming traffic. The simulation results for combination 2-6-2-2, as captured in Fig. 5.52, show that there is almost zero cell loss for high priority cells because **(a)** whole buffer space is available to high priority cells; and **(b)** high priority cells are very small in number as compared to low priority cells. The FIFO queue has losses 2.8 times more than ADPBS queue as it is insensitive to priority classes. Fig. 5.53 compares the low priority cell loss ratios of ADPBS, SPBS and FIFO queues. For low priority cells (that are in majority), the cell loss in ADPBS queue is reduced upto 1.25 times as compared to its cell loss in SPBS queue. The ADPBS scheme is not advantageous over FIFO scheme since FIFO scheme does not include a priority class based algorithm.

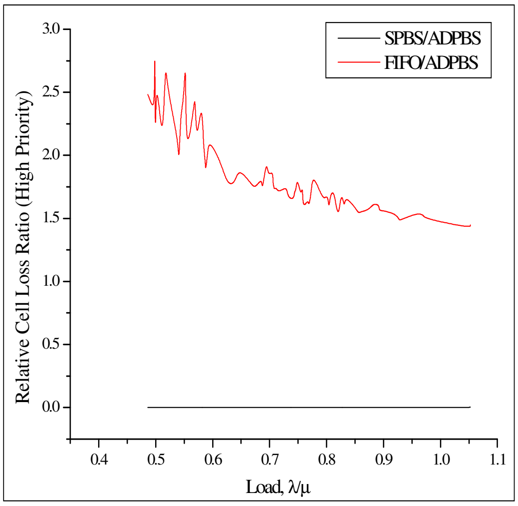


Fig. 5.52: High priority cell loss for different traffic load values (2-6-2-2).

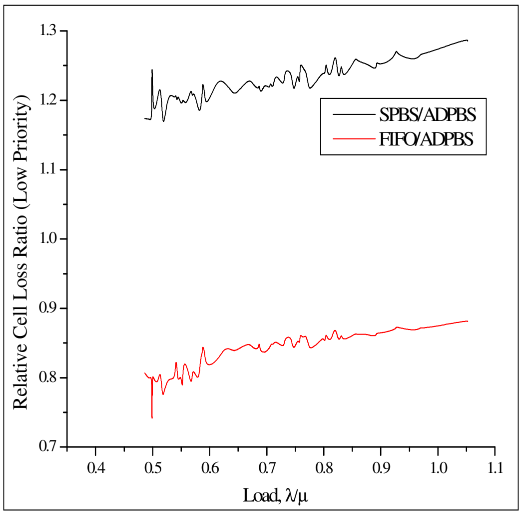
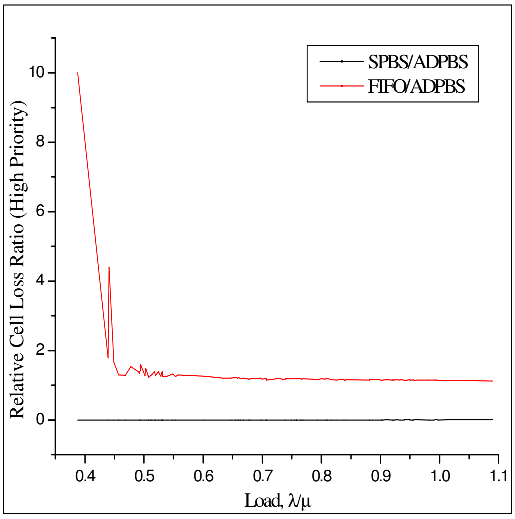


Fig. 5.53: Low priority cell loss for different traffic load values (2-6-2-2).

Similar pattern in results is observed with combination 2-4-1-1, as shown in Fig. 5.54 for high priority cells and in Fig. 5.55 for low priority cells. The cell loss ratio for FIFO queue with respect to ADPBS queue is high upto load value 0.7. This ratio decreases as load value increases. It has also been observed that for very high load values, this ratio tends to become equal to 1. The low priority cells being in majority, enjoy the adaptive threshold advantage and hence the losses in ADPBS queue are upto 40% less than the losses in SPBS queue. Over the variation of traffic load this cell loss ratio remains constant. Similar results are observed for FIFO queue as well.



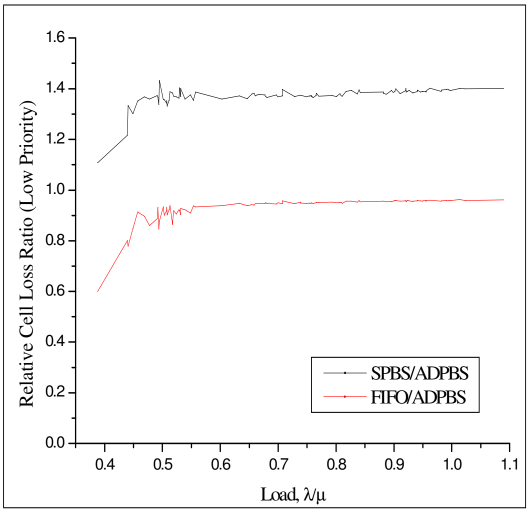


Fig. 5.54: High priority cell loss for different traffic load values (2-4-1-1).

Fig. 5.55: Low priority cell loss for different traffic load values (2-4-1-1).

5.4.2.2 Results of combinations with loss control limit of high priority cells greater than loss control limit of low priority cells

For combination 6-2-1-1, the preference is given to retain low priority cells, which have very high share in the incoming traffic. From Fig. 5.56, this combination has resulted in almost zero cell loss for high priority cells in SPBS queue as these cells are having access to full buffer space. It can be inferred from Fig. 5.57 that for low priority cells, the loss in SPBS queue is initially 85% higher in comparison with the low priority cell loss in ADPBS queue. If we further increase the load value, this loss tends to become constant at a level of 45% of losses in SPBS queue. For FIFO queue also, no change is observed in the cell loss ratio. Similar patterns have been observed for combination 6-2-2-2. The results of simulation study for comparison of high and low priority cells is shown in Fig. 5.58 and Fig. 5.59, respectively.

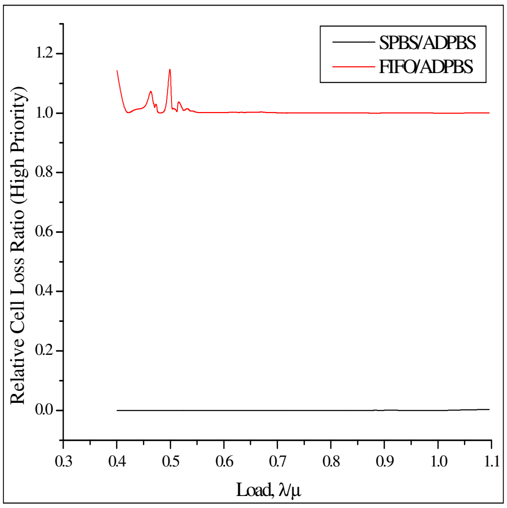


Fig. 5.56: High priority cell loss for different traffic load values (6-2-1-1).

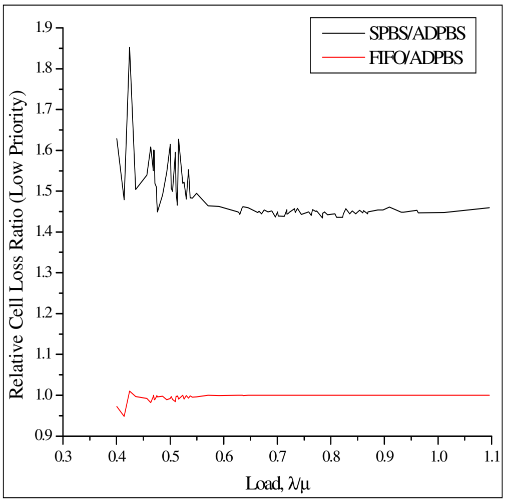


Fig. 5.57: Low priority cell loss for different traffic load values (6-2-1-1).

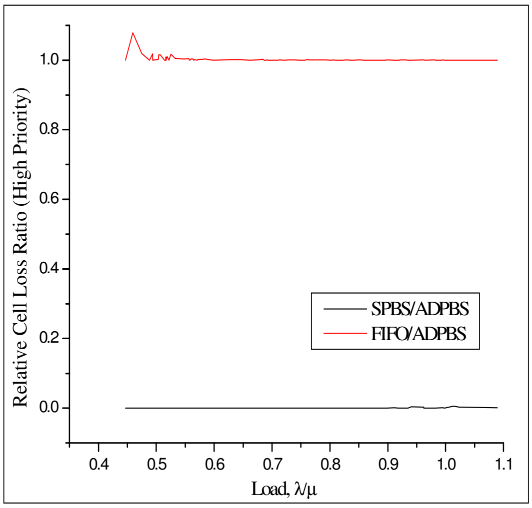


Fig. 5.58: High priority cell loss for different traffic load values (6-2-2-2).

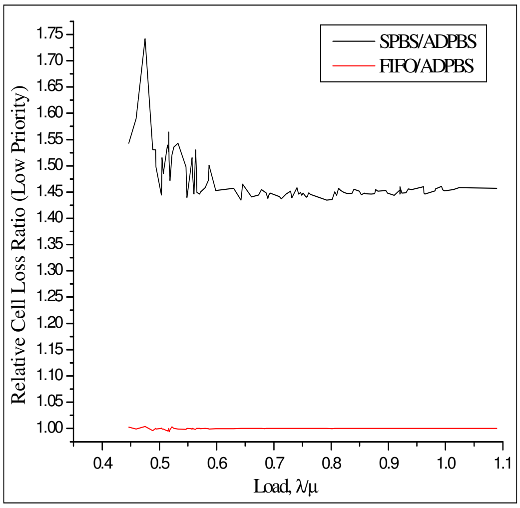


Fig. 5.59: Low priority cell loss for different traffic load values (6-2-2-2).

5.4.2.3 Results of combinations with loss control limit of high priority cells equal to loss control limit of low priority cells

For combination 6-6-2-2, the results as shown in Fig. 5.60 illustrate that for lower load values upto 0.55, the ADPBS queue performs better with respect to FIFO queue. However, high priority cell losses for SPBS scheme are nearly zero due to the reason that traffic content has very less high priority cells and complete buffer space is available for the high priority traffic. ADPBS scheme allocates major part of the buffer space for low priority cells by adjusting the threshold, thus the loss of low priority cells is less for ADPBS queue when compared with SPBS queue. As shown in Fig. 5.61, for lower load values, the relative cell loss ratio of low priority cells is 20% and goes upto 47% for higher load values.

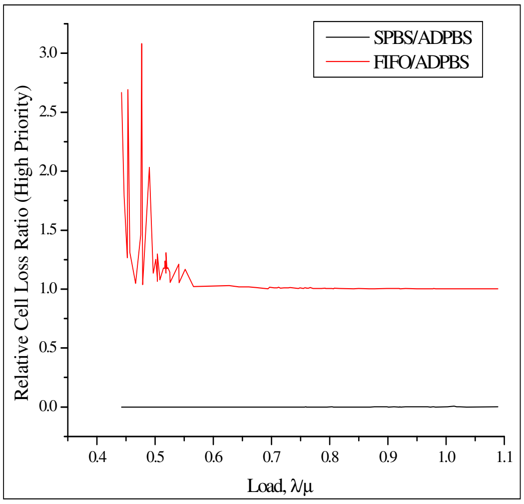


Fig. 5.60: High priority cell loss for different traffic load values (6-6-2-2).

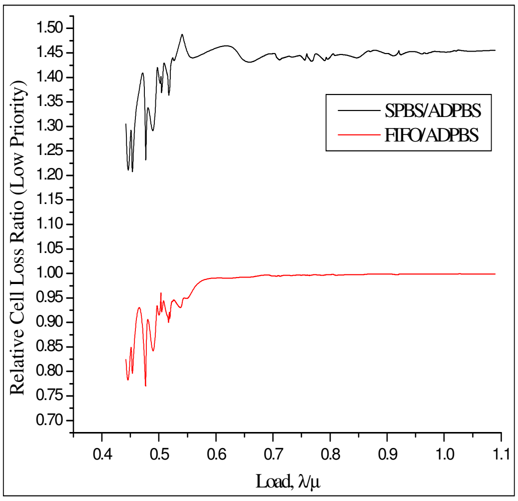


Fig. 5.61: Low priority cell loss for different traffic load values (6-6-2-2).

Similar pattern exists for combination 4-4-1-1 also, as shown in Fig. 5.62 and Fig. 5.63. ADPBS queue manages to reduce loss of low priority cells as compared with loss in SPBS queue by 50%. This indicates that ADPBS scheme controls the loss of priority class which is in majority in the incoming traffic stream.

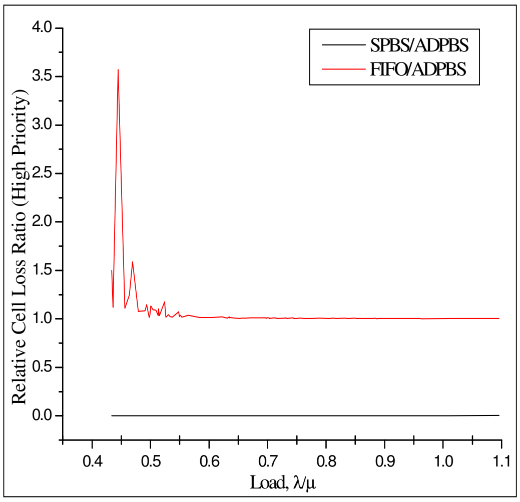


Fig. 5.62: High priority cell loss for different traffic load values (4-4-1-1).

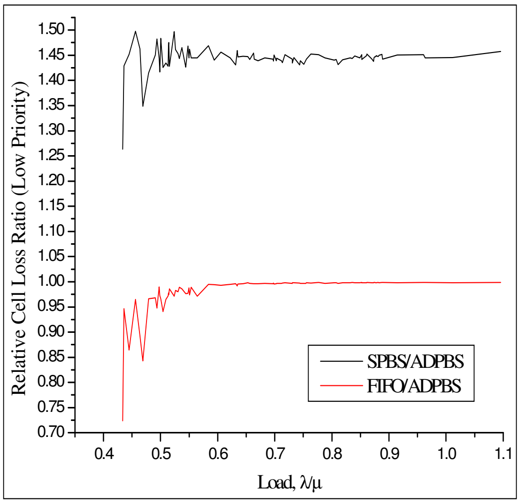


Fig. 5.63: Low priority cell loss for different traffic load values (4-4-1-1).

5.4.3 Equal proportion of high priority cells and low priority cells

When low and high priority cells are in equal ratio in the input data stream, the simulation is carried out for these cases – **(i)** when loss control limit of high priority cells is less than loss control limit of low priority cells, *i.e.,* combinations 2-6-2-2 and 2-4-1-1; **(ii)** when loss control limit of high priority cells is greater than loss control limit of low priority cells, *i.e.*, combinations 6-2-1-1 and 6-2-2-2; and **(iii)** when loss control limit of high priority cells is equal to loss control limit of low priority cells, *i.e.*, combinations 6-6-2-2 and 4-4-1-1. The performance of the proposed ADPBS scheme is compared with SPBS and FIFO schemes, based on different load values and traffic cases, in the following sub-sections.

5.4.3.1 Results of combinations with loss control limit of high priority cells less than loss control limit of low priority cells

We have analysed the behavior of three queues for traffic load variation for combinations 2-4-1-1 and 2-6-2-2 in this sub-section. With combination 2-4-1-1, ADPBS queue is able to control high priority cell loss with respect to FIFO queue only and loss ratio goes upto 22, as shown in Fig. 5.64. As high priority traffic can access the complete buffer space, its loss will be lesser in comparison to low priority cells. For higher load values, the threshold in ADPBS queue tends to retain high priority cells, hence high priority cell loss in SPBS queue in comparison with the high priority cell loss in ADPBS queue increases beyond load value of 0.65. Since low priority cells get partial access to

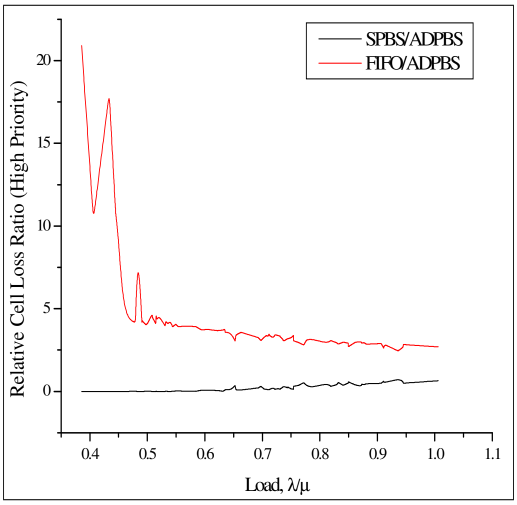


Fig. 5.64: High priority cell loss for different traffic load values (2-4-1-1).

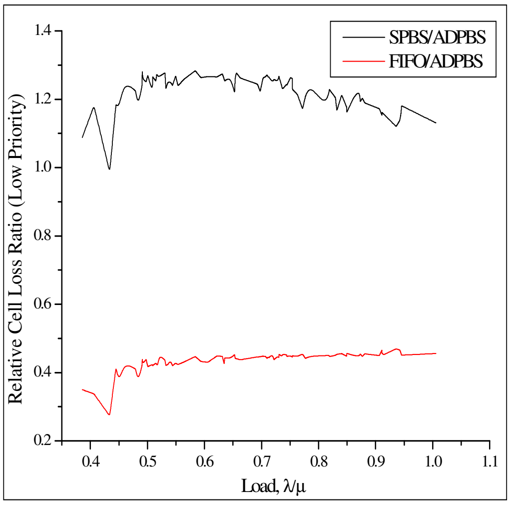


Fig. 5.65: Low priority cell loss for different traffic load values (2-4-1-1).

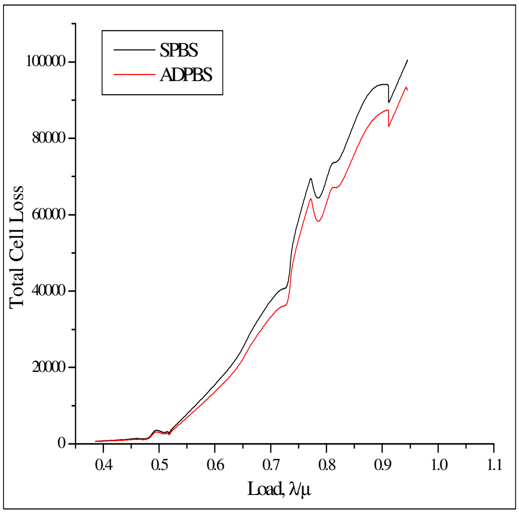


Fig. 5.66: Total cell loss for different traffic load values (2-4-1-1).

buffer space, its loss is higher than that of high priority cells. The ADPBS queue adjusts the threshold to reduce cell loss for low priority traffic by 20% for load values less than 0.75. For higher load values, it attempts to retain high priority cells also and this effect is presented in Fig. 5.65. However, Fig. 5.66 shows that the total cell loss (high and low priority combined) in ADPBS scheme is less than the total cell loss in SPBS queue.

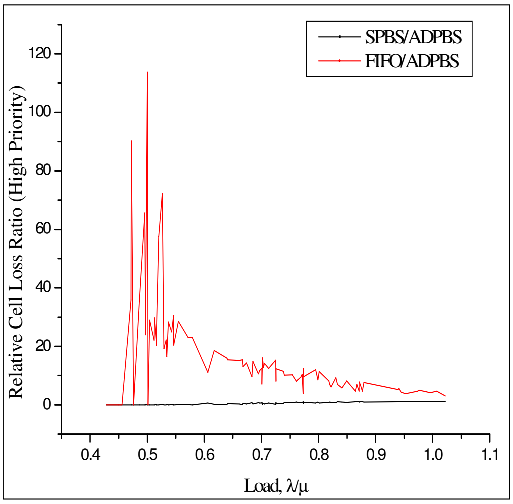


Fig. 5.67: High priority cell loss for different traffic load values (2-6-2-2).

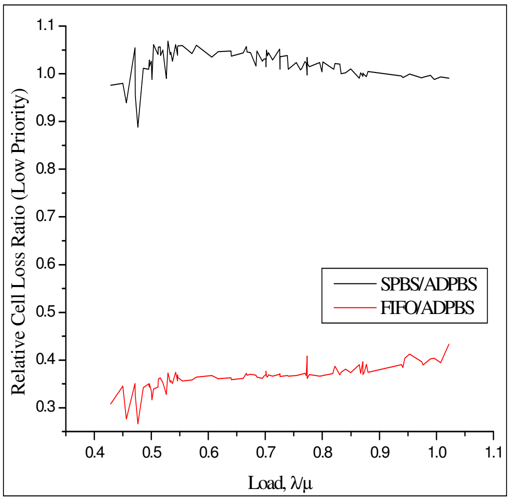


Fig. 5.68: Low priority cell loss for different traffic load values (2-6-2-2).

It can be inferred from Fig. 5.67 and Fig. 5.68 that threshold control parameter combination 2-6-2-2 also follows a similar pattern for high and low priority cells, respectively. To improve the results further with this traffic case, the combination 2-6-3-1

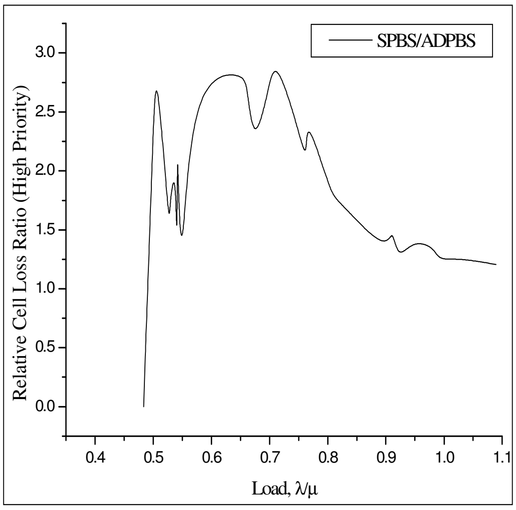


Fig. 5.69: High priority cell loss for different traffic load values (2-6-3-1).

is selected, in which modification step limit of high priority traffic, s_h, is greater than modification step limit of low priority traffic, s_l. The loss of high priority cells of ADPBS queue is 3 times less than the loss of high priority cells in SPBS queue as presented in Fig. 5.69.

5.4.3.2 Results of combinations with loss control limit of high priority cells greater than loss control limit of low priority cells

The preference is given to control the loss of low priority cells when threshold control parameters combination is 6-2-1-1. The results given in Fig. 5.70 illustrate that high priority cell loss in ADPBS queue is greater than the loss of high

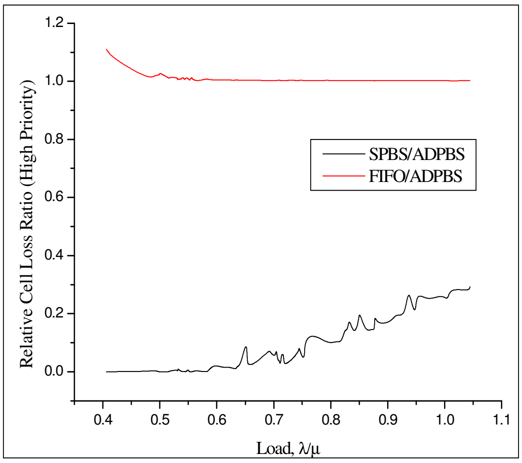


Fig. 5.70: High priority cell loss for different traffic load values (6-2-1-1).

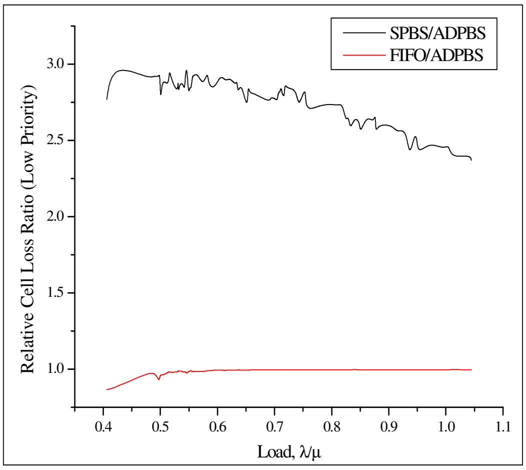


Fig. 5.71: Low priority cell loss for different traffic load values (6-2-1-1).

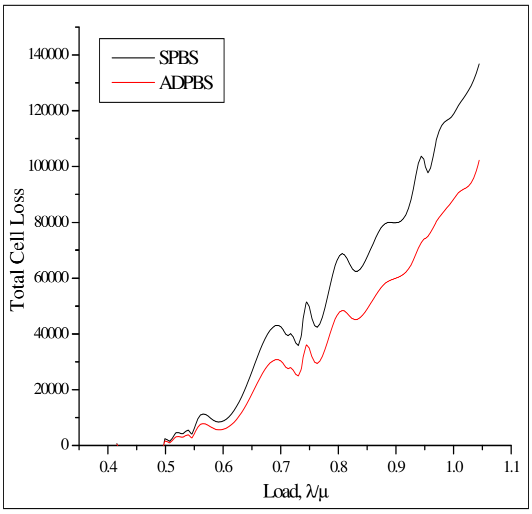


Fig. 5.72: Total cell loss for different traffic load values (6-2-1-1).

priority cells in SPBS queue. However, when total cell loss is compared, ADPBS queue has 40% less loss as compared with the total cell loss in SPBS queue (Fig. 5.72). The results given in Fig. 5.71 illustrate that SPBS queue experiences low priority cell loss almost 3 times more as compared with low priority cell loss in ADPBS queue.

In Fig. 5.73 and Fig. 5.74, cell loss behavior for ADPBS, SPBS and FIFO queues is compared for combination 6-2-2-2 for high and low priority cells, respectively. For lower load values up to 0.60, the performance of SPBS scheme is better than the performance of ADPBS scheme but it degrades as load value increases. For low priority cells, the loss in ADPBS queue is less than low priority cell loss in SPBS queue.

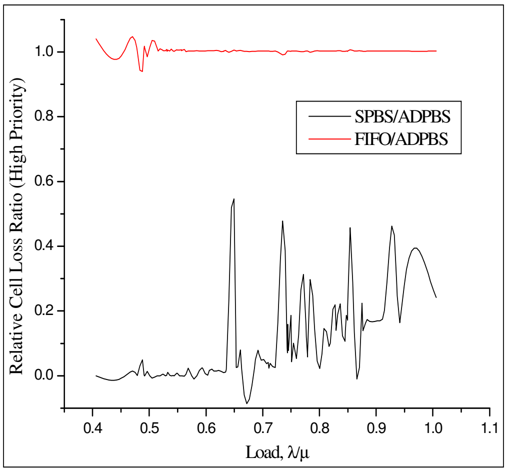


Fig. 5.73: High priority cell loss for different traffic load values (6-2-2-2).

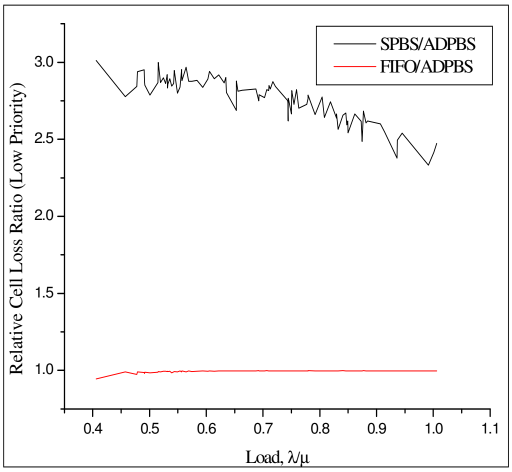


Fig. 5.74: Low priority cell loss for different traffic load values (6-2-2-2).

5.4.3.3 Results of combinations with loss control limit of high priority cells equal to loss control limit of low priority cells

For combination 6-6-2-2, when input traffic has equal proportion of high and low priority cells, the FIFO queue exhibits more cell losses than the losses in ADPBS queue, with relative cell loss ratio ranging from 1.11 to 3.89 as depicted in Fig. 5.75. This ratio tends to decrease as load increases because buffer occupancy level becomes high. For SPBS queue, the high priority cell loss ratio is very negligible because the high priority cells have complete access to buffer space. The advantage of ADPBS scheme is seen when total cell loss is compared with SPBS scheme in Fig. 5.77. The total cell loss in case of ADPBS queue varies from 70% to 80% of the total cell loss in SPBS queue for the different load values. Fig. 5.76 illustrates that the low priority cell loss in SPBS queue is approximately 2.25 times higher than the low priority cell loss in ADPBS queue for a

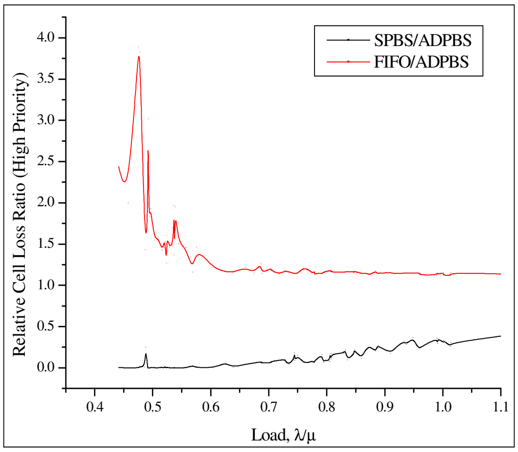


Fig. 5.75: High priority cell loss for different traffic load values (6-6-2-2).

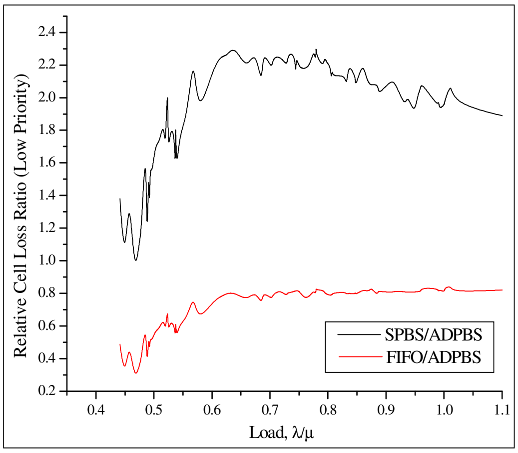


Fig. 5.76: Low priority cell loss for different traffic load values (6-6-2-2).

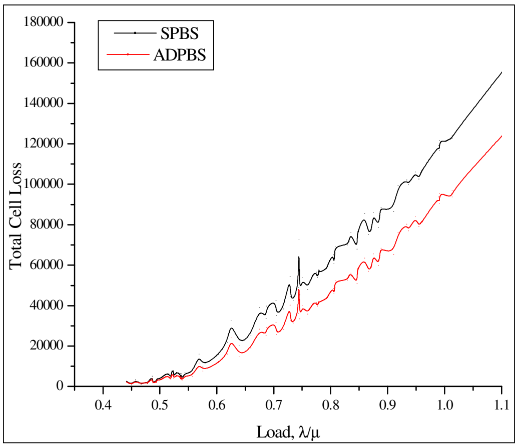


Fig. 5.77: Total cell loss for different traffic load values (6-6-2-2).

large variation of the traffic load values. The low priority cell loss in FIFO queue is significantly less with respect to ADPBS queue since complete buffer access is available for both priority classes; and no preference is given to high or low priority cells. In Fig. 5.78, the comparison of high priority cell loss ratio for combination 4-4-1-1 shows that FIFO queue, on average, has 20% more loss than the loss of high priority cells in ADPBS queue when load is varied. For lower load values, this cell loss ratio goes upto 95%. The loss of high priority cells in SPBS queue is almost negligible (Fig. 5.79), but it can be inferred from Fig. 5.80 that the total loss in SPBS queue is approximately 35% higher in comparison with the total cell loss in ADPBS queue. This shows that due to adaptive nature of the threshold control mechanism in ADPBS scheme, the loss is reduced as compared to fixed threshold in SPBS scheme.

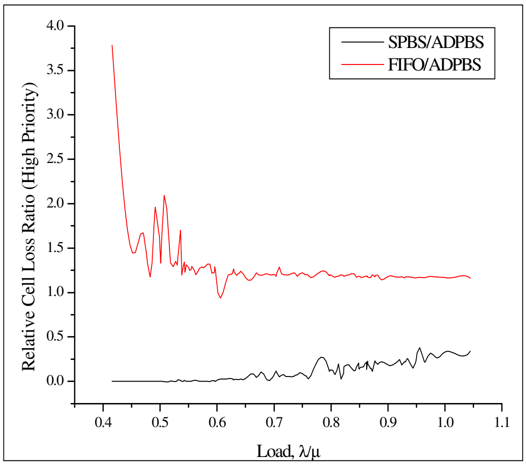


Fig. 5.78: High priority cell loss for different traffic load values (4-4-1-1).

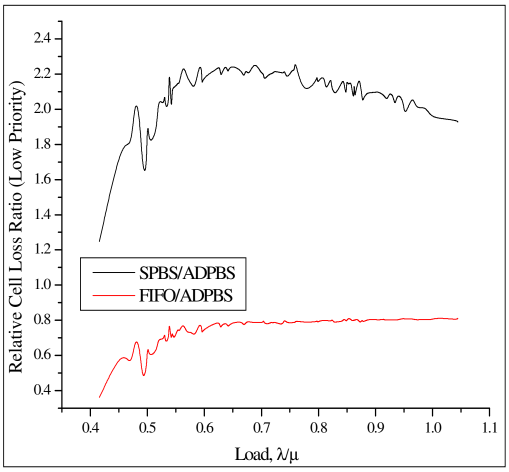


Fig. 5.79: Low priority cell loss for different traffic load values (4-4-1-1).

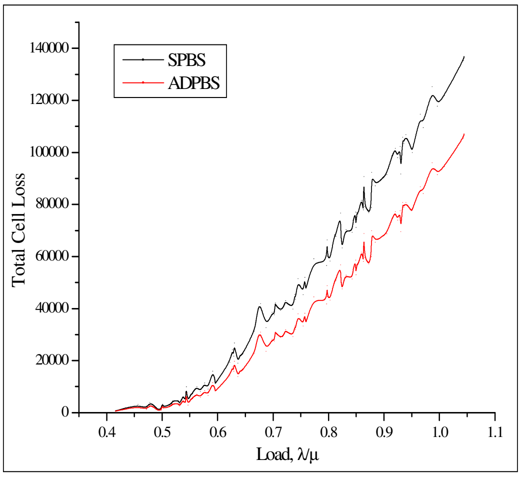


Fig. 5.80: Total cell loss for different traffic load values (4-4-1-1).

5.5 ANALYSIS OF ADPBS QUEUE WITH INPUT TRAFFIC MIX VARIATION

The ratio of arrival rate of high priority cells to that of low priority cells, *i.e.*, λ_h / λ_l (input traffic mix ratio), has been used to analyse the performance of ADPBS queue in this section. This ratio is varied from 0.1 to 6.0 to study its effect on cell loss behavior of ADPBS queue with respect to SPBS and FIFO queues with different combinations of threshold control parameters as selected in section 5.3.

5.5.1 Results of combinations with loss control limit of high priority cells less than loss control limit of low priority cells

The cell loss behavior of high priority cells in ADPBS, SPBS and FIFO queues is shown in Fig. 5.81, with combination 2-4-1-1. When input traffic mix ratio is varied from 0.1 to 1.0, the major content in the input traffic is low priority cells; hence high priority cell loss in SPBS queue and ADPBS queue is negligible. However, as shown in Fig. 5.82, the low priority cell loss in SPBS queue is 1.23 to 1.44 times higher than the low priority cell loss in ADPBS queue.

When the input traffic mix ratio is larger than 1.0, *i.e.*, when major part of incoming traffic contains high priority cells, the ADPBS queue tends to reduce the loss of high priority cells, which is also observed in Fig. 5.81. It can be inferred that for high priority cells, the cell loss in SPBS queue is approximately three times that of high priority cell loss in ADPBS queue. When the cell loss behavior of FIFO queue is compared with the ADPBS queue, it is observed that the cell loss in FIFO queue is 3 to 45 times the cell loss in ADPBS queue. The low priority cell loss is less in SPBS queue as compared to low priority cell loss in ADPBS queue as depicted in Fig. 5.82 due to trade-off effect in the available buffer space. One can observe that loss in FIFO queue is less than ADPBS irrespective of content of high/low priority cells in the input traffic mix. The major reason for this is again that FIFO queue does not follow any priority rules. Simply based upon incoming traffic, the queue performs normal operation and services the cells. Thus, high priority or low priority traffic segregation is not possible with this particular case.

The results with combination 2-6-2-2 also follow the same pattern. The cell loss in ADPBS queue is less than FIFO queue for all input traffic mix combinations. Fig. 5.83 shows that ADPBS queue is better than SPBS queue beyond input traffic mix ratio equal to 2.0 since high priority cells are in majority after the input traffic mix ratio of

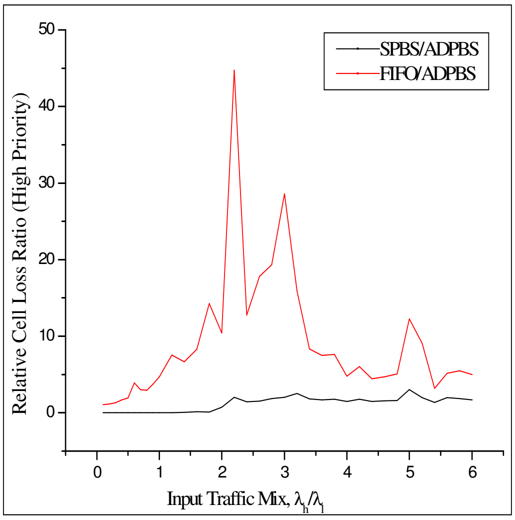


Fig. 5.81: High priority cell loss for different traffic mix ratios (2-4-1-1).

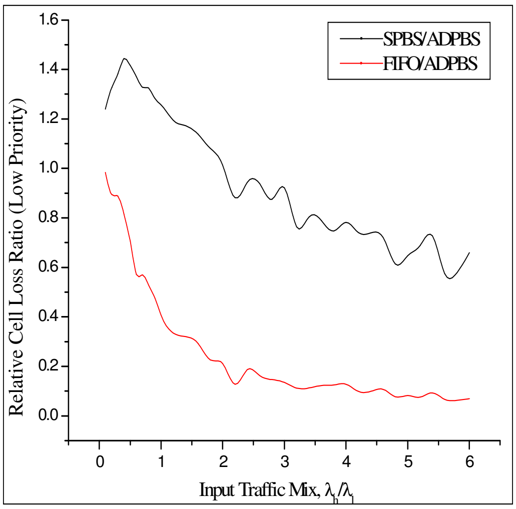


Fig. 5.82: Low priority cell loss for different traffic mix ratios (2-4-1-1).

1.0. As FIFO queue functions irrespective of priority of incoming cells, any burst in incoming traffic leads to cell loss since the queue becomes full. It is important to note that when FIFO queue experiences peak loss at input traffic mix ratio equal to 1.3, the SPBS queue observes steady state behavior because of its priority control mechanism. Fig. 5.84 shows that in terms of low priority cell loss, ADPBS queue is better than SPBS queue upto input traffic mix ratio of 1.2 because after that its main aim is to control high priority cells. As such, low priority cells suffer higher losses.

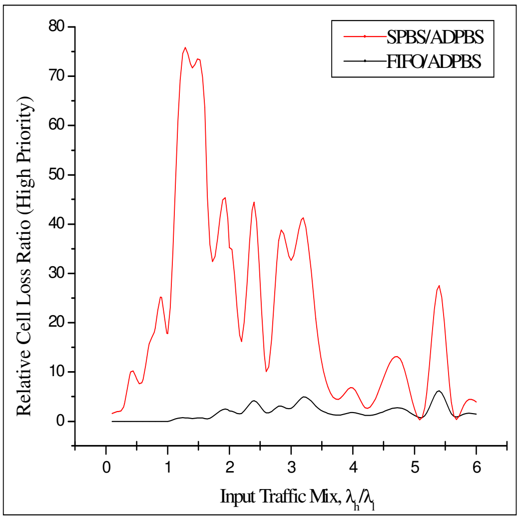


Fig. 5.83: High priority cell loss for different traffic mix ratios (2-6-2-2).

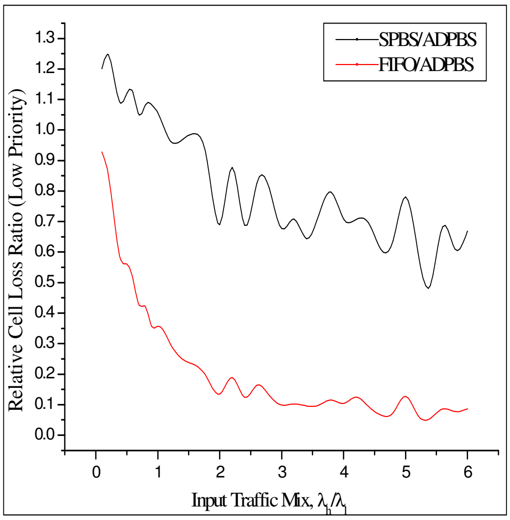


Fig. 5.84: Low priority cell loss for different traffic mix ratios (2-6-2-2).

5.5.2 Results of combinations with loss control limit of high priority cells greater than loss control limit of low priority cells

For the parameter combination 6-2-1-1, the threshold change in ADPBS queue, on the consecutive loss of low priority cells, will be triggered more frequently than the consecutive loss of high priority cells. From the results captured in Fig. 5.86, it can be inferred that in comparison with SPBS queue, the loss of low priority cells in ADPBS queue is less for any value of input traffic mix and the losses in FIFO queue are almost same. However, the high priority cell losses of ADPBS queue are higher because of higher value of its loss control limit. As the high priority traffic content tends to increase in the input traffic, the high priority cell losses in ADPBS queue also tend to decrease as shown in Fig. 5.85.

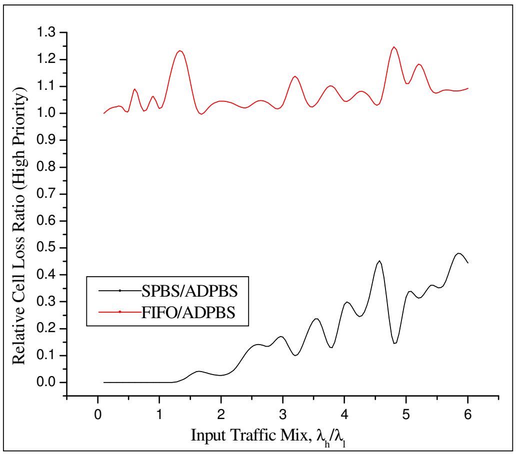


Fig. 5.85: High priority cell loss for different traffic mix ratios (6-2-1-1).

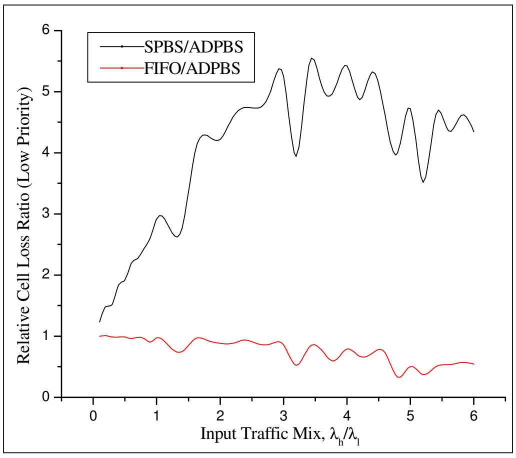


Fig. 5.86: Low priority cell loss for different traffic mix ratios (6-2-1-1).

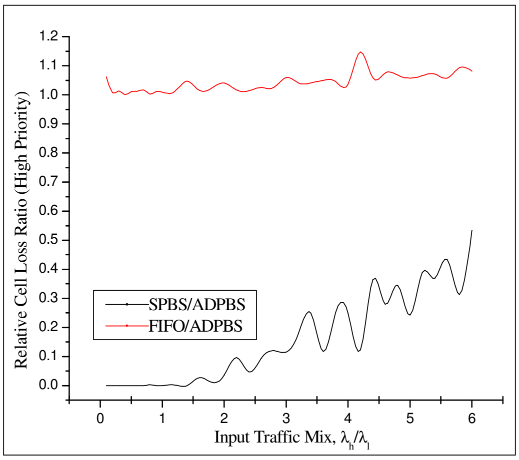


Fig. 5.87: High priority cell loss for different traffic mix ratios (6-2-2-2).

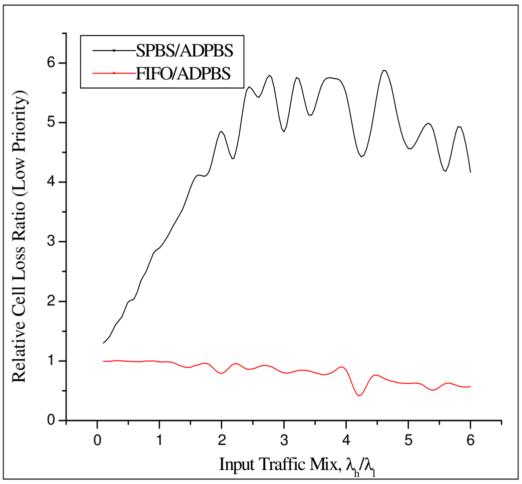


Fig. 5.88: Low priority cell loss for different traffic mix ratios (6-2-2-2).

It can be inferred from Fig. 5.87 and Fig. 5.88 that the results follow a similar pattern when s_h and s_l are set equal to 2, *i.e.*, combination 6-2-2-2.

5.5.3 Results of combinations with loss control limit of high priority cells equal to loss control limit of low priority cells

If the loss control limit for high priority and low priority cells is same, the ADPBS queue adapts to accommodate the kind of traffic that has majority in input. The results with combination 6-6-2-2 are shown in Fig. 5.90 for low priority cells. In this case, as long as input traffic has majority of low priority cells, losses in the ADPBS queue are almost half as compared with losses in SPBS queue. In this case, as the high priority content tends to increase (beyond input traffic mix ratio of 1.0), the losses of low priority cells also increase. The reason behind this is that the major portion of the limited buffer space is allocated to accommodate high priority cells so the low priority cells suffer losses. It can be inferred from Fig. 5.89 that initially SPBS queue exhibits very less losses as compared with losses in ADPBS queue. However, it starts increasing beyond the input traffic mix ratio 2.0, and reaches upto 14 times as compared with ADPBS queue for high priority cells. Corresponding to this, the loss in FIFO queue with respect to ADPBS queue is as high as 26 times. Primarily the reason for this variation is that the series of high priority traffic could not be accommodated by FIFO and SPBS queues and it results in overflow, as such the high priority cells are lost. However, for the same condition, the ADPBS queue was able to handle the traffic and manages to control cell losses. The graph for FIFO queue shows that as input traffic mix ratio increases, the loss in FIFO queue also increases till a particular point, that is, when input traffic mix ratio reaches 3.0. Beyond this point, it tends to decrease but still the losses in FIFO queue are higher than losses in ADPBS queue.

It has also been observed that the results follow similar pattern with combination 4-4-1-1. Fig. 5.91 shows simulation results for high priority cells in ADPBS, SPBS and FIFO queues. The high priority cell loss in ADPBS queue is initially higher than the high priority cell loss in SPBS queue. The loss tends to decrease as the majority traffic constitutes high priority cells beyond the input traffic mix ratio of 3.2, as depicted in Fig. 5.91. When compared with FIFO queue, the loss in ADPBS queue is less for all the input traffic mix ratios. Fig. 5.91 reveals that the low priority cell loss in ADPBS queue is less than the low priority cell loss in SPBS queue upto traffic mix ratio of 2.8, but the loss tends to increase as the high priority content increases. FIFO queue also follows the similar trend as illustrated in Fig. 5.92.

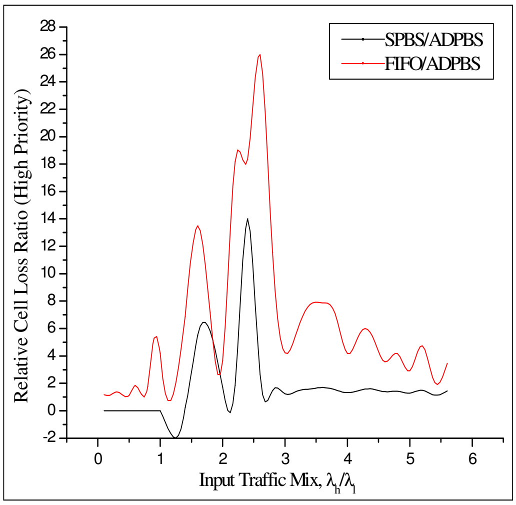


Fig. 5.89: High priority cell loss for different traffic mix ratios (6-6-2-2).

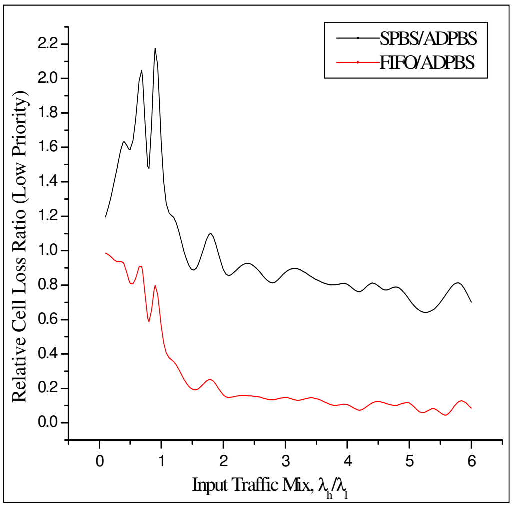


Fig. 5.90: Low priority cell loss for different traffic mix ratios (6-6-2-2).

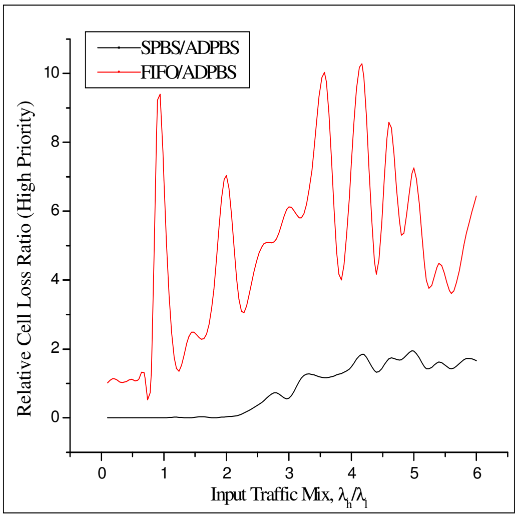


Fig. 5.91: High priority cell loss for different traffic mix ratios (4-4-1-1).

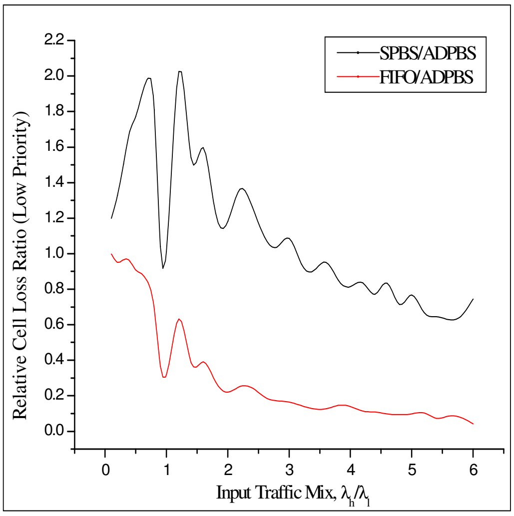


Fig. 5.92: Low priority cell loss for different traffic mix ratios (4-4-1-1).

5.6 ANALYSIS OF ADPBS QUEUE FOR BUFFER SIZE VARIATION

In this section, the sensitivity of cell losses with respect to the buffer size is studied for high priority cells. The buffer size is varied from 100 to 1400 and the cell losses for ADPBS, SPBS and FIFO queues are captured, as shown in Fig. 5.93. The optimum performance of ADPBS scheme can be seen to be achieved when the buffer size is 1000. It can also be inferred from Fig. 5.93 that the consecutive cell losses in ADPBS scheme are consistently less than the consecutive cell losses in SPBS and FIFO schemes.

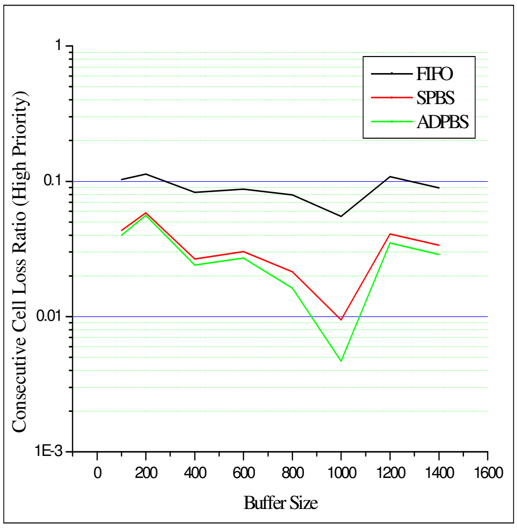


Fig. 5.93: Effect of buffer size on consecutive cell loss of high priority cells in FIFO, SPBS and ADPBS queues.

5.7 CONCLUSION

In this chapter, performance analysis of ADPBS scheme over SPBS and FIFO schemes is discussed using a video traffic model based on two second order AR processes. The model generates frame-wise cells of high and low priority classes. The threshold is dynamically controlled by a set of parameters that enable to reduce consecutive cell loss in ADPBS queue. The various combinations of control parameters are used in simulation study for different bursty traffic conditions. When compared for different input traffic mix ratios, the consecutive loss of high priority cells in SPBS scheme is 14 times the consecutive loss of high priority cells in ADPBS scheme. The consecutive loss of low priority cells in SPBS scheme is 2.2 times the consecutive loss of low priority cells in ADPBS scheme. As such, consecutive cell loss in ADPBS scheme is 83% less than the consecutive cell loss in SPBS queue for high priority traffic and 54% less for low priority traffic. The cells of priority class that has a higher proportion in the incoming traffic stream are observed to have least losses. Hence, this leads to a better quality of service with ADPBS scheme.

CHAPTER 6

CONCLUDING OBSERVATIONS

The primary objective of this study was to seek optimal solution for buffer management mechanisms for improving QoS that includes design and development of methods for priority mechanisms. The research findings transpired from this study are briefly recapitulated here point wise and certain pointers to future research in this direction have been demarcated in this chapter.

6.1 REVIEW OF RESULTS EMERGED FROM THIS STUDY

In Chapter 3, we have implemented a fixed threshold partial buffer sharing model using MATLAB 7.0. An algorithm based on recursive equations has been implemented to calculate cell loss probabilities in a fixed block size using a finite buffer. The cell loss probabilities have been calculated for low priority traffic as it can not access the buffer space beyond a threshold value. The results obtained were then compared with the independent assumption and it was observed that the independent assumption under-estimates the consecutive cell loss probabilities. The effect of varying threshold on loss probability of low priority traffic was also studied. It has been noticed that an increase in the threshold value results in significant improvement of QoS in terms of reduced cell loss for low priority traffic. At a threshold level equal to half of buffer size, the loss probability decreases by 67.75% and 96.60% for buffer size value of 30 and 50 respectively, when compared with the buffer size value of 20.

The analysis of partial buffer sharing scheme revealed that due to fixed threshold in buffer, the cell loss control is effective only for single priority class, irrespective of the input traffic model and its characteristics. To make the buffer adaptive for adjusting relative cell loss ratios among two priority classes according to input traffic conditions, the dynamically controlled threshold method, namely, ADaptive Partial Buffer Sharing (ADPBS), has been designed and implemented in MATLAB 7.0. This analytical model is a discrete-time finite queue which incorporates adaptive threshold to adapt for network traffic changes. The performance of ADPBS scheme has been analysed for different input traffic models under various traffic conditions.

Chapter 4 analyses the performance of ADPBS queue with Poisson process based input traffic model. The threshold is dynamically varied in runtime based on consecutive cell loss behavior for two priority classes, *i.e.*, high priority class and low priority class. The performance has been analysed by comparing the cell loss ratio of three queues, namely, ADPBS queue, SPBS queue and FIFO queue. Each queue gets the same input, in which the inter-arrival time of cells is distributed exponentially. The analysis was carried out for three different traffic cases, *i.e.*, when loss control limit of high priority cells is less than loss control limit of low priority cells; when loss control limit of high priority cells is greater than loss control limit of low priority cells; and when loss control limit of high priority cells is equal to loss control limit of low priority cells. Each of the above cases has been simulated under traffic conditions with different proportions of high and low priority cells as input to the queue, *i.e.*, high priority cells in majority, low priority cells in majority and both types of cells in equal proportion. For each combination as mentioned above, 30 samples were captured by running simulation experiments. The cell loss ratio for the queues has been compared and analysed under various traffic conditions, namely, threshold control parameters, traffic load variation and input traffic mix variation.

The ADPBS scheme implemented in this chapter based on the Poisson input traffic outperformed the conventional SPBS scheme and FIFO scheme. Under traffic load variation, when incoming traffic stream contains major proportion of high priority cells and equal proportion of both high and low priority cells, the consecutive loss of high priority cells in ADPBS queue has been reduced upto 93%, if the threshold control parameters' combination favors high priority cells. For low priority cells, in the same case, consecutive cell loss in ADPBS queue is reduced upto 23% if combination of threshold control parameters favors low priority cells. When low priority traffic is in majority in the incoming data stream, its consecutive cell loss is reduced upto 6% in ADPBS queue as compared with consecutive cell loss of low priority cells in SPBS queue for all combinations of threshold control parameters. The results further revealed that when ratio of arrival rate of high priority cells to arrival rate of low priority cells, *i.e.*, λ_h / λ_l, is varied in the input traffic, then also ADPBS queue performs upto 80% better for consecutive loss of high priority cells and upto 28% better for consecutive loss of low priority cells as compared with SPBS queue.

In Chapter 5, the performance of ADPBS queue is analysed with VBR based video traffic model for frame sizes of MPEG encoded video sequence based on second order nested autoregressive processes. With the nested autoregressive processes in traffic model, the empirical video sequences have been captured at both small and larger lags. The implementation of complete model along with the three queues has been done using MATLAB 7.0. The simulations have been carried out under different traffic conditions, such as, various combinations of threshold control parameters, varying traffic load, input traffic mix variation and different buffer sizes. Alike Chapter 4, the simulation experiments have been carried out by taking 30 samples under each category. The results of simulations were captured, compiled and compared for all three queues for their performance analysis. The point observed in the previous chapter that the cells of priority class that has majority proportion in the incoming traffic stream have least consecutive loss in ADPBS queue is also valid for this source traffic model. It has also been observed that for larger buffer sizes, the value of threshold control parameters can suitably be increased.

The simulation results show that when high priority cells are in majority in the incoming traffic stream, the consecutive loss of high priority cells in SPBS queue are 5.89 times higher than the consecutive loss of high priority cells in ADPBS queue for the combinations of threshold control parameters favoring high priority cells. When low priority cells are in majority or in equal proportion as that of high priority cells in the input traffic, the consecutive cell loss of low priority cells in SPBS queue is upto 3 times the consecutive cell loss of low priority cells in ADPBS queue for a number of combinations of threshold control parameters. On varying input traffic mix ratio in simulation experiments, the results reveal that the high priority cell losses in SPBS queue are upto 14 times the high priority cell losses in ADPBS queue for combinations of threshold control parameters with equal loss control limits of high and low priority cells. The consecutive losses of low priority cells with ADPBS scheme are 6% less as compared with the consecutive losses in SPBS scheme. Hence, the proposed ADPBS scheme achieves distinctive characteristics as compared to SPBS scheme.

On the whole, in view of the research findings emerged from this thesis, it is concluded that ADPBS scheme has significant potential in allocating sufficient buffer space for the kind of traffic class that is in majority in the incoming traffic and hence, improves QoS of the network.

6.2 LIMITATIONS AND FUTURE SCOPE

Although a number of models have been proposed in literature for reducing cell loss in ATM multiplexers, the ADPBS scheme described in the thesis provides a flexible and adaptive method at switch level, to effectively control cell losses. The proposed scheme can further be tested rigorously with more traffic models suitably representing the traffic converged from different sources in multi-priority packet environment. This scheme can be refined to consider maximum delay requirements of the cells in input traffic stream. The cell delay, being another important QoS parameter in networks handling real-time traffic, when controlled through dynamic traffic management schemes further improves the system performance. VoIP is a relevant example of delay-sensitive networks which transports voice in form of packets over IP based networks.

VoIP networks deploy buffers and routing elements that improve QoS, in terms of reduced packet delay and loss, by scheduling and routing the packets efficiently. The finite size buffer at receiver end in the VoIP network absorbs jitter and plays the packets at regular interval. An adaptive buffer control scheme has strong potential of controlling jitter and packet loss problems. Therefore, the future work on buffer management could be initiated to overcome the problems of network jitter and variable size payloads in VoIP networks.

LIST OF PUBLICATIONS BY THE AUTHOR

[A] Papers in refereed journals (published/communicated):

1. **Kaushal, Sakshi**., Sharma, R. K., 2006. Effect and Analysis of Sustainable cell rate using MPEG Video traffic in ATM Networks, *Journal of Systemics, Cybernetics and Informatics* 4(2), 6-9.
2. **Kaushal, Sakshi**., Sharma, R. K., 2007. On a Recursive Algorithm for Analysis of Loss Probabilities in High Speed Networks under Partial Buffer Sharing Scheme, *International Journal of Systemics, Cybernetics and Informatics* 1(2), 14-18.
3. **Kaushal, Sakshi**., Sharma, R. K., 2007. Modeling and Analysis of Adaptive Buffer Sharing Scheme for Consecutive Packet Loss Reduction in Broadband Networks, *International Journal of Computer Systems Science and Engineering* 4(1), 8-15.
4. **Kaushal, Sakshi**., Sharma, R. K., 2009. Modeling and Analysis of Adaptive Buffer Management Mechanism using Nested Autoregressive Process based MPEG encoded Traffic Model", Accepted for publication in International Journal of Modeling and Simulation.
5. **Kaushal, Sakshi**., Sharma, R. K., 2009. Performance Analysis of Adaptive Buffer Management Mechanism using Autoregressive based MPEG-4 encoded Video Traffic Model, Communicated to *International Journal of Simulation Modeling Practice and Theory.*

[B] Papers in conference proceedings (full length):

6. **Kaushal, Sakshi**., Sharma, R. K., 2005. Effect and Analysis of Sustainable cell rate using MPEG Video traffic in ATM Networks", presented and published in Proceedings of 9th World Multi-Conference on Systemics, Cybernetics and Informatics (WMSCI'2005), Orlando, USA, Vol. 2, pp. 64-67.

7. **Kaushal, Sakshi**., Sharma, R. K., 2006. Extending Broadband Services through Mobile Networks using WiMAX, in Proceedings of International Conference on Embedded Systems, Mobile Communications and Computing, Banglore.

8. **Kaushal, Sakshi**., Sharma, R. K., 2004. Comparison and Analysis of Routing Protocols for Mobile Adhoc Networks, in Proceedings of National Conference - Issues and Trends in Wireless Networks (IT-WiNS2004), Thapar Institute of Engineering and Technology, Patiala, pp. 53-57.

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