Efficient Neighbor Channel Reservation (ENCR) for Contention Resolution in OBS Networks

By

Alam Jan

2008-NUST-MS-PhD IT-03

Supervisor

Dr. Khurram Aziz

NUST-SEECS

A thesis submitted in partial fulfillment of the requirements for the degree of Masters of Science in Information Technology (MS IT)

In

School of Electrical Engineering and Computer Science,
National University of Sciences and Technology (NUST),
Islamabad, Pakistan.

(March 2012)

Approval

It is certified that the contents and form of the thesis entitled "**Efficient Neighbor Channel Reservation (ENCR) for Contention Resolution in OBS Networks**" submitted by **Alam Jan** have been found satisfactory for the requirement of the degree.

Advisor: **Dr. Khurram Aziz**

Signature: ______________
Date: ______________

Committee Member 1: **Dr. Adeel Baig**

Signature: ______________
Date: ______________

Committee Member 2: **Dr. Anjum Naveed**

Signature: ______________
Date: ______________

Committee Member 3: **Mr. Muhammad Ramzan**

Signature: ______________
Date: ______________

Abstract

Optical burst switching (OBS) is an intermediate solution between optical packet switching and optical circuit switching. In OBS, resources are reserved on the fly and released when the burst is passed. Contention occurs when two bursts want to use the same wavelength on an intermediate node and ultimately one of the burst has to be dropped. There are several solutions proposed in wavelength, time, and space deflection domain but each has its own limitations. We propose an algorithm for contention resolution in the domain of space deflection, named as Efficient Neighbor Channel Reservation (ENCR). Among resource reservation protocols for OBS we use JET (Just Enough Time), whose performance is generally considered superior to other protocols. If contention occurs we utilize a neighbor link instead of dropping the packet straight away. We send the contending burst to a neighbor node, from where it is returned back to the deflecting node before following its original path. Two flags are used in the control packet to differentiate a deflected burst from an original burst and for returning it back to the deflecting node from where it arrives. Our proposed scheme does not use any extra hardware, and addresses several limitations of previous schemes including eliminating the use of bulky Fiber Delay Lines (FDLs), preventing out of order arrivals that may happen when burst segmentation is used, preventing resource wastage that occurs in case of pre-reservation schemes and prevention of loop formation that exists in current deflection routing schemes. Extensive simulations in NCUTns simulator have been conducted to test various parameters and effectiveness of the proposed algorithm and the results verifies our research hypothesis.

Index Terms- OBS, ENCR, Contention Resolution, Routing Optimization, Path Selection.

Certificate of Originality

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at National University of Sciences & Technology (NUST) School of Electrical Engineering & Computer Science (SEECS) or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at NUST SEECS or elsewhere, is explicitly acknowledged in the thesis.

I also declare that the intellectual content of this thesis is the product of my own work, except for the assistance from others in the project's design and conception or in style, presentation and linguistics which has been acknowledged.

Author Name: **Alam Jan**

Signature: ____________________

Acknowledgment

First and foremost, I am immensely thankful to Almighty Allah for letting me pursue and fulfill my dreams. Nothing could have been possible without His blessings.

I would like to thank my Parents and my Uncles for their support throughout my educational career, specially in the last year of my Master degree. They have always supported and encouraged me to do my best in all matters of life. I dedicate this work to them. I would also like to thank my Brothers, Cousins and Sisters for their love and prayers for the successful completion of this work.

My heart felt thanks to my committee members, Dr. Adeel Baig, Dr. Anjum Naveed, Sir. Muhammad Ramzan and to everyone at CERN Lab, and all others who contributed in any way towards the successful completion of this thesis.

Finally, this thesis would not have been possible without the expert guidance of my advisor, Dr. Khurram Aziz, who has been a great source of inspiration for me during these years of research. Despite all the assistance provided by Dr. Khurram Aziz and others, I alone remain responsible for any errors or omissions which may unwittingly remain.

Alam Jan

Contents

List of Abbreviations

Abbreviations	Descriptions
OBS	Optical Burst Switching
OPS	Optical Packet Switching
OCS	Optical Circuit Switching
JIT	Just In Time
JET	Just Enough Time
WDM	Wavelength Division Multiplexing
DWDM	Dense Wavelength Division Multiplexing
QoS	Quality Of Service
MPLS	Multi Protocol Label Switching
GMPLS	Generalized Multi Protocol Label Switching
OSPF	Open Shortest Path First
OSPF-TE	Open Shortest Path First Traffic Engineering
RSVP	Reservation Protocol
RSVP-TE	Reservation Protocol Traffic Engineering
LSA	Label Switching Advertisement
LSR	Label Switching Router
LDP	Label Distribution Protocol
LSP	Label Switched Path
LMP	Link Management Protocol
FEC	Forward Equivalence Class
FDL	Fiber Delay Line
NCTUns	National Chiao Tung University Network Simulator

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Background and Motivation

The number of internet users and internet applications is increasing day by day. This has led to the requirement of high bandwidth at the core networks. Optical networks provide us high bandwidth, low attenuation and is immune to electromagnetic interference, which makes it a viable solution for the core networks. Three optical technologies have been studied: optical circuit switching, optical packet switching and optical burst switching.

In Optical circuit switching and end-to-end light path (resource reservation) is established. The transmission medium in optical networks is light which is either routed by an opaque or transparent switch. Opaque switch is the one that performs O/E/O conversion before switching the packet while the transparent switch performs switching in optical domain. There are multiple wavelengths available on a single link and circuits are established in optical domain. An end-to-end optical connection is called a light path in which there is no O/E/O conversion. The primary concern in optical circuit switching is delay and blocking, which occurs when there are not sufficient resources (Wavelengths) available to establish a circuit between source and destination.

The idea of delay can be clear from figure [1.1], here we can see that when there are not enough resources on a node to further establish a connection the control packet is sent back from that point and the data have to wait for connection to be established. The key challenges to optical circuit switching is adapting itself to traffic fluctuations and connection requests. A light path is established from source to destination and the data is generated after the connection establishment which is wastage of resources. One client is holding resources for a long amount of time. Here the Qos parameter is hard

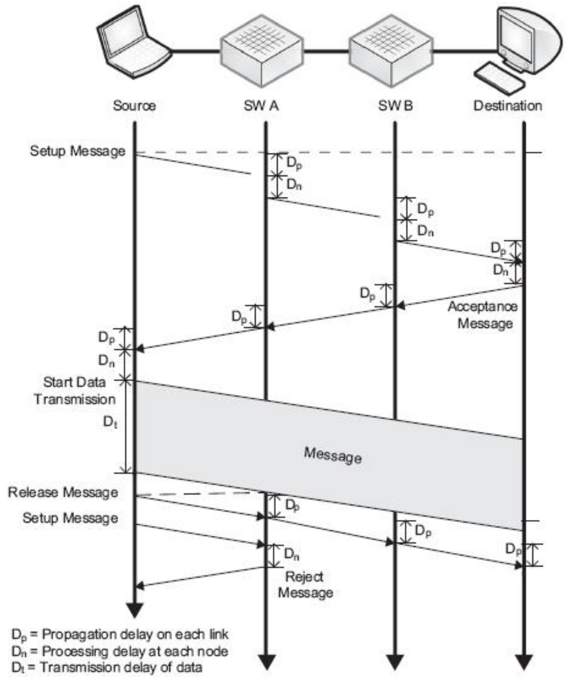

Figure 1.1: Delay in Circuit Switching[2]

to achieve.

Optical Packet switching does not reserve any resources and switching is done as the packet arrives but it is not a mature technology, because processing the header in optical domain is limited. The true benefit of optical packet switching could not be achieved until optical packet processing is implemented in the network. Nowadays the header is processed electronically and the packet is passed in the optical domain. As each packet goes through O/E/O conversion therefore in optical switching we come across much delays which degrades its performance. Latest studies shows that optical processing is possible but it performs only packet forwarding and cannot take any routing decision based on the routing tables maintain by the switches.

Optical burst switching does not require optical routing on the core nodes, it only performs forwarding. The control packet is sent ahead of the burst so that it reserve resources prior to the release of the burst. At this time the burst is buffered and is soon released after the expiry of the offset time. The control packet is processed on the intermediate nodes and undergoes through a certain delay which is also added to the offset time. Optical burst is a collection many packets. In optical burst switching we have to reserve resources from node to node on the fly and they are released when the burst passes the node. We can say that in optical burst switching we do circuit switching but on small scale therefore it is also called an intermediate solution between circuit switching and packet switching. Optical burst switching is a promising technology for the next generation optical networks. One of the main characteristics of OBS [1]is that the control plane is separated from the data plane. Control packet is transmitted on a separate channel and goes through O/E/O conversion process for configuring the switch for the incoming bursts while the burst is passed through optically. The client data pass through the core nodes in a transparent manner which also increases its integrity.

Data is collected at the ingress node and is assembled to form a burst. In burst assembly process various packets are entering the ingress node and then a data burst is formed along with the control packet. We can extract burst size, offset time and wavelength information from the control packet. Control packet needs this information for switching and synchronization at the intermediate nodes. The egress node performs disassembly and packets are forwarded to their local destinations. The burst travels in the optical domain while the control packet is processed electronically for configuring the switch.

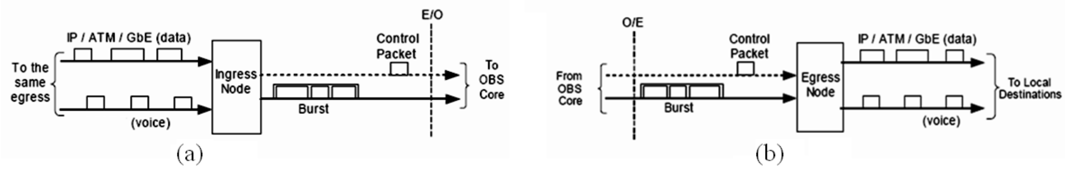

Figure 1.2: Burst Assembly (a) Burst Disassembly (b)[3]

Burst assembly and disassembly is shown in the figure above, here we can see that packets from different networks are assembled at the egress nodes which are destined for various clients. They are assembled to form an optical burst. The burst travels through the network in optical domain and is disassembled at the egress node. There are three algorithms for burst aggregation at the ingress node namely threshold based, timer based and Hybrid. In threshold based algorithm the ingress node collects packets until a threshold value is reached. The drawback of threshold base algorithm is that when traffic is low at the ingress node it will have to wait for other packets to be accumulated, thus leading to more delays for the packets which are arrived first at the ingress node. In the timer based mechanism the ingress node collect packets to form a burst until the timer expires. In situations where network traffic is high this algorithm will make large bursts which will take more time on the switch, thus its chances of collision are high which will affect many users. On the other hand if traffic is low it will result in the formation of smaller bursts that will generate excess of traffic on the control channel leading to congestion and high delays. The last one is the hybrid which is the combination of timer based and threshold based burst assembly algorithms. In this algorithm a burst is formed either when the timer expires or the threshold value is reached. The offset time between data

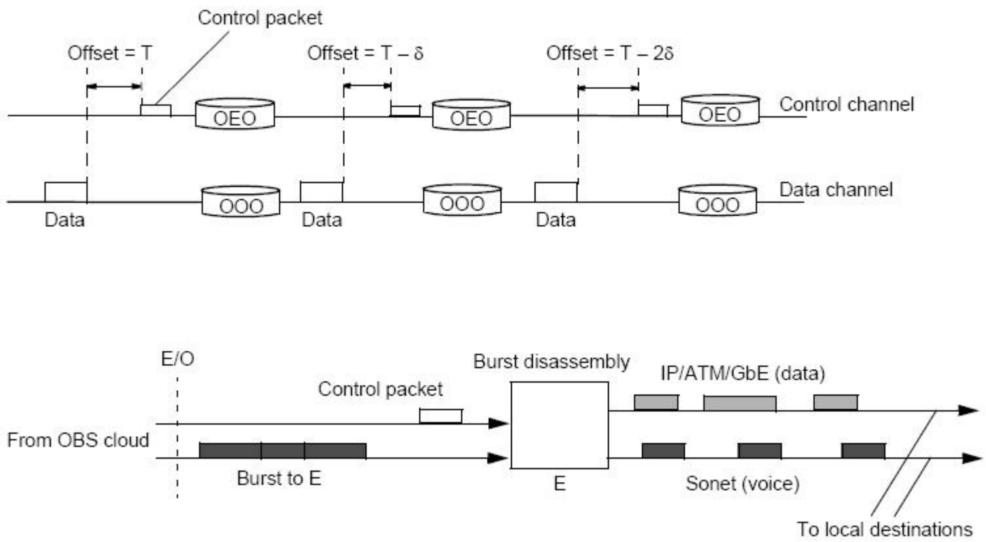

Figure 1.3: Control Packet and the Offset Time [4]

burst and control packet is reduced at each core node due to processing of control packet in the electronic domain. When a burst is formed, a control packet is created for it by the burst schedular. The offset time is adjusted for each burst depending on the size of the burst. Scheduling bursts and control packets on each intermediate links is performed by the burst schedular [5]. As we have mentioned earlier that offset time between control packet and data burst is reduced at each hop, so the ingress node have to carefully decide the offset time keeping in view the number of hops and delay on the intermediate links.

Contention is one of the main problems in OBS netowrks. Contention takes place when two or more bursts want to travel on the same wavelength at the same time on an intermediate node. If there is no contention resolution mechanism available or control packet fail to reserve resources, then one of the burst has to be dropped and large amount of data is lost as the burst is a combination of many packets from various users. Keeping in view the above effects of burst loss we propose an efficient contention resolution algorithm to minimize burst loss. OBS is the best technique to utilize the high bandwidth of optical fiber but resolving contention is one of the main issue to achieve best performance of OBS networks.

1.2 Research Statement

Since all-optical header processing is not viable due to immaturity of Optical Packet Switching (OPS) approach which require every packet to go through O/E/O conversion process in the switch. Optical burst switching has drawn substantial interest as an architecture for utilizing the high capacity offered by the optical networks. One way resource reservation reservation is used for setting up the connection for each burst, so a burst does not have to wait for an acknowledgment of the path setup between source and destination, but the transmission is initiated after the offset time. The chances of dropping in this scenario are high. As an optical burst is a collection of many packets, so when a burst is dropped it effects many users. Therefore, it is a leading area in research to benefit from high capacity of optical networks. We are interested to reduce the burst dropping rate in OBS networks in such a way that no extra cost of equipment or optical fiber is required. We are specifically focusing on JET protocol for reservation because its performance is better than the other protocols[9]. We propose an optimization model for contention resolution through a novel deflection technique and then we implement an algorithm to reduce the percentage burst loss in optical burst switched networks.

1.3 Thesis Contributions

The main contributions drawn from this research work are

- An optimization model for contention resolution in optical burst switched networks that use deflection routing.
- A novel algorithm based on reflection routing, to reduce the burst loss.
- Development of a module for simulation of optical burst switched networks in NCTUns.

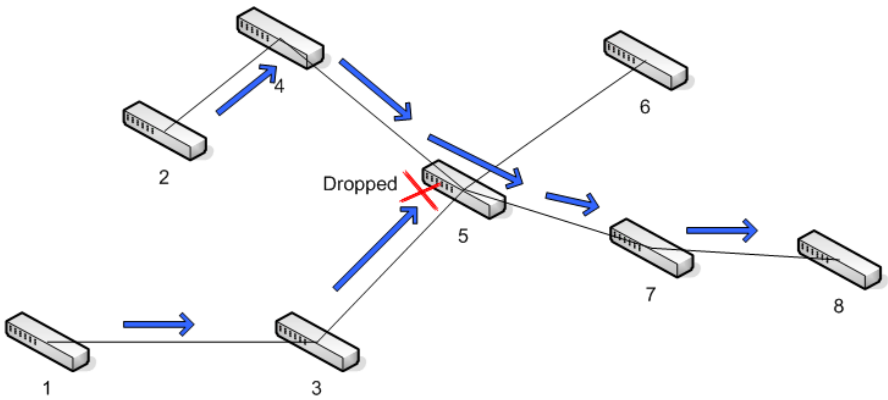

Figure 1.4: Contention Between Bursts at Core Nodes

- Implementation of our proposed algorithm in NCTUns and comparison of our model with existing schemes.

1.4 Thesis Organization

Chapter 2 discusses an overview of the research work including the background and motivations. We present the problem statement and how it is being addressed in the current research work.

Chapter 3 provides discussion on existing contention resolution techniques like deflection, wavelength conversion and Fiber Delay Lines (FDL's). We investigate the limitation of each of the above schemes. We present an overview on the performance evaluation of signalling protocols like JET, JIT and Horizon. This chapter also discusses the drawbacks which motivate us for this work.

Chapter 4 is dedicated to the optimization model for the proposed algorithm for contention resolution.

Chapter 5 presents the results of the optimization model and the simulation results of the algorithm. Extensive simulations have been performed to test the functionality of our proposed algorithm under a variety of parameters. We discuss how factors like delay and load on the contention link affect the performance of our algorithm.

Chapter 6 discuses future work and summarize our results.

1.5 Summary

This chapter presented an overview of the thesis organization and our contributions. The problem statement was also discussed, which motivated our work.

Chapter 2

Signalling and Routing Protocols for OBS Networks

In optical burst switching networks, a setup message is transmitted before the burst. The aim of this message is to inform the intermediate bursts about the transmission of the burst. Signaling protocols are used for service provisioning including switching path establishment, path teardown and modifications. A control packet is send ahead of data burst to reserve resources for the burst and then the burst follow the path which has already been established by the signaling protocol. The main protocols for resource reservation are JIT (Just In Time), JET (Just Enough Time) and Horizon. On the intermediate node if resources are not reserved by these protocols then the burst has to be dropped on that intermediate node, because the burst can not be buffered. Once the resource reservation step is performed then the actual bust follows the reserved path. Routing protocols are used for the burst to travel along the path. The optical burst does not go through O/E/O conversion. The routing protocol for OBS is GMPLS which comprised of Resource Reservation Protocol with Traffic Engineering(RSVP-TE), Open Shortest Path First with Traffic Engineering(OSPF-TE) and Link Management Protocol with Traffic Engineering(LMP-TE). In this chapter we will discuss the signalling and routing protocols in detail.

2.1 Signaling Protocols

For transmitting a burst in the optical domain a signalling scheme must be implemented to configure optical switches for the burst at the intermediate nodes. There are three main types of signaling protocols for optical burst switching: JET, JIT, and Horizon.

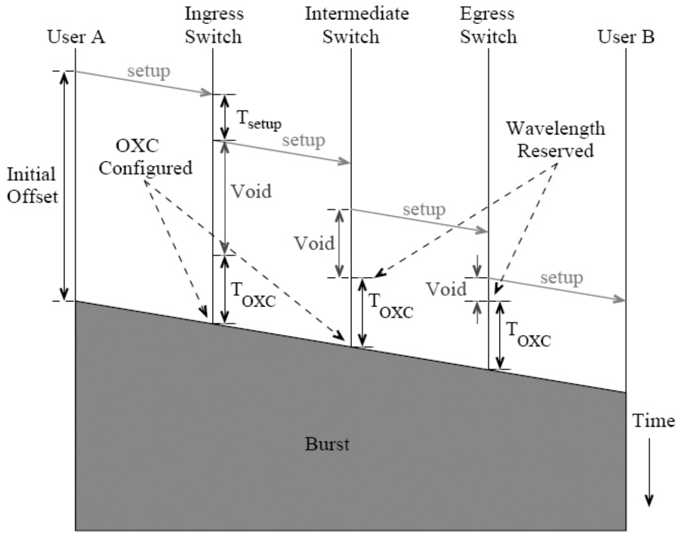

Figure 2.1: JET and Horizon Protocols

2.1.1 JET (Just Enough Time)

In JET the control packet carries an offset time and travels just before the burst and perform delayed reservation. The reservation starts from the burst arrival time instead of the arrival time of the control packet [1]. The control packet contain information about the length of the burst, so JET exactly knows when to release the resources. It does not need an explicit message for releasing the resources. Time label is an instant at which the data burst arrives at the the intermediate node. We can determine the exact time of the burst departure from the corresponding time label and burst length. Thus, from hop count and delay we can measure the time in which it will reach the other node. We can see that time label is more refined in JET because it is based on the prediction of control-processing time at each intermediate node. Void filling is a phenomena in which a burst can utilize the free resources available between burst reservation and the actual burst arrival. JET uses this phenomena to better utilize the network resources.

2.1.2 JIT(Just In Time)

In JIT protocol when a control packet arrives at the node, as soon as it configures the switch for the burst at that time. As shown in figure 2.2 the control packet arrives at the intermediate node, it reserve resources from that

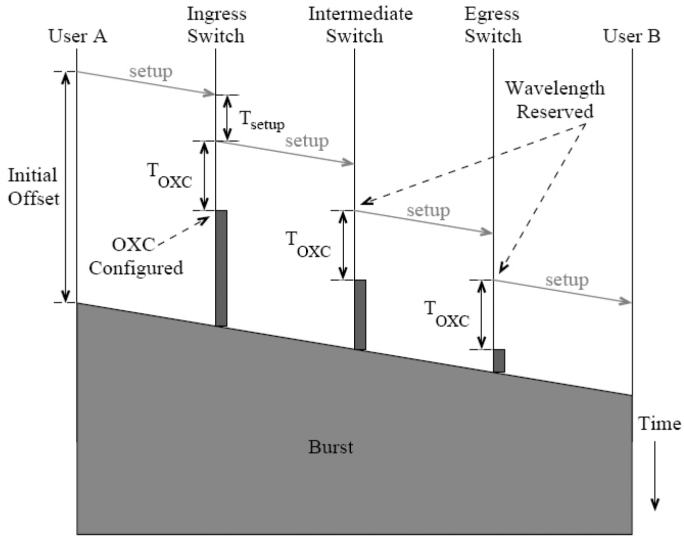

Figure 2.2: JIT Protocol

time though the actual burst is to be released after the offset time. If another control packet want to reserved resources during this time, its request will be discarded despite the link lies free at that time. This results in wastage of resources and is the main drawback of the JIT protocol. It does not allow void filling and resources are reserved for a longer period of time.

2.1.3 Horizon

Horizon is also a late reservation protocol like JET but it does not allow void filling. If resources are reserved for a burst at time t4 and now it is time t1 one can not reserve resources in the middle of that time.

2.2 Routing Protocols for OBS

We have discussed earlier that there are two set of protocols used in optical burst switching networks, one is signalling protocols and other is routing protocols. Signalling protocols establish path for the optical burst through the transmission of the control packet ahead of the burst, then routing protocols routes the burst from ingress router to the egress router without O/E/O conversion. The routing protocol used in optical burst switched networks is GMPLS (Generalized Multiprotocol Label Switching) which is an extension of MPLS to support switching in time, wavelength and space. GMPLS clearly separate the control plane and the forwarding plane, it has a simple mechanism for forwarding based on the label and Forward Equivalence Class (FEC). For each specific service an equivalence class is created. A label is assigned to each FEC and the switching is then performed based on the label. At the ingress node a label is assigned and then the packets are forwarded through Label Switch Paths (LSP's). At the egress node the label is removed and the packets are sent to their respective destinations. The label in GMPLS represents wavelengths or timeslots. The design of the label is such that one can embed specific kind of information in it like port number, wavelength when you are using the optical switching networks. Generally GMPLS label contain the information about the encoding type whether it is lambda, packet or sonnet. It also have the information about the packet switching like timeslot, wavelength and the payload type (Ethernet,ATM).

GMPLS protocol suite contains three kind of protocols namely routing, signalling and link management protocols which are discussed in the section below.

2.2.1 OSPF-TE

Routing protocols: OSPF-TE (Open Shortest path First-Traffic Engineering) is an extension of OSPF protocol to allow traffic engineering and non-IP networks. Routers should generate traffic engineering LSA's (Link State Announcment) when ever state of the network changes or when it is required to the OSPF. It is not necessary that each time the state change, information about the network is flooded to the network. There are mechanisms in which flooding is performed only after the timer expires or some significant changes in the paths, by this way we can minimize flooding. When a router receives a traffic engineering LSA it should update its database.

2.2.2 RSVP-TE

Signaling: RSVP-TE (Resource Reservation Protocol-Traffic Engineering) and LDP (Label Distribution Protocol) are used for the generation of traffic engineered Label Switched Paths (LSP's). In order to setup a light path we need a signaling protocol. In GMPLS we have RSVP and CR-LDP that do the job for us. These protocols exchange information between the nodes by distributing labels and reserve the light path as they move from one node to another. Quality of service and wavelength selection information can be passed through RSVP, which is highly scalable and robust. There are two kind of RSVP messages one is resv which reserve resources along the path and the other is the path message which stores the path state at each node.

2.2.3 LMP

Link Management: LMP (Link Management Protocol) manages the control and data links. GMPLS uses Link Management Protocol (LMP) for link provisioning and fault isolation. It automatically generate and maintain associations between links and labels. It manage the control channel, performs verification of link bundling and link connectivity verification. When two LSR's are connected by multiple links, it is possible through link bundling to advertise it as a single link to OSPF.

2.3 Summary

In this chapter we discussed the Signaling and routing protocols. Signaling protocols reserve resources for the optical burst and the routing protocol routes the actual burst throughout the path without O/E/O conversion. Among the signaling protocols JET performs better than the rest. We carried out a detailed literature review of the protocols used in OBS.

Chapter 3

Literature Review

OBS differ from the optical packet switching networks in such a way that one control packet can perform switching for many packets (Burst), thus reducing the control packet processing. Control packet is going ahead of the burst reserving a wavelength for the burst which will be released after the offset time. When the burst is passed through the link the wavelength is released which depends upon the reservation scheme: JET, JIT, Horizon. In case the control packet fails to reserve resources for the burst it will be dropped on the intermediate node. Network resources are wasted if the burst is dropped in the middle because it has already traversed some nodes. In non-optical networks buffering is used to temporarily store the packet which cannot be switched when resources are not available. In optical networks we do not have optical buffer, so we have to apply other techniques in order to reduce the possibility of burst dropping.

In an optical network, contention is usually resolved in the following dimension.

1. Wavelength domain (on another)
2. Space Domain (on different output port)
3. Time domain (Optical buffer, FDL)

3.1 Wavelength Domain

The system which uses wavelength conversion for contention resolution relaxes the wavelength continuity constraint[6]. When contention occurs one burst is passed through its opted wavelength and the other is converted to another available wavelength and is guided on the same output port. Wavelength converters are used for this purpose [7]. Wavelength conversion can be either dense or sparse and partial or full. In dense wavelength conversion all switches perform wavelength conversion. In sparse wavelength conversion few switches are equipped with the wavelength conversion capability and others works as normal. In partial wavelength conversion a switch perform limited conversion i-e it have the ability to convert some wavelengths but not the other, while in full wavelength conversion every incoming wavelength can be converted to other desired wavelength. Wavelength converters are very costly devices, so to reduce the cost of the network partial wavelength conversion is preferred. Placement of wavelength converters in the network is also an issue. A heuristic approach is proposed in [8] for the placement of wavelength converters. Wavelength conversion reduces the burst dropping but it is very costly solution and the need for fast tunable wavelength converters restricts their use in OBS networks. The figure below describe the wavelength conversion process.

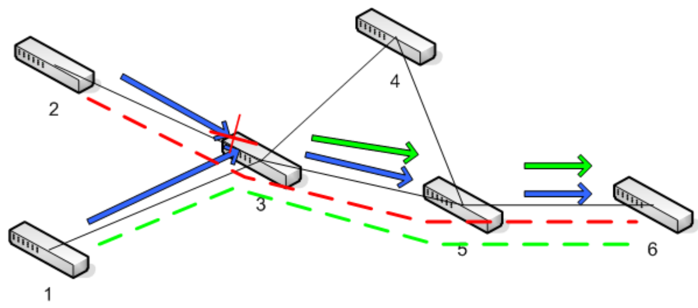

Figure 3.1: Wavelength Conversion Process

3.2 Space Domain

In space domain instead of sending contended burst to the correct output port, it is routed to an alternate output port [9][10][11][12]. The burst then itself finds its way to the destination and if not then it will be discarded after some hops. If no such mechanism is implemented the burst will form loops inside the network and consume resources. On the other hand if we have a network with high connectivity, it works well because the node have several neighbors and the burst most probably finds its way to the destination. If the connectivity is low, then the deflected burst may not reach its destination soon which incurs out of order arrivals. This approach can destabilize the system. Network resources are wasted if a burst is not finding its way and is circulating in the network. Using deflection routing, the actual path of the burst is prolonged and does not remain the shortest path. If we have real time traffic, these extra delays produces a jitter effect. Another main disadvantage of this approach is that if one burst follows a longer path and the second burst follows its normal path we have out of order arrivals. Offset time is difficult to manage in this scheme. From below figure we can see that the deflected burst is routed to a longer path, thus causing our of order arrivals.

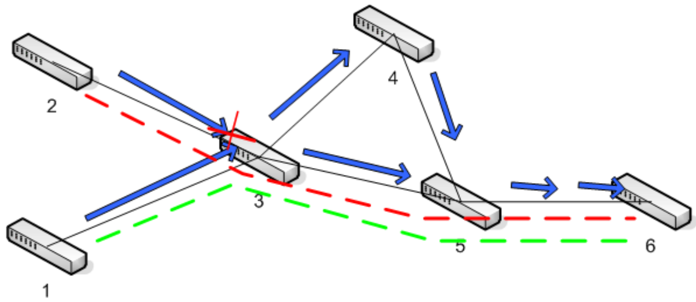

Figure 3.2: Deflection Routing Mechanism

3.3 Time Domain

Another approach for contention resolution is using Fiber Delay Lines (FDL) [13][14][15]. A fiber delay line is a piece of fiber optic cable which is attached with the switch. The idea is when contention occurs the contending burst is passed through FDL and upon returning back is then passed through its original path. FDL is used as an optical buffer in time domain and can help in reducing burst loss in optical networks [16]. One of the problem in FDL is that a burst can not be extracted in the middle, though contention might be resolved by that time. When a burst is passed through an FDL it experience attenuation and we need an amplifier to improve the strength of the signal. Blocking rate is reduced if we increase the length of fiber delay lines[17]. FDL is bulky and needs lot of physical space and due to fixed length of FDL each data burst having different size gets delayed for fixed duration, which creates unnecessary delay, particularly for shorter data bursts. One idea would be using FDL's of different lengths which is more costly and needs more space. Latest development for providing optical buffer is that of encoding data into a photon, slowing the data down for storage and then retrieving the data intact [18]. There has been a great research in the field of optical buffing these days. Below figure shows the phenomena of fiber delay lines used for contention resolution. If no contention resolution method exists then one

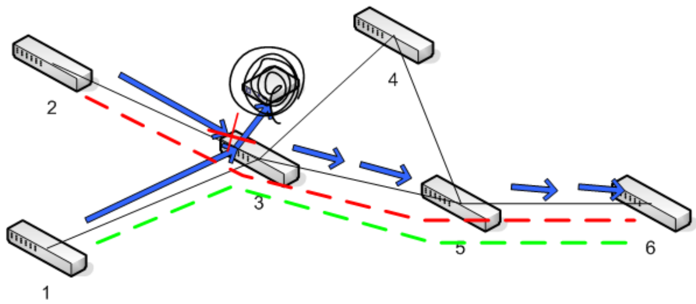

Figure 3.3: Fiber Delay Lines

of the burst has to be dropped. If we are using priority based routing it is possible that one burst is preempted and the other with higher priority is passed through the switch. Burst segmentation is another technique for contention resolution [19, 20]. The approach is to segment an overlaid part between conflicting bursts instead of dropping the complete burst.

One approach for contention resolution in optical burst switching network is that one should collect burst loss statistics on different wavelengths and then assign priorities. Bursts are then assigned to higher priority wavelengths which have lower burst loss, whenever possible [21]. Control in the above mentioned scheme is very difficult and this approach can only be implemented by edge nodes in a network.

Drop segments can be selected evenly from the contending data bursts [22]. With this technique contention does not affect a single burst, but partially to both contending bursts. Contention can also be resolved by a method OBS flex in which the transmission of burst is delayed at the source for the duration of the contention period [24]. When the control packet reaches a core node and finds contention there, it quickly informs the source node to delay the transmission of the burst for the contention period.

All the contention resolution techniques have some disadvantages, so there is a need for such a contention resolution solution that is more efficient and having least disadvantages. Studies have shown that JET performs better than other signaling protocols in terms of burst loss probability [25], therefor these results motivate us to use JET protocol in the proposed solution for contention resolution. We choose space domain deflection area because it tries to resolve contention by saving both the contending bursts.

There are various contention resolution schemes in wavelength domain, time domain and space domain but these schemes have a fundamental limitation that they work very good in normal conditions but when the traffic

Table 3.1: Summary of Drawbacks in Existing Approaches

Contention Resolution Technique	Advantage	Disadvantage
Wavelength Conversion	Much lower Burst Loss	Immature And Expensive Technology
FDL buffer	Conceptually Simple	Bulky FDL,s
Deflection Routing	No Extra Hardware Required	Loops Formation
Burst Segmentation	Finer Contention Resolution	Complicated Control
Optical Buffer	Good BreakThrough	Immature technology

load is high these schemes have poor performance[26]. Mathematical modeling is used to depict the performance of our algorithm under various traffic conditions.

Previously a number of optimization models has been proposed. In [27] the authors have proposed a linear model for optical burst switching but did not consider burst loss probability as a key metric and it takes an estimated value of it. A joint scheme for congestion and contention resolution is formulated in [28]. In [29] the authors have made an optimization model for optical burst switching in which they have formulated the control packet delay, burst assembly delay and burst blocking probability. They have shown the comparison with a stochastic system. Their model lake the simulations of the gain they get from the simulation model. Klause et all [30] have proposed a model for two different class of traffic i-e low class traffic and high class traffic. High class traffic is experiencing little loss but low class traffic is still very high. In [31] different offset times are assigned to different type of traffic to ensure quality of service. All of the above optimization models are varying the basic parameters of OBS networks such as offset, assembly queue, control packet queue and no focus on the routing path selection. The proposed optimization model is based on routing path selection. A burst is dropped on a most congested link, so to minimize the link which is more congested and route the burst through a deflection node for the contention period and then pass through its original path.

3.4 Summary

In this chapter we discussed contention resolution techniques which are organized in three main categories wavelength, time and space. We have discussed that wavelength conversion has much lower burst loss but it is an amateur and expensive technology. FDL buffer is conceptually simple but is bulky.

Deflection routing does not need any extra hardware but has the issue of loop formation and out of order arrivals. Burst segmentation has finer contention resolution but a part of burst must be either dropped or routed another way which makes it very complicated. Optical buffer is a good breakthrough but it is an amateur technology. Optical buffer has to be improved. All of the contention resolution techniques have some limitations and are described in detail in this chapter.

Chapter 4

Optimization Model and Proposed Algorithm

In this chapter we present our optimization model and the proposed algorithm for contention resolution in optical burst switched networks. The objective of the optimization model is to maximize the link usage in such a way to reduce contention. First, we will present our objective function that will be achieved under the given constraints. Then we will present our novel contention resolution algorithm, which is based on the idea that if contention occurs do not drop a burst but rather deflect it to the neighbor which will deflect it back and ultimately the burst will follow its original route without being dropped like conventional OBS technique. In the next section we will describe the parameters and notations followed by the optimization model.

4.1 Parameters and Notations Used

In this section, we formally define some parameters as shown in Table 4.1. N is the set of all nodes while S is the set of source nodes and D is the set of destination nodes. e_i is the link between node v_k and v_l.

4.2 Optimization Model

We now formulate the optimization model to maximize number of active links by reducing contention of bursts inside the optical burst switched networks. We first describe the decision variable and then a series of constraints over

Table 4.1: Parameters used in the Model with Description

Parameters	**Description**
N	Set of Nodes
N_i	Set of Intermediate Nodes
N_s	Set of Source Nodes
N_d	Set of Destination Nodes
E	Set of Edges
E_f	Set of First Links of Flows
E_l	Set of Last Links of Flows
T	Set of time slots
D_s	Demand of source $s \in S$
F	Set of flows
e_i	Edge $e_i(v_k, v_l) \in E$ is an edge between nodes $v_k, v_l \in N$

the proposed model. The decision variable $Y(t, f, e)$ shows the number of edges e in E to be active in flow f in F on time t in T.

$$Y_{(t,f,e)} = \begin{cases} 1 & \textit{if flow f is active on edge e at time t} \\ 0 & \textit{otherwise} \end{cases}$$

4.2.1 Objective Function

The objective of the proposed model is to select those links that experience less contention. We sum it on all the time slots and activate single flow on each link to resolve contention. We maximize the number of first links while reducing contention in the optical burst switching network under the given constraints, explained below.

$$Max \sum_{t \in T} \sum_{e_i \in E_f} Y_{(t,f_i,e_i)}$$

4.2.2 Demand Constraint

This constraint ensures that the actual data rate allocated to each source must be equal to or less than its demand. This constraint describe that the number of times the first link is active for each flow should be less than or equal to the demand of the flow.

$$\sum_{t \in T} Y_{(t,f,e_i)} \leq D_s \qquad \forall_{e_i \ in \ E_f} \tag{4.1}$$

4.2.3 Single Flow Constraint

Contention occurs when two links are active at the same timeslot in two or more different flows. This constraint will ensure that no contention will occur which alternatively means no two flows will be active in the same timeslot on a link. We take a flow in a timeslot and sum it over all the edges to see whether it is less than or equal to 1 and the same process is repeated for all the flows. In this constraint if we change 1 to 2 on the right hand side, in such case two flows will be active in a given timeslot on a single link, which is actually contention. For evaluation purpose we will keep it 1 in the beginning but if we want to measure contention then we will change it to some value greater than 1 that may be 2 or 3.

$$\sum_{f_i \in F} Y_{(t,f_i,e)} \leq 1 \qquad \forall_{(e\, in\, E)},\ \forall_{t \in T} \tag{4.2}$$

4.2.4 Flow Conservation Constraint

This constraint is divided into two parts, one is flow conservation on intermediate nodes and the other is flow conservation from source to destination. Flow conservation on intermediate nodes will ensure that the amount of data received is sent out from an intermediate node and flow conservation on the destination will ensure that each destination will get the data. The reason behind dividing this constraint is that on the source nodes there is outflow but no inflow and on the destination nodes we have inflow but not outflow. On the other hand at intermediate nodes we have both inflow and outflow. If we write this constraint as one then the idea behind conservation is mixed therefor in equation 4.3 we have implemented the conservation on intermediate nodes and in equation 4.4 we have implemented the conservation from source to destination. In equation 4.4 we get an edge (a, x) and see that it was active on $t - 1$ or not and if it was active then it should be active in the next time slot as well, which is t. We will check this on all links at all time slots. In equation 4.5 we check the number of edges from source to destination that if data has been sent by the source it must have reached the destination.

$$\sum_{e_a \in E} Y_{(t-1,f,e_a)} = \sum_{e_b \in E} Y_{(t,f,e_b)} \qquad \substack{e_a(v_k,v_l),e_b(v_m,v_n)\in E,\, v_l=v_m \\ \forall t\in T, \forall f\in F} \tag{4.3}$$

$$Y_{(t-1,f,e_i)} = Y_{(t,f,e_j)} \quad \forall_{f\in F}\forall_{t\in T}\ where\ e_i \in E_f,\, e_j \in E_l \tag{4.4}$$

4.2.5 Single Flow per Timeslot Constraint

This constraint ensure that when one packet do not reach the destination another can not start.

$$\sum_{e \in E} Y_{(t,f,e)} \leq 1 \qquad \forall_{f \, in \, F} \forall_{t \in T} \tag{4.5}$$

From this model we can compute delay, contention, burst loss and goodput. We will solve the optimization model in AMPL and the results will be incorporated in the simulations. The results of the model will be discussed in next chapter now we present our proposed algorithm for contention resolution.

4.3 Proposed Algorithm

In the proposed solution we have tried to overcome most of the deficiencies in the previous schemes proposed for contention resolution. We are not using any extra hardware in the form of a fiber delay line nor any wavelength converters. We are using space domain deflection routing which will not form any loops in the network nor utilize any extra resources. In the proposed algorithm, we resolve contention following the steps described below.

1. Each node in optical network will maintain a table of its neighboring nodes.

2. Values of the table will be sorted on the basis of distance between the neighboring nodes represented by Neighboring Node Distance (NND).

3. In normal conditions (no contention) it works normally as OBS network with JET protocol.

4. In case of contention (which can be easily detected by the control packet), we will first get the size of the Data Burst (DB) from the Control Packet (CP) and calculate the Fiber Length required (FL) for the contending data burst.

5. Then we will divide the fiber length by 2, match this value to NND in the table by using the binary search and find closest neighbor in such a way that: FL /2 $\geq$ NND

6. After selecting the neighbor, contending node will send a Copy of the Control Packet (CCP) to that neighbor on control packet channel and keep the resources reserved for that period.

7. We will perform Contention Resolution in the following phases

    (a) In our first phase we simply send the burst to the next available neighbor that will send it back to the originating node.

    (b) In the second phase we extend the number of wavelengths to k amount where k=1,2,3,4,.....

    (c) In the third phase we perform check on the neighboring node. If the the neighbor is busy on the required λ then algorithm will select the next available neighbor in the table, satisfying the above equation. This will be performed by sending a packet with the loopback address.

8. The Control Packet (CP) is modified with two Flags. One is R(Reflection Flag) and other is AR(Already Reflected) flag for the burst to loop back from the neighbor and now the new control packet becomes (CP+).

9. The neighboring node will reserve the required channel for the time required to bounce back the burst.

10. As the contended node will get DB it will deflect it towards the selected neighbor, which will reflect the burst back to it.

11. The contended node will get DB again and send it to the next node normally towards the destination node.

Two flags are used for deflection. R flag is used to let the neighbor know that it is not a normal packet but it has to be deflected back and AR flag will be set to 1. The AR flag will indicate for the next nodes that the burst is already been deflected once and if again contention occurs then it will be discarded. This solution is shown graphically in figure 4.3.

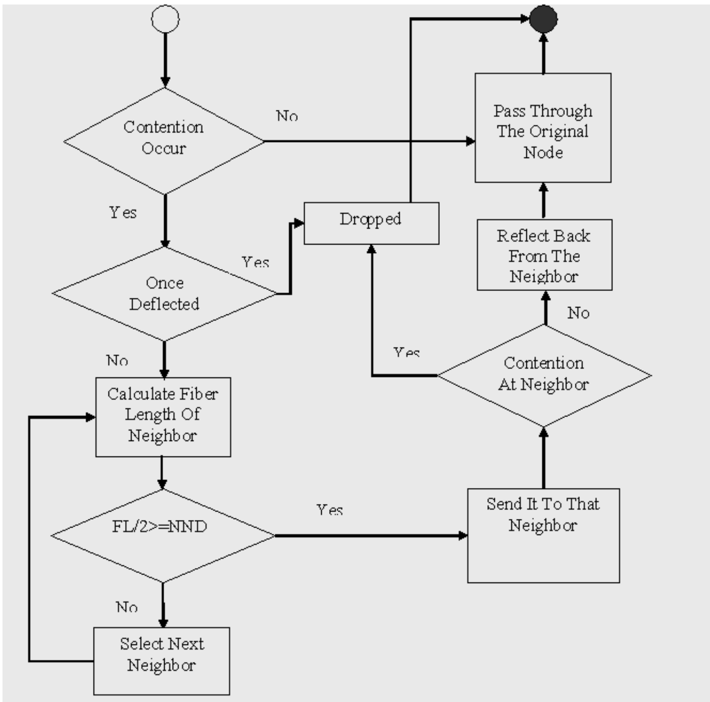

Figure 4.1: Flow Chart of the Proposed Algorithm

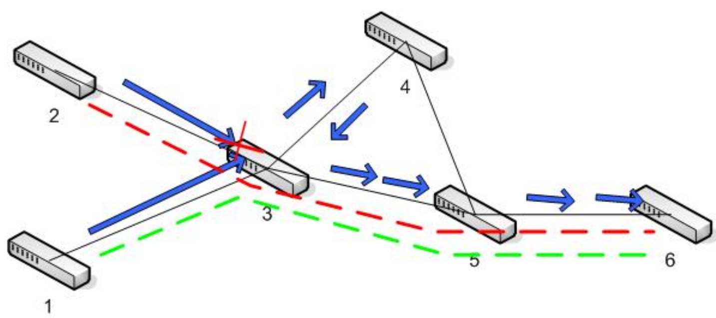

Figure 4.2: Working of our Algorithm

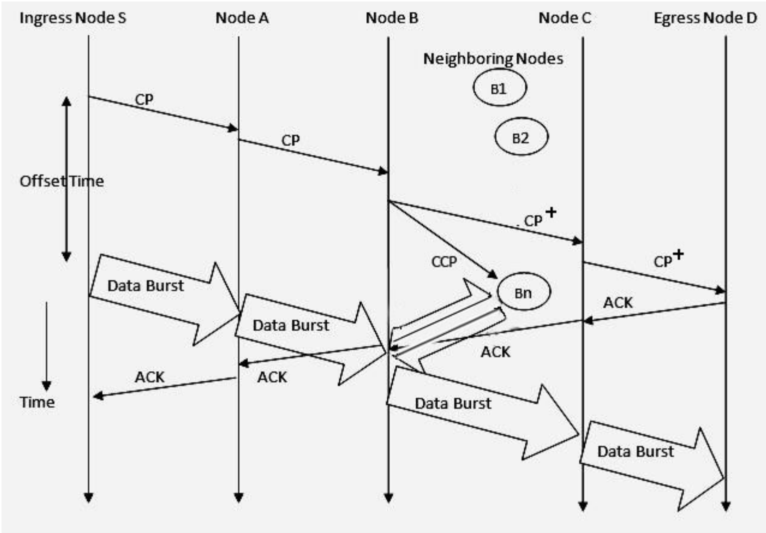

Figure 4.3: Proposed ENCR Time Line Diagram

4.4 Summary

In this chapter we discussed the proposed methodology for contention resolution. We first presented optimization model for contention resolution then we discussed the proposed algorithm. In optimization model we loopback a packet to the neighbor node and then deflect back. In the next timeslot when contention is resolved, the deflected burst follows its original route to the destination. In our algorithm we have addressed the previous issues discussed in chapter 3. We have discussed that our proposed scheme does not use any extra hardware which was used in the case of wavelength conversion, and addresses several limitations of previous schemes including eliminating the use of bulky Fiber Delay Lines (FDL's), preventing out of order arrivals that may happen when burst segmentation is used and also in case of deflection routing, preventing resource wastage that occurs in case of pre-reservation schemes and prevention of loop formation that exists in current deflection routing schemes. The objective of the optimization model is to maximize throughput. We have limited the network not to use any links simultaneously on the same timeslot. So contention is reduced and throughput is ultimately increased.

Chapter 5

Simulations and Results

In This chapter we present the results of the optimization model and simulations performed in NCTUns (National Chiao Tung University Network Simulator) developed by Prof. S.Y. Wang of National Chiao Tung University[33]. Results of the optimization model are obtained from AMPL (A Mathematical Programming Language). In order to completely evaluate the performance of the optimization model and proposed algorithm we have devised different simulation scenarios. In this study we analyzed that when neighbor is available for deflection, burst loss is significantly reduced. As we increased traffic on the neighbor node, which is used for deflection, burst loss is increased but overall average burst loss is still reduced. All these results are discussed in the below sections.

5.1 Simulation Scenario

Fig 1.1 shows our simulation topology. In topology we have 4 OBS switches to route the optical burst. There are four routers, Three of them are ingress routers and one is egress router. The routers where the bursts are assembled are the ingress routers, which are connected with the source nodes and the one which is connected with the destination node is the egress router. Here our focus is on the optical burst switches. Data is entering in the OBS network from router 1,2,3 and is leaving the network from the egress router 4. The paths are given below.

(Router1$\rightarrow$ Switch 1 $\rightarrow$ Switch 2 $\rightarrow$ Switch 4 $\rightarrow$ Router4)

(Router2$\rightarrow$ Switch 2 $\rightarrow$ Switch 4 $\rightarrow$ Router4)

(Router3$\rightarrow$ Switch 3 $\rightarrow$ Switch 2 $\rightarrow$ Switch 4 $\rightarrow$ Router4)

From these paths we can see that switch 2 is the contention switch. Traffic generated by the source nodes is poison traffic with a value of λ varying for each scenario and each burst formed has a maximum size of 1.6Mb because the size of the packet is also variable with mean value 900 bytes minimum value 800 bytes and maximum value bytes 1000. When data is passing from switch 2 there will be contention and ultimately one of the bursts has to be dropped. Our algorithm will send the burst to its neighboring node and deflect it back and then go through its original route from source to destination. To evaluate our algorithm under variety of traffic parameters we have devised four scenarios, each one of which is discussed below in detail. The simulation parameters for the following 4 scenarios are stated in the table below.

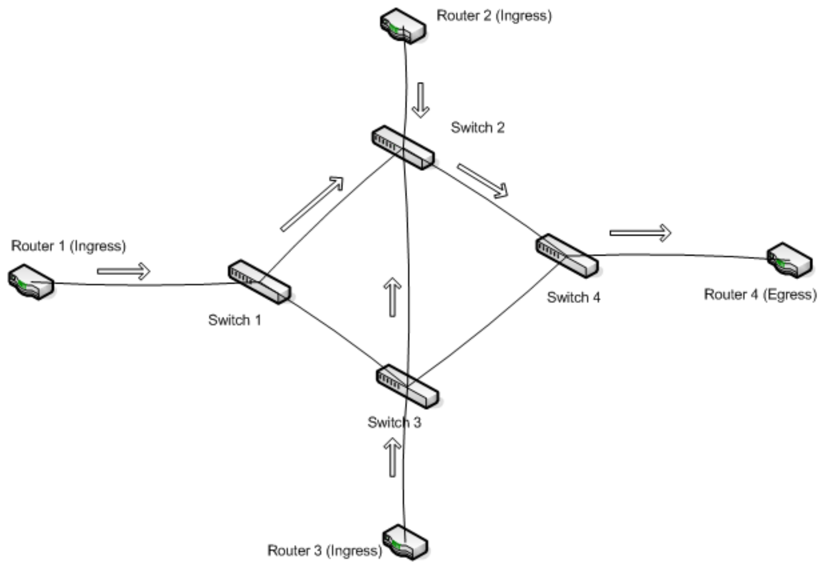

Figure 5.1: Our Simulation Scenario

5.2 AMPL Results of the Optimization Model

We use AMPL for solving the optimization model. We have two flows on the contention node and the demand for each flow is 2 Mbps. We can see that the objective function give us a value of 4 which mean that each first link of the flow is active twice and we have two flows. Here we can also notice that demand of each flow is fulfilled and no flow is exceeded than its demand. If we display the value of the decision variable y, we can see we get a matrix of [0's] and [1's], which is actually telling us which link is active at which timeslot. The horizontal values and the vertical values are the set of nodes.

The decision variable Y[1,2,*,*] means that on time slot 1 flow 2 is active on (*,*) link which can be computed from the matrix of [0's] and [1's]. The -

in the matrix indicate that there is no link between the corresponding nodes. In figure 5.2 the first row indicates the first time slot and the two flows. In the first time slot we can see that flow 2 is active on link (2,3), flow 9 is active on (9,3). In the second timeslot we can see that flow 2 is active on (3,4) and flow 9 is also active on (3,4). From here we can see that contention is occurred at timeslot 2 because two flows are active on the same timeslot on a single link. Now one of the flows has to be dropped if no contention resolution scheme is available. Now we will change our constraint and don't allow two flows to be active on one edge at the same timeslot and see what we get from the results.

```
ampl: solve;
MINOS 5.5: ignoring integrality of 148 variables
MINOS 5.5: the current point cannot be improved.
18 iterations, objective 4
Nonlin evals: constrs = 42, Jac = 41.
ampl: display y;
  [1,2,*,*]                                    [1,9,*,*]
:    3   4   5   6   7   8   10  11       :    3   4   5   6   7   8   10  11
1    0   .   .   .   .   .   .   .        1    0   .   .   .   .   .   .   .
2    1   .   .   .   .   .   .   .        2    0   .   .   .   .   .   .   .
3    .   0   0   .   .   .   .   0        3    .   0   0   .   .   .   .   0
4    .   .   .   0   .   .   0   .        4    .   .   .   0   .   .   0   .
5    .   .   .   0   .   .   .   .        5    .   .   .   0   .   .   .   .
6    .   .   .   .   0   0   .   .        6    .   .   .   .   0   0   .   .
9    0   .   .   .   .   .   .   .        9    1   .   .   .   .   .   .   .
11   0   .   .   .   .   .   .   .        11   0   .   .   .   .   .   .   .

  [2,2,*,*]                                    [2,9,*,*]
:    3   4   5   6   7   8   10  11       :    3   4   5   6   7   8   10  11
1    0   .   .   .   .   .   .   .        1    0   .   .   .   .   .   .   .
2    0   .   .   .   .   .   .   .        2    0   .   .   .   .   .   .   .
3    .   1   0   .   .   .   .   0        3    .   1   0   .   .   .   .   0
4    .   .   .   0   .   .   0   .        4    .   .   .   0   .   .   0   .
5    .   .   .   0   .   .   .   .        5    .   .   .   0   .   .   .   .
6    .   .   .   .   0   0   .   .        6    .   .   .   .   0   0   .   .
9    0   .   .   .   .   .   .   .        9    0   .   .   .   .   .   .   .
11   0   .   .   .   .   .   .   .        11   0   .   .   .   .   .   .   .
```

Figure 5.2: AMPL Results for Contention Occurring

In figure 5.3 we can see that in the first timeslot flow 2 is active on link (2,3) and flow 9 is active on (9,3). In the second time slot we can see that flow 2 is active on link (3,4) and flow 9 is active on link (3,11), which is the loopback node used for contention resolution. Now we can see that no contention is occurred and one of the flows is passed from the loopback node. Now let see what happen to the flow in the next timeslot which is passed through the loopback node. We can see that in the third time slot it loop backed from (11,3) and now there is no contention as the other flows are passed from that node. In timeslot 4 flow 9 is active on (3,4) and hence goes towards its destination.

```
ampl: solve;
MINOS 5.5: ignoring integrality of 148 variables
MINOS 5.5: optimal solution found.
28 iterations, objective 4
Nonlin evals: constrs = 15, Jac = 14.
ampl: display y;
 [1,2,*,*]
:    3   4   5   6   7   8  10  11
1    0   .   .   .   .   .   .   .
2    1   .   .   .   .   .   .   .
3    .   0   0   .   .   .   .   0
4    .   .   .   0   .   .   0   .
5    .   .   .   0   .   .   .   .
6    .   .   .   .   0   0   .   .
9    0   .   .   .   .   .   .   .
11   0   .   .   .   .   .   .   .

 [1,9,*,*]
:    3   4   5   6   7   8  10  11
1    0   .   .   .   .   .   .   .
2    0   .   .   .   .   .   .   .
3    .   0   0   .   .   .   .   0
4    .   .   .   0   .   .   0   .
5    .   .   .   0   .   .   .   .
6    .   .   .   .   0   0   .   .
9    1   .   .   .   .   .   .   .
11   0   .   .   .   .   .   .   .

 [2,2,*,*]
:    3   4   5   6   7   8  10  11
1    0   .   .   .   .   .   .   .
2    0   .   .   .   .   .   .   .
3    .   1   0   .   .   .   .   0
4    .   .   .   0   .   .   0   .
5    .   .   .   0   .   .   .   .
6    .   .   .   .   0   0   .   .
9    0   .   .   .   .   .   .   .
11   0   .   .   .   .   .   .   .

 [2,9,*,*]
:    3   4   5   6   7   8  10  11
1    0   .   .   .   .   .   .   .
2    0   .   .   .   .   .   .   .
3    .   0   0   .   .   .   .   1
4    .   .   .   0   .   .   0   .
5    .   .   .   0   .   .   .   .
6    .   .   .   .   0   0   .   .
9    0   .   .   .   .   .   .   .
11   0   .   .   .   .   .   .   .

 [3,2,*,*]
:    3   4   5   6   7   8  10  11
1    0   .   .   .   .   .   .   .
2    0   .   .   .   .   .   .   .
3    .   0   0   .   .   .   .   0
4    .   .   .   1   .   .   0   .
5    .   .   .   0   .   .   .   .
6    .   .   .   .   0   0   .   .
9    0   .   .   .   .   .   .   .
11   0   .   .   .   .   .   .   .

 [3,9,*,*]
:    3   4   5   6   7   8  10  11
1    0   .   .   .   .   .   .   .
2    0   .   .   .   .   .   .   .
3    .   0   0   .   .   .   .   0
4    .   .   .   0   .   .   0   .
5    .   .   .   0   .   .   .   .
6    .   .   .   .   0   0   .   .
9    0   .   .   .   .   .   .   .
11   1   .   .   .   .   .   .   .

 [4,2,*,*]
:    3   4   5   6   7   8  10  11
1    0   .   .   .   .   .   .   .
2    0   .   .   .   .   .   .   .
3    .   0   0   .   .   .   .   0
4    .   .   .   0   .   .   0   .
5    .   .   .   0   .   .   .   .
6    .   .   .   .   0   1   .   .
9    0   .   .   .   .   .   .   .
11   0   .   .   .   .   .   .   .

 [4,9,*,*]
:    3   4   5   6   7   8  10  11
1    0   .   .   .   .   .   .   .
2    0   .   .   .   .   .   .   .
3    .   1   0   .   .   .   .   0
4    .   .   .   0   .   .   0   .
5    .   .   .   0   .   .   .   .
6    .   .   .   .   0   0   .   .
9    0   .   .   .   .   .   .   .
11   0   .   .   .   .   .   .   .
```

Figure 5.3: AMPL Results for Contention Resolution

5.3 Burst Loss for Increasing Load

In our first simulation scenario we observed the performance of the proposed algorithm under varying traffic load. The bandwidth is 100 Mbps while the number of flows on a single link is 3. The traffic is poisson and results are obtained for varying the traffic load from 0.1 to 1. We have kept a variable packet size with a maximum value of 1000 bytes and minimum value of 800 bytes and mean value of 900 bytes. In the burst assembly algorithm on the ingress router we have kept a threshold value of 1.6 MB for the burst which means that the burst size would not exceed this value. Delay is also the same throughout the simulation and it is kept as 1μ s. The simulation time is 5 seconds. The same parameters were used for all of the following scenarios.

Table 5.1: Simulation Parameters for Traffic Load

Bandwidth	100 Mbps
Number of flows on contention link	3
Maximum burst size	1.6 MB
Delay on a link	1 μ s
Simulation time	5 sec

An ideal scenario will be the one in which the reflected burst always come back to the contention node. In our case a burst will be deflected only once and if again contention occurs it will be dropped ultimately.

5.3.1 Scenario 1: No Traffic on the Reflection Link

In our first scenario, traffic is coming from router 1 and router 2 while there is no data coming from Router 3. The reason behind this assumption is that we want to evaluate the performance of our algorithm when the neighbor is always available to deflect the burst back to the contention node. This will be an ideal case. The bandwidth is kept constant at 100Mbps and load on the links is increased gradually. Simulation time is 5 second. First the load is 0.1 which mean that 10 Mbps traffic is generated on each link. The traffic is aggregated at switch 2 where contention occurs and some bursts are dropped as no contention resolution technique is available at switch 2. While in our ENCR technique we will not drop a burst, instead we will send it to the neighbor node which is switch 3 in this case. As, there is no traffic coming from router 3 so there are no chances of contention at neighbor and the burst will be successfully deflected back to the original node from where it will follow its original path. From the results we can see that there is very less drop percentage in ENCR, this is due to the fact that its neighbor is not sending any data and is always available for reflection. As the traffic load is increased burst loss is increased, but ENCR performs better than the conventional optical burst switching scheme. In our model we have less contention and hence fewer drops. We drop a packet if it is contending on the same link with another packet in the same time slot. In order to avoid contention we send a packet to its neighbor node for reflection and when it returns back all the other packets are passed to the next nodes. Each time a burst is deflected it do not find its consequent packet in contention, therefor burst loss is significantly reduced in our Model.

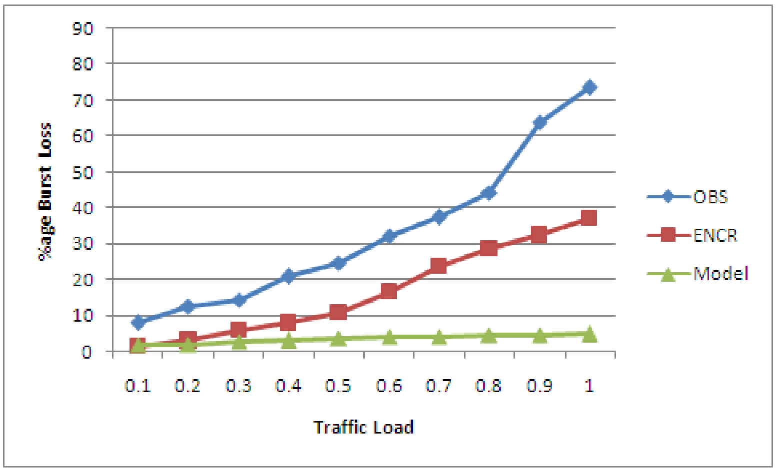

Figure 5.4: No Traffic on the Contention Link

5.3.2 Scenario 2: Low Traffic on the Reflection Link

In this scenario we generated some traffic on the contention link. The load on the contention node is kept low to 0.1. In this case router 3 is now contributing 10 Mbps of traffic. Now there is some traffic on the contention link so the neighbor node will not always be available for deflection. Other parameters like capacity of the link are kept as the previous scenario which is 100 Mbps and simulation time is 5 sec. Traffic from router 3 is kept constant at 0.1 while the load of other sources is increased from 0.1 to 1.0. Now in this scenario the node is sometime busy and the deflected burst does not return back successfully and is dropped at the neighbor node. From the results we can see that loss for ENCR is increased to some extent because the neighbor is not always available to the switch to deflect the contending burst. Loss of the OBS scheme is also increased to some extent because now there are three flows on switch 2. For this scenario in the optimization model we have added some traffic on the contention link in the model and hence a packet deflected to its neighbor now finds another packet send from the neighbor and hence a packet is dropped at the neighbor.

5.3.3 Scenario 3: Medium Traffic on the Reflection Link

Now we have increased the load on the link to its half capacity that is 0.5 and hence the chances to find a neighbor busy is increased. Under such traffic conditions the burst deflected would most probably be dropped on the neighbor node. The traffic load on other links is increased gradually. We can

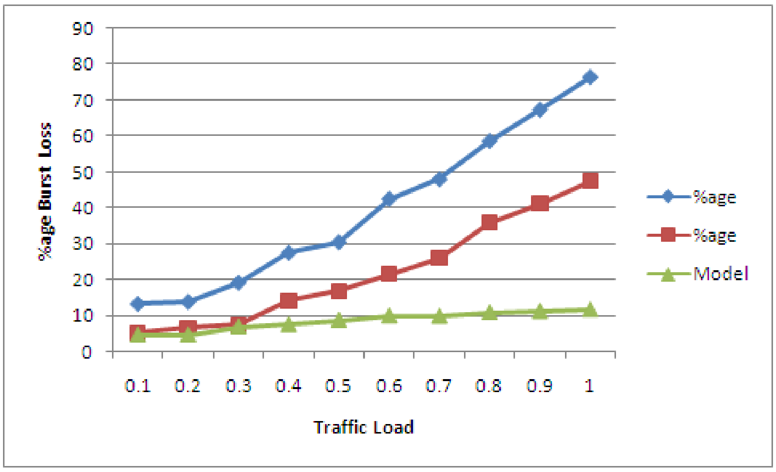

Figure 5.5: Low Traffic on the Reflection Link

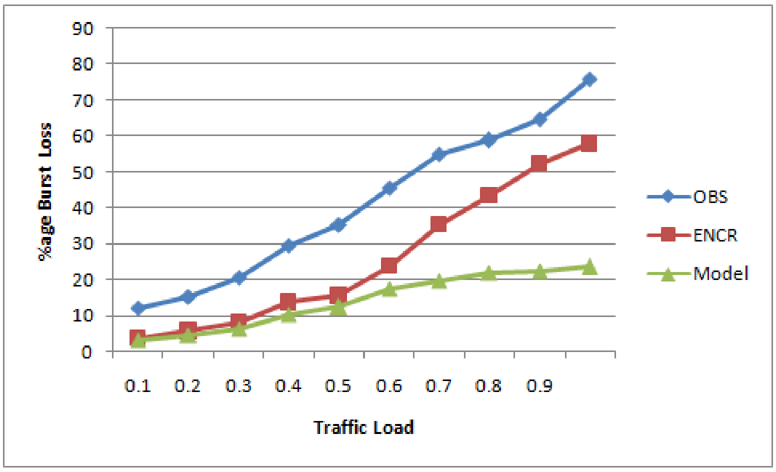

Figure 5.6: Medium Traffic on the Reflection Link

see from the results that the gap between the curves of OBS conventional scheme and ENCR is further reduced. Now burst dropping is increased in our algorithm to a considerable amount. The reason behind this is that now the the neighbor node is itself transmitting at half of its capacity so it is most of the time busy when a deflected burst is send to it by the contention switch. In model increasing traffic on the contention link causes more drops but still it is fewer from simulation.

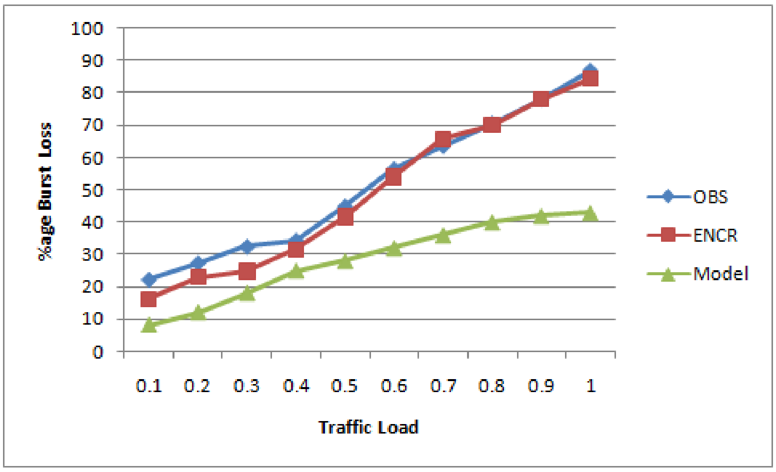

Figure 5.7: High Traffic on the Reflection Link

5.3.4 Scenario 4: High Traffic on the Reflection Link

Now we have increased the load on the neighbor node to its full capacity that is 1.0. This scenario can also be termed as worst case scenario in a sense that whenever we deflect a burst to neighbor it finds another burst in the node to be going on the same port on which the contended burst will deflect back. In this case the performance of ENCR is reduced to a great extent because the neighbor is very busy and cannot reflect the burst back, which is ultimately dropped. The results reflect our idea of contention and from the graph we can see that now the curves are almost the same for OBS and ENCR. At first when the traffic load on the other links is low burst loss in less in both ENCR and OBS but as the load is increased burst loss is increased and the curves are almost the same. ENCR deflected the burst to the neighbor but it is dropped over there while OBS is dropping the burst at the contention switch.

Figure 5.8 shows a complete picture of the four scenarios we discussed previously over the entire input traffic range of loads. The figure show the percentage drop of all the four scenarios. In first scenario we can see that the average percentage drop for OBS scheme is much high than ENCR. That was the scenario when the neighbor was always available for deflection. In scenario 2 the gap between OBS and ENCR is reduced due to the fact that now the deflection node is little busy in sending its own data. In scenario 3 we are generating traffic by 0.5 load i-e half of the capacity of the link. This time the node is very busy and the chances of a burst to find its neighbor busy are increased. From figure we can see that the gap is further is reduced and now the performance of ENCR is degraded to some extent. In scenario 4 we have increased the load on the deflection link to 1.0. Now the chances of finding a neighbor busy by the deflected burst is increased to a great extent and thus is the performance of ENCR. This is the worst case scenario for our Algorithm. From the results of the previous four scenarios we can conclude that when there is no traffic on the neighbor ENCR performance is excellent but as the node starts generating traffic performance is degraded gradually. First on low load it is still deflecting the bursts and dropping is reduced and so is the case of medium load but for high load ENCR performance is degraded but this is the worst case scenario. This case occurs in very few circumstances so we can conclude that ENCR has considerably reduced burst loss under different traffic loads and network conditions. Our optimization model performs better in every scenario and has greatly reduced the burst loss.

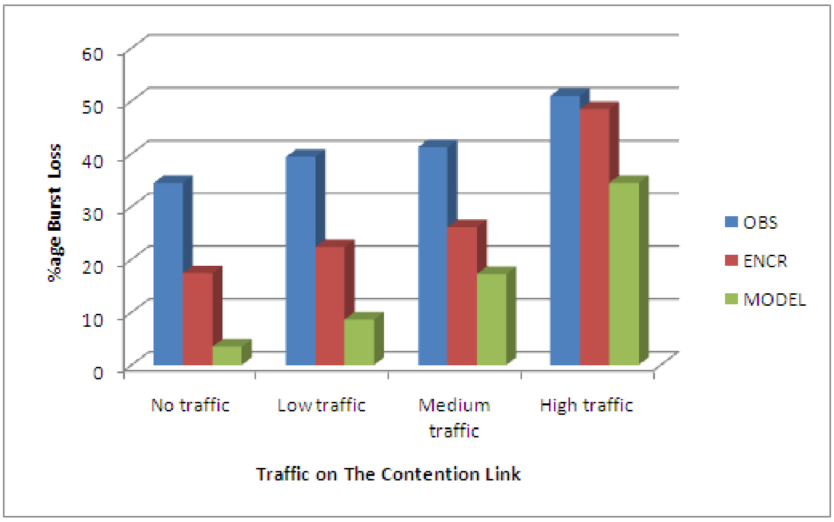

Figure 5.8: Average Loss of the Four Scenarios

Table 5.2: Simulation Parameters for Selecting Neighbor for Deflection

Bandwidth	100 Mbps
Number of flows on contention link	3
Maximum burst size	1.6 MB
Simulation time	5 Sec

5.4 Selecting A Neighbor for Deflection

Now we want to analyze the performance of our algorithm on selecting the neighbor with variable distance. We want to see that if we deflect a burst to a neighbor which is very near to us so what will happen and in the other case if we deflect it to a neighbor which is very far from the contention node, So what will be its impact on the burst dropping. For this scenario we have taken three neighbors. Neighbor one (n1) with a delay of 0.1 Micro Seconds. Neighbor two (n2) with a delay of 2 Micro Seconds and Neighbor three (3) with a delay 4 Micro seconds. Bandwidth is kept constant at 100 Mbps and there is no traffic on the deflection node which means that neighbor is always available for deflection. First we are sending the contending burst to n1 and gradually increasing load on the links. Then we send the burst to n2 and then to n3. From the results we can see that if we deflect the burst to n1 which is very near most of the burst are dropped because if they return back they still find the contending burst in the switch so upon returning the burst is dropped. On the other hand if we see the results of n2 which is at a medium distance performs well. Its drop rate is reduced than n1 which was deflecting the burst very quickly. Now we move to n3 which is very far from the deflection node. The first point to mention here is that it is giving more time in the offset so it is scheduling fewer packets than the first two cases and the other point is that as the deflection node is very far from the contention node, so its drop percentage is reduced but to very little extent From these results we can conclude that we should neither send a burst very far to a deflection node nor very near to a deflection node. From the results of the optimization model we conclude it we increase delay burst loss is reduced.

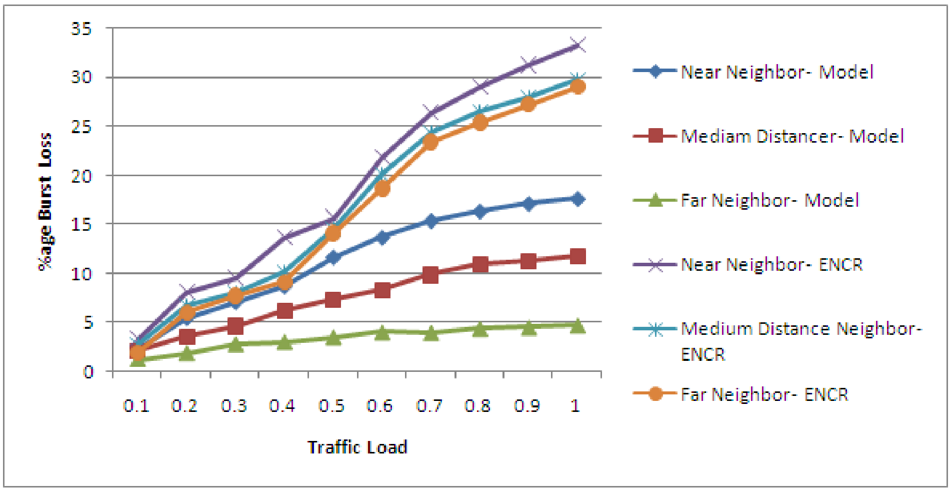

Figure 5.9: Selecting A Neighbor for Reflection

5.5 Goodput Results for Increasing Traffic Load

In the results below we want to show the goodput(Burst received) at the destination. Total capacity of the link is 100Mbps and there are 3 flows on the contention switch. Here we take an aggregated traffic and load 0.1 means that 10Mbps aggregate traffic is generated on the links. Traffic load is calculated as accumulative data rate divided by total capacity of the link. When the traffic load is increasing goodput is gradually Increasing. While calculating the results we assume that there is no traffic on the contention link, therefore the neighbor is always available for deflection, so goodput is very good under these parameters.

Table 5.3: Simulation Parameters for Goodput Results

Bandwidth	100 Mbps
Number of flows on contention link	3
Packet size	1000 Bytes
Maximum burst Size	1.6 MB
Delay	1 μ s
Simulation time	5 Sec

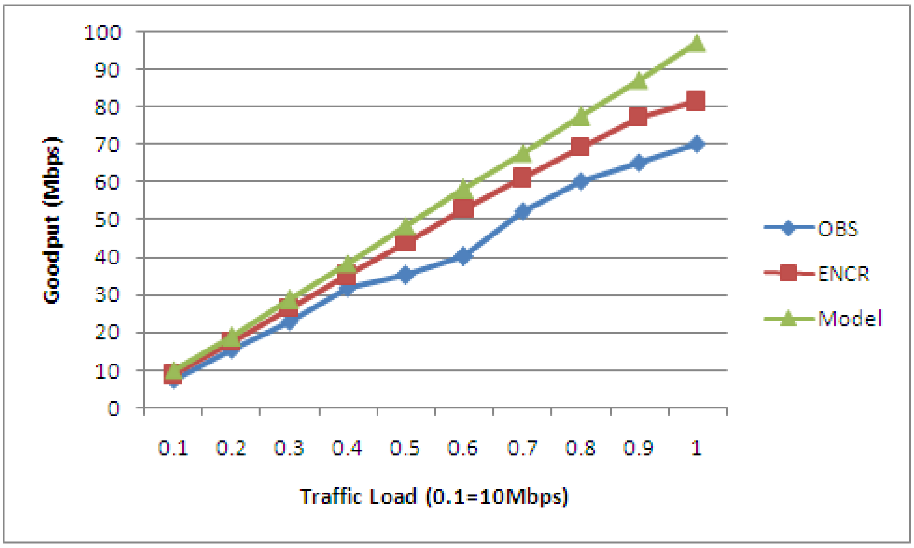

Figure 5.10: Goodput Results for Increasing Traffic Load

5.6 Summary

In this chapter we discuss the results by changing various parameters. We have shown the topology figure From which we can clearly see the contention switch. We have evaluated our algorithm under various traffic scenarios. In first scenario we have no traffic on the contention node and the burst is always deflected back, so the results are very good in this scenario. In the next scenario we start some traffic on the contention node. The traffic is low so most of the bursts are deflected back and some are dropped at the neighbor node. When we increase traffic to its full capacity then burst dropping is increased to a much higher rate. The reason behind this is that now the burst finds the neighbor node busy most of the time and is never returned back. We can also term this case as a worst case scenario, in which the neighbor is always busy sending its own data. The Combined results shows Our algorithm give satisfactory results under heavy traffic load. We have evaluated our algorithm under variety of parameters. We change the burst size, delay on a link and change neighbor distance, in all scenarios our scheme performs better than conventional OBS schemes.

Chapter 6

Conclusion and Future Work

Contention Resolution in optical switching has remained under a lot of research in the past decade and many contention resolution schemes has been proposed to meet the desired objective of maximizing throughput and reducing burst loss. All of the schemes were either using extra hardware which make it a costly solution or using extra resources. ENCR is an example of such a contention resolution scheme which did not use any extra hardware or resources, which make it a cheap and promising solution. We proposed an algorithm in which existing hardware is used and contention is minimized. Moreover there is very little change to resource allocation algorithm. The following important conclusions are made after performance evaluation of algorithm in NCTUns and the optimization model in AMPL.

- We have reduced the burst loss percentage to a significant amount. We have evaluated the algorithm under varying traffic loads and it gives very satisfying results.
- We have not used any extra hardware for contention resolution which makes our solution very viable.
- If we route a burst on a link with maximum length it means that the burst will get more time to be switched, in such case burst loss is significantly reduced.
- We also have provided a limit that neither one should send a burst to a neighbor which is very far i.e. when the burst returns back there are more chances of another burst in the switch to be in contention with the deflected burst nor one should give deflection to a very near neighbor so that if it returns back and finds its consecutive burst in contention with it. We have provided a balance for the deflection path that it should be neither very far nor very near.

- Our optimization model also gives very satisfying results in terms of burst loss percentage.

We have implemented this algorithm on a single switch i.e. when the burst is deflected to a neighbor it does not check whether there is contention on that neighbor. This work should be extended in such a way that if there is contention on the neighbor node it should know in advance and not send burst to that node. Implementation of such scheme needs a central control system that would keep information of all the nodes. We can also implement contention avoidance schemes by the use of a central control system. Another future direction would be that if the neighbor is busy on the reflection link, that neighbor should be able to send the burst to its own neighbor temporarily after receiving the reflected packet from its neighbor. In such a scenario the burst loss may be considerably reduced. Another research direction would be to send only the contending part to the neighbor and let the rest of the burst to be switched as normal, so by dropping the whole burst only the contending part will be dropped. One can integrated our algorithm with fiber delay lines to achieve considerably good results, instead of dropping the burst on the neighbor one should pass it through a fiber delay line and then return back the burst on the reflection link. From the optimization model we get an idea that if a burst is not in contention with its subsequent bursts, burst loss is much lower. One can improve the results of our proposed technique by carefully scheduling bursts at the ingress node so that they could contend minimally with there own bursts after reflection.

Bibliography

[1] C. Qiao and M. Yoo, "Optical burst switching (OBS)-a new paradigm for an optical Internet," Journal of High Speed Networks, vol. 8, no. 1, pp. 69-84, 1999.

[2] A tutorial on circuit switching by Fare Dr. Farid Farahmand and Dr. Qiong (Jo) Zhang, Central Connecticut State University and Arizona State University at West Campus, May 2007.

[3] Yang Chin et. el. "Optical Burst Switching (OBS): A New Area in Optical Networking Research",IEEE Communications Society,Volume 18 pp. 16-23, June 2004 .

[4] Chunming Qaio et. el. "The Potentials of Optical Burst Switching (OBS)",Optical Fiber Communication Conference (OFC)Atlanta, Georgia pp. 219-20, March 2003

[5] Y. Xiong, M. Vandenhoute, and H. Cankaya, "Control architecture in optical burst-switched WDM networks," IEEE Journal on Selected Areas in Communications, vol. 18, pp. 1838-1851, October 2000.

[6] Hui Zang et. el. "A Review of Routing and Wavelength Assignment Approaches for Wavelength-Routed Optical WDM Networks",Optical Networks Magazine, Volume 1, pp.47-60, January 2000.

[7] Chu et. el. "Sparse-partial wavelength conversion in wavelength-routed all-optical networks",Proceedings of SPIE Opticomm 2003.

[8] J. Iness, "Efficient use of optical components in WDM-based optical networks," Ph.D. dissertation, Univ. California, Davis, 1997.

[9] C. Qiao and M. Yoo, "Optical burst switching (OBS)-a new paradigm for an optical Internet," Journal of High Speed Networks, vol. 8, no. 1, pp. 69-84, 1999.

[10] Kim et. el. "Contention Resolution For Optical Burst Switching Networks Using Alternative Routing",Conference On Communications, IEEE International, Vol. 5, pp. 2678-2681, 2002.

[11] SuKyoung Lee et. el. "Contention-Based Limited Deflection Routing Protocol in Optical Burst-Switched Networks", IEEE Journal On Selected Areas In Communications,August 2005, VOL. 23, NO. 8.

[12] SuKyoung Lee et. el. "A Survey On Deflection Routing In Optical Burst Switched Networks",Photonic Network communication, pp. 51-59, 2003.

[13] Imrich Chlamtac et. el. "CORD: Contention Resolution by Delay Lines",IEEE Journal On Selected Areas In Communications, VOL. 14, NO. 5, June 1996.

[14] Fan Yu et. el. "A Contention Resolution Scheme by Using Fiber Delay Lines for Optical Burst Switching",IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications,, vol. 2, pp.1287-1290, August 2005.

[15] Pedro et. el. "Efficient Optical Burst-Switched networks using only Fiber Delay Line buffers for contention resolution",BROADNETS Fourth International Conference on Broadband Communications, Networks and Systems, pp. 2-11, 2007.

[16] C. Gauger, "Contention resolution in Optical Burst Switching networks," in Advanced Infrastructures for Photonic Networks: WG 2 Intermediate Report, pp. 62-82,2002.

[17] Yong-Gyu Lee et. el. "Decision of the Fiber Delay Line Length in Optical Burst Switching Networks",The 7th International Conference on Advanced Communication Technology, pp. 1049-1051,ICACT 2005.

[18] John Howell et. el. "Optical Buffer Uses Single Photon for Storage", 2007.

[19] V. M. Vokkarane and J. P. Jue, "Segmentation-based non-preemptive scheduling algorithms for optical burstswitched networks," in Proceedings of First International Workshop on Optical Burst Switching (WOBS), October 2003.

[20] V. M. Vokkarane and J. P. Jue, "Prioritized burst segmentation and composite burst-assembly techniques for QoS support in optical burst-switched networks," IEEE Journal on Selected Areas in Communications, vol. 21, no. 7, pp. 1198- 1209, 2003.

[21] X. Wang, H. Morikawa, and T. Aoyama, "Priority-based wavelength assignment algorithm for burst switched photonic networks," in Proceeding of Optical Fiber Communication Conference, pp. 765-767, 2002.

[22] A. Abid et. el. "On the resource allocation in OBS network", Journal of applied sciences 7(20): 3057-3062, 2007.

[23] Jaume Comellas et. el. "Pre-reservation of resources and controlled loops for CR in OBS network",ETRI Journal, Volume 29, Number 5, October 2007.

[24] Ashok K et. el., "A flexible CR scheme for QoS provisioning in OBS networks", Computer communications, 2006.

[25] Jing Teng, and George N. Rouskas, "A Comparison of the JIT, JET, and Horizon Wavelength Reservation Schemes on A Single OBS Node", 2003.

[26] Zalesky et. el. "Reduced load Erlang fixed point analysis of optical burst switched networks with deflection routing and wavelength reservation",Proceedings of the First International Workshop on Optical Burst Switching 2003.

[27] Esa Hyyti and Laura Nieminen "Linear Program Formulation for Routing Problem in OBS Networks",Computers and Communications, 2004, pp.252 - 257 Vol.1 .

[28] Won-Seok Park et. el. "A Joint Design of Congestion Control and Burst Contention Resolution for Optical Burst Switching Networks",Journal Of Lightwave Technology, VOL. 27, NO. 17, September 1, 2009.

[29] Jolyon White "A Framework for Optical Burst Switching Network Design", Ieee Communications Letters, VOL. 6, NO. 6, JUNE 2002.

[30] Dolzer et. el. "Evaluation Of Reservation Mechanisms For Optical Burst Switching",AEU-International Journal of Electronics and Communications, vol 55, pp. 18-25, 2001.

[31] Jing Teng "Traffic engineering approach to path selection in optical burst switching networks",Journal Of Optical Networking, Vol. 4, No. 11, November 2005.

[32] Prof. Shie-Yuan Wang, Chih-Liang Chou, and Chih-Che Lin "The Protocol Developer Manual for the NCTUns 6.0 Network Simulator and Emulator" Department of Computer Science National Chiao University Taiwan, Jan 15, 2010.

[33] Prof. Shie-Yuan Wang, Chih-Liang Chou, and Chih-Che Lin "The GUI User Manual for the NCTUns 6.0 Network Simulator and Emulator" Department of Computer Science National Chiao University Taiwan, Jan 15, 2010.

[34] M.C. Yu, H.J. Tsai, C.Y. Huang, and S.Y. Wang "Supporting Optical Network Simulations (OBS)on the NCTUns Network Simulator and Emulator" Department of Computer Science National Chiao University Taiwan, Summer, 2004.