QUALITY OF SERVICE PROVISIONING IN OPTICAL BURST SWITCHING NETWORK

SURIANI BINTI MOHD SAM

UNIVERSITI TEKNOLOGI MALAYSIA

QUALITY OF SERVICE PROVISIONING IN OPTICAL BURST SWITCHING NETWORK

SURIANI BINTI MOHD SAM

A thesis submitted in fulfilment of the requirements for the award of the degree of Doctor of Philosophy (Electrical Engineering)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

APRIL 2013

To my parents, Hj. Mohd Sam & Hajjah Rusmani, and husband, Fairos Idrus,
thank you for all the love and support

&

To my beloved children, Nurul Dania, Nurul Batrisyia and Amirul Daniyal
May some day this work inspire you to become better person

ACKNOWLEDGEMENT

Alhamdullilah, I am grateful that I have been given this opportunity to seek knowledge by Allah.

I am very much indebted to my supervisor Prof. Dr. Norsheila Fisal for believing in me. There's so much that I have learned from her. Thank you for the guidance and patience.

My appreciation also goes to Universiti Teknologi Malaysia for funding my studies and to the Faculty of Electrical Engineering, UTM who gave me the chance to carry out this research. The experience gained from this research is invaluable.

Last but not least, I would like to acknowledge those special people around me that were to talk to with their encouraging words and positive attitude during the course of my study. Thanks Hamdan, and friends from UTM. I appreciate the friendship very much. Special thanks also goes to my family members; my parents, my husband and my children for their unselfish support, great understanding and convincing attention during the hectic periods.

ABSTRACT

Future trend in communication system is to move to all-optical network. Optical Burst Switching (OBS) has been proposed as a new paradigm for switching and data transfer in all-optical network. One of the main challenges in deploying OBS network is to ensure QoS guarantee in minimising the contention and latency. The objective of this thesis is to develop OBS network that can ensure Quality-of-Service (QoS) by designing the ingress node that minimises delay and core node that minimises contention. In the ingress node, priority queueing (PQ) and burst assembly are deployed in differentiated service aware environment to decrease packet delay. Meanwhile, in the core node, integral of Fiber Delay Line, Wavelength Assignment and Wavelength Preemption (FDL-WA-WPremp) are proposed to minimise Burst Loss Probability (BLP) due to contention. In FDL, contending bursts are sent to travel over a longer fiber line and are, thus, delayed for a specific amount of time. In wavelength assignment, each traffic class has a pre-assigned wavelength for the transmission of bursts. Finally the wavelength preemption technique allows the higher priority traffic to preempt the lower priority traffic, when there is contention or, no available bandwidth for the transmission of the higher priority traffic. Three DiffServ class types that represent multimedia applications, including real time constant bit rate Expedited Forwarding (EF) traffic, real-time variable bit rate Assured Forwarding (AF) traffic and non-real time Best Effort (BE) traffic are investigated in the study. The proposed OBS network and traffic models have been developed using JAVA platform simulator and validated with mathematical analysis. The proposed OBS network performance parameters have been analysed based on BLP, packet end-to-end delay, bandwidth utilisation and throughput. The results show that the proposed OBS network with FDL_WA_WPremp, PQ and hybrid burst assembly; that is an event where burst is generated whenever the maximum assembling time is achieved or a minimum burst size is obtained, whichever occurs first, significantly improve the OBS network throughput by 10% compared to the technique without contention resolution. The proposed OBS network enhances the performance of EF, AF and BE traffic with BLP reduction of up to 70%, 42% and 34% respectively compared with OBS network with FDL only. In addition, the end-to end delay performance of the EF and AF traffic deploying FDL_WA_WPremp with hybrid based assembly environment give 21.7% and 17.2% improvement compared to FDL_WA_WPremp with timer based. The overall findings prove that QoS provisioning can be guaranteed through FDL_WA_WPremp, PQ and hybrid burst assembly in OBS network. The proposed OBS network can therefore be deployed in the future all-optical network.

ABSTRAK

Sistem perhubungan di masa hadapan mempunyai hala tuju kearah rangkaian optik menyeluruh. Pengsuisan letup optik (OBS) telah dicadangkan sebagai pengsuisan paradigma baru. Antara cabaran di dalam merealisasikan rangkaian OBS adalah untuk memberi jaminan kualiti perkhidmatan dalam meminimakan kotensi dan lengah masa. Objektif tesis ini adalah untuk membangunkan rangkaian OBS dengan reka bentuk nod masuk bagi tujuan mengurangkan lengah masa dan nod teras untuk mengurangkan berlakunya kotensi. Di nod masuk, giliran keutamaan (PQ) dan himpunan letup ditempatkan di dalam persekitaran DiffServ. Manakala, di dalam nod teras, penggabungan talian lengah fiber, tugasan panjang gelombang dan penindasan panjang gelombang (FDL_WA_WPremp) dicadangkan bagi mengurangkan kebarangkalian kehilangan letup (BLP) disebabkan kontensi. Tiga kelas trafik DiffServ yang mewakili aplikasi multimedia, iaitu trafik dengan kadar bit tetap masa sebenar (EF), trafik dengan kadar bit berubah masa sebenar (AF) dan trafik dengan masa tidak sebenar (BE) akan dikaji. Model-model rangkaian dan trafik untuk kajian dibangunkan dahulu menggunakan perisian platform JAVA untuk simulasi rangkaian dan disahkan dengan analisis matematik. Parameter prestasi rangkaian OBS yang perlu dikaji ialah berdasarkan BLP, lengah masa paket hujung-ke-hujung, penggunaan lebarjalur dan keberjayaan paket diterima. Keputusan yang diperolehi menggunakan rangkaian OBS yang dicadangkan dengan FDL_WA_WPremp, PQ dan himpunan letup hibrid; iaitu keadaan bilamana letup dihasilkan apabila mencapai masa maksima himpunan atau saiz himpunan letup minima merujuk kepada mana yang berlaku dahulu, menghasilkan 10% peningkatan di dalam keberjayaan paket diterima jika dibandingkan dengan teknik tanpa penyelesaian kontensi. Rangkaian OBS yang dicadangkan juga menunjukkan prestasi yang lebih baik dengan pengurangan BLP sebanyak 70%, 42% dan 34% bagi trafik EF, AF dan BE masing-masing. Prestasi lengah paket EF dan AF hujung-ke-hujung juga menunjukkan peningkatan yang baik iaitu sebanyak 21.7% dan 17.2% di dalam FDL_WA_WPremp dengan himpunan letup hibrid jika dibandingkan dengan FDL_WA_WPremp dengan himpunan letup masa tetap. Keputusan keseluruhan membuktikan yang kualiti perkhidmatan dapat dijamin melalui FDL_WA_WPremp, PQ dan himpunan letup hibrid di dalam rangkaian OBS. Maka, rangkaian OBS yang dicadangkan boleh digunakan dalam rangkaian optik menyeluruh pada masa akan datang.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADM	-	Add-and-Drop Multiplexing
AF	-	Assured Forwarding
AHDR	-	Adaptive Hybrid Deflection and Retransmission
AI	-	Artificial Intelligence
ATM	-	Asynchronous Transfer Mode
BA	-	Burst Assembler
BAM	-	Burst Assembly Modules
BCP	-	Burst Control Packet
BE	-	Best Effort
BHP	-	Burst Header Packet
BLP	-	Burst Loss Probability
BLR	-	Burst Loss Rate
CBR	-	Constant Bit Rate
CCG	-	Control Channel Group
CN	-	Core Node
CR	-	Core Router
DBA	-	Dynamic Burst Aggregation
DCG	-	Data Channel Group
DiffServ	-	Differentiated Services
DRD	-	Delayed Reservation Decision
DWDM	-	Dense Wavelength Division Multiplexing
EDFA	-	Erbium-Doped Fiber Amplifier
EF	-	Expedited Forwarding
ER	-	Egress Router
ER 1	-	Egress Router 1
FB	-	FeedBack
FF	-	Feed Forward

FIFO	-	First In First Out
FP	-	Fully Preemption
GPD	-	Generalized Pareto Distribution
HDR	-	Hybrid Deflection and Retransmission
ILP	-	Integer Linear Programming
IntServ	-	Integrated Services
IP	-	Internet Protocol
IN	-	Ingress Node
IR	-	Ingress Router
IR 1	-	Ingress Router 1
JET	-	Just-Enough-Time
JIT	-	Just-In-Time
JVM	-	JAVA Virtual Machine
LAN	-	Local Area Network
LHDR	-	Limited Hybrid Deflection and Retransmission
LRD	-	Long Range Dependence
LSP	-	Lambda Switch Path
LWA	-	Learning-based Wavelength Assignment
MTU	-	Maximum Transfer Unit
NACK	-	Negative Acknowledgement
nrtVBR	-	Non-real time Variable Bit Rate
O/E/O	-	Optical/Electrical/Optical
OBS	-	Optical Burst Switching
OCS	-	Optical Circuit Switching
OPS	-	Optical Packet Switching
OXC	-	Optical Cross Connect
PostRes	-	Post-Reservation
PP	-	Proportional Preemption
PQ	-	Priority Queueing
PreRes	-	Pre-Reservation
PWA	-	Priority Wavelength Assignment
QoS	-	Quality-of-Service
RAM	-	Random Access Memory

RCBP	-	Resource Consumption Based Preemption
RFP	-	Rate Fairness Preemption
RM	-	Routing Module
RTP	-	Real-time Transport Protocol
rtVBR	-	Real time Variable Bit Rate
SCU	-	Switch Control Unit
SDH	-	Synchronous Digital Hierarchy
SONET	-	Synchronous Optical Networking
TAG	-	Tell-and-Go
TAW	-	Tell-and-Wait
TCP	-	Transmission Protocol
TE	-	Traffic Engineering
UBR	-	Unspecified Bit Rate
UDP	-	User Datagram Protocol
WA	-	Wavelength Assignment
WADM	-	Wavelength Add-Drop Multiplexers
WCC	-	Wavelength Conversion Capable
WCI	-	Wavelength Conversion Incapable
WDM	-	Wavelength Division Multiplexing
WPremp	-	Wavelength Preemption
WQS	-	Waiting-Queueing Schedule
XTP	-	Xpress Transport Protocol

LIST OF SYMBOLS

σ	-	Scale parameter
ζ	-	Shape parameter
τ	-	Constant service time
λ	-	Arrival rate
μ	-	Service rate
ρ	-	Load

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Optical Network for Future Internet

Internet in communication networks has appeared to be the source of privilege in today's society. It has become the driver of current economy and today's civilization. Huge increase in commercial users alleviates the demand for higher bandwidth and better services. In addition, the massive increase in online content and the necessity in granting complete access to broadband Internet services are further pushes the capabilities of existing technologies to the edge.

Event though the Internet has effectively allowed multiple waves of advances, the current Internet framework is incapable of managing the vast varieties of emerging networked applications, usage patterns, business models and increasing number of users. The existing "best-effort" Internet has its limitation in delivering new applications which demands networks with recognized and predictable characteristics and performance. Therefore, there is a need to create future internet and these new efforts depend on strategic and multidisciplinary research on new internet ideas and concept.

The dynamic urge towards the Future Internet faces many challengers. Some of the challengers that Future Internet needs to address include [1]:

- The demand of bandwidth for every user or device will continue to grow.

- Extreme growth in content and quality of content which requires Quality-of-Service (QoS) guarantee.
- A massive increment in the number of users.
- Substantial data transmission between users, remote instrumentation and computing or data centers.

Optical technologies can offer huge bandwidth as a highway for high bit rate data transmission to provide effective solutions for the above challengers.

Among the optical network technology that has been widely used to overcome theses challengers and to support Future Internet is the optical circuit switching (OCS), optical packet switching (OPS) and optical burst switching (OBS). The technologies related to OCS are relatively easy to implement however, there are problems relating to fluctuating traffic and dynamic links. Meanwhile, OPS provides statistical multiplexing of bursty traffic at the packet but such require system buffer and the optical logic is too immature. Due to the shortcomings of the OCS and OPS, OBS has been developed extensively and gained much attention in research communities.OBS is capable in alleviating some of the optical problems of OPS and it only require less optical processing. Unlike OCS, no circuit setup delay is deployed even though OBS uses statistical multiplexing at burst level [2].

1.2 Optical Burst Switching Network

Optical burst switching was introduced for optical WDM networks. As mentioned in the previous section, the OBS is designed based on combining the advantages of OCS and OPS and make it realistic as a promising switching technology for the exploitation of the potential benefits of today's optical communication. As such, it is assumed that a burst may be regarded as having an intermediate characteristic as compared to circuit and packet switching.

Optical burst switching networks are capable of supporting different networking modes. The networking mode is primarily either connection-oriented or connectionless [3, 4, 5, 6, 7 and 8]. Connection-oriented networks are those wherein the connection setup is carried out prior to information transfer. On the contrary, in connectionless networks, no explicit connection setup actions are executed prior to transmitting data. As an alternative data packets are sent to their destinations based on information in their header. Figure 1.1 shows different examples of connection-oriented and connectionless networks [9].

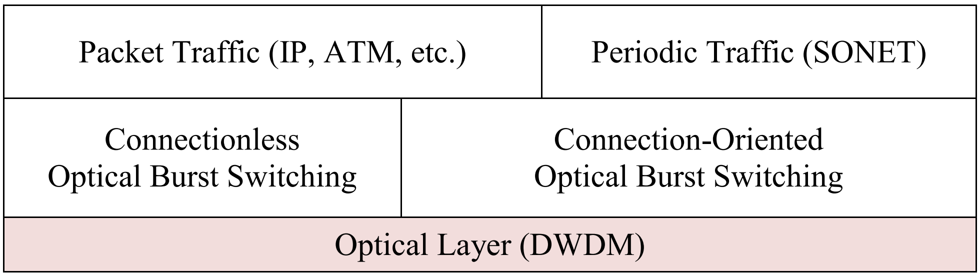

Figure 1.1 Supported Service on Optical Burst Switching Networks

In order to support connection-oriented services on OBS, a two-way reservation protocol, such as tell-and-wait (TAW) can reserve the end-to-end path for the requested period, prior to data transmission. Connectionless services on OBS can be supported by several one-way reservation protocols, for example tell-and-go (TAG) and Just-Enough-Time (JET) [10]. This thesis will focus on the connectionless mode of operation of OBS.

Table 1.1 shows comparison between the three different all-optical transport models relating to their networking capabilities [9]; it clearly acknowledged the abilities of optical burst switching over both OCS and OPS, while avoiding their limitations. As indicated in the figure, the main advantages of OBS technology are its low requirement for optical buffering and low average setup latency. Although the burst latency setup is low and furthermore packets must be delayed until the burst is ready to be transmitted, this results to the packets experiencing longer average end-to-end delay.

Table 1.1 : Comparing Different Optical Switching Technologies

Optical Transport Networks	Bandwidth Utilization	Traffic Adaptability	Latency (set-up)	Overhead	Optical Buffer Requirements	Data Loss
Optical Circuit Switching (OCS)	Low	Low	High	Low	None	Low
Optical Packet Switching (OPS)	High	High	Low	High	High	Low
Optical Burst Switching (OBS)	High	High	Low	Low	Low	High

Furthermore, OBS tends to reduce the total overhead as well as the processing power requirement. These are mainly due to the fact that fewer individual packets are transmitted in OBS for the same number of incoming IP packets. On the other hand, the main concern in OBS networks is high loss rate. Furthermore, issues such as contention resolution, quality-of-service and others, become important issues that require close attention in OBS networks [9]. Figure 1.2 summarizes some of these issues.

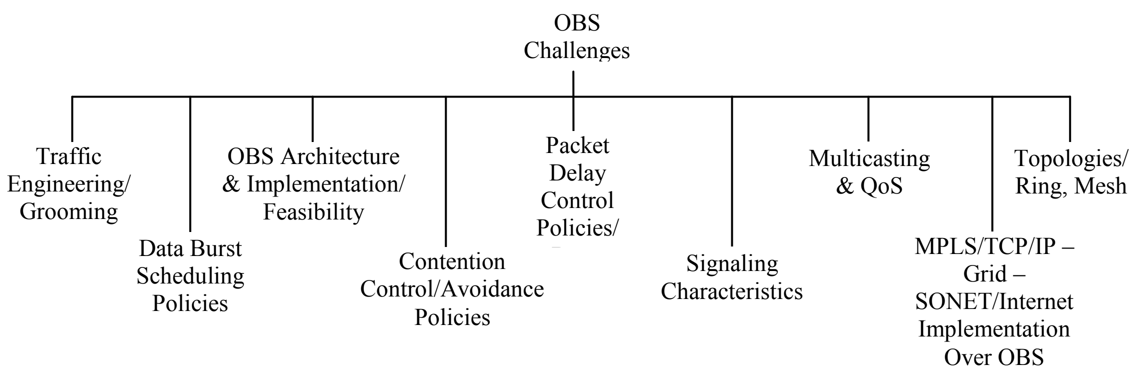

Figure 1.2 OBS technologies and challenges

Aside from technical challenges, evolution of OBS technology highly depends on its ability in supporting diverse applications. Many researches have been taking place investigating the implementation of OBS technology to support various applications. Nevertheless, the main criteria in supporting such applications are that they must be able to tolerate a degree of delay and loss as part of the QoS requirement in optical communication.

1.3 Quality of Service in OBS Network

OBS paradigm plays an important role in next generation networks framework for which quality-of-service (QoS) provisioning is an essential feature [11]. The lack of efficient optical buffers makes the task of designing QoS provisioning mechanisms for OBS networks less straightforward compared to the case of traditional electronic network for which QoS mechanisms are based on the store-and-forward concept. Indeed, the enhanced buffering capabilities of electronic networks allows QoS provisioning using per-class queueing, buffer management, and advanced scheduling policies, which are not possible to be applied at the core of the OBS network because the lack of efficient buffers [4].

In addition, any QoS provisioning mechanism for OBS networks has to take into account on techniques to deal with wavelength contentions. It is a phenomenon when two or more bursts aim to take the same output fiber on the same wavelength at the same time for each class of traffic. By minimizing the occurrence of contention in the network, it helps to reduce loss probability for the OBS network. In the context of multiclass traffic, performing privilege to a particular class when contention occurs helps in minimizing the loss probability of a particular traffic class.

Relative QoS differentiation [12, 13] and absolute QoS differentiation [14-18] are two types of QoS differentiation techniques in OBS network QoS provisioning. In the relative QoS model, it just guarantees that high priority bursts will be served with higher quality and will produced smaller loss probability compared to the low priority burst. Whereas the absolute QoS guarantees, quantitatively, hard QoS requirements for high priority bursts. Since data bursts are switched in the optical domain at each OBS switch without any queueing delay, it is being said that the key QoS parameter within the OBS network is loss probability.

Since QoS refers to the level of performance that can be expected in the transfer of information [19], its provisioning has become an essential component in today's optical communication. Most common networking QoS parameters and also to the OBS network environment comprise of [20]:

- Delay which the time is taken for a packet to traverse from the source to the destination.
- Jitter is a timing variation that would cause the packet to arrive at an inconsistent rate.
- Bandwidth utilization is used to describe the rated throughput capacity of a given medium, protocol or connection.
- Throughput is the amount of data transferred between source and destination.

From the above parameters mentioned, this thesis addresses the ability of OBS network to provide absolute QoS provisioning in terms of loss probability and other QoS requirements i.e., end-to-end delay, bandwidth utilization and throughput.

1.4 Problem Statement and Motivation

Providing QoS guarantees in an OBS network faces several issues. One of the problems that a network experienced is the delay. Different traffic classes require different level of tolerable delay. For example, real-time traffics are very stringent in its delay performance compared to best-effort traffic. Besides that, in an OBS ingress network, the packets are assembled into bursts and therefore the type of burst assembling method used would determine the delay before the burst is transmitted into the core network. Furthermore, the delay is also contributed by the buffering of packets at the ingress node. Hence, the challenge is to minimize the average packet delay of different classes of traffic. Although there are several scheduling techniques available in reducing the delay, the most appropriate and easy implementation is yet to be identified for the transmission in an OBS network.

Apart from the delay issues mentioned above, another QoS problem in an OBS network is the contention. This problem happens since optical burst switched networks is using connectionless transport. The likelihood that bursts might contend with one another at core nodes is likely to occur. Contention is a condition when multiple bursts from different input ports are intended for the same output port at the same time. When contention happens, the contending burst will be dropped and this introduces low overall throughput to the OBS network and indirectly the QoS is not achieved. Several contention resolution schemes are available for used to provide QoS in an all-optical core network in terms of reducing the burst loss. Nevertheless, determining which contention resolution schemes to be implemented in the OBS network to obtain guarantee end-to-end bounds on the overall burst loss probability (BLP) on a path [1, 2] is still an open problem to be solved.

The challenges described above require proper packet scheduling technique together with appropriate contention resolution scheme in order to reduce the average packet delay and minimize BLP to guarantee QoS level of the various differentiated services.

1.5 Research Objectives

The main goal of the research is to provide QoS in the OBS network. The QoS of concern is to reduce end-to-end delay, maximize bandwidth utilization, minimize BLP and to maximize overall throughput in the proposed OBS network. The proposed OBS network consists of ingress and core nodes. The objectives of the work are as follows:

i. to develop an ingress node for the proposed OBS network that can minimize the average packet delay due to buffering and burst assembling.

ii. to develop a core node for the proposed OBS network with contention resolution mechanism to minimize burst loss probability due to contention in the core network.

iii. to implement and characterize the QoS network performance of the proposed OBS network consisting of the ingress and core network.

The proposed ingress node is based on the DiffServ-aware OBS network. It provides different classes of traffic with differentiated service. In addition, priority queuing is used as the packet scheduling method. The packets that have been scheduled are assembled into burst by two different types of burst assembling techniques which is either fixed timer based or hybrid based. Meanwhile, the proposed core node which is all-optical uses combination of fiber delay line (FDL), wavelength assignment (WA) and wavelength preemption (WPremp) technique to combat contention in the core network.

1.6 Scope of Work

The network architecture that is being investigated in this study comprised of a DiffServ-aware OBS network that includes the OBS edge node and core node. The scope of the work is divided into three aspects as explained below.

- **Development of Ingress Network.**
  The ingress node is a DiffServ network that acts as a multiplexer. It comprises of buffer, scheduler and burst assembler. Besides that, a traffic generator has also been developed with three differentiated classes. The traffic model used is the premium, assured and best effort traffic classes. The premium traffic represents real time voice traffic, assured traffic represents video streaming and best effort traffic represents the non-real time traffic. A simulator is developed using JAVA. The ingress network model for the different traffic distributions are validated analytically using various queueing models such as N.D/D/1 [192], Pareto/D/1 [196] and M/D/1 [199] for homogeneous traffic and M/G/1 [201] for heterogeneous traffic and Priority Queuing (PQ). Once the simulator is validated, it is assumed that it represents

the real network. The scheduled packets are assembled into burst by using either fixed timer based assembly or hybrid based assembly before transmitting it to the core. The resulting burst is then appended with a burst header packet (BHP). The signaling used in this proposed work is the JET signaling which introduces an offset time. The offset time is the time taken for the burst to be transmitted prior to the BHP.

- **Development of Core Network**

  The core network is all-optical which comprises of optical cross connect switches and fiber lines. Two channels are available which is data channel to carry the data burst and control channel to carry BHP. On top of that, the proposed contention resolution scheme, FDL_WA_WPremp is also carried out here. FDL is provisioned dynamically between the sources in the OBS network and is implemented when packets have been assembled into data bursts. It allows data burst to travel over a longer fiber line and are thus delayed for a specific amount of time. Meanwhile, in wavelength assignment, each traffic class has a pre assigned, wavelength for the transmission of a burst. And finally the preemption technique allows the highest priority traffic to preempt the lowest priority traffic in the case of contention or when there is no available bandwidth for the transmission of the high priority traffic.

- **Network Performance Study**

  A proposed OBS network which consist of ingress and core nodes are developed using discrete event JAVA platform simulator. The simulator has been validated using mathematical analysis. The simulation study will investigate the performance of the proposed OBS network. The QoS parameters of the proposed OBS network include the end-to-end delay, bandwidth utilization, BLP and the overall throughput. The performance evaluation is carried out for the FDL_WA_WPremp with either the fixed timer burst assembly or hybrid burst assembly with differentiated service requirements.

By determining, supervision and minimizing loss, the novel techniques introduced in this thesis will overcome serious hurdles in current optical burst switching networks and to support the implementation of QoS. This will improve and enhance network performance as well as making the service delivery more cost effective and to bring OBS towards practicability and prospective deployment.

1.7 Contribution of Thesis

Listed below are the major contributions of this study. Contributions are organized in order of appearance in the chapter of the thesis.

1) Development of the proposed OBS network simulator for the ingress and core node using the JAVA platform.

2) Development of OBS ingress node architecture and validation of the OBS network simulator by analytical techniques (queueing models) and simulation for homogeneous traffic and introduction to priority queuing in heterogeneous traffic in packet level which highlights the function of the OBS ingress node in achieving minimum average packet delay.

3) Development and analysis of the novel contention avoidance algorithms FDL_WA and FDL_WA_WPreemp at the core OBS node using timer burst and hybrid burst assemblies' environment. Validation of the developed network simulator with analytical model is executed using Erlang B loss formula.

4) Analysis of the integral QoS performance of OBS network such as the end-to-end delay, throughput and bandwidth utilization under the proposed contention resolution algorithms with timer burst assembly and hybrid burst assembly.

The significance of the thesis is that it is the first time three contention resolution techniques are combined together to obtained the minimal burst loss probability of a DiffServ OBS network and together with the implementation of two different types of burst assembly techniques.

1.8 Significance of Work

The significance of the proposed OBS network with its QoS provisioning can be deployed in the long-haul communications systems which require high bandwidth demand. Long-haul communications are characterized by a higher level of users, more rigorous performance requirements, longer distances between users, including worldwide distances, higher traffic volumes and densities, and larger switches. The example of the long-haul transmission would be the Wide Area Network (WAN) with services provided by the telecommunication company.

1.9 Thesis Outline

The thesis comprises of seven chapters, presented as Chapter 1, an introduction to the thesis with a brief outline of the OBS network and the potential to facilitate QoS support using contention resolution scheme in the network. The problem statement, scope of work, research objectives, contribution of the thesis and thesis outline are also laid out in this chapter.

Chapter 2 provides a survey of the current literature on the fundamental issues in optical burst switching, such as network architecture, burst assembly, edge scheduling, signaling, and quality-of-service. Related work on contention schemes are covered which include optical buffering, wavelength conversion, deflection routing respectively. The bandwidth constraint models for the Diffserv OBS network are also discussed in this chapter. Related preemption in OBS network is also being discussed here.

Chapter 3 covers in depth the methodology of proposed QoS enhancement in OBS. The chapter starts off with the proposed OBS network model topology followed by the proposed ingress node and core node architecture. Methodology on three different traffic models, namely expedited forwarding (EF), assured forwarding (AF) and best-effort (BE) are also given. The proposed contention resolution which includes the Fiber Delay Line (FDL), Wavelength Assignment and Wavelength Preemption (WA_WPremp) and the integration of FDL and WA_WPreemp is presented generally. An analytical approach for validation and verification of the proposed OBS network model and the review of the simulator used, i.e. JAVA platform is also depicted here.

Chapter 4 presents the development of the ingress OBS node architecture and validation of the various traffic models with its analytical approach on queueing analysis. Two types of traffic are discussed in this chapter, namely, homogeneous traffic and heterogeneous traffic. The performance studies are measured using calculation and simulation in order to validate the simulator created and the minimize packet delay obtained as part of the QoS requirement.

Chapter 5 presents the work on contention resolution techniques in the OBS network specifically at the core node. The network and traffic models as well as the performance evaluation of the contention resolution schemes proposed FDL_WA_WPremp for two different burst assembly techniques are presented and discussed here. Performance studies on the impacts of increasing loads of respective traffic class on different burst assembly are highlighted here.

Chapter 6 chapter describes the study of QoS provisioning in OBS DiffServ network using the proposed FDL_WA_WPremp contention resolution scheme. The performance of each QoS will be compared based on the three different burst assembly techniques, i.e. fixed timer burst and hybrid burst. A packet level study is conducted based on the traffic that enters into the network. The study is focused on looking at bandwidth utilization, end-to-end packet delay and packet throughput.

Finally, chapter 7 completes the thesis with a concluding section and a discussion of future work.

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