QoS AWARE DATA-PATH ROUTING IN DWDM/GMPLS NETWORK

Suraj Kumar Naik

Roll No: 209EC1112

Department of Electronics and Communication Engineering
National Institute of Technology, Rourkela
Rourkela, Odisha, 769 008, India
MAY 2011

QoS AWARE DATA-PATH ROUTING IN DWDM/GMPLS NETWORK

A thesis submitted in partial fulfillment
of the requirements for the degree of

Master of Technology

in

Electronics and Communication Engineering

by

Suraj Kumar Naik
(Roll No: 209EC1112)

Department of Electronics and Communication Engineering
National Institute of Technology, Rourkela
Rourkela, Odisha, 769 008, India
May 2011

QoS AWARE DATA-PATH ROUTING IN DWDM/GMPLS NETWORK

A Technical Report submitted in partial fulfillment
of the requirements for the degree of

Master of Technology

in

Electronics and Communication Engineering

by

Suraj Kumar Naik
(Roll No: 209EC112)

under the guidance of

Prof. Santos Kumar Das

Department of Electronics and Communication Engineering
National Institute of Technology, Rourkela
Rourkela-769 008, Odisha, India
May 2011

Dedicated to my parents

Department of Electronics and Comm Engineering
National Institute of Technology, Rourkela
Rourkela-769 008, Odisha, India.

Certificate

This is to certify that the work done for the direction of thesis entitled **QoS AWARE DATA-PATH ROUTING IN DWDM/GMPLS NETWORK** submitted by ***Suraj Kumar Naik*** in partial fulfillment of the requirements for the award of Master Of Technology in Electronic and Communication Engineering with specialization in Telematics and Signal Processing, at National Institute of Technology Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Place: NIT Rourkela
Date: 25 May 2011

Santos Kumar Das
Professor
Dept. of ECE
NIT, Rourkela

Acknowledgment

My first thanks are to the Almighty God, without whose blessings I wouldn't have been writing this "acknowledgments".

I am deeply indebted to Prof. Santos Kumar Das, Dept. of ECE, my supervisor on this project, for consistently providing me with the required guidance to help me in the timely and successful completion of this project. His advices have value lasting much beyond this project. I consider it a blessing to be associated with him. Also I am very thankful to him for reviewing my report.

I would like to express my humble respects to Prof. G. S. Rath, Prof. S.K.Patra, Prof. K. K. Mahapatra, Prof. S. Meher, Prof. P. Singh, Prof. S. K. Behera, Prof. D.P. Acharya, Prof. S. Ari, and Prof. A. K. Sahoo for teaching me and also helping me how to learn. I would like to thanks all faculty members of ECE department for their help and guidance. They have been great sources of inspiration to me and I thank them from the bottom of my heart.

I would like to thank all my friends and especially my classmates for all the thoughtful and mind stimulating discussions we had, which prompted us to think beyond the obvious. I have enjoyed their companionship so much during my stay at NIT, Rourkela.

Finally, I thank my parents and all my family members for their unlimited support and strength. Without their dedication and dependability, I could not have pursued my M.Tech. degree at the National Institute of Technology Rourkela.

Suraj Kumar Naik

Abstract

Quality of Service Routing is at present an active and remarkable research area, since most emerging network services require specialized Quality of Service (QoS) functionalities that cannot be provided by the current QoS-unaware routing protocols. Now-a-days QoS based data routing is a demanding factor for telecommunication clients. In order to provide better QoS, the service provider network needs to have dynamic light-path provisioning technique. This technique can help to change the quality of the light-path dynamically based on existing traffic load and clients QoS requirements, which can be solved by properly designing Generalized Multi-Protocol Label Switching (GMPLS) capable hybrid network. This network is the combination of physical layer as well as network layer information. In optical networks, physical layer impairments (PLIs) incurred by non-ideal optical transmission media, accumulates along the optical path. The overall effect of PLIs determines the feasibility of the light-paths. Hence it is important to understand the process that provide PLI information to the control plane protocols and use this information efficiently to compute feasible routes and wavelengths. Thus, a successful and wide deployment of the most novel network services demands that we thoroughly understand the essence of QoS Routing dynamics, and also that the proposed solutions to this complex problem should be indeed feasible and affordable.

Keywords: Q-Factor, Bandwidth, Delay, General Purpose Router, Traffic Control Manager, Quality of Service.

List of Abbreviations

QoS	Quality of Service
TCM	Traffic Control Manager
MPLS	Multi Protocol Label Switching
GMPLS	Generalized Multi Protocol Label Switching
WDM	Wavelength Division Multiplexing
DWDM	Dense Wavelength Division Multiplexing
IP	Internet Protocol
RSVP	Resource Reservation Setup Protocol
IETF	Internet Engineering Task Force
LSP	Label Switched Path
PON	Passive Optical Network
LSP	Label Switching Path
GPR	General Purpose Router
SAN	Storage Area Network
ATM	Asynchronous Transfer Mode
UMTS	Universal Mobile Telecommunication System
OXCs	Optical Cross Connects
OADM	Optical Add-Drop Multiplexer

List of Symbols

$=$	Equality
λ	Wavelength
$\prod$	Product
$\sum$	Summation
δ	Pulse Bodening Factor
$\forall$	For All

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Motivation

Proposed Work

Organization of rest of the report

Chapter 1

Introduction

The concept of Quality of Service (QoS) in communication systems is closely related to the network performance of the routing system. Recent trend of telecommunication network has put high demand of guaranteed QoS for data communication from one client to another. Guaranteed Quality of Service (QoS) [1] requires a good traffic engineering control manager (TCM), which can be applied to any router. TCM algorithm considers different QoS constraints such as bandwidth and end-to-end delay in order to provide guaranteed services to the client. Further those constraints depend on physical layer impairments [2] constraints such as dispersion, spectral width and wavelength of light. Here, the QoS requirements of the client have been considered in terms Q-Factor, which can be expressed as either link or light-path cost, which is related to bandwidth and delay product. The network is specified based on all QoS parameters by providing an end-to-end delay bound [3, 4] model for a source-destination pair. The network determines the derivation of Q-Factor based on the QoS parameters required by the client. The main objectives of this work is to when and how to provision a light-path for the incoming traffics at the access router. The problem can be solved by formulating a mathematical TCM model for the network. TCM model is based on the idea of differentiated services [5], which maintains the QoS for all the incoming traffic. In this research work we will consider a GMPLS [6] capable hybrid network with general purpose routers (GPR), which is the combination of IP and WDM network. The GPRs supports QoS guarantees and may be used as access or gateway routers for optical switching equipment leading to the core transport network. Based on the global monitoring and control information of the TCM, it is proposed a light-path control mechanism for the provisioning of light-paths.

Similar works has been reported in [5, 7, 8]. RSVP [7] defines a purely flow based protocol to ensure about the individual flow requirements. The differentiated services architecture [5] works with aggregated flows based upon the notion of per hop behaviours. It takes static decision for the re-routing of specific flows. Another issues reported in [8], which says how Bandwidth broker works centrally and provides QoS to the clients. In all the above reported works the implication of end-to-end QoS support in IP-WDM domain are not been considered.

1.1 Motivation

The concept of Quality of Service (QoS) with its multidimensional service requirements was born in the late 1980 with the advent of ATM. In early days, QoS has been introduced in the Internet by a series of IETF contributions like Intserv, Diffserv, RSVP and MPLS. Currently, the IETF working group on traffic engineering is continuing to shape QoS induced features from the network provider's point of view. The interactivity of multimedia communication in the Internet is still increasing; real-time communication and QoS-awareness are regarded as valuable. Today, it is unclear what the role of QoS will be in newer types of networking such as mobile ad-hoc networks, sensor networks, WIFI and UMTS, grid computing, and overlay networking. In wired networks and especially in traditional telephony, network operators are facing the problem of replacing their relatively old classical telephony equipment. Their concern is the question whether it is possible or not to offer large-scale telephony (VoIP). In spite of the apparent importance of QoS, it does not seem to exist yet a business model for a QoS aware Internet. Perhaps the main importance of QoS lies in its lever function between economy and technology (QoS Routing, QoS control, and QoS network management). But, undoubtedly the main dis-advantage of QoS is the notorious complexity, which causes that QoS will only be implemented abundantly if we fully understand the QoS dynamics and can demonstrate its feasibility (in practice) and the associated economic gain.

1.2 Proposed Work

Main aim of the work is to select the data-path, which provides better QoS for the user. To o design a QoS Routing systems, it is necessary to better understand about the routing parameter. These parameters are not fixed, however, but are influenced by the characteristics of the network. Several issues are there in the selection of guaranteed QoS data-path based on WDM network such as bandwidth, minimum delay and Q-Factor for path selection. We proposed a method of data-path selection mechanism, which allow us to provide guaranteed QoS as per the client requirement (based on bandwidth, delay and Q-Factor). Also we proposed a method to select best fiber material based on delay parameter, which can improve the QoS of a data-path.

1.3 Objective of the Thesis

The Objective of the thesis are:

- To discuss various aspects of Light-Path selection mechanism and its related theories.
- Highlights different network protocol,Where we can use our proposed method.
- To propose a new Path selection Mechanism scheme based on quality of service requirements, applicable to all possible kind packet forwarding technique.
- The resulting method is cost effective as compare to other light-path selection mechanism, as it taking care of client requirement.
- To propose a light-path selection mechanism for communication between the client, doesn't required any particular protocol. So, it can be further used to develop several path selection aplications.

1.4 Organization of rest of the report

We have described the need for QoS Routing, given that the main goals of this report is to design an algorithm, which can provide the method of data-path selection based on the described parameter for a network topology. This report is organized in different sections covering a significant spectrum of the recent and future work to be done in QoS Routing as follows.

- Chapter 2 gives an introduction to basic concept about WDM, DWDM, MPLS and GMPLS.
- Chapter 3 discusses about different path selection method based on bandwidth, delay and Q-Factor. Also it highlights path selection algorithms.
- Chapter 4 discusses about simulation and results for the selection of data path.
- Finally, Chapter 5 concludes the work.

Chapter 2

WDM/GMPLS

Basic Concepts

WDM

DWDM

MPLS

GMPLS

Chapter 2

WDM/GMPLS

As we know, the telecom industry and in particular optical networking has been experiencing some challenging time over last several year. The evolution of Wavelength Division Multiplexing (WDM) Technology and the rapid progress in this technology has made the deployment of all optical networks possible [6]. The WDM based network has been consider the up growing solution for providing high bandwidth in the next generation of the private network. This technique meets the growing requirement/demand and it is expected to be the right solution to provide higher transmission capacity. DWDM has been traditionally used just to increase the transport capacity in IP over optical scenarios. The optical network demands optical switching equipment, such as high-capacity and high-density optical cross connects (OXCs), optical add-drop multiplexer (OADM) for managing high-capacity optical signals.

There has been much progress in architectures and frameworks for optical networks, namely by International Engineering Task Force (IETF) generalized multiprotocol label switching (GMPLS) framework [9] has adapted packet based multi-protocol label switching (MPLS) protocols for provisioning ”non packet” circuit-switched connections [10]. The WDM technique has been widely used as key technology for high bit-rate data transmission. The recent commercial development of photonic switches has created much new semi-transparent optical architecture with core nodes made up of an all-optical switch controlled by an IP router. GMPLS extends MPLS to provide the control for devices in any of following domains: packet, time, wavelength, and fiber. In this way, data from multiple layers are switched over Label Switched Paths (LSPs).

2.1 Basic Concepts

In the following section, we explain about the basic concept of optical networking.

2.1.1 Optical Networks

A network consists of a collection of nodes interconnected by links (In any topology). The links require ”transmission equipment,” while the nodes require ”switching equipment.” Technology developments to date have taught us that optics is fantastic for transmission, e.g., an optical amplifier can simultaneously amplify all of the signals on multiple wavelength channels (perhaps as high as 160) on a single fiber link, independent of how many of these wavelengths are currently carrying live traffic.

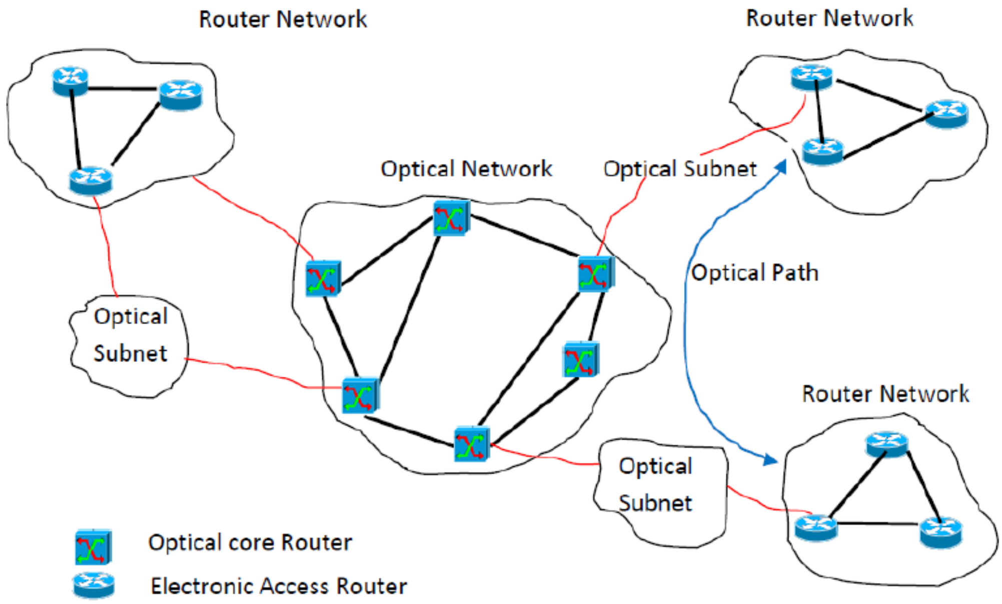

Figure 2.1: IP over WDM Network

The model shown in Fig.2.1 shows the physical topology of an IP over optical network. It consist of two layers the optical core layer, the service provider layer. The optical layer is interconnected with the electronic layer which is also known as IP layer. IP and optical network are treated as a single integrated network for control purposes in a transmission process.

- Services are not specifically defined at IP-optical interface, but folded into end-to-end MPLS services.
- Routers may control end-to-end path using traffic engineering (TE)-extended routing protocols deployed in IP and optical networks.

An optical network is not necessarily all-optical, the transmission is certainly optical, but the switching could be optical, or electrical, or hybrid. Also, an optical is not necessarily packet-switched. It could switch circuits, or sub-wavelength-granularity bandwidth pipes, or ”bursts,” where a burst is a collection of packets. Based on the various optical technologies, the most-prevalent deployment of optical networks today consists of optical-electrical-optical (OEO) switches (also called opaque switches), with each input operating at OC-192 (approx. 10 Gbps) rate. However, inside the OEO switch, each input channel can be de-multiplexed into STS-1 timeslots” and the switch can perform switching at STS-1 granularity. Thus, a network operator can support a variety of connection requests ranging in bandwidth from STS-1 to OC-192.

2.1.2 Wavelength Division Multiplexing (WDM)

Wavelength-division multiplexing (WDM) is a technique that can exploit the huge opto-electronic bandwidth mismatch by requiring that each end user's equipment operate only at electronic rate, but multiple WDM channels from different end-users may be multiplexed on the same fiber [11]. Thus, by allowing multiple WDM channels to co-exist on a single fiber, one can tap into the huge fiber bandwidth, with the corresponding challenges being the design and development of appropriate network architectures, protocols, and algorithms. End-users in a fiber-based WDM backbone network may communicate with one another via optical (WDM) channels, which are referred to as light-paths. A light-path may span multiple fiber links, e.g., to provide a ”circuit-switched” interconnection between two nodes which may have a heavy traffic flow between them and which may be located ”far” from each other in the physical fiber network topology. Each intermediate node in the light-path essentially provides an optical bypass facility to support the light-path.

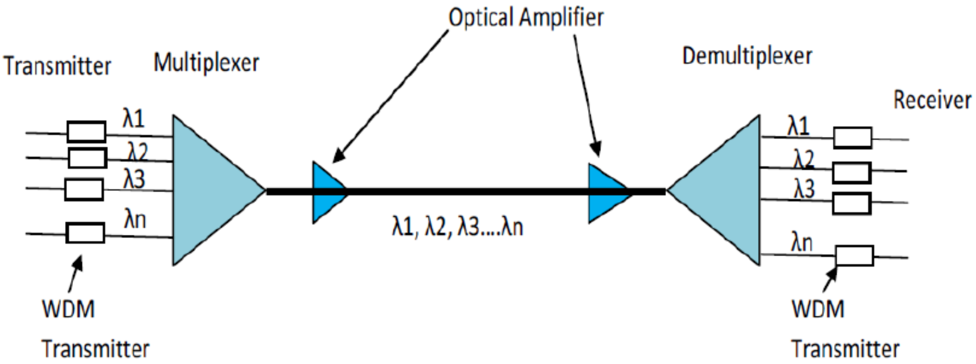

Figure 2.2: WDM Transmission System

A wavelength division multiplexing schemeFig.2.2 usually comprised of following system

1. *Transmitter*: The optical transmitter converts the electrical signal into optical form and launches the resulting optical signal into the optical fiber. It consists of an optical source, a modulator, and a channel coupler. Semiconductor lasers or light-emitting diodes are used as optical sources because of their compatibility with the optical-fiber communication channel. The optical signal is generated by modulating the optical carrier wave.

2. *Communication Channel*: The role of a communication channel is to transport the optical signal from transmitter to receiver without distorting it. Most light-wave systems use optical fibers as the communication channel because silica fibers can transmit light with losses as small as 0.2 dB/km [12]. Even then, optical power reduces to only 1 percent after 100 km. For this reason, fiber losses remain an important design issue and determine the repeater or amplifier spacing of a long-haul light-wave system. Another important design issue is fiber dispersion, which leads to broadening of individual optical pulses with propagation. If optical pulses spread significantly outside their allocated bit slot, the transmitted signal is severely degraded. Eventually, it becomes impossible to recover the original signal with high accuracy. The problem is most severe in the case of multimode fibers, since pulses spread rapidly because of different speeds associated with dif-

ferent fiber modes. It is for this reason that most optical communication systems use single-mode fibers. Material dispersion (related to the frequency dependence of the refractive index) still leads to pulse broadening, but it is small enough to be acceptable for most applications and can be reduced further by controlling the spectral width of the optical source.

3. *Receiver*: An optical receiver converts the optical signal received at the output end of the optical fiber back into the original electrical signal. It consists of a coupler, a photo-detector, and a demodulator. The coupler focuses the received optical signal onto the photo-detector. Semiconductor photodiodes are used as photo-detectors.

2.1.3 Dense Wavelength Division Multiplexing (DWDM)

Light has an information-carrying capacity 10,000 times greater than the highest radio frequencies. It is seen that due to transmission of signal in an optical medium, signal strength will be reduced, known as attenuation loss. Further developments in fiber optics are closely tied to the use of the specific regions on the optical spectrum where optical attenuation is low. These regions, called windows, lie between areas of high absorption. The earliest systems were developed to operate around 850 nm, the first window in silica-based optical fiber. A second window (S band), at 1310 nm, soon proved to be superior because of its lower attenuation, followed by a third window (C band) at 1550 nm with an even lower optical loss. Today, a fourth window (L band) near 1625 nm is under development and early deployment (shown in Fig.2.3).

Dense Wavelength Division Multiplexing (DWDM) is an important technology in nowadays fiber optic network. DWDM and CWDM both use WDM technology to arrange several fiber optic lights to transmit simultaneously via the same single fiber optic cable, but DWDM carry more fiber channel compared with CWDM (Coarse Wavelength Division Multiplexing). DWDM is usually used on fiber optic backbones and long distance data transmission and DWDM system has higher demand of fiber amplifiers. Due to DWDM technology, a single optical fiber capacity nowadays could reach

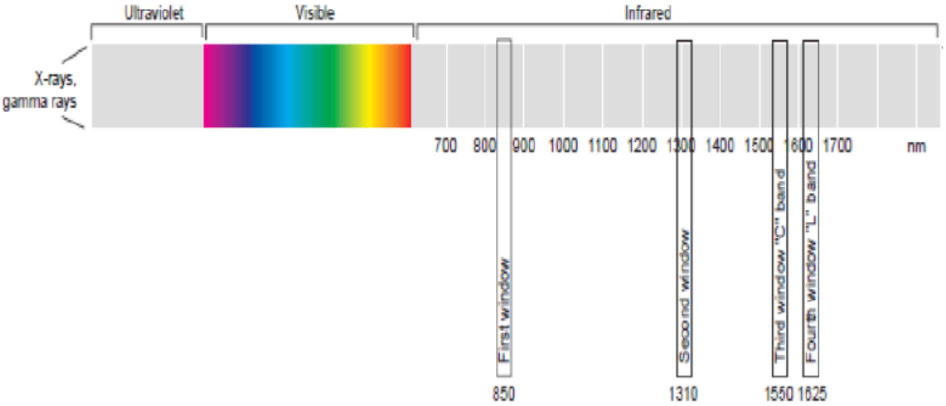

Figure 2.3: Wavelength Region

400Gb/s, and this capacity may even enlarge with more channels are added in DWDM. A critical advantage of DWDM is its protocol is not related to its transmission speed, thus IP, ATM, SONET/SDH, Ethernet, these protocols could be used and transmission speed between 100Mb/s to 2.5Gb/s. DWDM could transmit different type of data at different speed on the same channel.

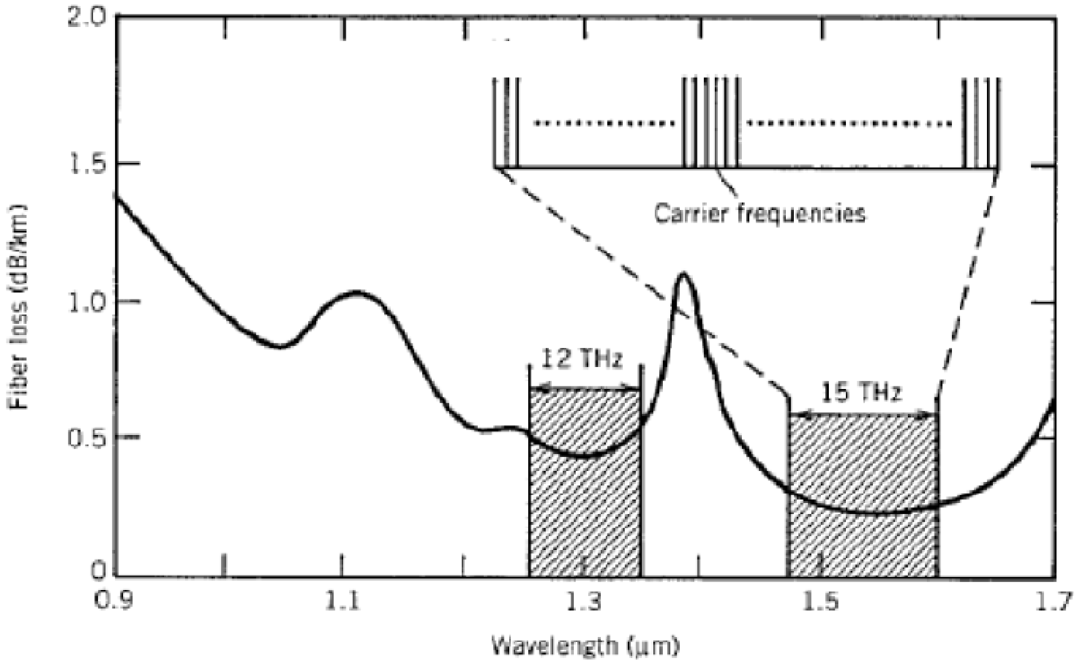

Figure 2.4: low Loss Transmission window of Silica fiber

Fig.2.4 shows the low-loss transmission windows of optical fibers centered near 1.3 and 1.55?m. Of the two types of WDM (broadband and narrow band), broadband WDM uses the 1300nm and 1550nm wavelength for full duplex transmission, that is, if a signal is sent in one direction by 1300nm, it can be sent back by 1550nm via the same optical fiber. Narrowband WDM, which is the DWDM we are talking here, is the multiplexing of $4, 8, 16, 32$ or more wavelengths in the range of 1530nm to 1610nm range with a very narrow separation between the wavelengths. Nowadays, the word WDM often refers to the DWDM systems.

2.2 Multi Protocol Label Switching (MPLS)

MPLS has its roots in several IP packet switching technologies under development in the early and mid 1990s. In 1996 the IETF started to pull the threads together, and in 1997 the MPLS Working Group was formed to standardize protocols and approaches for MPLS. IP packet switching is the process of forwarding data packets within the network, based on some tag or identifier associated with each packet. In some senses, traditional IP routing is a form of packet switching, each packet carries a destination IP address that can be used to determine the next hop in the path toward the destination by performing a look-up in the routing table. However, IP routing has concerns about speed and scalability, and these led to investigations of other ways to switch the data packets. Added to these issues was the desire to facilitate additional services such as traffic aggregation and traffic engineering.

2.2.1 MPLS Layering Structure

Multiprotocol Label Switching (MPLS) is a data forwarding technology for use in packet networks. It is a switching technology high-performance telecommunications networks which directs and carries data from one network node to the next with the help of labels. It is a connection-oriented data carrying mechanism that traverses packets from source to destination node across networks. It has the feature of encompassing packets in the presence different network protocols.

In IP routing, packets undergo analysis at each hop, followed by forwarding decision using network header analysis and then lookup in routing table. In an MPLS network, packets carrying data are assigned with labels on each node and the forwarding decision is totally based on these label headers. This is different from the conventional routing mechanism. Packet header is analyzed only once while they enter the MPLS cloud from then the forwarding decision is ’label-based’ that ensures fast packet transmission between local-local and local-remote nodes.

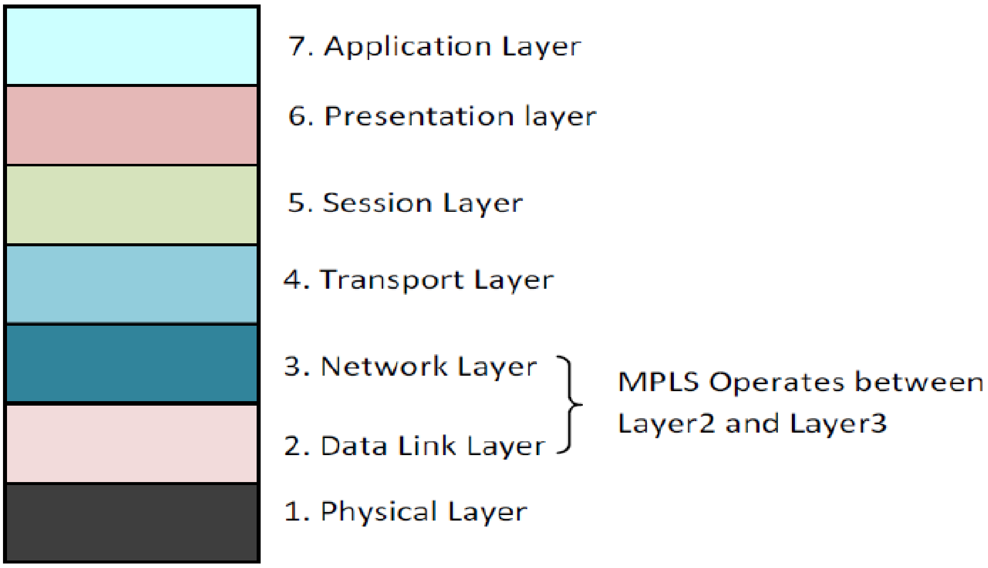

Figure 2.5: OSI Model

MPLS operates at an OSI Model layer that is generally considered to lie between Layer 2 (Data Link Layer) and Layer 3 (Network Layer), and thus is often referred to as a ”Layer 2.5” protocol (Fig.2.5). This technology provides data-carrying service for both circuit-based clients and packet-switching clients. It can be used to carry many different kinds of traffic, including IP packets, as well as native ATM, SONET, and Ethernet frames.

2.2.2 Benefits of MPLS

MPLS offers the following benefits:

- IP over ATM scalability-Enables service providers to keep up with Internet growth.

- IP services over ATM-Brings Layer 2 benefits to Layer 3, such as traffic engineering capability.
- Standards-Supports multivendor solutions.
- Architectural flexibility-Offers choice of ATM or router technology, or a mix of both

2.2.3 Notation and Definitions

In this section we describe the notations and definitions used in our work.

- LSR - Label Switching Router-It operates at the edge of the MPLS network.
- LSP - Within the MPLS domain, a path is setup for a given packet to travel based on an FEC, which is called a label switching path (LSP).
- LER - Label Edge Router-It support multiple ports connected to different networks and forward to the MPLS network after establishing LSP. It plays a important role in the assignment and removal of labels as traffic enters or exits an MPLS networks.
- LIB - Each LSR build a table to specify how packets must be forwarded. This table is called a label information base (LIB).
- FEC - Forward Equivalent Class is a group of IP packets. Each LSR build a table to specify how a packet must be forwarded. This table is called a Label Information Base (LIB).

2.2.4 MPLS Labels

1. MPLS header: The 32-bit MPLS header contains the following fields.
    - The label field (20-bits) carries the actual value of the MPLS label.
    - The Class of Service (CoS) field (3-bits) can affect the queuing and discard algorithms applied to the packet as it is transmitted through the network. Since the CoS field has 3 bits, therefore 8 distinct service classes can be possible.

- The Stack (S) field (1-bit) (Fig.2.6) supports a hierarchical label stack. Although MPLS supports a stack, the processing of a labeled packet is always based on the top label, without regard for the possibility that some of other labels may have been above it in the past, or that some number of other labels may be below it at present. An unlabeled packet can be thought of as a packet whose label stack is empty (i.e., whose label stack has depth 0). If a packet's label stack is of depth m, we refer to the label at the bottom of the stack as the level 1 label, to the label above it (if such exists) as the level 2 label, and to the label at the top of the stack as the level m label. The label stack is used for routing packets through LSP Tunnels.
- The TTL (time-to-live) field (8-bits) provides conventional IP TTL functionality.

2. If the Layer 2 technology supports a label field, the native label field encapsulates the MPLS label. However, if the Layer 2 technology does not support a label field, the MPLS label is encapsulated in a standardized MPLS header that is inserted between the Layer 2 and IP headers.

3. MPLS label: is used to identify a FEC, usually of local significance.

4. Label Switched Path (LSP): The path through one or more LSRs at one level of the hierarchy which is followed by packets in a particular FEC.

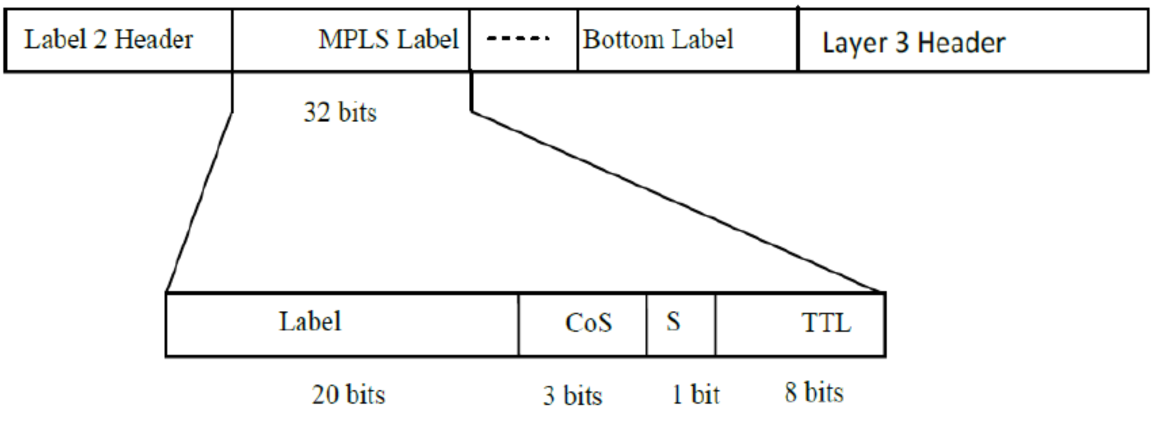

Figure 2.6: MPLS Label Format

In MPLS, the assignment of a particular packet to a particular FEC is done just once, as the packet enters the network. The FEC to which the packet is assigned is encoded as a label. When a packet is forwarded to its next hop, the label is sent along with it. At subsequent hops, there is no further analysis of the packet's network layer header. Rather, the label is used as an index into a table which specifies the next hop, and a new label. The old label is replaced with the new label, and the packet is forwarded to its next hop.

2.2.5 MPLS operations

The implementation of MPLS for data forwarding involves the following four steps:

1. MPLS label assignment (label creation and Distribution).
2. MPLS LDP (between LSRs/ELSRs).
3. MPLS label distribution (using a label distribution protocol).
4. MPLS label retention

MPLS operation typically involves adjacent LSR's forming an LDP session, assigning local labels to destination prefixes and exchanging these labels over established LDP sessions. Upon completion of label exchange between adjacent LSRs, the control and data structures of MPLS, namely FIB, LIB, and LFIB, are populated, and the router is ready to forward data plane information based on label values.

2.3 Generalised Multi Protocol Label Switching (GMPLS)

Generalized Multi-Protocol Label Switching (GMPLS) is developed by the IETF for transport network control planes [6]. GMPLS is a new protocol suite that uses advanced network signaling and routing mechanisms to automate set up for end-to-end connections for all types of network traffic. GMPLS is becoming increasingly widely used as a control plane in optical circuit switched networks due to its capability to allow a seamless integration of a multitude of technologies, especially circuit switched systems, with packet-switched networks [13].Fig.2.7 show the major protocol used in GMPLS ,Which mainly consist of OSPF (Open Shortest Path First) extension of the routing protocol,The RSVP-TE extension of the signaling protocol and the link management protocol (LSM).

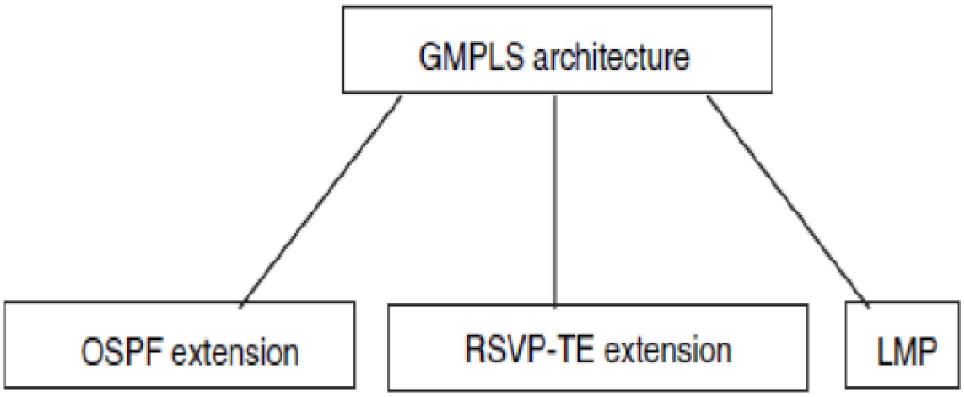

Figure 2.7: GMPLS Architecture

The control packets of the routing protocol, the signaling protocol, and the LMP are described in the next section. In a GMPLS network, these packets are transferred through the control plane, which is logically separated from the data plane.

2.3.1 Routing Protocol

The routing protocols used in an IP/MPLS network are OSPF (Open Shortest Path First) or IS-IS (Intermediate System to Intermediate System) [14]. In a GMPLS network, the OSPF that has been utilized in IP network is extended. In the OSPF extension, such concepts as a traffic-engineering (TE) link, hierarchization of the LSP, unnumbered links, link bundling and LSA (link-state advertisement) were introduced. In a GMPLS network, a lower-layer LSP can become a link of an upper-layer LSP. For example, when an LSP is set on a certain TDM path, the TDM path behaves like a fixed link that has been there permanently for a long time. When the lower-layer LSP is set, the originating node of the LSP, when viewed from the upper layer, is advertised within the network as an upper-layer link. This LSP is called a TE link. When PSC-LSP is set up, the route is selected according to the topology that is constructed by TE links. In general, in the topology of a GMPLS network, a physical link, such as an optical fiber, is also called a TE link. The interface of a link in an MPLS network is generally assigned an IP address. According to this IP address, it is possible to identify the link inside the network. However, in a GMPLS network, because it is possible to accommodate more than 100 wavelengths per one optical fiber, the number of required IP addresses becomes huge if an IP address is assigned to each interface of these wavelengths. In GMPLS, to identify the link a link identifier (link ID) that is assigned to the interface of the link has been introduced. It is possible to identify the link inside the network from a combination of the router ID and the link ID.

2.3.2 Signaling Protocol

The signaling protocol is a protocol that sets up the LSP and manages the setup status of the LSP. RSVP-TE signaling of an MPLS network is extended for use in a GMPLS network. Setting up the LSP means to switch the packets according to the label conversion table, in which correspondence between the label of the input link and the label of the output link of the node on the route of the LSP has been set, by assigning the label of the link through which the LSP passes. In MPLS, label assignment executes just to set up the LSP route, but not to assign the bandwidth or network resource. In GMPLS, the label corresponds to the time slot in the TDM layer, to the wavelength in the λ-layer, and to the fiber in the fiber layer. Therefore, assigning the label in a GMPLS network means to assign the bandwidth or network resource in layers other than the packet layer. This point that label assignment means to assign the bandwidth or network resource is a characteristic of the extended RSVP-TE for GMPLS.

2.3.3 Link Management Protocol

To manage the link between neighboring nodes, a Link Management Protocol (LMP) has been introduced as a GMPLS protocol [15]. LMP has four functions: Control-channel management, Link-property correlation, Connectivity certification, Failure management. Control-channel management and link-property correlation are indispensable functions of LMP, and connectivity certification and failure management are optional functions.

Chapter 3

System Design

Bandwidth Model

Delay Model

Q-Factor Model

Chapter 3

System Design

As defined in previous chapter WDM technology, allow a single optical fiber to transmit multiple optical carrier signals by using different wavelength to carry different carrier of signal. DWDM increases this capacity of transmission of signal in optical fiber communication. This technique multiplex signals of different wavelengths and provides data capacity in hundreds of gigabits per second over thousands of kilometers in a single mode fiber with more security. Similarly MPLS, GMPLS protocol make it easy to transmit signal in different layers of communication system.

In this Chapter, first section discuses about the system model. Second section gives the overview control plane protocol and TCM algorithm, third section deals with the design of different mathematical model, Fourth section explain about path selection algorithm.

3.1 System Model

A System model gives the layout of interconnections of the various elements like links, nodes, etc. of a network system. Nodes in a network are represented by the coordinate where the location of a node is given by point in a coordinate system. In a network, a node is a connection point, either a redistribution point or an end point for data transmissions. Link in a network is a connection through optical fiber link between two nodes. In a system link between too nodes is represented by the line joining between two nodes. The model shown in Fig.3.1 shows the physical topology of the network, consisting of three layers, the Service provider layer shown as the outermost layer, the Optical core layer which is the innermost Optical network layer [16], and the Electronic intermediate layer or also known as IP layer.

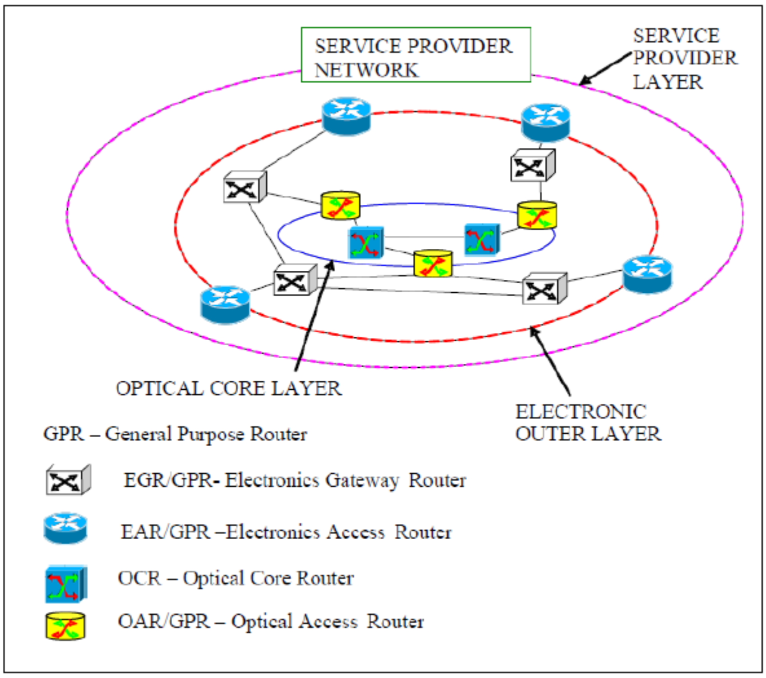

Figure 3.1: physical Topology

This is an abstraction of the combined electro-optical network which allows us to focus on that portion of the network where our innovation applies, i.e. the combined electro-optical network. The optical layer provides point-to-point connectivity between routers in the form of fixed bandwidth circuits, which is termed as light-paths. The collection of light-paths therefore defines the topology of the virtual network interconnecting electronics/IP Routers. In IP layer the IP routers are responsible for all the non-local management functions such as management of optical resources, configuration and capacity management, addressing, routing, topology discovery, traffic engineering, and restoration etc. The IP router communicates with the TCM (Traffic Control Manager) of service provider network and provides the information about the status of the optical layer.

Ideally the service provider layer will include elements of the access network such as the PON (Passive Optical Network) related elements and other devices/equipment located at the premises/home. However for this invention such details are not necessary.

We assume that the service provider has access to General Purpose Routers and also optical components in the core optical network. Such an assumption is reasonable, given the fact that the prices of optical switching equipment have fallen by orders of magnitude till the point that they are being used in the premises of large corporations in order to interconnect buildings etc. Thus it is reasonable to assume, as we have done, that the service provider has information about the GPRs and the optical equipment within its domain of control.

The service provider layer controls all the traffic corresponding to both IP and optical layers. All the routers shown in the figure are controlled by the service provider (SP). The SP maintains a traffic matrix in a Traffic Control Manager (TCM) for all the connected general purpose routers, i.e. all the Electronic Gateway Routers (EGR), Electronic Access Routers (EAR) and Optical Access Routers (OAR) within its domain of control.

The Traffic Control Manager (TCM) maintains the network as well as PLI constraints such as Capacity, delay, and Q-factor matrices for all the GPRs in the network, belonging to all the layers. In the following sections we outline our algorithms that carry out the computations necessary for the decisions that lead to provisioning/deprovisioning of data-paths.

3.2 Control Plane Protocol and TCM Algorithm

If i and j are connected GPRs within the network, then the Traffic Control Matrix element $T(i, j)$ provides useful information regarding the flow of traffic between i and j. The Table 3.1 shows all control protocols used for GPRs pair (i, j) and shows how our algorithm provides a solution in areas where other approaches do not. We assume that the information maintained by $T(i, j)$ includes capacity, end-end-delay, and overall Q-Factor between the GPRs, as well as the total quantum of committed traffic between the two routers. An admission control algorithm operating within the control of the service provider allows traffic flows to operate between the routers after making sure that capacity is available. There are various techniques for achieving this in the IP routers, such as RSVP, Diff-Serv and Bandwidth Broker. Any of these techniques are acceptable

Table 3.1: Control Plane Protocol

i,j	OCR	OAR	EGR	EAR
OCR	G+A	G+A	Not Possible	Not Possible
OAR	G+A	G+A	M+G+A	M+G+A
EGR	Not Possible	M+G+A	M+A	M-TE+A
EAR	Not Possible	M+G+A	M-TE+A	M+A

for the algorithms presented herein.

Notations: G = GMPLS, M = MPLS, M-TE = MPLS-TE, A = Our Algorithm From Table 3.1, we see that our algorithm applies to all possible combinations of all types of routers.

3.3 Problem Formulation

We consider a virtual topology model shown in Fig.3.2. In this model, a number of flows for different applications are multiplexed at the source GPR *i* to destination GPR *j*, for a data-path. This formulation is for the provisioning and de-provisioning of data-path based on the client requirements and existing traffic. The problem formulations are based on different QoS parameters such as, Bandwidth, Delay bound, and PLI based Q-Factor, which are explained in following sections.

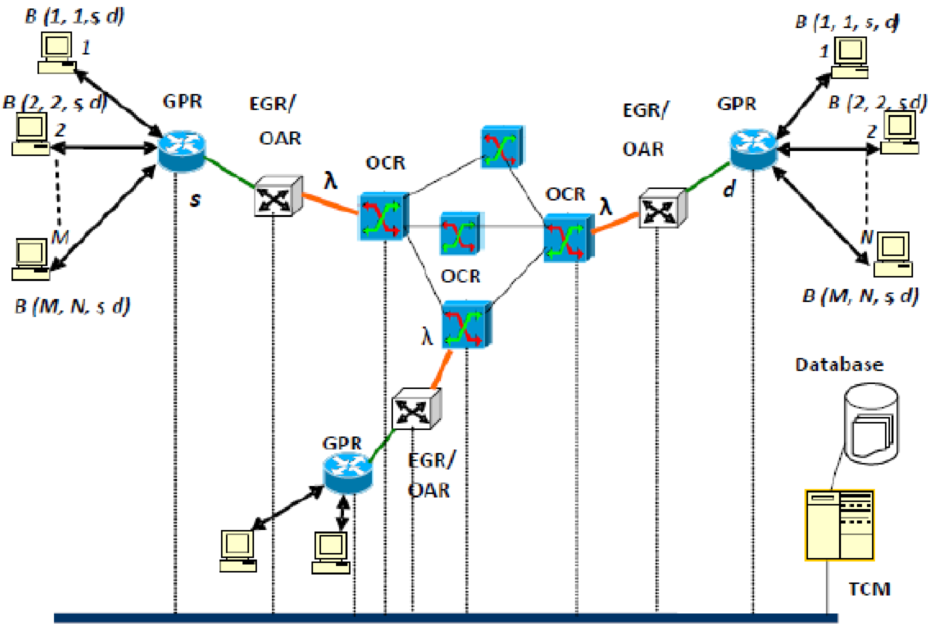

Figure 3.2: System Topology Graph

3.3.1 Bandwidth Model

Assume every DWDM client end point is attached to at most one GPR. Suppose a flow for client m and n with light-path from source s to destination d has bandwidth/traffic requirement $BR(m, n, s, d)$. The aggregated traffic flow for them is defined as:

$$T_{Aggrt}(m, n, s, d) = \sum_{m,n} BR(m, n, s, d) \tag{3.1}$$

As per the network condition, for every edge GPR, a free available capacity matrix, $B(m, n, s, d)$ has been considered, where s and d are the source and destination edge GPRs for a light-path.

Assume the physical layer constants are dispersion, spectral width of light and link length. If $DS(i, j)$ is the dispersion of the fiber at the operating wavelength with units seconds per nanometer per kilometer, and $L(i, j)$ is the length of fiber link pair (i, j) in kilometers, the bandwidth matrix can be mentioned [17] as follows:

$$B(i, j) = \frac{\delta}{DS(i, j) \times \sqrt{L(i, j)}} \tag{3.2}$$

where, δ represents the pulse broadening factor should typically be less than 10 parcent of a bit's time slot for which the polarization mode dispersion (PMD) can be tolerated [10] and $D(i, j) = L(i, j) = \infty$, when there is no link from i to j. The bandwidth matrix for a light-path will be:

$$B(m, n, s, d) = Min\{B(i, j)\}, \forall(i, j) \in P(s, d) \tag{3.3}$$

Where,$p(s, d)$ is the computed light-path for source (s) to destination (d) containing a group of links.The capacity metrics $B(m, n, s, d)$ calculation is derived from a single link to a group of links in a Light-path.

3.3.2 Delay model

Next, we estimating the delay requirement for the clients that support guaranteed service in terms of end-to-end delay bound. In Fig.3.2, suppose the delay requirement of flow for (m, n) client pair from source s and destination d is $D(m, n, s, d)$. The maximum acceptable delay between s and d is as follows:

$$D_{Max}^{Accept}(m, n, s, d) = Min\{D(m, n, s, d)\}, \forall(m, n) \tag{3.4}$$

Where,$m = 1, 2 \cdots M$ and $n = 1, 2, \cdots N$and M and N are the total number OVPN clients attached to source s and d respectively. As per the network condition if $D(i, j)$ is the link pair delay, then the end-to-end delay is the sum of link delays suffered by a connection at all routers along with the light-path $p(s, d)$ and given as:

$$D_{Max}^{Bound} = \sum_{(i,j)\in P(s,d)} D(i, j) \tag{3.5}$$

Where, according to [18],

$$D(i, j) = a + b\lambda_{i,k}^{2} + c\lambda_{i,k}^{-2} \tag{3.6}$$

Where a,b and c are fiber material dependant constants also known as fit parameter, $\lambda_{i,k}$ is the wavelength at i_{th} node and its k_{th} light-path. Here we have taken aluminium oxide and Silicon oxide as the fiber material for simulation work.

3.3.3 Q-Factor Model

We defined the link cost as the ratio of bandwidth and delay, which is termed as Q-Factor and will be represented as below.

$$QF(i, j) = \frac{B(i, j)}{D(i, j)} \tag{3.7}$$

Then for a complete light-path $p(s, d)$ of source (s) and destination (d), the Q-Factor will be:

$$QF(m, n, s, d) = Min\{Q(i, j)\}, \forall(i, j) \in P(s, d) \tag{3.8}$$

Assume $QF_r(m, n, s, d)$ is the Q-Factor required from OPVN client m and n for source (s) and destination (d) pair. It can be defined as follows:

$$QF_r(m, n, s, d) = \frac{T_{Aggrt}(m, n, s, d)}{D_{Max}^{Accept}(m, n, s, d)} \tag{3.9}$$

3.4 TCM Mechanism for Light-Path Provisioning

The TCM algorithm for the provisioning of new Light-Path based on the equations 1 to 9. The edge GPR aggregates the bandwidth, acceptable delay and Q-Factor requirement of the flows as mentioned in equation 3.1, 3.4 and 3.9. This aggregated bandwidth and acceptable delay will be compared with the estimated bandwidth and delay bound mentioned in equation 3.3 and 3.5 respectively. Also both estimated Q-Factor and required Q-Factor mentioned in equation 8 and 9 will be compared in order find a best suitable network. The comparison takes decision, whether to provision a network for the requested services.

3.4.1 Light-Path provisioning based on only Bandwidth and Delay

The provisioning of Light-Path for any of the following conditions.

$$D_{Max}^{Accept}(m, n, s, d) \geq D_{Max}^{Bound}(m, n, s, d) \tag{3.10}$$

$$T_{Aggrt}(m, n, s, d) < B(m, n, s, d) \tag{3.11}$$

3.4.2 Light-Path provisioning based on Q-Factor

The provisioning of Light-Path occurs for any of the following conditions.

$$QF_r(m, n, s, d) \leq QF(m, n, s, d) \tag{3.12}$$

3.4.3 De- provisioning based on Q-Factor based on Required Q-Factor

The de-provisioning of light path occurs for the following condition.

$$QF_r(m, n, s, d) << QF(m, n, s, d) \tag{3.13}$$

3.5 Algorithm for Light-Path Selection

3.5.1 Algorithm for light-path selection based on Bandwidth and Delay

- STEP1: Calculate Delay for each link using the delay equation (3.6).
- STEP2: To find the overall Delay bound find the sum of delay of the links belong to the possible light-path using equation (3.5).
- STEP3: Compare the acceptable delay value and bound delay in STEP2 and check the condition in equation (3.10).
- STEP4: Check whether aggregate traffic is less than bandwidth or not using equation (3.11).
- STEP5: If condition in STEP3 and STEP4 satisfy, provision OVPN light-path, which is the selected light-path.
- STEP6: STOP

3.5.2 Algorithm for light-path selection based on Q-Factor

- STEP1: Calculate the Q-Factor for each link for the Q-Factor equation (3.7).
- STEP2: Then calculate the overall light-path Q-Factor for source s and destination d, which is the minimum value of links Q-Factor using equation (3.8).
- STEP3: Required Q-Factor for OVPN client m and n for source s and destination d using equation (3.9).
- STEP4: Check for condition in equation (3.12), If satisfy provisioning of light-path occur based on Q-Factor, else repeat STEP1, STEP2, STEP3 for other light-path.
- STEP5: If the condition in equation (3.13) is satisfy, de-provisioning occur and repeat above steps to compute a light-path.

3.6 Fiber Material Selection Mechanism for QoS Enhancement

The fiber material which provides minimum delay during route computation that will be considered to be used in fiber network back bone. The following is the flow chart Fig.3.3 for the above mechanism.

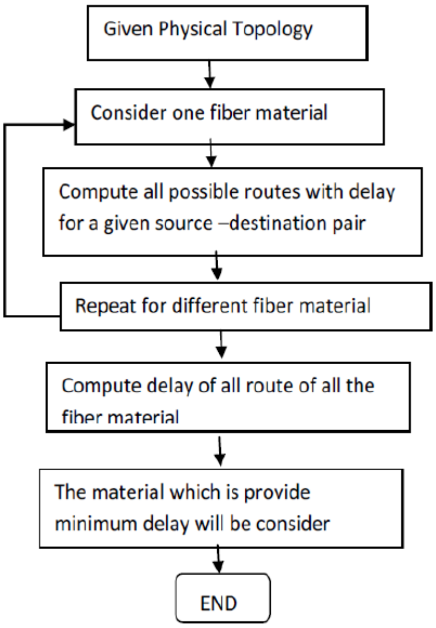

Figure 3.3: Fiber material selection Flow-Chat

The selection mechanism show how to select fiber material based on the minimum delay.Delay play a major role in data transmission technology.If we are able to select a Light-Path before sending any data with minimum delay, then it is advantageous for the client.

Chapter 4

Simulation and Results
Network Model

Selection based on Bandwidth

Selection based on Delay Q-Factor

Comparison Results

Chapter 4

Simulation and Results

This chapter discusses the simulation of light-path selection mechanism for the client based on Bandwidth, Delay and Q-Factor requirement as describe in the earlier chapter. Here we have considered three scenarios of how to obtain the best suitable light-path depending on the above parameters. Also we simulate Path selection technique based on delay for different fiber material to provide best light-path for the client.

4.1 Network Model

We have considered Fig.4.1 for the simulation, The Fig.4.1 shows the basic network topology with 6 nodes. Here we computed three pair of source and destination nodes $(1,4)$, $(5,3)$, and $(1,6)$ and their possible paths to choose the best path based on client requirement. The light-path selection mechanism considers quality parameters such as bandwidth, delay and Q-Factor for the finding of best suitable path.

In our simulation, we have considered three scenarios of how to obtain the best suitable light-path, such as:

1. By considering bandwidth as the only quality requirement.
2. By considering Delay as the only quality requirement.
3. By considering both in terms of Q-Factor.

In this work we have taken silica glass as the fiber material and also doped material of silica wit increase refractive index. Silica exhibits fairly good optical transmission

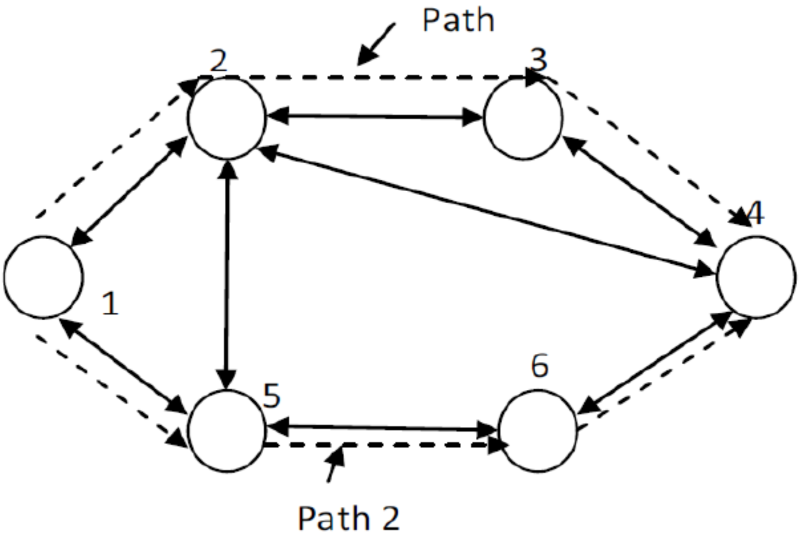

Figure 4.1: Physical Topology used For Simulation

over a wide range of wavelengths. In the optical network refractive index play a major role in the designing of optical fiber. Silica glass can be doped with different material to get raised refractive index such as Aluminium oxide. Here we have calculate the delay and Q-Factor of silicon oxide and increase refractive index material Aluminium oxide to study their behavior for the light-path.

4.2 Simulation Result for light path selection based on Bandwidth

This section Discuss the simulation results for selection of light-path for a given set of source (s) and destination (d) pair based on bandwidth as the required parameter. The Fig.4.2 shows the graphical representation of best light-path based on bandwidth computation for each path of different source-destination pair. The plot shows more than one estimated paths for a source-destination pairs and all those paths are serially assigned with path reference numbers 1, 2, 3, 4 etc. The path corresponding to highest bandwidth for a source and destination pair is the best estimated light-path.

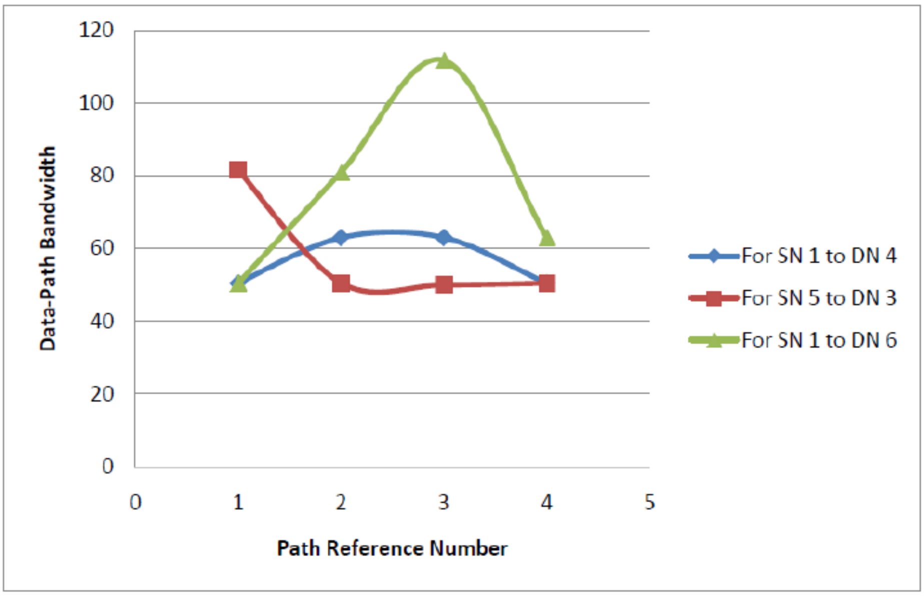

Figure 4.2: Bandwidth Vs Path Reference Number

4.3 Simulation Result for light path selection based on Delay

This section Discuss the simulation results for selection of light-path for a given set of source (s) and destination (d) pair based on delay as the required parameter. Fig.4.3 and Fig.4.4 shows the plot between the delays vs. path reference number for each source-destination pairs. The delay for a path is computed by taking different wavelength values. Here the plot shows the best suitable light-path based on delay constraints. The path corresponding to the lowest delay values is the best suitable light-path for the client.

4.4 Simulation Result for light path selection based on Q-Factor

This section Discuss the simulation results for selection of light-path for a given set of source (s) and destination (d) pair based on both bandwidth and delay in terms of Q-Factor. The Fig.4.5 and Fig.4.6 shows the Q-Factor of the light-paths with their

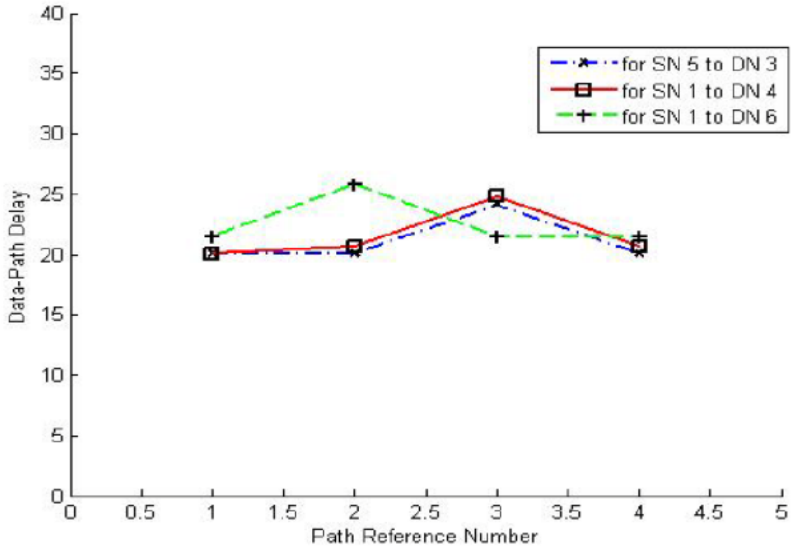

Figure 4.3: Delay Variation for multiple Light-Path of Alumina

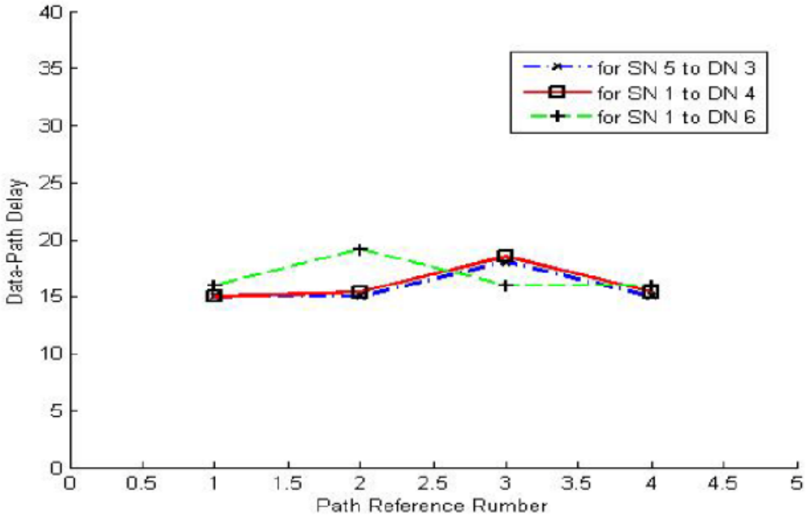

Figure 4.4: Delay Variation for multiple Light-Path of Silica

Table 4.1: Simulation for Best path Selection of Alumina

SN	DN	P-P	PRN	QF	PPRN	RQF	BP
1	4	1-2-3-4	1	24.9	2	25.6	3
		1-2-4	2	31.017	4		
		1-6-4	3	25.84	3		
		1-5-4	4	24.0	1		
5	3	5-6-3	1	39.44	4	25.6	4
		5-1-2-3	2	24.40	2		
		5-2-3	3	20.72	1		
		5-4-3	4	24.81	1		
1	6	1-2-3-6	1	23.489	1	25.6	2
		1-4-6	2	31.4104	3		
		1-5-6	3	31.992	4		
		1-2-6	4	29.1937	2		

corresponding path reference number and presented the best estimated light-path. The path corresponding to highest Q-Factor is the best estimated light-path.

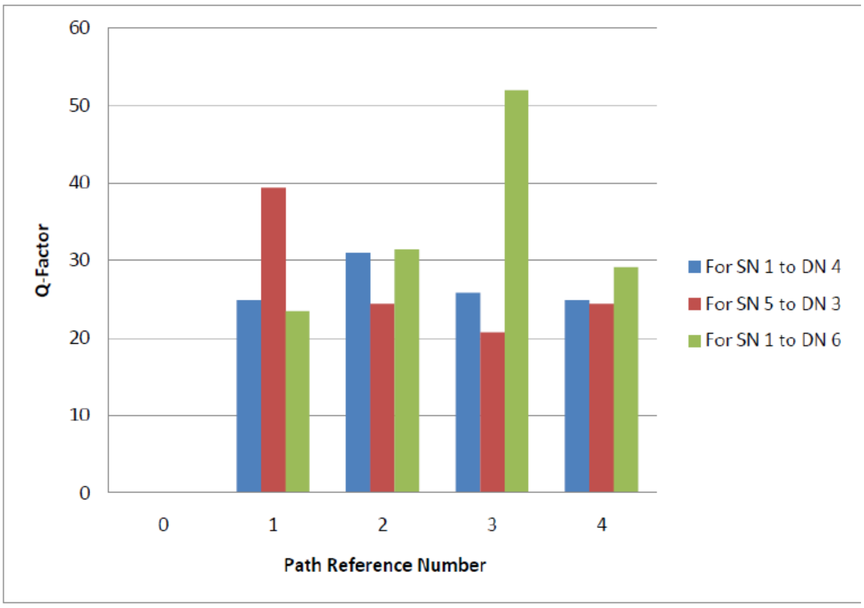

Figure 4.5: Q-Factor variations for multiple Light- Paths of Alumina Material

Note: PP = Possible Path,BP = Best path, PPRN = Possible path reference number, RQF = Required Q-Factor of Clients

The Table 4.1 shows the simulation results for computation of overall Q-Factor, best path reference number and the best path selection. We have taken Q-Factor of 25.6

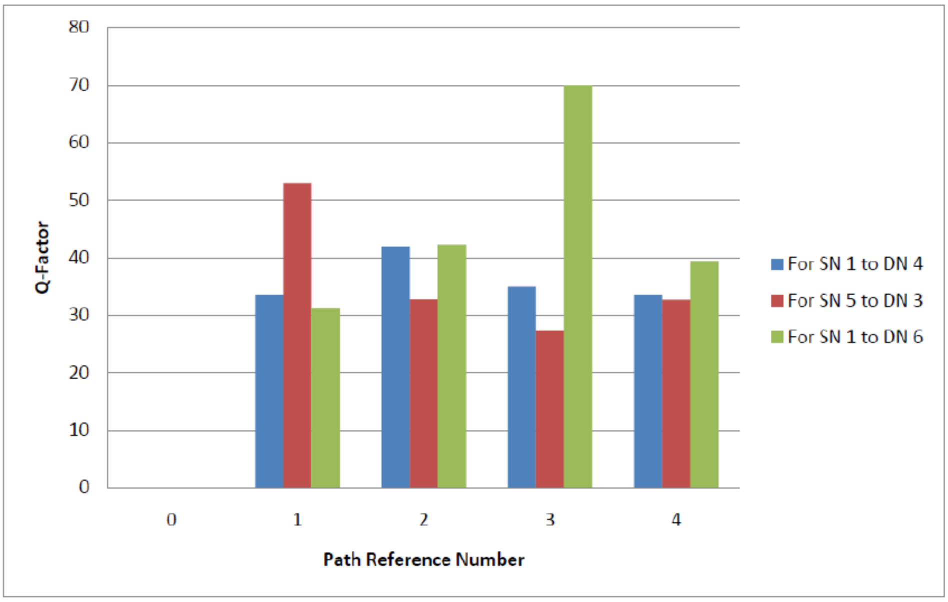

Figure 4.6: Q-Factor variations for multiple Light- Paths of Silica Material

as the client requirement for all the source-destination pair and the corresponding best path (BP) is shown in the table. According to the Table 4.1, Fig.4.7 shows the plot of Q-Factor vs. the best possible path reference number, which is nothing but the assigned new path reference number. From this plot, the best data-path can be selected for a source-destination pair of a client based on their required Q-Factor. For example, if a client has average Q-Factor requirement of 25.6 for the source destination pair $(5, 3)$, then in accordance with the proposed algorithm, the new path reference number 4, which will be the best path for the client.

4.5 Simulation for Fiber Material Selection

In our simulation, we consider the parameter mention in Table 4.1 we have obtain the best suitable OVPN connection by considering Delay as the only quality requirement. In this work we have taken silica glass as the fiber material and also doped material of silica with increase refractive index. Silica exhibits fairly good optical transmission over a wide range of wavelengths. In the optical network refractive index play a major role in the designing of optical fiber. Silica glass can be doped with different material to get raised refractive index such as Aluminium oxide. Here we have calculated the delay

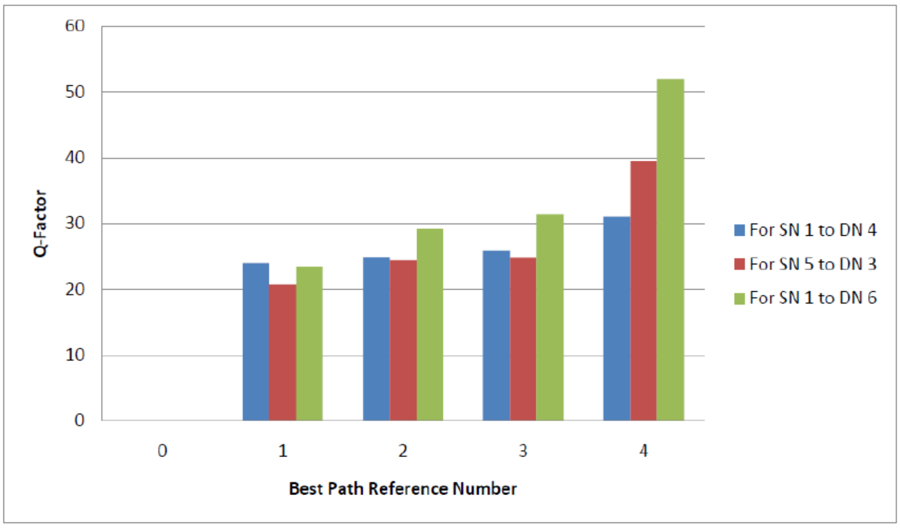

Figure 4.7: Q-Factor variation with Best Light- paths of Alumina material

Table 4.2: Parameters For Simulation

Parameters	Value
Pulse Broadening Factor(δ)	0.1
Wavelength(λ)(nm)	1280,1300,1330
Fit Parameter(Alumina)	a=1.5586,b=1.52365,c=0.010997
Fit Paremeter (Silica)	a=1.30907,b=1.04683,c=0.01025
Fit Paremeter (Beta Barium Borate)	a=146357,b=1.26172,c=0.01628

constrains of silicon oxide and increase refractive index material Aluminium oxide to study their behavior for the OVPN connection.

Following are the results for source node1 and destination node4, when above described algorithm is simulated using MATLAB.

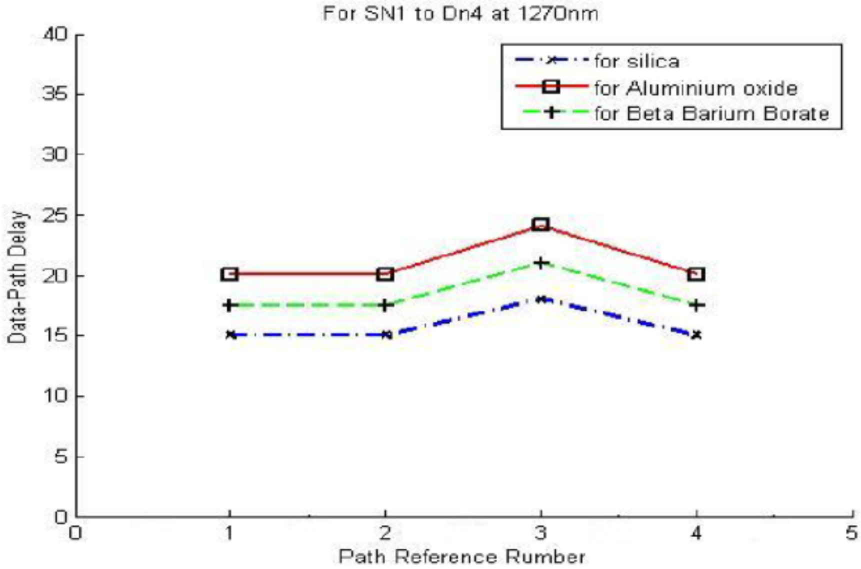

Figure 4.8: Delay variations with Light- paths for SN1 to DN4 at 1270 nm for diff fiber material

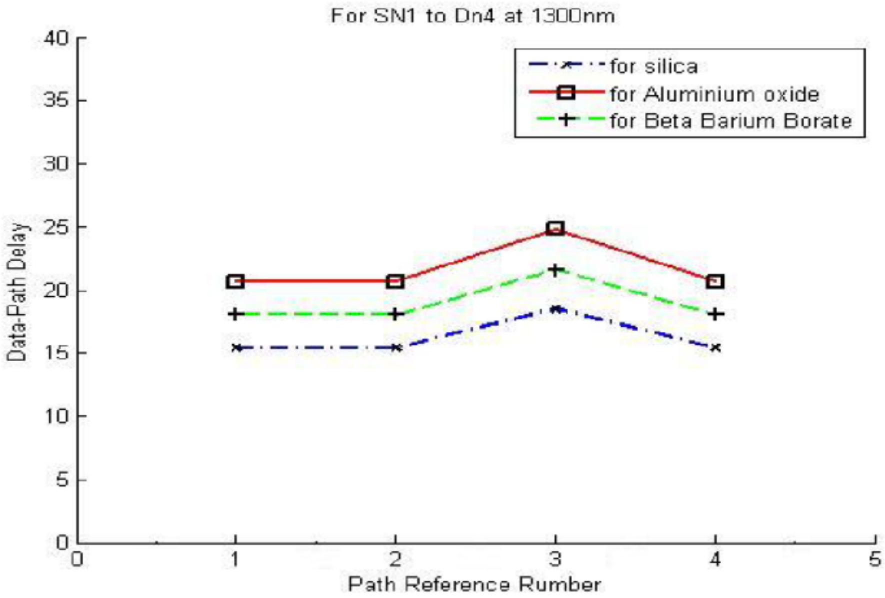

Figure 4.9: Delay variations with Light- paths for SN1 to DN4 at 1300 nm for diff fiber material

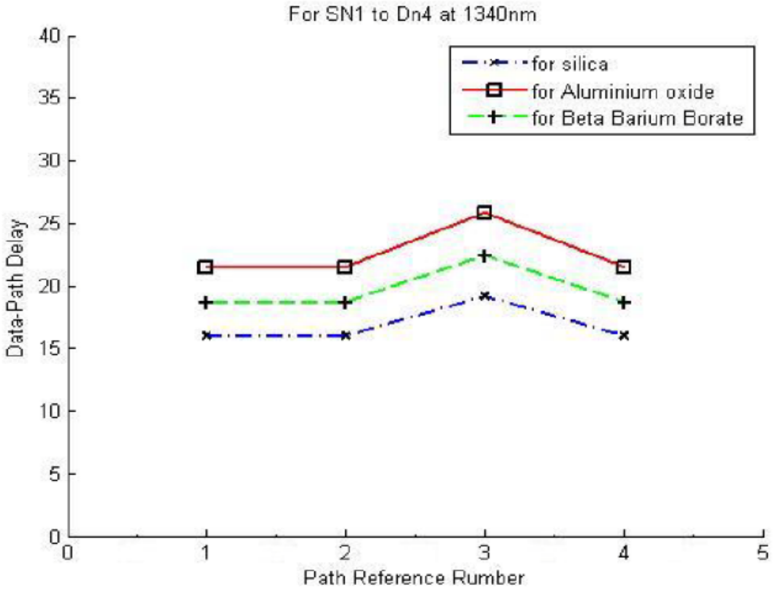

Figure 4.10: Delay variations with light- paths for SN1 to DN4 at 1340 nm for diff fiber material

Following are the results for source node1 and destination node6, when above described algorithm is simulated using MATLAB.

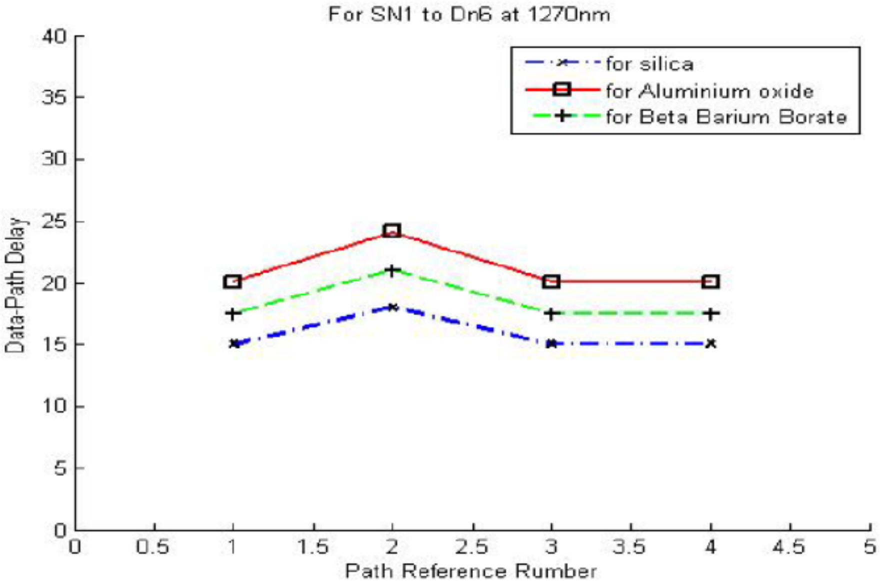

Figure 4.11: Delay variations with Light-path for SN1 to DN6 at 1270 nm for diff fiber material

Here we have taken three fiber material such as Alumina (aluminium Oxide) ,Silica,and Beta Borium Borate and compare their delay for different source and destination pair.From this comparisiom we can choose the minimum delay material for the Light-Path

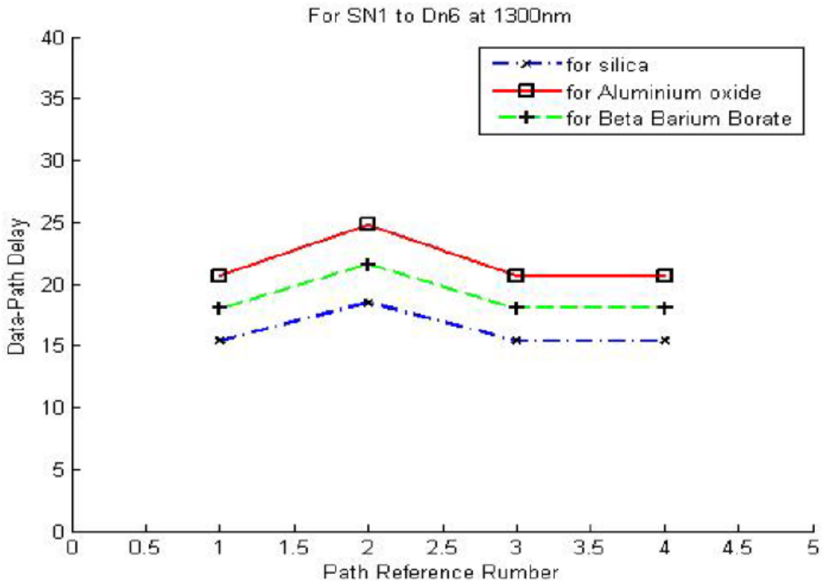

Figure 4.12: Delay variations with Light- paths for SN1 to DN6 at 1300 nm for diff fiber material

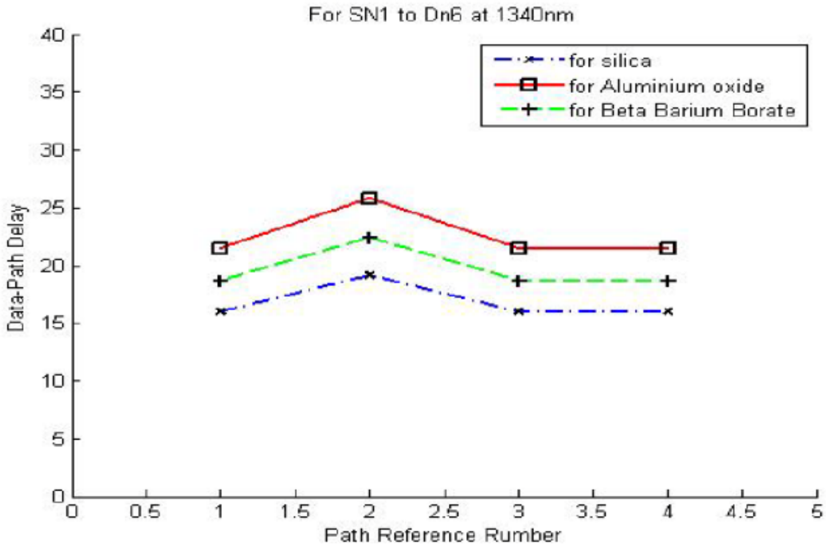

Figure 4.13: Delay variations with Light- paths for SN1 to DN6 at 1340 nm for diff fiber material

Chapter 5

Conclusion and Future Work

Concluions

Future Work

Chapter 5

Conclusion and Future Work

This chapter presents the conclusion of the thesis and describing future directions. Section 5.1 summarizes the conclusion of the thesis. Section 5.2 highlights the directions for the future work.

5.1 Conclusions

In this thesis, We have presented an algorithm that determines the condition when to provision light-paths or remove existing ones in a GMPLS network. Here we have considered three scenarios to provision a best suitable light-path as per the client requirements of bandwidth and delay. If the light-path provisioned by bandwidth and delay, the corresponding light-paths might not be suitable for one of the requirements. In case of light-path provisioning based on Q-Factor, the corresponding path will be well suited to both the requirements, which we say a guaranteed service. What makes the algorithm unique is the fact that it performs traffic engineering at TCM for both IP and Optical layer by allocating light-path to the end clients. This mechanism performs a global optimization based upon three factors such as aggregated flow, delay and Q-Factor requirements. The outcome of the global optimization is a new allocation rate and decision criteria to drop or add light-paths for an existing or new clients.

5.2 Future Works

The proposed method provides a Light-Path selection mechanism, which flexible to the service provider as well as the client.Based on the client requirement our method provide the suitable path by considering the required parameters. This method can be further enhanced by adding a concept of Generalised Multi Protocol Label Switching (GMPLS), which is applied in Optical Virtual private Network (OVPN). Also this is method can be improved in data transmission of Storage Area Network (SAN).

Bibliography

[1] H. Beyranvand and J. Salehi, “Multiservice provisioning and quality of service guarantee in wdm optical code switched gmpls core networks,” *Lightwave Technology, Journal of*, vol. 27, pp. 1754 –1762, june15, 2009.

[2] C. Saradhi and S. Subramaniam, “Physical layer impairment aware routing (pliar) in wdm optical networks: issues and challenges,” *Communications Surveys Tutorials, IEEE*, vol. 11, pp. 109 –130, quarter 2009.

[3] L. Georgiadis, R. Guérin, V. Peris, and R. Rajan, “Efficient support of delay and rate guarantees in an internet,” *SIGCOMM Comput. Commun. Rev.*, vol. 26, pp. 106–116, August 1996.

[4] J. Glasmann, M. Czermin, and A. Riedl, “Estimation of token bucket parameters for videoconferencing systems in corporate networks,” *SoftCOM*, vol. 2000, pp. 10–14, 2000.

[5] S. Blake, D. Black, M. Carlson, E. Davies, Z. Wang, and W. Weiss, “An architecture for differentiated service,” 1998.

[6] N. Zhang and H. Bao, “Research on wdm optical transport network with gmpls technology,” in *Computer Science and Information Technology, 2009. ICCSIT 2009. 2nd IEEE International Conference on*, pp. 323 –326, aug. 2009.

[7] L. Zhang, S. Deering, D. Estrin, S. Shenker, and D. Zappala, “Rsvp: a new resource reservation protocol,” *Communications Magazine, IEEE*, vol. 40, pp. 116 –127, may 2002.

[8] Z.-L. Zhang, Z. Duan, L. Gao, and Y. T. Hou, "Decoupling qos control from core routers: a novel bandwidth broker architecture for scalable support of guaranteed services," *SIGCOMM Comput. Commun. Rev.*, vol. 30, pp. 71–83, August 2000.

[9] G. Bernstein, B. Rajagopalan, and D. Saha, *Optical Network Control: Architecture, Protocols, and Standards*. Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc., 2003.

[10] Q. Liu, M. Kok, N. Ghani, V. Muthalaly, and M. Wang, "Hierarchical inter-domain routing in optical dwdm networks," in *INFOCOM 2006. 25th IEEE International Conference on Computer Communications. Proceedings*, pp. 1 –5, april 2006.

[11] B. Mukherjee, *optical WDM Networks*. Optical Network Series, Springer.

[12] G. Agrawal, *Fiber-Optic Communications Systems*. Wiley, 3rd ed., 2002.

[13] O. Komolafe and J. Sventek, "Rsvp performance evaluation using multi-objective evolutionary optimisation," in *INFOCOM 2005. 24th Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings IEEE*, vol. 4, pp. 2447 – 2457 vol. 4, march 2005.

[14] E. O. Naoaki Yamanaka, Kohei shiomoto, "Gmpls technologies broadband backbone networks and systems," Taylor and Francis 4th ed, 2006.

[15] J. Lang, "Link management protocol (lmp)," ietf draft, http://www.ietf.org/internet-drafts/draft-ietf-ccamp-lmp-10.txt, Oct 2003.

[16] J. Strand, A. Chiu, and R. Tkach, "Issues for routing in the optical layer," *Communications Magazine, IEEE*, vol. 39, pp. 81 –87, feb 2001.

[17] Y. Huang, J. Heritage, and B. Mukherjee, "Connection provisioning with transmission impairment consideration in optical wdm networks with high-speed channels," *Lightwave Technology, Journal of*, vol. 23, pp. 982 – 993, march 2005.

[18] Y. Miyajima, M. Ohnishi, and Y. Negishi, "Chromatic dispersion measurement over a 120 km dispersion-shifted single-mode fibre in the 1.5 micrometer wavelength region," *Electronics Letters*, vol. 22, pp. 1185 –1186, 23 1986.

Dissemination of Work

1. S. K. Das, S. K. Naik and S. K. Patra ``Centralized Data-path Control Mechanism for DWDM/GMPLS Network ˝, *International Conference on Signal Acquisition and Processing (ICSAP 2011)*, February 26-28, 2011, Singapore.
2. S. K. Das, S. K. Naik and S. K. Patra ``Fiber Material Dependent QoS Analysis and OVPN Connection Setup Over WDM/DWDM Network ˝, *TENCON-2011*, November 21-24, 2011, Bali, Indonesia.(Submitted).
3. S. K. Das, S. K. Naik and S. K. Patra ``A GMPLS based QoS framework for Optical Virtual Private Network ˝,*IEEE/OSA, Journal Of Light wave Technology*, May 2011.(In Press).