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ARCHITECTURAL ASPECTS, COMPARATIVE PERFORMANCE ANALYSIS AND NETWORK MANAGEMENT OF NEXT GENERATION OPTICAL NETWORKS

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CERTIFICATE

This is to certify that that the dissertation entitled *"Architectural Aspects , Comparative Performance Analysis And Network Management of Next Generation Optical Networks"* which is being submitted by **Mr. Rakesh Mohanty** to the School of Computer & Systems Sciences, JAWAHARLAL NEHRU UNIVERSITY, NEW DELHI for the award of Master of Technology in Computer Science & Technology is a bonafide work carried out by him under my supervision.

This is an authentic work and has not been submitted in part or full to any university or institution for award of any Degree.

4-01-02

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ABSTRACT

The tremendous growth of internet and explosion of WWW have brought about an acute need for broadband communications , which have led people to explore optical networking technology. The high capacity optical networks have witnessed a rapid transition from research laboratories to commercial deployments , the revolution being shifted from First generation SONET/SDH to Next generation ATM-PON networks.

The dissertation highlights on architectural aspects of SONET/SDH , Broadcast and Select networks , Wavelength Routing networks and Access networks. Then special emphasis is given on architectures of current and next generation optical networks like OTDM , DWDM , OTN , IP o WDM and ATM –PON . Architectural variations for next generation optical networks are analyzed thread bare.

A comparative performance analysis of all optical networks are done . The factors considered includes Transmission capacity , Traffic and Congestion control , Efficient routing , Efficient switching and Degree of transparency . Eventually , network management functions of optical networks are discussed , which includes Configuration management , Performance management and Fault management . The dissertation also incorporates many existing problems in the current generation and networking solutions for next generation optical networks.

CONTENTS

CHAPTER 1 - INTRODUCTION

The bandwidth explosion in communication networks due to tremendous growth of internet & World Wide Web have brought more and more users online . Thus large amount of bandwidth is consumed due to data transfers involving video and images . Traffic growth has also significant effects in all parts of networks all the way from access to the core .

1.1. Why Optical Networks ? :

High speed Optical networks with enormous capacity is a new technology to meet the increasing demands for Quality of Service (QoS) within emergent multimedia applications. This also results in reducing cost of bandwidth , increasing transmission capacity & handling network traffic growth efficiently.

The promises of Optical Networks are tempered by the technology implemented in the elements of Optical Networks so that the networks become bit rate and protocol independent .Advances in networking architectures , protocols and optical communication components have increased the overall value of optical networks by enabling more applications.

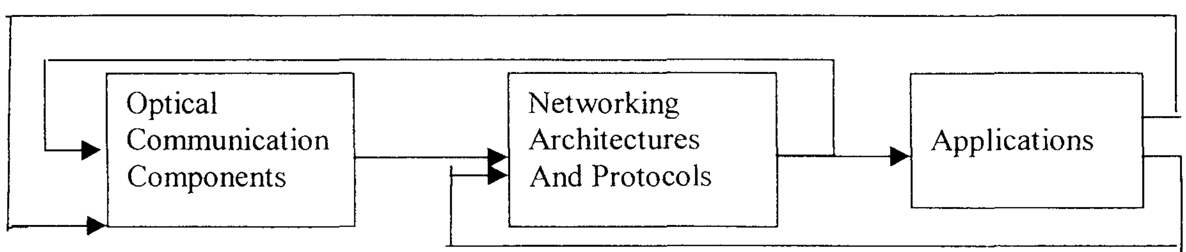

FIG. 1 Advancing the Value of Optical Networks

1.2. Upgrading Transmission Capacity :

The transmission capacity of an optical network can be upgraded using multiplexing techniques. Multiplexing is the simultaneous transmission of different messages over the communications network through a partitioning of the available band width or other resource.

Optical Networks make use of 3 types of multiplexing techniques namely Space Division Multiplexing (SDM) , Wavelength Division Multiplexing(WDM) and Time Division Multiplexing (TDM) .

1.2.1. Space Division Multiplexing :

It is the partitioning of physical space to increase transport bandwidth. For example combining multiple traffic stream having a set of fibers into a composite high speed single fiber or using several cables within a given network link.

1.2.2. Wavelength Division Multiplexing :

It is the partitioning of frequency spectrum into a set of independent channels(also called Frequency Division Multiplexing) . In Optical Networks , it is referred to as (Dense) Wavelength Division Multiplexing (DWDM or WDM) which enables a given fiber to carry traffic on many distinct wavelengths.

1.2.3. Time Division Multiplexing :

It divides the band width's time domain into repeated time slots of fixed length . Using TDM , multiple signals can share a given wavelength , if they are nonoverlapping in time.

1.3. First Generation Optical Networks :

First generation Optical Networks use optical fiber purely as transmission medium. All switching , processing and routing are done electronically. All the networks are single wavelength networks as well. Examples are SONET , SDH , FDDI etc.

In first generation networks , the electronics at anode must not only handle all the data intended for that node , but also all the data that is being passed through that node into other nodes in the networks . If the later data could be routed through in the optical domain , the burden on underlying electronics at the node will be significantly reduced. This is one of the key drivers for the second generation optical networks.

1.4. Second Generation Optical Networks :

Second Generation Optical Networks attempt to perform more functions in optical domain such as routing and switching wavelengths and packets in optical form. Examples are OTDM , WDM networks .

Second generation optical networks may offer 3 types of services to higher network layers.

They are (1) Light path Service.

(2) Virtual Circuit Service.

(3) Datagram Service.

1.4.1. Lightpath Service :

It is applicable for WDM networks and can be thought of as circuit switched service . A Lightpath is a connection between two nodes in the network and set up by assigning a dedicated wavelength to it on each link in its path. Here individual wavelengths are likely to carry data at higher bitrates and entire bandwidth is provided by to the higher layer by a Lightpath . This lightpath service is likely to be most commonly used service to start with and can be used to support high speed connections for a variety of overlaying networks.

1.4.2. Virtual Circuit Service :

Here the network offers a circuit switched connection between two nodes . The bandwidth offered on the connection can be smaller than the full bandwidth available on a link or wavelength. The network must incorporate some form of Time Division Multiplexing to combine multiple virtual circuits onto a wavelength in WDM links or onto the transmission bit rate in case of OTDM links.

1.4.3. Dtagram Service :

This service allows short packets or messages of information to be transmitted between the nodes in the network without the overhead of setting up explicit connections. IP (Internet Protocol) is an example of protocol providing datagram services.

1.5. Classes of Optical Networks :

Based on networking mode , Optical Networks can be either Connection Oriented (CO) or Connection Less (CL).

CO networks are those , in which connection set up is performed prior to information transfer .

In contrast , In CL networks , No explicit connection set up actions are performed prior to transmitting data . Instead data packets are routed to their destinations based on information on their headers.

Based on types of optical components used , Optical Networks can be divided into 4 Classes of networks.

They are (1) Optical Link Networks.
(2) Broadcast & Select Networks .
(3) Wavelength Routing Networks .
(4) Photonic Packet Switched Networks.

Optical Link Networks :

It consists of all electronics switches interconnected by optical links which can be single channel or multichannel point-to-point links or shared medium broadcast links . Point-to-point multichannel links are created by placing WDM multiplexors /demultiplexors at the ends of the fiber. Shared medium broadcast links are created through the use of WDM passive star couplers. Electronics switches used can be all packet switches or all circuit switches or a hybrid of both packet and circuit switches.

Broadcast and Select Networks :

Here the data is broadcast on all the outgoing links and receivers are programmed to select the channels , they should receive. It may be single hop or multihop. In single hop , the user data only traverses optical switching components on the end to end path. In multihop , the user data traverses a combination of optical and electronics switching components.

Wavelength Routing Networks :

It includes optical circuit switches and optically tunable transmitters and receivers . It may be singlehop or multihop.

Photonic Packet Switched Networks :

It includes optical packet switches and optionally optical circuit switches and tunable transmitters and receivers.

Based on packet switched modes ,Optical Network can be divided into 2 categories : Slotted (Synchronous) and Unslotted (Asynchronous).

Slotted Networks :

In slotted networks , all packets have the same size. They are placed together with the header inside a fixed time slot , which has a longer duration than packet and header to provide guard time.

Unslotted Network :

In an unslotted network , the packets may or may not have the same size . Packets arrive and enter the switch without being aligned.Therefore packet switch action can take place at any point of time.

CHAPTER 2 - GENERAL ARCHITECTURES

The general architectures of Optical networks includes SONET/SDH , Broadcast & Select Networks , Wavelength Routing Networks and Access Networks.

2.1. SONET/SDH :

SONET (Synchronous Optical Networks) is the current transmission and multiplexing standard for high speed signals within the carrier infrastructure in North America. It provides framing as well as a rate hierarchy and optical parameters for interfaces ranging from 51 Mb/s upto 9.8 Gb/s. Initially developed by Bell Communications Research, it has been adopted as a standard by ANSI (American National Standard Institute). SDH has been adopted in Europe and Japan.

SONET/SDH defines explicit multiplexing method s that makes it easy to extract low speed streams from a high speed stream. It defines standard optical interfaces that enables interoperability between equipments of different vendors on the link . It also incorporates specific network topologies and specific optical protection schemes to provide high availability services.

2.1.1. SONET / SDH Layered Architecture :

It consists of 4 sublayers . They are (1) Path Layer
(2) Line Layer
(3) Section Layer
(4) Physical Layer

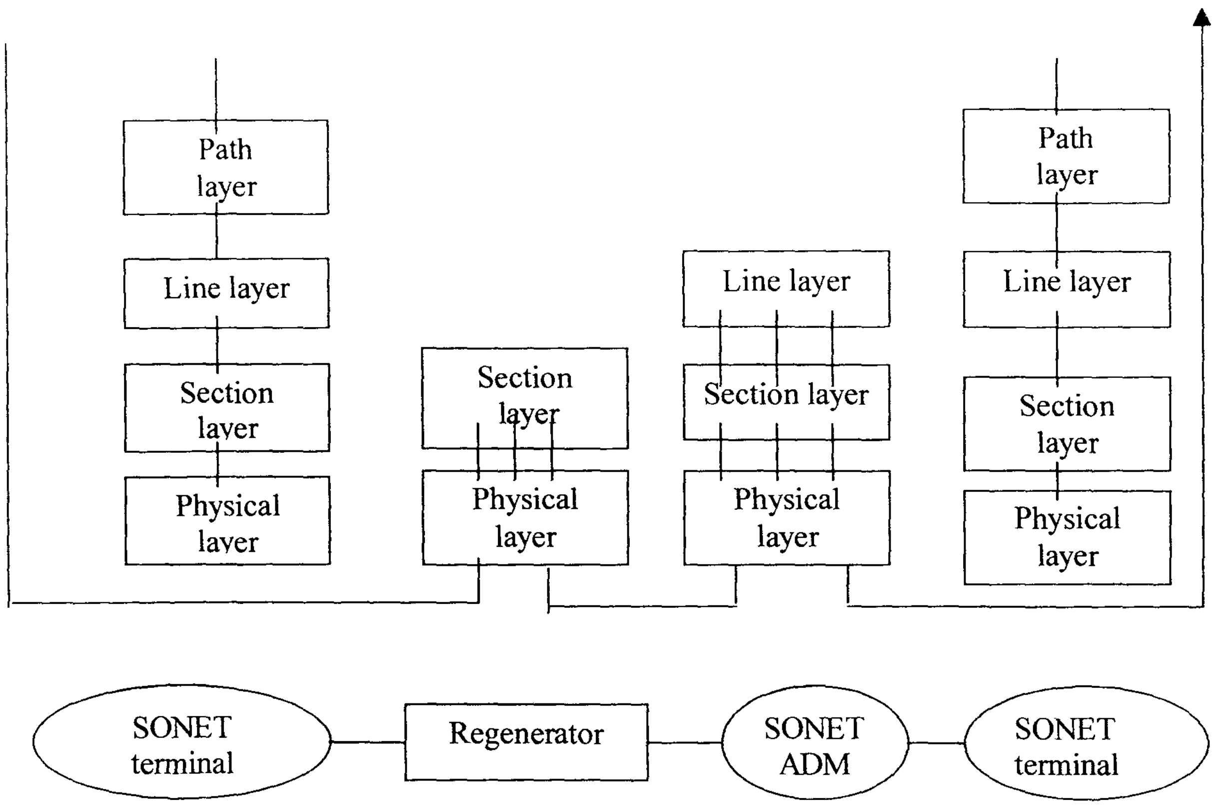

FIG. 2 SONET/SDH Architecture

Path Layer :

It is responsible for end to end connections between nodes and is needed only at the ends of a SONET connection . It also monitors and tracks the status of a connection. The Path Layer may be thought of as being equivalent to network Layer in the classical protocol hierarchy.

Line Layer :

It multiplexes a number of path layer connections onto a single link between two nodes. It is also known as Multiplex section sublayer. Thus the line layer is present at each intermediate node along the route of a SONET connection. It is also responsible for performing certain types of protection switching to restore service in the event of a line failure.

Section Layer :

The Section layer is present at each regenerator in the network. Each link consists of a number of sections corresponding to link segments between regenerators . Line & Section layer both together correspond to Datalink layer in the classical protocol hierarchy.

Physical Layer :

It is responsible for actual transmission of bits across the fiber.

2.1.2. **SONET / SDH Technology :**

SONET/SDH uses a specific frame format to carry data plus overhead bytes . SONET channels are synchronous. The synchronization of channels are supported by pointers , which dictate the initial byte position of each channel within the SONET frame. These pointers are used to multiplex digital signals within a single SONET frame efficiently.

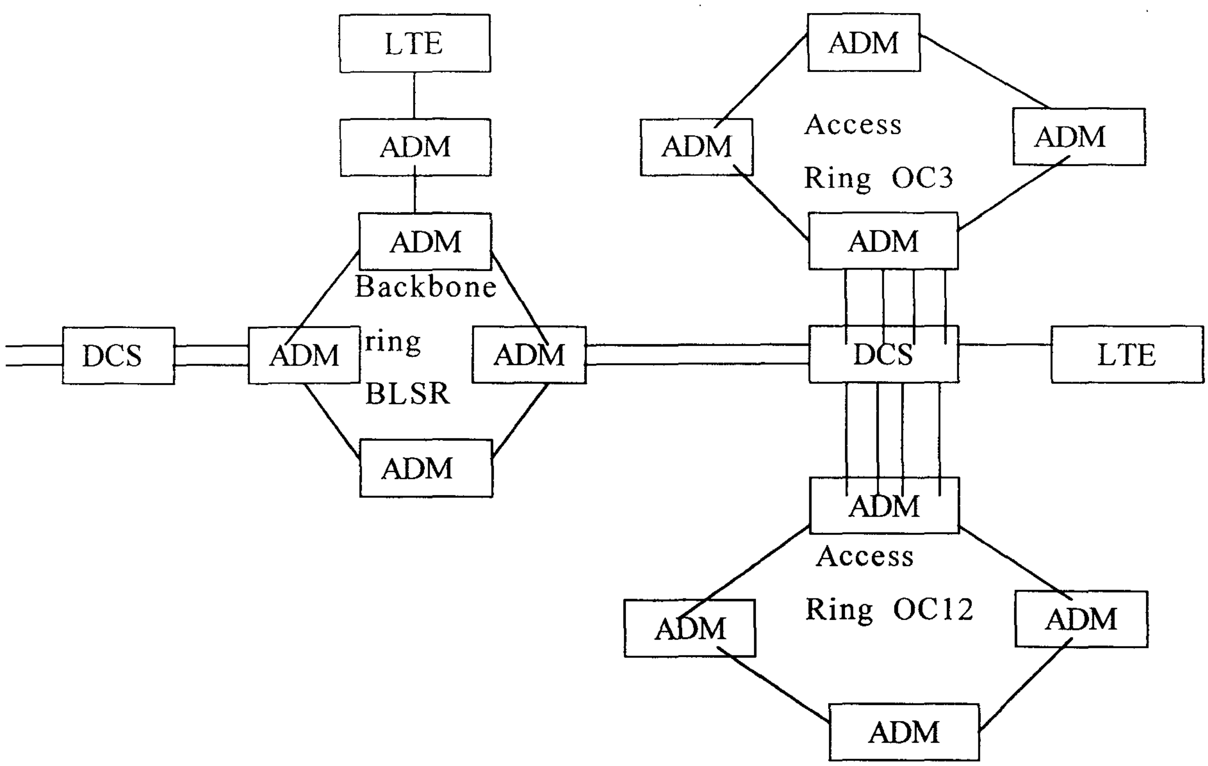

FIG. 3 SONET Ring Network

The SONET network consists of SONET rings, composed mainly of Add/Drop multiplexors (ADMs). ADMs are SONET devices , which perform low rate signal grooming into the high speed SONET signals used in the rings. Rings can be of various speeds OC3 , OC12. Rings can be UPSR (Unidirectional Path Switched Rings) and BLSR (Bi-directional Line Switched Rings). DCS (Digital Cross Connect) devices are used to connect rings together. A DCS crossconnects low speed signals across rings providing multiplexing/demultiplexing and switching functions. LTE are Line Terminating Equipments where SONET signals terminate.

2.2. Broadcast and Select Networks :

In networks based on Broadcast architecture , the connectivity is provided in an almost trivial fashion. Here the network sends the the signals received from each node to all the nodes. Thus no routing function is provided by the network. Each node must select the desired signal for reception from the set of signals transmitted simultaneously. A sharing medium is called for sharing the information originating at anode with all the other nodes . Examples are Ethernet , Token ring , FDDI (Fiber Distributed Data Interface) networks.

2.2.1. Topologies For Broadcast Networks :

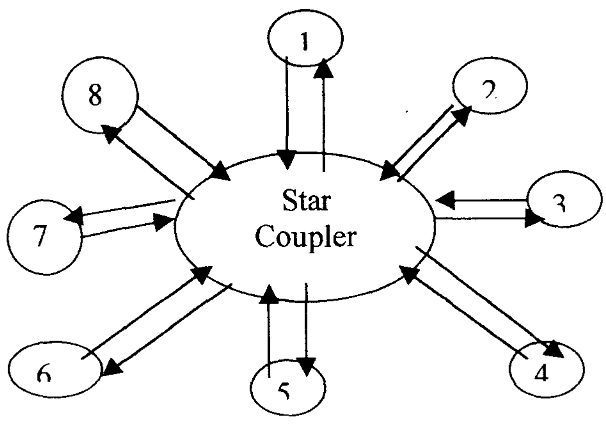

FIG. 4 STAR Topology

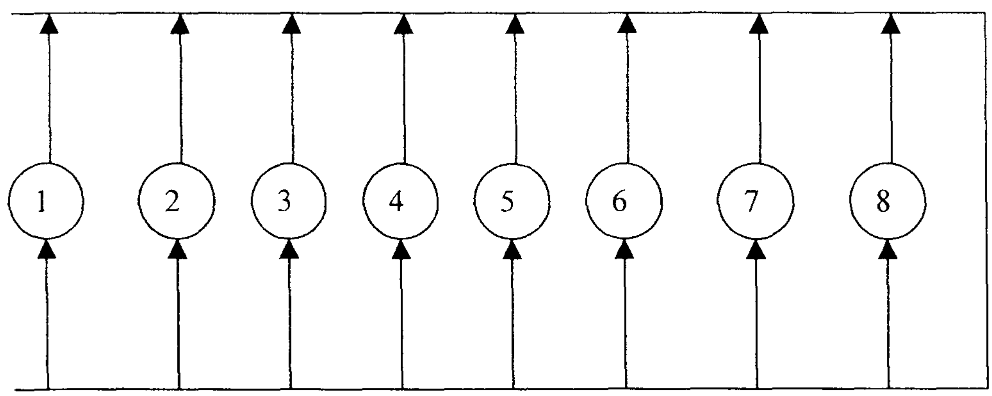

FIG. 5 BUS Topology

The most popular topologies are Star and Bus topology. An N * N star coupler can be realized using (N/2) log N individual 2 * 2 couplers. (assuming N is a power of 2) or directly in integrated form with a common coupling region. A bus topology with N nodes calls for 2N 2* 2 couplers . The bus topology suffers from greater signal losses and is not widely used

2.2.2. A WDM B & S network Architecture :

WDM B & S networks are implemented using star topology because of its superiority over other topologies in distributing the transmitted power equally to all the stations without inducing much excess loss.

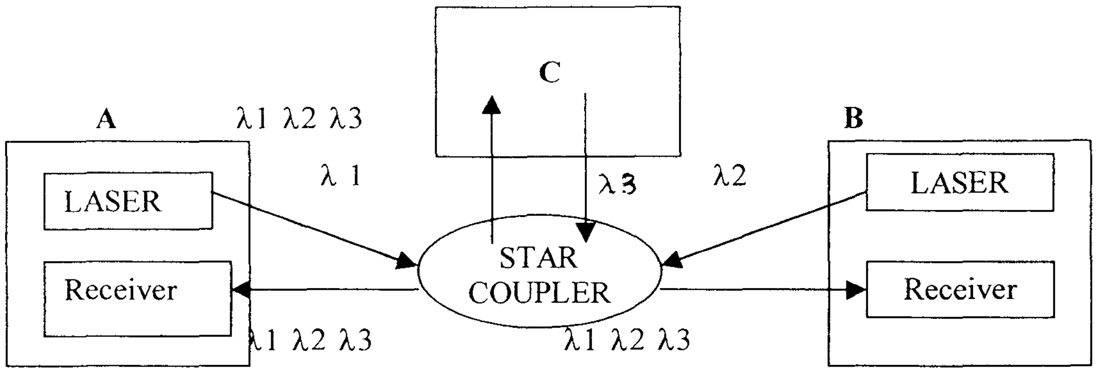

FIG. 6 WDM B & S Architecture

Here different nodes transmit at different wavelengths. Their signals are broadcast by a passive optical star coupler situated in the middle of the network to all the nodes .The coupler combines the signals from all the nodes and delivers a fraction of power from each signal onto each output port. Each node employs a tunable optical filter to select the desired wavelength for reception.

2.2.3. Limitation :

The number of nodes in these networks is limited because the wavelengths can not be reused in the network. There can be at most one simultaneous transmission on a given wavelength because transmitted power from a node must be split among all the receivers in the network.

2.3. Wavelength Routing Networks :

The nodes in the network are capable of routing different wavelengths at an input port to different output ports. This enables us to set up many simultaneous lightpaths using the same wavelength in the network. Thus the capacity of the network can be used spatially.

2.3.1. Topology for WR Network :

In general , the topology of a WR network is an arbitrary mesh Network . It consists of wavelength cross connect (WXC) nodes interconnected by fiber links. The network provides lightpaths between pair of network nodes . A lightpath is simply a high bandwidth pipe , carrying data at up to several Gigabits per second . It is realized by allocating a wavelength on each link on the path between the two nodes . . Clearly we can not assign the same wavelength to two lightpaths on any given link.

2.3.2. Principle :

High speed data flows , which consists of TDM channels , are associated with specific optical wavelengths. They are routed through the optical network by means of their wavelengths. Without being optoelectronically converted , demultiplexed and electronically routed . This allows the realization of all optical routers , which can handle many WDM channels simultaneously without the need of very high speed electronics. The main feature of this type of optical network lies in the possibilities of performing the operations directly in the optical domain without requiring costly high speed electronic equipment.

2.3.3. <u>Architecture of a WR Network :</u>

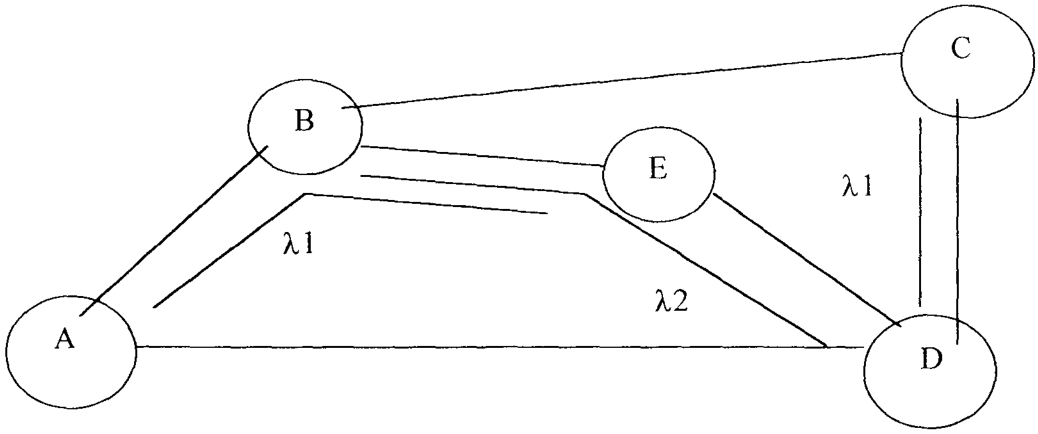

FIG. 7 WAVELENGTH ROUTING NETWORK

Here there are 3 light paths .The light path between A & D and the light path between C & D do not share any links in the network. They can therefore be set up using the same wavelength λ1 . At the same time , the light path between B & D share s a link with the ligthpath between A & D , hence must use a different wavelength. These lightpaths all use the same wavelength on every link on their path. . This constraint must be dealt with if there is no wavelength conversion capabilities within the network.

Suppose we had only 2 wavelengths available in the network and need to set up a new lightpath between nods C & E via node D . Without wavelength conversion , we would not be able to set up this lightpath. But if node D can perform wavelength conversion , then we can set up this light path using wavelength λ2 on link CD and wavelength λ1 on link DE. This architecture avoids broadcasting the power to unwanted receivers in the network.

2.4. Access Networks :

The network that runs from the service provider's facility to the home or business is called Access network . High capacity optical network should accommodate various forms of Video , high definition TV service , internet access, telecommuting , distance learning , teleconferencing.

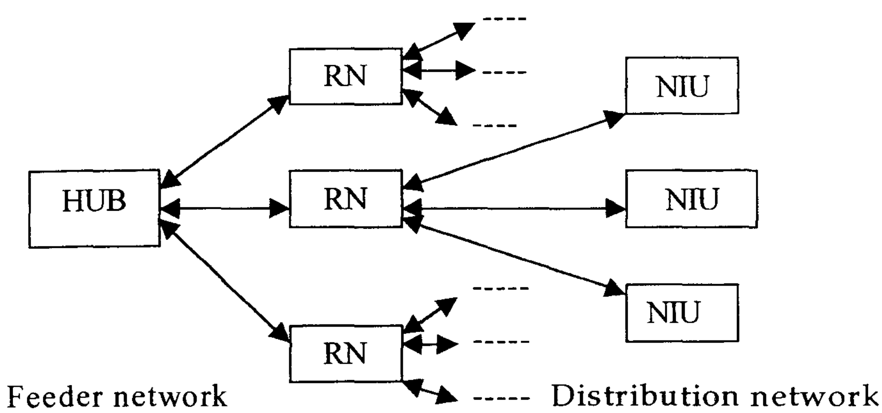

FIG. 8 Access Network

2.4.1. Architecture of Access Networks :

In broad terms , access network consists of a hub , Remote Nodes (RNs) and Network Interface Units (NIUs). A Hub is a telephone company Central Office (CO) or Cable company Headend , which serves several homes via NIUs. An NIU either may be located in a home or it may serve several homes .

Each Hub may be connected to several RNs deployed in the field, with each RN serving a separate set of NIUs. The network between the hub and the RN is called Feeder Network and the network between the RN & the NIUs is called the Distribution Network.

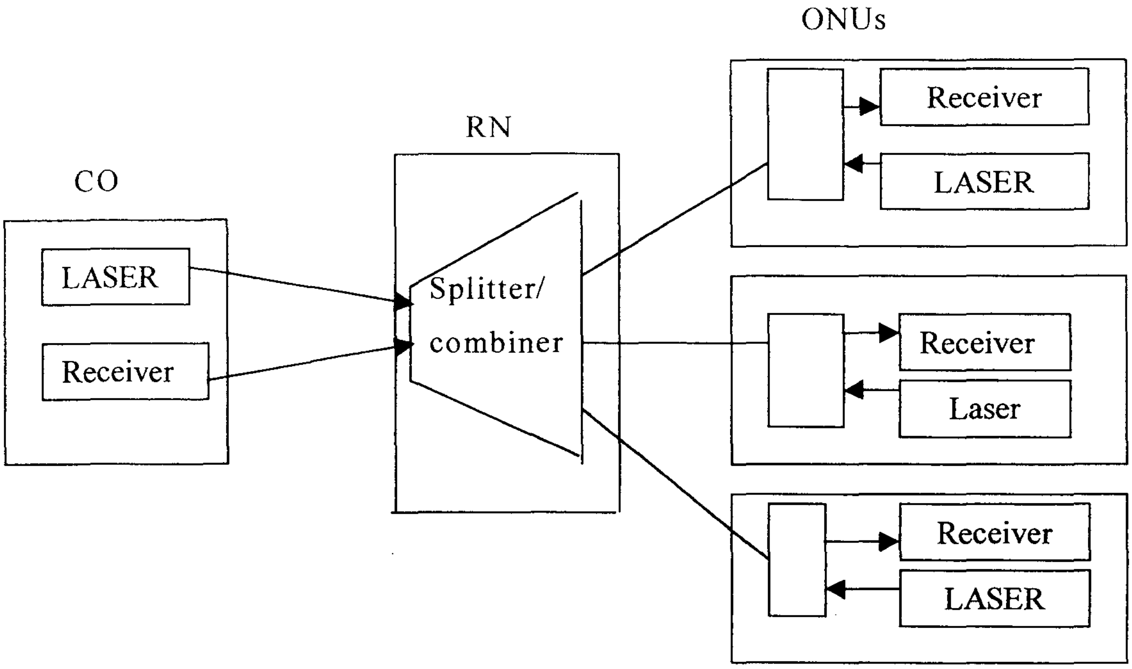

FIG. 9 OPTICAL ACCESS NETWORK

2.4.2. Optical Access Network architecture :

Optical Access Network must be simple , easy to operate and service. Passive architectures are preferable so that the network itself does not have any switching in it and does not need to be controlled .

Here data is digitally transmitted over optical fiber from the Central Office (CO) to terminating nodes called ONUs (Optical Network Units) via RNs. RN may be a passive device such as optical star coupler.

The downstream traffic is broadcast by a transmitter at Co to all the ONUs. For upstream channel , the ONUs share a channel that is combined using a coupler via fixed TDM or some other multi-access protocol. The CO transmitter can be an LED or LASER . The number of ONUs that can be supported is limited by the splitting loss in the star coupler.

The optical access network provides a generic optical access line to a variety of different classes and categories of customers. It offers both dimensions of time and wavelength in order to support a multitude of bit rate and service requirements.

CHAPTER 3 - CASE STUDY AND ARCHITECTURAL VARIATIONS

A case study of the current generation and next generation optical networks includes OTDM , DWDM , OTN , IP o WDM , ATM-PON networks. Each architectures are analyzed at length.

3.1. OTDM (Optical Time Division Multiplexing) :

The simplest form of OTDM network is Broadcast & Select network. Instead of wavelengths , different nodes get different time slots to transmit their data . The OTDM may be fixed or Statistical .

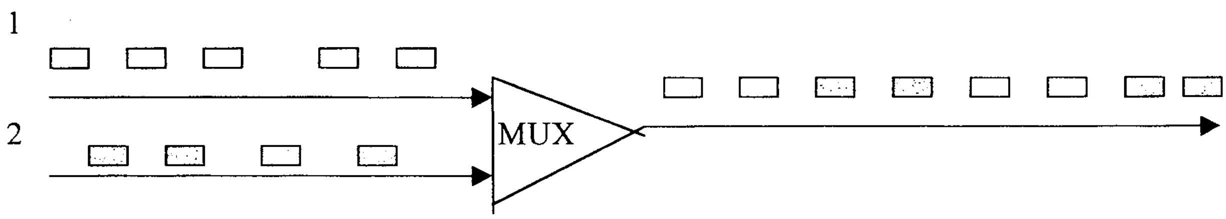

FIG. 10 FIXED TDM

3.1.1. Fixed OTDM :

It allocates a guaranted amount of bandwidth to each virtual circuit . The bandwidth of all virtual circuits on a link must be equal to the link bandwidth. This form of OTDM is widely used in telephone network to support voice traffic.

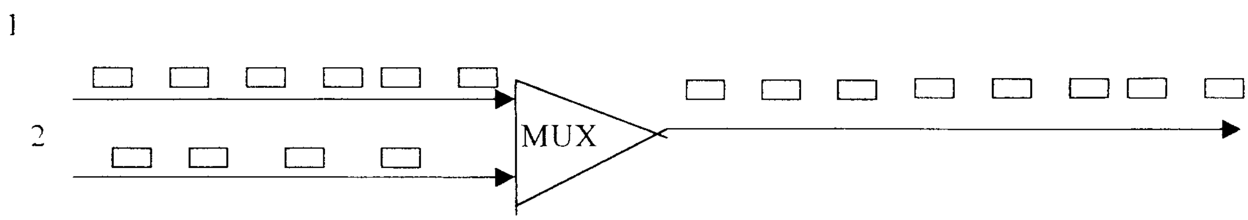

FIG. 11 STATISTICAL TDM

3.1.2. Statistical OTDM :

It uses the link bandwidth more efficiently by supporting a large number of virtual circuits on the link. It makes use of statistical properties of virtual circuits . It is implemented by breaking up the data on each circuit into short packets . This form of OTDM is widely used in internet.

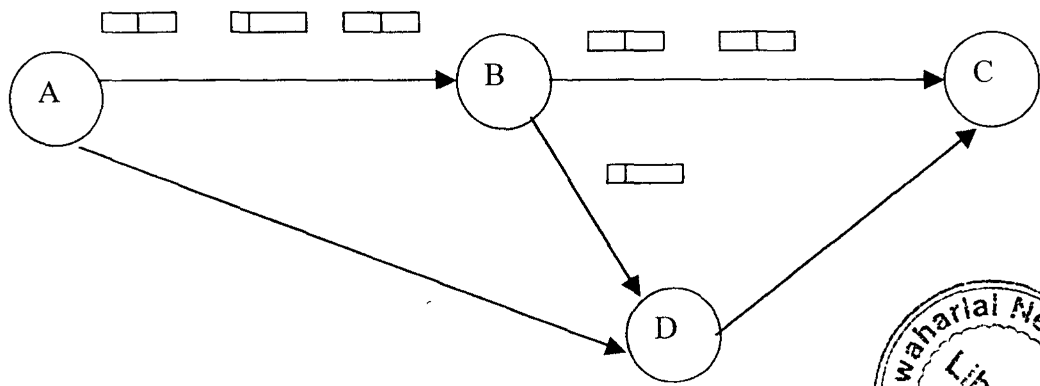

FIG.12 OPTICAL PACKET SWITCHED NETWORK

3.1.3. Optical Packet Switched Network Architecture :

A form of OTDM network is OPSN (Optical Packet Switched Network) This network attempts to perform all functions by packet switched network . It uses high speed optical packet switches instead of electronics packet switches . A node takes a packet coming in , reads its header and switches it to appropriate output port . The node may also impose a new header on the packet . It must also handle contention for output ports . If two packets coming in on different ports need to go out on the same output port , one of the packet must be buffered or sent out on another port. Ideally all the functions inside the node can be performed in the optical domain except certain functions such as processing the header and controlling the switch , which is relegated to electronic domain.

3.2. DWDM (Dense Wavelength Division Multiplexing) :

WDM is a technology that enables various optical signals to be transmitted by a single fiber . Its principle is that several signals are transmitted using different carriers occupying nonoverlapping parts of a frequency spectrum . In case of WDM the spectrum band used is in the region of 1300 nm or 1500 nm , which are two wavelength windows at which optical fibers have very low signal loss. With current technology , over 100 optical channels can be multiplexed into a single fiber . The technology is called Dense wavelength Division Multiplexing (DWDM). DWDM 's main advantage is its potential to cost effectively increase the optical fiber bandwidth many folds.

3.2.1. Long Haul DWDM Architecture :

A long haul DWDM architecture consists of a terminal node at one end , a series of line amplifiers in between and a terminal node at the other end . The transmitters are wavelength specific where as the receivers are not wavelength specific .The passive multiplexor and demultiplexor optics create fixed routing based on wavelengths such that only one signal arrives at a given receiver. The optical spectrum used is closest to the Multiplexor/Demultiplexor . Each line in the spectrum is a wavelength or optical carrier whose modulation carries data independent of other carriers There are typically 40 wavelengths separated by 100 GHz each all carried on the same fiber . Bit rate per channel is 2.5 Gb/s or 10 Gb/s . The wavelengths range over conventional band from 1530 to 1560 nm . The standard link distance is 600 km with 80 km between optical amplifiers.

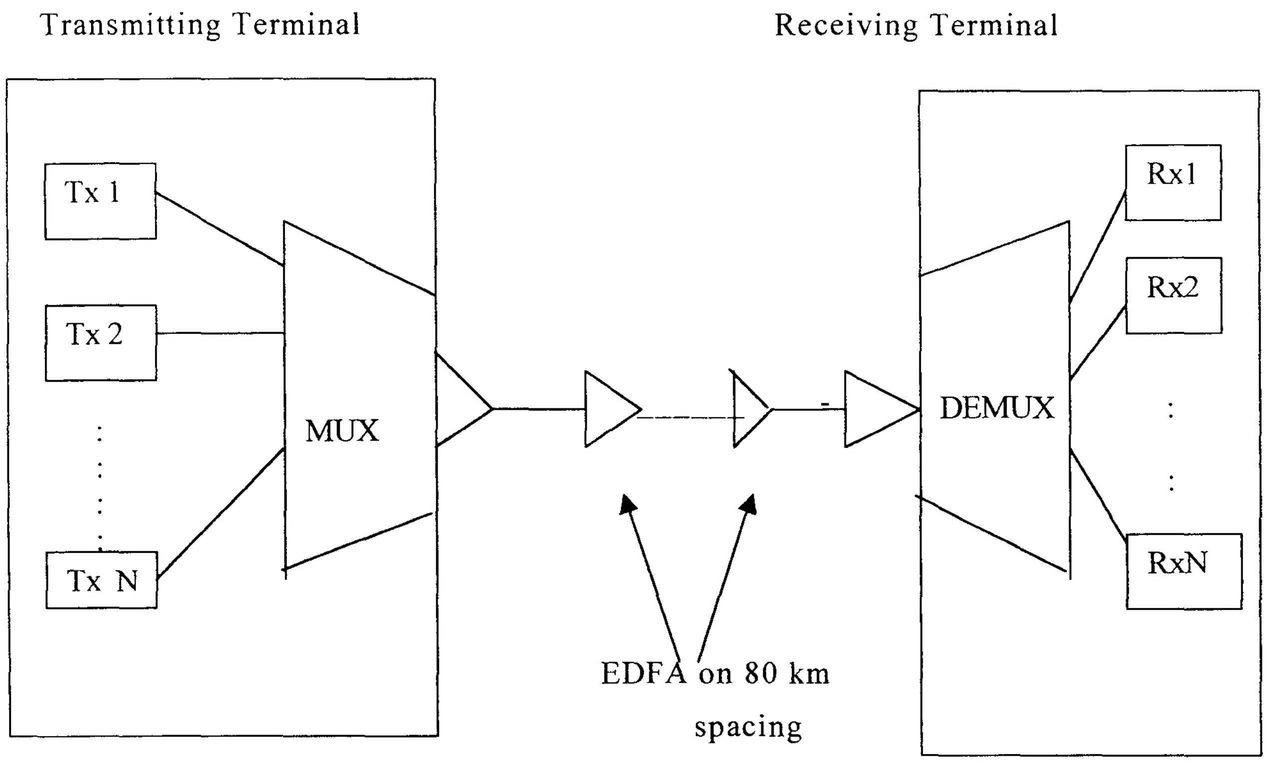

FIG. 13 DWDM ARCHITECTURE

3.3. OTN (Optical Transport Network) :

Optical Transport Networks are WDM networks providing transport services the speed of the light path is determined by the technology of the optical components (LASER , Optical amplifiers etc .).

An OTN is composed of WXC nodes plus a management system which controls the setup and teardown of light paths through supervisory functions , such as monitoring of optical devices , fault recovery and so on. There is a lot of flexibility in deployment of OTNs depending upon the transport services to be provided . One reason of this flexibility is that most optical components are transparent to signal encoding.

3.3.1. **The OTN Architecture :**

The layered architecture for OTN comprises of functional capabilities provided by optical network elements for transport , multiplexing ,routing , supervision and survivability of client signals that are processed predominantly in the optical domain. The optical network elements include optical regenerators , optical amplifiers , optical wavelength multiplexor/demultiplexors , OADMs and OXCs .

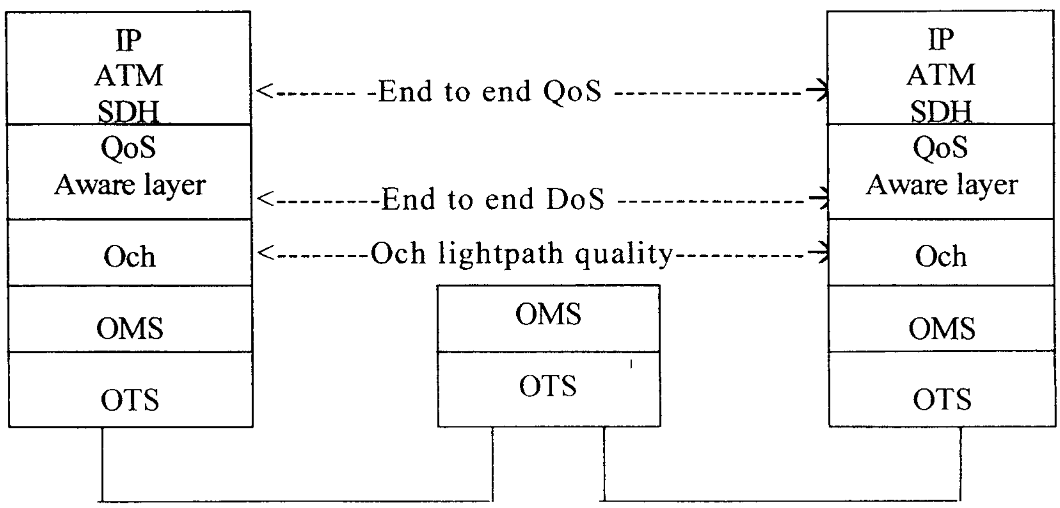

FIG. 15 OTN ARCHITECTURE

The generic functional capabilities of OTN can be decomposed into 3 independent logical transport layers.

1. OTS : (Optical Transmission Section)

It provides the functionality for transmission of optical signals on various types of optical media . Functions provided by the optical amplifiers reside in this layer .

2.OMS : (Optical Multiplex Section)

It provides the transport of a multiwavelength optical signal , including the insertion of the multiplex section overhead to ensure the integrity of the signal. It also provides multiplex section survivability . Optical network elements belonging to this layer are wavelength multiplexors and fiber crossconnects.

3.OchS :(Optical Channel Section)

It provides end to end networking of optical lightpaths for transparently carrying various client signals. It also prepares and inserts an overhead for the channel configuration information such as wavelength tag , port connectivity , pay load label (rate , format , linecode) and wavelength protection capabilities . This layer contains OXC and OADM functionality.

The quality of optical services provided on the path is measured by a set of optical parameters (bit error , delay) and behaviors (protections , monitoring and security capabilities . The QoS aware layer , where electrooptical conversion takes place , contains most of QoS functionality and provides a mapping of differential services onto equivalent optical services . QoS aware layer is closely coupled to the OTN network management required to provide end to end support for fault, configuration and performance management .

3.4. IP oWDM (Internet Protocol over WDM) :

An IP centric controlplane within optical network can support dynamic provisioning and restoration of lightpaths .Specifically Ip routing protocols and MPLS (Multi Protocol Label Switching) signaling protocols can be adopted for optical networking needs.

In an IP over optical network model , IP routers are attached to an optical core network and connected to their peers over dynamically established switched lightpaths .The optical core is incapable of processing individual IP packets . The interaction between IP routers and optical core is over a well defined signaling and routing interface called User Network Interface (UNI) . The optical network consists of multiple optical subnetworks interconnected by optical links and switches from multiple vendors. The interaction between subnetworks is over a well defined signalling an routing interface called Network Network Interface (NNI). The optical network provides point to point connectivity between the routers in the form of fixed band width light paths .

3.4.1. An Integrated IP o WDM Architecture :

Here the IP layer performs the functions of addressing and routing. The LOBS (Labeled Optical Burst Switching) MPLS layer provides Optical Burst Switching services .This includes burst assembly , WDM topology and resource dissemination survivability etc . The monitoring layer which is optional may or may not use data framing . It performs all recovery actions .The physical layer performs function so for burst switching . wavelength conversion , Burst delay / buffering , optical amplifications etc .

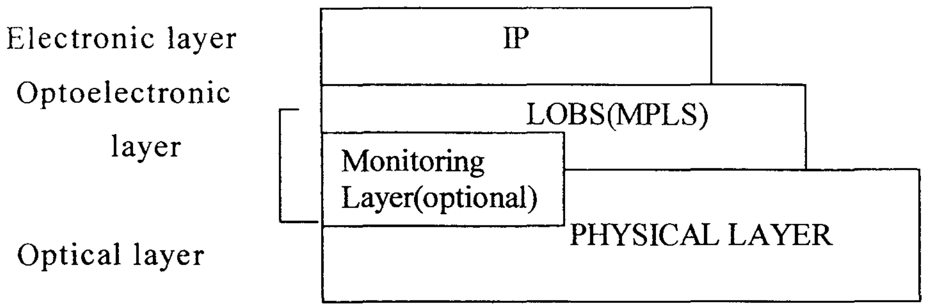

FIG. 16 IP o WDM ARCHITECTURE

3.5. ATM-PON (Asynchronous Transfer Mode Passive Optical Network):

Recently , an optical broadband access network is being deployed ,which is called APON (ATM based Passive Optical Network) . In 1998 ITU (International Telecommunication Union) standardized the transport system of an APON . APON is the most cost effective architecture for broadband FITL (fiber In the Loop) deployment .

Here the transport system allows up to 64 ONUs to be connected over a tree and branch architecture , within a range of up to 20 Km. The bandwidth that can be shared in a flexible way between the ONUs is 622 Mb/s or 155 Mb/s in the upstream direction and 155 Mb/s in the down stream direction . At the access node , the OLT (Optical Line Terminal) gather the APON traffic from the ONUs .

3.5.1 A SuperPON Architecture and Transport System :

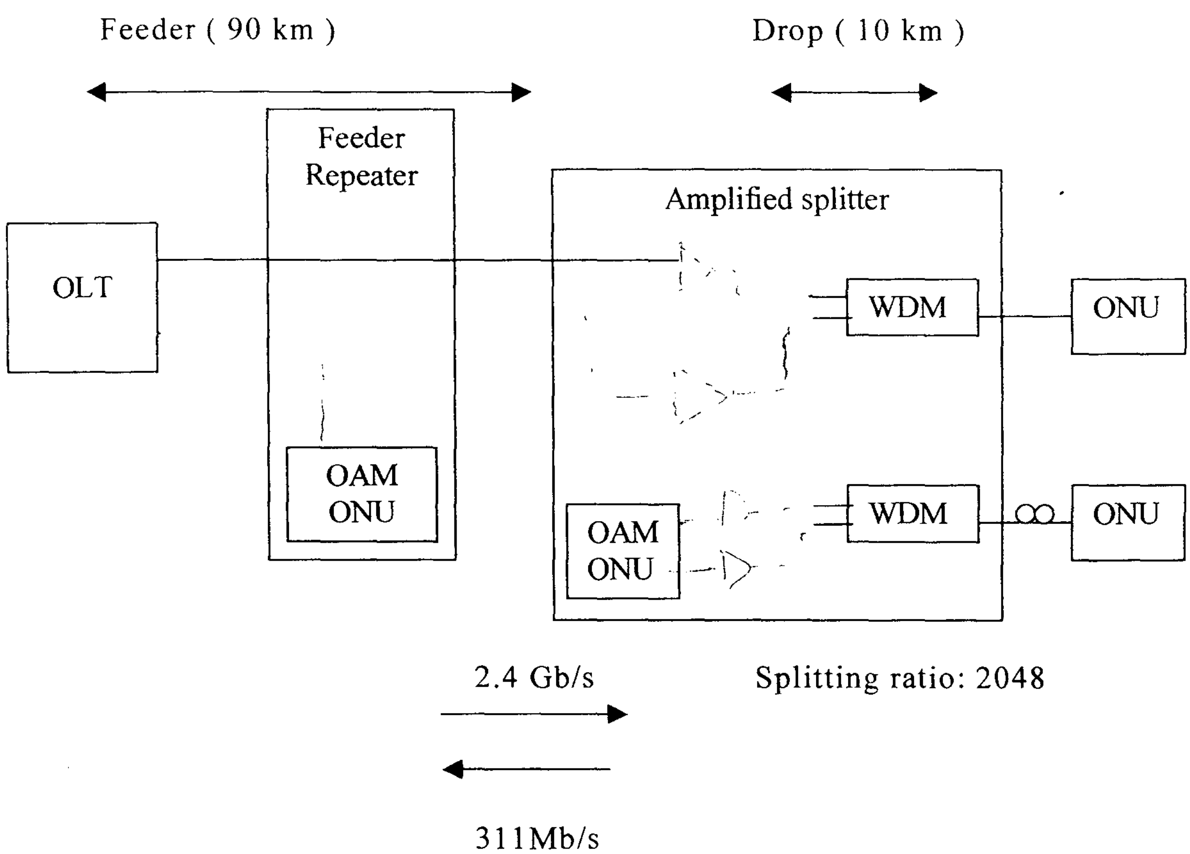

FIG. 17 Super PON ARCHITECTURE

The SuperPON architecture supports along range , a high splitting factor and a large bandwidth capacity .Optical amplifiers are introduced in the PON architecture to increase the optical power .Using optical amplifiers instead of electronic devices is their transparency to format , bit rate , wavelength and their simple management .

In the architecture , the realized system parameters are a total splitting factor of 2048 and a span of 100 km. The span consists of a maximum feeder length of 90 km and a drop section of 10 km .The transport system supported on SuperPON is based on ATM cells . A down stream bit rate of 2.5 Gb/s is distributed to the ONUs using TDM . A TDMA protocol is used to share the 311 Mb/s upstream bit rate . In order to assure efficient upstream transmission with minimum overhead , all the ONUs are synchronized in time .The OLT distributes permits in the downstream propagation direction towards the various ONUs to prevent collision in the upstream data path .

The optical amplifiers are housed in Optical Repeater Units (ORUs). They are located at the feeder section and at the intersection between the feeder and the drop section (amplified splitters) to compensate for fiber and splitting ratios losses .An Operation Administration and Maintenance (OAM) ONU is located at each repeater location for burst mode control of the ORUs and for operation and maintenance tasks .

3.6. Architectural Variations in Next Generation Optical Networks

The new internet environment is characterized by global access that has huge amounts of data transitioning multiple regional networks.Competitions in the industry is deriving down customer rates while cost of the building and maintenance networks is on the rise. Hence the new network models must be based on a network transition that increases the focus on optical layer of the network instead of SONET layers. Today's network is made up of multiple layers : generally refereed as Service layer and SONET layer. The service layer consists of computers , network servers and telephone switches. This layer typically interfaces with SONET layer, which provides transport and multiplexing functions for the service layer. The SONET layer utilizes Add/Drop functions, crossconnect functions and restoration to support the service layer.

SONET equipment manufacturers have introduced increased line rates to deal with the increase in traffic capacity. However SONET ADMs and crossconnects are limited by the constraints of electronic switching. Hence carriers are planning the deployment of WDM systems capable of supporting 120 to 240 wavelengths on a single fiber. The opportunity is to migrate from SONET layer to the optical layer, which will optimize networking functions utilizing photonic signals. The promise of optical networking is to simplify the network by reducing the number of networks deployed elements and their better management.

The architecture of the network is changing to more efficiently handle both data and traffic flow. The new architecture readies a carriers network , where the optical switches are the key enablers. There are two obvious choices for the switch fabric of an optical switch either all optical or opaque. All optical switches are bit rate independent and crossconnect or route at optical speeds of 2.5 , 10 or 40 Gb/s. Opaque switches allow the switching of higher bit rates ,providing a scalability advantage over digital crossconnects.

Developing signaling protocols for dynamic control and internetworking of optical layer is one of the most critical challenge today. Two primary models are emerging in the industry for interoperability between the IP and the optical layer. The Peer model is based on the premise that the optical layer control intelligence can be transferred to the IP layer, which may assume end to end control. It is based on a packet routing view of the network architecture. The Signal overlay model is based on the premise that the optical layer is independently intelligent and serves as an open platform for the dynamic internetworking of multiple client layers including IP. It is based on a circuit switched view of the network architecture. Both models assume development of next generation mesh networks with a simplified IP based controlplane based on MPLS (Multi Protocol Label Switching). The application of MPLS to optical signal overlay is called GMPS (Generalized Multi Protocol Switching)The GMPS control architecture provides a simple and mature set of protocols on which to base the next generation communications.

Regardless of which models is adopt by standard bodies , there are several critical issues to be resolved for a successful standard to emerge. A major area that needs standardization is the MPLS based control planes for optical networks comprising of multiple interconnected subnetworks. This include dynamic provisioning and fast restoration optical across optical networks as well as routing and signaling protocols. Specific work includes development of a common global addressing scheme for optical path end points , propagation of reachability information across subnetworks , end to end path provisioning using standardized signaling , policy support and support for subnet specific provisioning and restoration algorithms.

Several trends are emerging in the standardization process. Provisioning of light path is reusing the MPLS traffic engineering framework and will likely to leverage CR-LDP/RSVP (Constraint Label Distribution Protocol/ Resource Reservation Protocol) for signaling light path establishment and teardown. Automated topology discovery is moving toward a Link Management Protocol (LMP) for link/port states and attributes. Routing protocol with TE extension for topology discovery are being developed . Signaling protocols based on CR-LDP and RSVP have been proposed.

CHAPTER 4 - PERFORMANCE ANALYSIS

A performance analysis of Optical networks is done based on the factors such as Transmission capacity , Traffic & Congestion control ,Efficient routing , Efficient switching & transparency of networks.

4.1. Transmission Capacity :

SONET/SDH have traditionally been perceived as high capacity transmission pipes with negligible delays and transmission errors. The highest speed at which they can operate today is typically 2.5 Gb/s.TDM provides away to increase the bit rates on each channel , where as WDM provides a way to increase transmission capacity using multiple channels at different wavelengths. DWDM allows the multiplexing of hundreds of wavelengths of high capacity signals ranging from 2.5 to 10 GB/s in the short term to 40 Gb/s in the long term . Multiple wavelengths in a strand of fiber have added a new dimension to fiber capacity. he physical (Higher number of fibers) and time dimensions have been used successfully to deliver more bandwidth. Broadcast & Select networks employed have a maximum of 100 wavelengths separated by 2 nm and modulated at 2.5 Gb /s. Wavelength Routing network employed have a maximum of 20 wavelengths , separated by 0.4 nm and modulated at 10 Gb/s. In APON , the gain in bandwidth efficiency due to statistical multiplexing increase the number of users connected to a single line termination.

The challenge of creating cost effective and efficient optical networks is often complicated by the conflicts in the low level activities of circuit routing and channel assignment . Grooming techniques – conversion

4.2. Congestion and Traffic Control :

Grooming is an industry term used to describe the optimization of capacity utilization in transport system by means of crossconnections or conversions between different transport systems or layers within the same system. It involves the use of frequency or time slot conversion to increase effective capacity and efficiency of a network.

Traffic grooming can be used as a bypass mechanism by low rate circuits are assigned to wavelengths in order to minimize the amount of electronic multiplexing equipments .The SONET architecture is potentially a wasteful of SONET ADMs , because every wavelength (ring) requires an ADM at every node . In order to limit the number of SONET ADMs required , the traffic should be groomed in such away that all of the traffic to and from a given node is carried on the minimum number of wavelengths.

4.2.1. Grooming Static Traffic :

Static traffic is common for applications where , a service provider designs and provisions network resources based on some estimate of network traffic . The static traffic grooming problem is a special instance of virtual topology design problem . Given a traffic demand for low rate circuits between pair of nodes , the problem is to assign traffic to wavelengths in such a way that minimize s the number of ADMs used in the network. Heuristic algorithms have been developed to design virtual topologies that minimizes the number of wavelength delays and blocking probabilities. The algorithms consider 3 different traffic scenarios . First , uniform traffic in a unidirectional and bi-directional ring Second , Distance dependent traffic , where the amount of traffic between the node pairs is inversely proportional the distance between them. Third , Hub traffic , where all of the traffic is grooming to one node on the ring . All of these cases yield optical algorithms that are optimal.

4.2.2. Grooming Dynamic Traffic :

The traffic changes over time can be attributed to the more rapid dynamics of internet traffic .The traffic is no longer restricted to be uniform and nodes are allowed to have dynamically changing connections. The approach taken is to design a network so that it can accommodate any t-allowable traffic matrix in a non-blocking way . The problem is formulated as a bipartite graph matching problem and algorithms are developed to minimize the number of wavelengths that must be processed at each node . These algorithms provide methods to each significant reductions in ADMs under a variety of traffic environments.

4.2.3. Grooming with Crossconnects :

To support dynamic traffic , a crossconnect node is used at one or more of the nodes in the network . The crossconnect is able to switch traffic from one wavelength onto any other to which it is connected . It is also used to reduce the number of ADMs required . One can place cross connects at all of the nodes and allow traffic to be switched and groomed at each node. The crossconnect provides flexibility for both single hop or point to point WDM to accommodate dynamic traffic . The use of multiple crossconnects can reduce the number of SONET ADMs needed. Using multiple smaller crossconnects rather than one large crossconnect at the hub reduces the cost of the crossconnects.

4.2.4. Grooming in IP Networks :

As network s evolve to become more and more IP focussed . IP traffic will become an important area of future optical networks. In future IP networks , SONET ADMs may no longer be needed to multiplex traffic on to wavelengths .Instead future IP networks will involve routers that are connected via wavelengths using WDM crossconnects . Unless optical bypass is intelligently employed , with the new architecture , all of the traffic on all fiber sand all wavelengths will have to be processed at every IP router. In order to achieve maximum efficiency through the use of WDM crossconnect , bundling of traffic onto wavelength is done so the number of wavelengths hat have to be processed at each router is minimized . This results in reducing both number of ports need on the routers and the total switching capacity of the router . Grooming traffic , in general Mesh networks is an important emerging problem for the future.

4.3. Efficient Routing :

The optical network provides point to point connectivity between the routers in the form of fixed bandwidth light paths . The collection of light paths therefore defines the topology of the virtual networks interconnecting IP routers . The IP over optical network is defined essentially by the organization of the controlplane. Especially , a controlplane based on IP routing protocols and MPLS signaling protocols is used in the optical network . The efficient routing approaches to support various interconnection models are Integrated routing , Domain specific routing and Overlay routing . Photonic slot routing (PSR) is an efficient routing approach for packet switched optical networks . There are many facets to routing that requires investigation for future networks. These include route computation for individual connections , topology information discovery and distribution , resource status information distribution and reachability information.

4.3.1. Routing Approaches :

(1)Integrated Routing:

This routing approach supports the peer interconnection model. Where the IP and optical networks are treated together as a single integrated network managed and traffic engineered in a unified manner. The topology and link state information maintained by all the nodes (OXCs and routers) is identical ., This permits a router to compute an end to end path to another router across the optical network . IP routers maintain a single topology database for a joint network consisting of IP and optical nodes . IP routers can compute full paths to other destinations across the network . The restoration of the lightpath within the optical network may be visible to all the nodes in the network , there by complicating the process.

(2) Domain Specific Routing :

This approach supports the inter domain interconnection model. Where there are actually separate routing instances in the IP and Optical domains , but information from one routing instance is passed through the other routing instance .Here routing within the optical and IP domains are separated , with a standard routing protocol running between the domains. The inter domain IP routing protocol may be adopted for exchanging routing information between IP and optical domain .This allow the router to advertise the IP address prefixes within their network to optical network and receive external IP address prefixes from the optical network.

A VPON (Virtual Private Optical Network)is defined by a lightpath topology that interconnects client devices belonging to a specific administrative or user group . When VPONs are implemented , the address prefixes advertised by the border routers must be accompanied by some VPON identification. Border OXCs then can filter external addresses before propagating to the routers.

(3) Overlay Routing :

This routing approach supports the overlay interconnection model where IP network routing , topology distribution and signaling protocols are independent of the corresponding protocols in the optical network. Here the optical networks implements a registry that allow border routers to register their IP addresses and VPON identifiers. A border router is allowed to query for external addresses belonging to the same set of VPONs to which it belongs . A successful query will return the addresses of egress optical port through which the extrenal destination can be reached .

(4)Photonic Slot Routing :

Photonic Slot Routing reduces node complexity , cost and facilitates network scalability. According to PSR concept , packets transmitted on all wavelengths are switched jointly. The switching node is only required to handle each slot as a whole without having to access and switch on different wavelengths individually. At each node , packet destined for a specific node are transmitted on the available wavelength in the slots assigned to that particular node. If a slot is not assigned ,it can be assigned by the first packet transmitted in that slot under a fairness control protocol . Contention can be resolved using switching delay lines. The PSR approach shifts the burden of wavelength selective switching to a problem of finding effective access protocols at the source codes.

The internet transport infrastructure is moving towards model of high speed routers interconnected by intelligent optical core networks. A consensus is emerging in the industry on utilizing an IP centric controlplane within optical networks to support dynamic provisioning and restoration of light paths . For implementing the IP centric controlplane , it is necessary to have a bi-directional point to point control channel between neighboring OXCs.

4.4. Efficient Switching :

Optical switching technologies enable fast dynamic allocation of WDM channels . The challenge involves combining the WDM technologies with emerging Optical switching capabilities to yield a high throughput optical platform directly underpinning next generation networks. For efficient switching the two techniques employed are OPS(Optical Packet Switching) and OBS (Optical Burst Switching).

4.4.1. Optical Packet Switching :

An optical packet network consists of optical packet switches interconnected with fiber running WDM. The switches may be adjacent or connected by lightpaths . The user data is transmitted in optical packets which are switched within each optical packet switch . Thus the user data remains as an optical signal in the entire path from source to destination . No optical –electrical-optical conversion is required .

4.4.2. Optical Burst Switching :

It is a technique for transmitting bursts of traffic through an optical transport network by setting up a connection and reserving resources. An OBS network consists of optical burst switches interconnected with WDM links. An optical burst switch transfers a burst coming from an input port to its destination output port. Depending on the switch architecture , it may or may not be equipped with optical buffering. The fiber links carry multiple wavelengths and each wavelength can be seen as a channel.. A burst is dynamically assigned to a channel. The control packet associated with a burst my also be transmitted over a channel or over a non optical network.. The burst may be fixed to carry one or more IP packets. Both OPS and OBS can be used to transport IP traffic and ATM traffic.

4.4.3. Optical Tag Switching :

Tag switching is an alternative approach proposed to simplify the packet forewarding process. It assigns a short fixed length label containing routing information ,called tag, to multiprotocol packet for transport across interconnected subnetworks. A tag switched network consists of Tag edge routers , Tag switches and Tag distribution protocol. Tag edge routers are located at the boundaries of the of the internet and apply tags to packets. Tag switches switch tagged packets based on the tags. Tag distribution protocol is used to distribute tag information between the nodes. When a tag edge router receives a packet for forwarding across the network , it analyses the network layer header,
Performs applicable network layer services , selects a route for the packet and applies a tag to the packet. Then it forwards the packet to the next hop tag switch. The tag switch receives the tagged packet and switches the packet based on the tag, without reanalyzing the network layer header. The packet reaches the tag edge router at the exit point of the network where the tag is removed and the packet delivered.

OPS and OBS techniques are currently at an experimental state. The lack of commercially viable Optical buffering technology imposes a constraint on the development of optical packet switches. The next generation optical network will be all optical packet switching, which will provide high throughput ,rich routing functionalities and excellent flexibilities.

4.5. Transparency :

Transparency refers to the fact that the light paths can carry data at a variety of bit rates , protocols and so forth and can be made protocol insensitive . A fully optical implementation may yield ahigh degree of transparency , namely insensitivity to digital/analog data , bit rate and modulation format . However an implementation consisting of an electronic SONET digital crossconnect switch may offer no transparency at all.

4.5.1. Light path Transparency :

The degree of light path transparency depends on the type of signal regeneration . They can be 3R , 2R and 1R . 1R regeneration is the simplest form of regeneration , where the signal received is transmitted without retiming and reshaping . 2R regeneration with out retiming offers some transparency but leads to jitter accumulation at each regeneration step . 3R regeneration with retiming and reshaping reclocks the signal but it completely eliminates transparency to bit rates and frame formats .

4.5.2. Protocol Transparency :

A few key protocols such as signaling protocols , routing protocols and transport protocols are added to enhance the value of optical networks . By implementing a signaling protocol in hardware, call can be set up and released for individual file transfers at high call rates and low delays in the call set ups . A transport protocol is needed to reliably carry user data bits on the circuit , once an end to end circuit is set up . Since end to end circuit can be considered a link at physical layer , the network layer is non existent and transport and datalink layer protocols are effectively merged . To support heterogeneous network , routing protocols are used. It allows the electronic and optical circuit switches to exchange topology and loading information as well as exchanging crossconnect rates .All these protocols achieve high network utilization and flexible architectures .

CHAPTER 5 - NETWORK MANAGEMENT

Network management is an important aspect of optical network. The cost of managing a large network in many cases dominates the cost of equipments deployed in the network .

5.1. Network Management Functions :

The most important functions in managing an optical network are configuration management , Performance management and Fault management . Configuration management deals with the set of functions associated with managing orderly changes in a network . Performance management deals with monitoring and managing various parameters that measures the performance of the network. Fault management is the function responsible for detecting failures (when occurs) , isolating the failed component and restoring traffic that may be disrupted due to failure .

The individual components to be managed are called Network Elements (NE), which include Optical Amplifiers , Crossconnects and Add/Drop multiplexors. Each NE is managed by its Network Element Manager . The element managers communicate with a Network Management Center through a management network .The information to be managed for each network element is represented in the form of a MIB (Management Information Base). MIB contain a set of variables representing the information to be managed. There are two primary standards relating to network management. The Internet world uses a management from work based on SNMP (Simple Network Management Protocol) which runs over a standard TCP/IP protocol stack. In telecommunication Management Network (TMN), NE manager usually communicates with the manager using (CMIP) Common Management Information Protocol that runs over an OSI protocol stack. The MIB has an object oriented structure and is based on a standard called GDMO (Guidelines for Description of Management Objects)

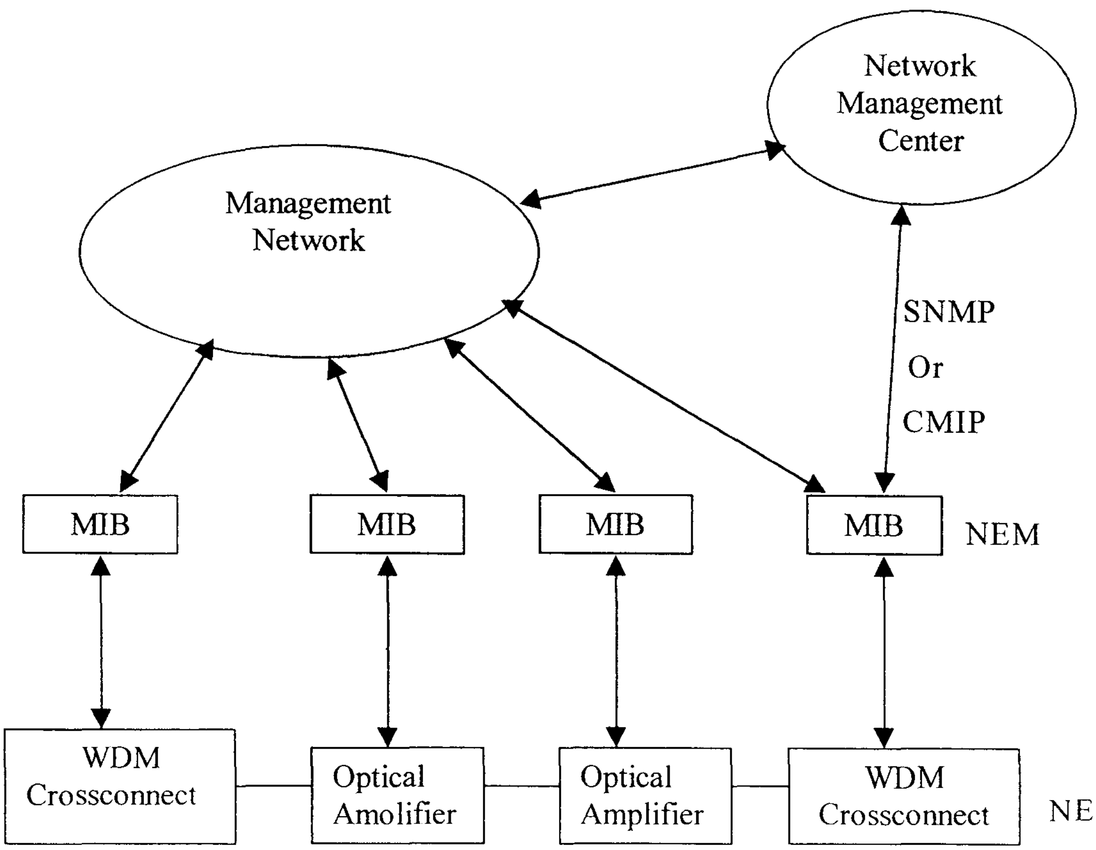

FIG. 18 Network Management in Optical Network

5.2. Configuration Management:

Configuration management includes Equipment management and connection management .

Equipment Management :

We must be able to keep track of actual equipment in the system as well as the equipment in each network element and its capabilities .We should be able to add existing equipments in a modular fashion . We may desire flexibility in associating specific port cards in the equipment with specific wavelengths.

Connection Management :

It deals with setting up connection, keeping track of them and freeing up the resources associated with them for other connections. Distributed methods may also have to be involved when setting up light path across network domain boundaries administrated by different managers. Distributed protocol have been used for connection setup purposes on other networks.

5.3. **Performance Management :**

It enables network operator to provide guaranteed quality of service to the user of the network. The performance parameter to be monitored depends very much on types of connection provided by the network. In a transparent optical network the management mechanism may have no prior knowledge of the protocols or bit rates being used on the network. Hence it is not possible to across overhead bits on the transmitted data to obtain performance related measures . Transmission related parameters that can be monitored includes optical power levels , optical signal to noise ratios, temperatures and electronic parameters. A most important function may be to monitor the actual service being utilize by the user. Determining the threshold values for the various parameters is another important problem.

5·4. Fault Management :

As optical networks carry more and more data the amount of disruption caused by network related outage becomes more and more significant. There are several techniques that provide reliable service to the network even in the presence of failures. The protection techniques involve providing some redundant capacity with in the network for remote traffic in the presence of failures. They are implemented mostly in a distributed manner with out requiring coordination between all the nodes in network. Survivability is another important aspects. It refers to a network's ability to continue provide service in the presence of failure. It can be addressed with in many layers in a network .

Control and Management Interface :

In order to enable the optical layer to setup and take down light paths, we must establish a control interface over which the users of network communicate with the network to perform all functions. The functions includes addressing, multicast capability , uni-directional and bi-directional light paths , quality of service parameters. For optical layers , quality of service parameters are degree of transparency, levels of protection , bit error rate/ signal to noise ratio, end to end delay and jitter requirements.

CHAPTER 6 - CONCLUSION

The dissertation work presented an indepth analysis of architectural aspects of current and next generation optical networks . At the technical level , The progress in optical networking are due to the advances in the following areas. They are

(1) improved architectural understanding
(2) Developments in purely optical crossconnects .
(3) More channels of higher bit rate.
(4) New kinds of optical components such as amplifiers and fiber
(5) longer lightpaths .
(6) lower technology costs.

WDM is recognised as a promising technology that can be used to increase the aggregate system bit rate . Future optical network architectures will mainly rely on multiple wavelengths to achieve full transparent all optical connectivity with features like scalability , modularity and survivability . Wavelength conversion is viewed as a much needed functionality in future WDM networks. Wavelength conversion can be used to resolve contention , reduce wavelength blocking and enable a multitude of new wavelength routing approaches. Protocols are needed to establish who can communicate on which wavelength , when and how . Among the important protocols which will be used for future optical networks will be Fixed assignment protocol ,Random access protocols and Hybrid protocols. It is important for network designers to reduce the number of protocol layers being used while preserving the functionality by many advanced optical technology.It over WDM integration and intelligence in the optical infrastructure for control , protection/reliability and management are the key areas for manufacturers and researchers . A novel approach to create an extensive , flexible and future proof optical infrastructure is through an optical packet switched WDM layer embracing many of the technological advances . As the world is rapidly converging to two layer model , IP becomes suitably updated particularly to add QoS to a short and hope architecture and the old fixed copper , microwave layer becomes all optical.

The point of departure is an assumed future two level structure in which the transport is by means of steadily grooming interconnected all optical islands of transparency , while the remainder of the communication layers are based on IP , both levels being managed by MPLS based controlplane.

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