POLITECNICO DI TORINO

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Communications and Computer Networks Engineering

Master thesis

LITERATURE REVIEW OF STANDARDS FOR OPEN OPTICAL NETWORKS

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Abstract

An optical network is considered as a communication system which utilizes light signals in order to transfer information and data between two or more points. It can cover from small scale points such as computers in the offices up to whole world.

The data transmission was developed from two types: wire and radio signals which have changed by invention of the fiber in the early 1970. In the 1980 the fiber optic cable was begun to use in communication up to now. The internet based traffic is significantly increasing every year and due to its dynamic shape it needs a new and flexible type of infrastructure to response this demand.

Nowadays, optical science is developed in many aspects such as transmission techniques by introducing new standards and protocols which provide data transferring along the optical networks in an efficient manner. These specific protocols are developed by the International Telecommunication Union. Some well-known approaches such as WDM and TDM are multiplexing standards that have the ability to response to this capacity increasing demand. Also several types of optical network equipment and applications such as OLTs, OXCs and OADMs with employing SDN facilities enhance the flexibility in wavelength allocation and increase the backbone bandwidth to satisfy the quality of the service (QoS) and transmission (QoT) requirement.

The aim of this research is to have an overview on the OSI model from network layer towards optical layer and control layer based on the protocols application in order to map them on the optical layer directly and indirectly in transmitting traffic where for routing traffic a control mechanism is required in traffic engineering. Also there will be a overview on the SDN based optical network to highlight the most important aspects of this standard as a new network management paradigm in recent years.

Key words: Optical network, WDM, Qos, QoT, standards and protocols, OSI model, SDN.

Acknowledgment

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All **figures** in the thesis are redraw from existing documents, books, articles, papers and websites.

Abbreviations

ADM	ADM
ALR	Adaptive Link Rate
AON	Active optical network
APLs	Application Programmable Interfaces
ASON	Automatically Switched Optical Network
ATM	Asynchronous Transfer Mode
ANSI	American National Standards Institute
BGP	Border Gateway Protocol
CBR	Constant Bit Rate
CCI	Connection Control Interface
CDMA	Code Division Multiple Access
CLP	Cell Loss Priority
CRC	Cyclic Redundancy Check
CR-LDP	Constraint-Based Label Distribution Protocol
CSMA	Carrier sense multiple access
EMM	Energy Management Mechanism
EPON	Ethernet Passive Optical Network
EOC	Electro Optical Components
FDMA	Frequency-Division Multiple Access
FEC	Forward Error Correction
FSC	Fiber Switching Capability
Gb/s	Gigabit per second (109 bits per second)
GHz	Gigahertz
GMPLS	Generalized Multi-Protocol Label Switching
GPON	Gigabit Passive Optical Network
HEC	Header Error Control
ICMP	Internet Control Message Protocol
IEEE	Institute of Electrical and Electronics Engineers
IGP	Interior Gateway Protocol
IP	Internet Protocol
ISIS	Intermediate System to Intermediate System
ISP	Internet Service Provider
ITU	International telecommunication Union
ITU-T	International Telecommunication Union-Telecommunication Standardization Sector

LAN	Local Area Network
LLC	Logical Link Control
LSC	Lambda Switching Capability
LSPs	Label switched paths
MAC	Media Access Control
MAN	Metropolitan Area Network
MPLS	Multi-Protocol Label Switching
ms	millisecond
NBIs	North Bound Interface
NCC	Network Connection
NFV	Network Functions Virtualization
NMI-A	Network Management Interface for the ASON Control Plane
NMI-T	Network Management Interface for the Transport Network
NMS	Network Management System
NNI	Network to Network Interface
NV	Network Virtualization
NX-GPON	Next Generation of Gigabit Passive Optical Network
OADM	Optical Add-Drop Multiplexer
OAM	Operations, Administration, and Maintenance
OBH	Controller Burst
OBS	Optical Burst Switching
OC	Optical Carrier
OCC	Optical Connection Controller
OCh-SPRing	Optical-Channel Shared Protection Ring
ODU	Optical Channel Data Unit
ODN	Optical Distribution Network
OLT	Optical Line Terminal
OMS	Optical Multiplexed Section
ONU	Optical Network unit
OPU	Optical Channel Payload Unit
OSI	Open Systems Interconnection
OSPF	Open Shortest Path First
OTN	Optical Transport Network
OTS	Optical Transmission Section
OTU	Optical channel Transport Unit
OUN	Optical User Network
O-UNI	Optical User Network Interface
OXC	Optical Cross-connect
PAN	Private Network
PI	Physical Interface
PON	Passive Optical Network
PPP	Point-to-Point Protocol
PS	Packet Switching
PT	Payload Type

QoS	Quality of Service
RC	Routing Controller
RIP	Routing Information Protocol
ROADM	Reconfigurable Optical Add/Drop Multiplexer
RSVP-TE	Resource Reservation Protocol Traffic Engineering
S	Second
SC	Signal Controller
SDH	Synchronous Digital Hierarchy
SDM	Space Division Multiplexing
SDN	Software-Defined Networking
SDONs	Software Defined Optical Networks
SNMP	Simple Network Management Protocol
SONET	Synchronous Optical Network
STB	Set-Top Box
STS	Synchronous Transport Signal
TCP	TCP
TDM	Time Division Multiplexing Capability
TDMA	Time Division Multiplexing Access
TED	Traffic Engineering Database
TNRC	Transport Network Resource Controller
TTL	Time to live
UNI	User to Network Interface
WAN	Wide Area Network
WDM	Wavelength Division Multiplexing
VCI	Virtual Circuit Identifier
VPI	Virtual Path Identifier
XGPON	10-Gigabit-capable passive optical network
YANG	Yet Another Next Generation
YDK	YANG Development Kit

Chapter 1

Introduction

The main methodology of thesis is considering common standards for open optical network from network layer toward optical layer.

1.1 Networks and optical communication systems

The main concept of a network refers to establishing the connection between two end-points; some parameters in the network from the transmitter to the receiver affect this connection and the result of all factors provides the desired network according to the capacity, scalability, cost and operational simplicity. The network designers most often try to intercommunicate with mentioned factors for improving networking. Many years ago, there were two ways for data transmission, first by the wire and second by the radio signal. In the early 1970s fiber was invented with the capability to send light among the glass. In many cases, this fiber has been installed more simple than copper. In the 1980s fiber optic cable was begun to replace with the copper-based physical layer. The optical fiber is a lightweight cable that establishes a low loss connection, moreover, the main outstanding feature of fiber is its high capacity.
Based on some benefits of fiber the optical network as a new paradigm was explored to the transmission signal. The optical network includes fiber-optic cables that transmit light. One of the earliest technological improvements was the capability to carry multiple lights in a single fiber channel. Each light or wavelength has a different frequency which combined together in a single fiber that is called wavelength division multiplexing. In recent years about 100 wavelengths could be multiplexed by WDM, which is a huge revolution in transmission signals in long distances.
Optical networks consist of optical transmitters and receivers, fiber-optic cabals, optical switches, optical terminals, optical amplifiers and other components that are required for communication.
Several kinds of transmission forms are recognized:

- Point-to-point networks
- Point-to-multipoint networks or broadcasting

Optical networks provide a structure with a variety of services that can be delivered, also they are able to deliver bandwidth in a flexible manner, with increasing traffic demands relative to video and voice.
Internet-based traffics are significantly growing every year; in addition, the shape of traffic is more dynamic, so a new and flexible type of infrastructure requires to handles these requests.
Two generations of optical networks were presented:
1- The first-generation: uses optical fiber for substituting with copper for increasing the capacity.
2- The second generation: supplies circuit-switched light-path by routing and switching wavelengths.

Fundamentally there are two well-known approaches for increasing transmission capacity: first, utilizing WDM to gain more wavelengths on fiber, second using TDM for enhancement bit rate.
In the second generation of optical networks, several optical types of equipment have a significant role to achieve goals such as Optical line Terminals (OLTs), optical cross-connects (OXCs) and optical add-drop multiplexers (OADMs).
Any optical network needs standards to perform synchronization, coding scheme, and support functionality, as SONET/SDH, also it presents some elements that are required in optical networks. With the deployment of synchronization technology, OADMs were changed and more flexibility was achieved in the late 1990s when SONET/SDH cross-connects were presented with the capability to enable mesh topology, besides SONET/SDH, optical switches had the ability to work with a mesh topology. Hence incoming optical signal should be terminated by the optical terminal, the optical to electrical domain and vice versa paradigm was introduced to convert the optical signal to electrical signal, this task was executed by transponders, when the level of traffic increases, it required two transponders for each node, so in cost point of view, it was not efficient. [1]

As mentioned, being cost-effective is one of the important benefits of WDM, for achieving that, the ebrium-doped fiber amplifier was introduced, which is responsible for regenerating the wavelength in fiber.
In the early EDFA, the regeneration period was estimated 40 km, in recent EDFA systems this interval has grown to 1500-2500 km. Another advantage of optical network is increasing bit rate of each wavelength, in the first-generation bit rate was about 2.5 Gb/s, while this rate ramped up to 400 Gb/s and 1Tb/s in recent years, moreover, the WDM technology has been developed and dense wavelength division multiplexing was presented as maturated WDM that each fiber link is able to transmit hundreds of wavelength channels simultaneously where each channel can handle multiple gigabits per second. [2]
While, in evaluating a network the transmission capacity is an only outstanding factor, but cost-effectiveness and scalability of the network are substantial. Although some electronic equipment are eliminated by EDFAs, but each wavelength is affected by electronic processing during switching or routing. When the network traffic level is increased, for handling a massive amount of traffic the network has to use electronic tools that create a bottleneck.
However, bit rate has grown and it handled a large number of wavelengths with help of EDFAs, but some electronic infrastructure was between the source and destination that made some bottlenecks by increasing power consumption, deployment time, physical space and reliability, so for overcome these bottlenecks the optical-bypass technology was deployed. Optical-bypass removes some electronic processing and permits a signal to remain in the optical domain during its path from transmitter to the receiver. Obtaining optical-bypass involves some improvements in optical switching, amplification, transmission formats and techniques.

With new approaches in optical communication technologies in recent years, the DWDM technology has important effects on growing transmission capacity and the size of networks. Hence DWDM can establish a point-to-point connection in long-distance, so in more complex network architecture, for compensating network limitations, the network should use OADM and OXC. In the last few years, ROADM technology was developed, so the new facility is added to DWDM, ROADM, OXC for automatic configuration, this approach enhances flexibility in bandwidth allocation and increases the backbone bandwidth. [2]

The configurable optical layer has a relation with higher electronic layers, such as IP over the optical scheme. With the reconfiguration of the optical layer, the optical network can transmit wavelength where is required by the IP layer. This scenario has effects on the IP layer, firstly when the additional wavelength is routed on the same IP path, it is able to add available capacity of the path. Secondly, it has an impact on the capacity of two adjacent routers, maybe exceeded capacity shifted on a new path, at the result of the mentioned effect, creates latency between routers.

By software controlling, the network can be configured remotely, in the late 1990s control automation software was presented in the optical network as optical control-plane which cooperated with series of software applications in each network element to configuration them.

The control-plane maintains four abilities:

1- Discovery

2- Routing

3- Path computation

4- Signaling

ITU and IETF have worked on standardization of optical control-plane, a few years ago ITU has extended Automatically Switch Optical Network (ASON) which provided demands for enabling control-plane.[1]

Software-Defined Network (SDN) is another approach in network architecture that separates control-plane and data-plane, and the logically centralized controller handles the network.

SDN has two important advantages:

1- Centralization: can support the whole of the network by a logically centralized controller, also the logically centralized employs the controller to have a better performance than a traditional network.

2- Abstraction: SDN permits to write applications for controller to manage OpenFlow switches. In a cost point of view, reforming the whole network to the SDN network is not appropriate because of the high substitution cost, therefore it is reasonable to implement SDN in the data center, this model called hybrid networks.[3]

The hybrid model provides a scheme where SDN and legacy networks are able to operate together, this model can support traditional network and SDN, also it is adaptable based on cost limitations.[4]

However, SDN was designed to control and manage layer two and IP layer in the electrical domain, but recently SDN implemented in optical transport network (OTN) to configure southbound interfaces (SBIs) with some protocols such as OpenFlow, YANG/NETCONF, YANG/RESTCONF and so on.[5]

Nowadays, optical science is developed in many aspects such as transmission techniques by introducing new standards and protocols which provide data transferring over optical networks in an efficient manner.

1.2 OSI Layered model

An overview of OSI layers are explained below:

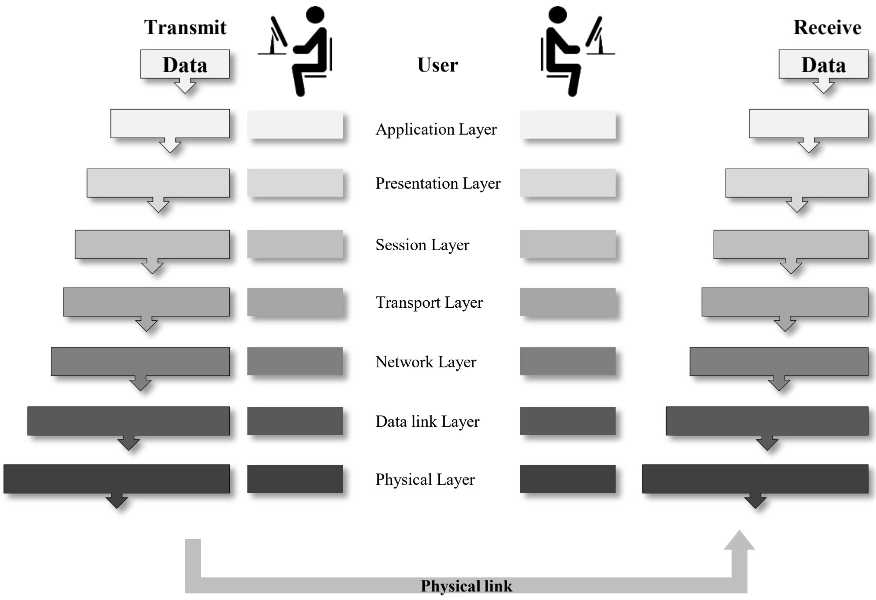


Figure 01: OSI Layered model.

1- Physical layer: is responsible for transmitting bits over the transmission channel.
2- Data link layer: transforms a series of raw bits from the physical layer into an error-free data frame for the network layer.
3- Network layer: manages the operation of the subnet, the main role is routing packets toward the destination.
4- Transport layer: receives data from the network layer and divides it smaller slices, also determines what type of services is required for the session layer.
5- Session layer: permits several users on different machines to create sessions.
6- Presentation layer: controls syntax and semantics of information shared between two machines.
7- Application layer: includes the various protocols which are required by users.

1.3 Purpose and organization of the thesis

The main aspect of the thesis is analyzing OSI model's protocols from network layer towards optical layer based on protocols and standards which are used, in addition, considering the application of these protocols in optical network and how to map them in the optical layer whether directly or indirectly, therefore:
• The second chapter includes Electronic Switching, Routing, Multiplexing, and related networks.
• The third chapter consists of physical and optical layers.
• The fourth chapter defines several control standards and protocols that are employed to provide some services in the network to satisfy the QoS and the quality of transmission in optical networks.
• Chapter five is related to Software Defined Networking for optical networks (SDONs).
• The Sixth chapter is the conclusion.

Chapter 2

Standards of Layer two and three

Introduction

A network has a specific architecture and features according to design a policy with complicated interacting. To gain a fundamental comprehension network performance should consider the network features based on, structure, partitioning, geographical coverage, and related protocols.

the Service provider, presents one kind of network which is called public network. The public network prepares a set of various services to clients. On the other hand, there is another kind of network which provides services for its clients, it is called a private network. The multiple kinds of network architectures based on fiber or electric were developed for delivering the data to specific IP based destinations, with using of several switching methods. Up to now, some standards are defined as employing in access-network which could be upgraded according to customer satisfaction (QoS) during the time.[6-7]

This chapter considers layer two and three network protocols and standards, their interactions and applications in the network. The first section includes the IP layer, and the role of IP in networking, routing algorithms and multi-protocol label switching. The second section mostly consists of layer two standards such as Ethernet, ATM. The third section defines some kinds of optical networks.

2.1 Structure of networks

Modern communication networks are complicated due to the careful analysis of complex networks in the data transmission area. Networks are divided into some particular sections:
• Network partitioning
• Layering
• Functional planes

2.1.1 Network partitioning

A simple network can be a point to point telephone connection with users talking on both sides, this connection is established on copper wire. In the larger and complex networks in the internet area, it is important to consider some sections during a connection, in this part, the concentration is on the data world. According to the network hierarchy, there are four types of paradigms for the network:
1- PAN (a private network)
2- LAN (local area network)
3- MAN (metropolitan area network)
4- WAN (wide area network) [8]

2.1.1.1 LAN
The LAN covers the smallest area about a few kilometers from one or more buildings. Access-network is a closet network to users that is responsible for distributes/collects traffic to/from network.

2.1.1.2 MAN
The MAN covers a few hundreds of kilometers also is called metropolitan networks. Metro-core network aggregates traffic from access-networks.

2.1.1.3 WAN
The WAN covers hundreds to thousands of kilometers.[8]
The comparison table shows the difference between LAN, MAN, and WAN:

	LAN	MAN	WAN
Support area	Local area Network	Metropolitan area Network	Wide area network
Ownership	Private	Private or public.	Might not be owned by one organization
Transmission speed	High	Average	Low
Propagation delay	Short	Moderate	Long
Congestion	Less congestion	More congestion	More congestion than MAN
Design and maintenance	Easy	Design and maintenance is difficult than LAN	Design and maintenance is difficult than LAN and MAN
Tolerance	More fault tolerance	Less fault tolerance	Less fault tolerance

Table 01: The comparison table of LAN, MAN, and WAN.

2.1.2 Geographic Hierarchy of Optical Network

In designing the network, the geographical coverage of the network should be considered. According to the geographical coverage, the network is segmented into several geographical categories. The key point in network partitioning is the number of clients and border distance.

• Access-network: the first network which has a direct relation with the client is access-network. Access-network includes an edge network that collects traffic from users and distributes traffic to users, this type of network can support tens to hundreds of clients and cover a few kilometers.

• Metro-core network: is responsible for collecting traffic from access-network and interlinking some connections. It gathers data from thousands of users and could cover tens to hundreds of kilometers.

• Regional network: several metro-core networks are interconnected within the regional networks which manage to cover multiple metro-core areas with thousands of customers and several hundred to thousands of geographical areas.

• Backbone Network: carries regional network traffic and can span millions of users.

Selecting among tiers depends on the characteristic of networks, for instance, backbone networks need an optical transport system, while same technology is not suitable for using in access-network, and also cost-effective parameter has a significant effect on choosing any technology.[8]

2.1.3 Network layering

Three combined layers from the OSI model are considered in this thesis:

1- The application layer; which includes some services such as voice, video, and data. (SDN, YANG, Open Flow, Netconf, SNMP)

2- The intermediate layer; contains multiplexing, transport, and switching. (IP, Ethernet switches, ATM, SONET/SD switches, OTN switches)

3- WDM layer (OADM, ROADM); the payload of the electronic layer is transiting to the optical layer which is transmitted by WDM technology and uses optical switches. The optical switches have the capability of routing dynamically. The matured optical switches can be configured.

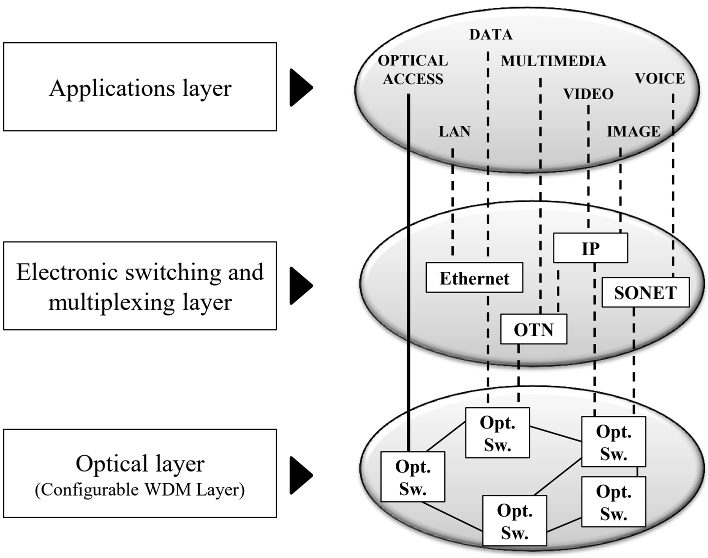


Figure 02: Three combined layers from the OSI model.[8]

2.2 Internet protocol

IP is one of Network layer protocols in the OSI model which was defined by the Internet layer for packet data format. The IP is responsible for delivering packets according to the destination address. Besides IP, the internet layer was introduced as ICMP (internet control message protocol) protocol to handle some testing functions.
The IP is manufactured by two versions (IPv4 and IPv6), this section demonstrates the common version IPv4. An IP address is divided into Network and Host address by Subnet Mask, also IP address belongs to different categories in five IP classes which are shown in table 02. [9]

Public IP Addresses

Class	Public IP Ranges
A	1.0.0.0 to 9.255.255 11.0.0.0 to 126.255.255.255
B	128.0.0.0 to 171.255.255.255 173.0.0.0 to 191.255.255.255
C	192.0.0.0 to 195.255.255.255 197.0.0.0 to 223.255.255.255
D	224.0.0.0 to 247.255.255.255 Multicast Addresses
E	248.0.0.0 to 255.255.255.254 Experimental Use

Table 02: Public IP Range.[9]

Private IP addresses:
Class A: 10.0.0.0 - 10.255.255.255
Class B: 172.16.0.0 - 172.31.255.255
Class C: 192.168.0.0 - 192168.255.255
Loopback range : 127.0.0.0 - 127.255.255.255

2.2.1 Subnet Mask ranges in each class of IP

As it is shown in figure 03, in class A, 8bits are allocated to network portion and 24 bits for the Host portion. In class B equally, 16 bits are assigned for both the network and the Host. For class C, 24 bits are considered for network and 8 bits for the Host.[10]

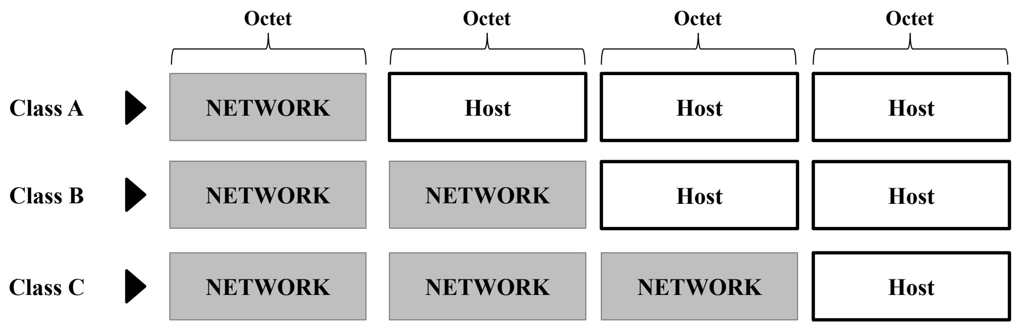


Figure 03: Subnet Mask ranges in each class of IP.

The network layer uses a packet switching technique for transmission data.

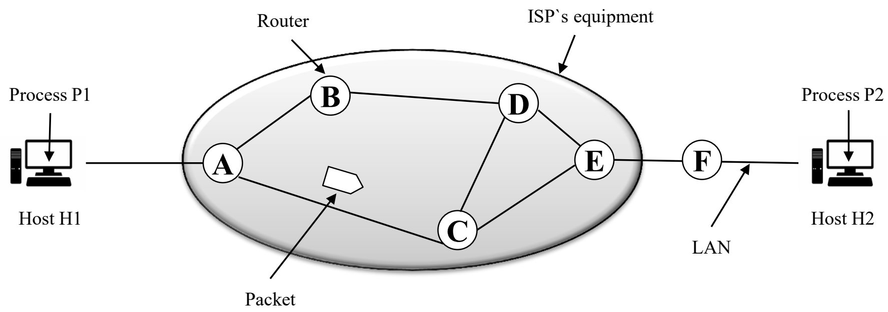


Figure 04: Store and forward packet Switching. [10]

According to the figure 04, when host1 transmits a packet toward host 2, first H1 connects with the nearest router in its LAN, the packet is stored in LAN until completely arrived and then processing will finish by verifying the checksum, then it will forward to the next router which is near to destination address.

According to the service operator company, two models of networks are provided:
1- If Connection-less service is offered, packets are thrown into network exclusively and routed independently, this is called data-gram networks.
2- If connection-oriented service will offer, the path of data from source to destination should be established before transmission, this connection is called virtual-circuit network.[10]
For routing traffic in the path and finding the best path for transmission, some parameters should be considerd, for instance in metro-core networks there is a large number of nodes with a big amount of traffics that are transmitting, so first wavelength line rate and the second number of wavelength per fiber are important factors. Moreover, the run time of network planning algorithm and real-time design have an important effect, so time to establishing any connection based on the size of the network is important.

2.3 Routing algorithms

It is a process to choose a path among some paths through the network for providing the best route between source and destination. For achieving this approach, several factors should be taken into account:
• Cost, should not add additional cost in choosing a path.
• Path distance, the number of links in any path is more relevant.[8]
Because of the mentioned reasons, some routing algorithms were defined:
• Static routing: routing table, support, and update are done manually.
• Dynamic routing: routing table, maintenance and updating runs by routing protocol.
• Distance vector: according to the hop counts.
• Link state: according to the state of the link.

In link-state routing each router should do below works to finding path:
1- Get information about its neighbors.
2- Set up distance or cost metrics for any neighbors.
3- Build a packet telling all it has learned.
4- Transmit that packet and receive it from all routers.
5- Compute the shortest to every other router.[10]

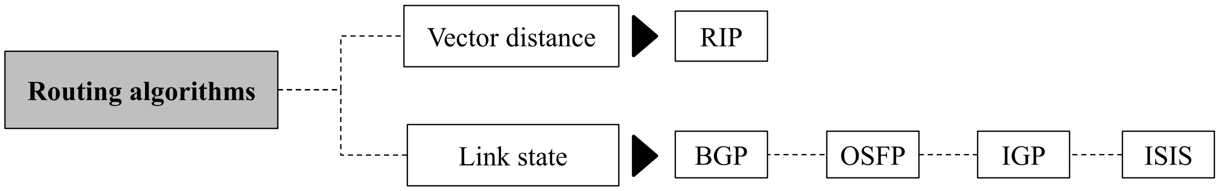


Figure 05: Routing algorithms.[9]

2.3.1 Shortest path algorithm

The idea is to make a graph of the network for some available paths, each node of the graph shows a router and each edge represents a communication link, the algorithm chooses among paths which one has less number of hops or metric way according to the geographical distance in kilometers. [8]

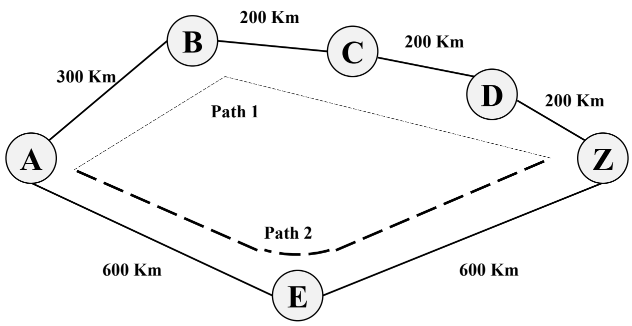


Figure 06: The shortest path algorithm example.[8]

Consider node A sends a packet toward node Z here have two paths:
• 1:A-B-C-D-Z
• 2:A-E-Z
• Path1 has 900km distance and 3 hops.
• Path2 has 1200km distance and 1 hop.
In the cost point of view, path2 in spite of having a short-distance than path1 has a lower cost, so path 2 will be chosen.[8]

BGP: border gateway protocol, it works according to the network policy, it can use hop count or shortest path.
OSPF: open shortest path first, it can be used in small and large networks. It can work both of P-to-P (SONET) link and broadcast networks (LAN)

ISIS: intermediate system to intermediate system
RIP: routing information protocol, works according to hop count.[9]
Internet network has a large number of Autonomous System which are commonly operated by internet service providers (ISPs), company and etc., inside of each AS, it has own routing algorithm called inter-domain routing.
The inter-domain routing protocol is named interior gateway protocol (IGP).

2.3.2 Label Switching and MPLS

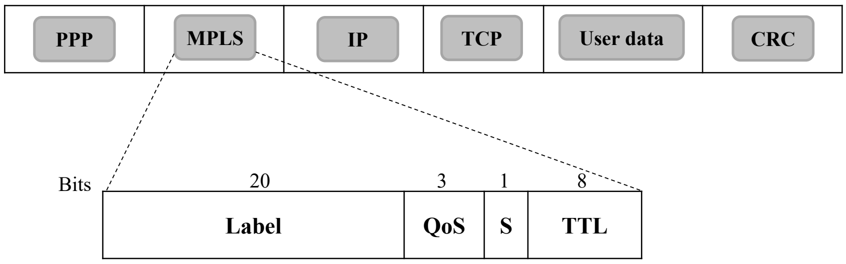


Figure 07: Label Switching and MPLS.

Multi-Protocol Label Switching is one kind of technology in order to forward internet traffic in the network. MPLS uses the label adding technique for each packet and transmits it based on the label. MPLS header is added after IP header between IP header and PPP Link-layer header, MPLS is not layer three protocol, it just uses IP for setting up the label path, also it is not layer two protocol, since forwards packet along hops. So it called layer 2.5 protocol. In addition, MPLS can move IP packet on non-IP networks.
For label switching in the network, the router is required which can switch traffic, it called label switched router. When the packet arrives at the label edge router, it will add a label of destination to the packet and forward it inside the MPLS network toward the correct path, when the packet reaches to edge router in another side of the MPLS network, the label will be eliminated and then transmitted to the next IP network.

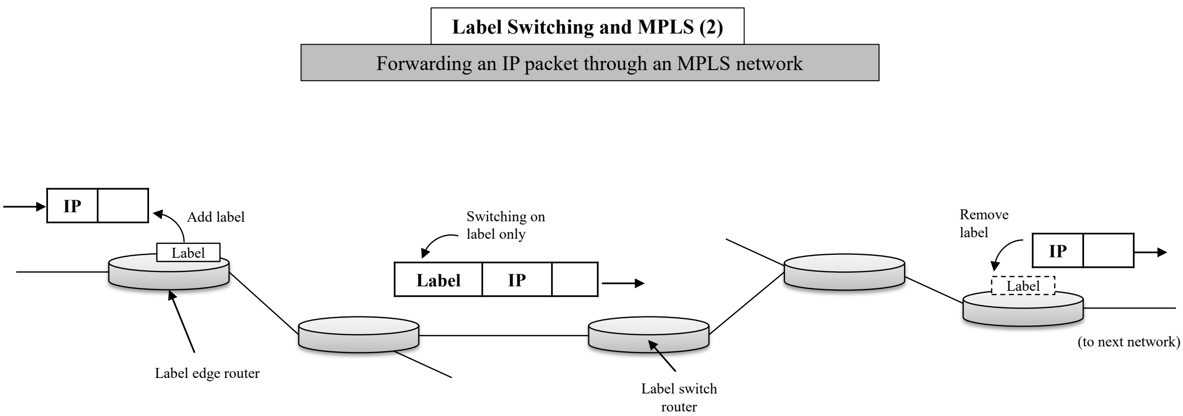


Figure 08: Label Switching and MPLS2.[10]

2.3.3 Ethernet

Ethernet was created in the 1970s, is used as a packet-switched in data link which connects network devices with a single coaxial cable. Ethernet is a layer two protocol in the OSI model. The data link layer in an interface layer between the physical and the Internet layer so it can use as a service of the physical layer to transfer and receive data over a channel.[11]

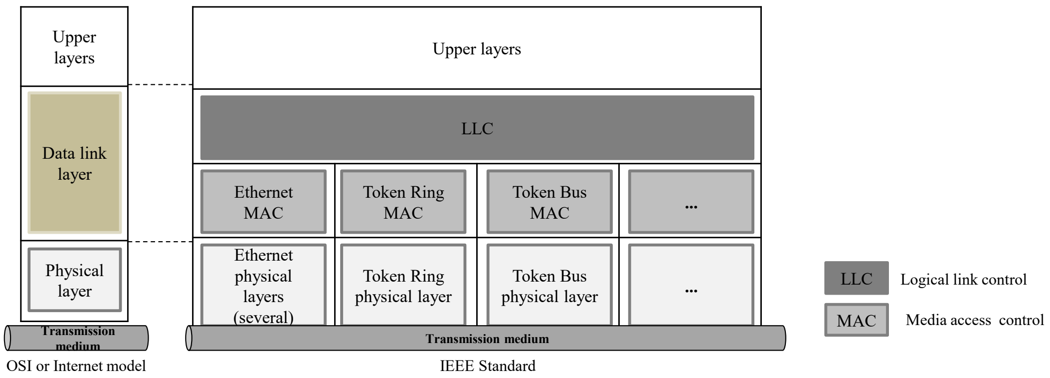


Figure 09: Data link layer overview.[11]

Here the Ethernet architecture is shown, which Ethernet includes the physical and data link layer of the OSI model. Ethernet layer hierarchy contains logical link control, medium access control, and Ethernet standards.

2.3.3.1 LLC (logical link control)

The Ethernet sub-layer handles addressing and multiplexing.
For IEEE 802 some standards are done in LLC:

- Flow control
- Error control

2.3.3.2 MAC

Provides addressing and channel access control mechanisms and performing framing. Protocols of accessing a channel in the MAC layer includes:

- Random access
- Controlled access
- Channelization

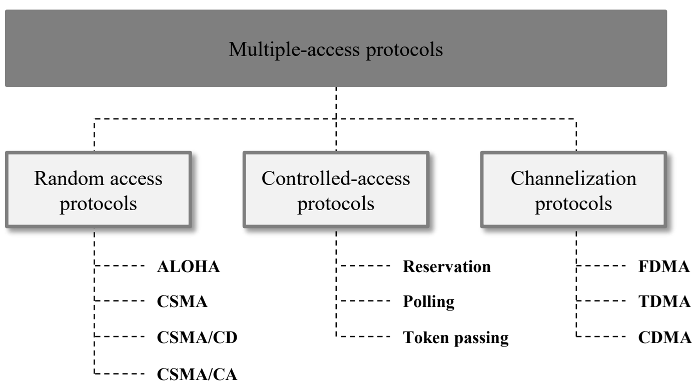


Figure 10: Multi-access protocols.[11]

Protocols and standards:
• Media Access Control (MAC)
In Ethernet standard, each computer for connecting to network needs a network interface card (NIC) and each NIC has a unique 6 byte Ethernet address which is allocated by NIC manufacturer. MAC address is used in switches for finding the destination of data.

• Carrier sense multiple access (CSMA)
when nodes decide to transmit a packet in Ethernet technology, at the same time the problem arises and collision will occur, for preventing collision the CSMA protocol is implemented, before the transmission packet the node listens to the link if the channel is idle, it sends data this method is named CSMA with a collision detection algorithm.
• Another algorithm is CSMA collision avoidance is used in Wi-Fi standards. CSMA makes a propagation delay in the link.
• Point to Point link:
Point to point is an important application of Ethernet for an end to end nodes, Ethernet has a full-duplex option that improves the performance of the link. With this option, the CSMA/CD is not essential because nodes can transmit simultaneously, so full-duplex channels have a higher transmission rate and are improved constraint of link capacity and data loss.[8]

MAC defined the special manner for each LAN:
- CSMA/CD as a media access way for Ethernet LANs.
- Token passing for the token ring and token bus.[11]
In the below diagram the procedure of packet encapsulation by the data link layer is shown.

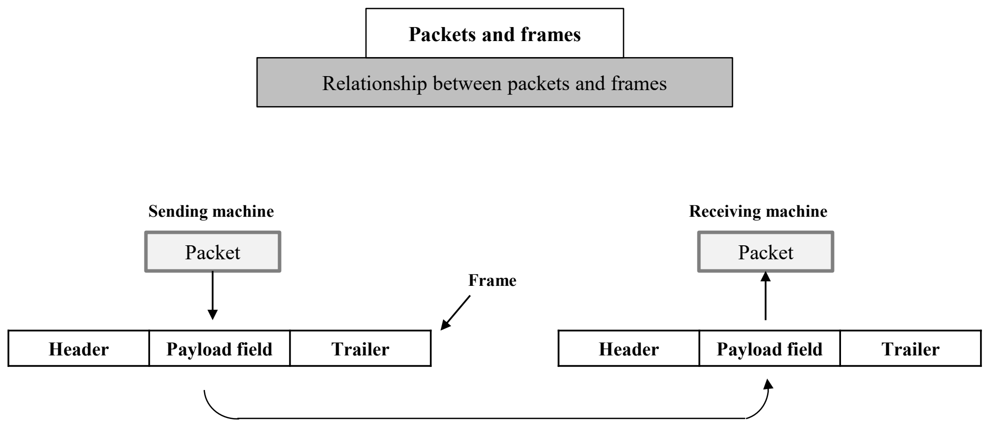


Figure 11: The procedure of encapsulation by the data link.[10]

2.4 Network topology

At first, early bus topology was used for Ethernet, and then new topologies were used. Ethernet is using a variety of topology including:
1- Point to point
2- Star
3- Ring
4- Bus
5- Mesh
6- Extended star
7- Hierarchical
Which are shown in figure 12:

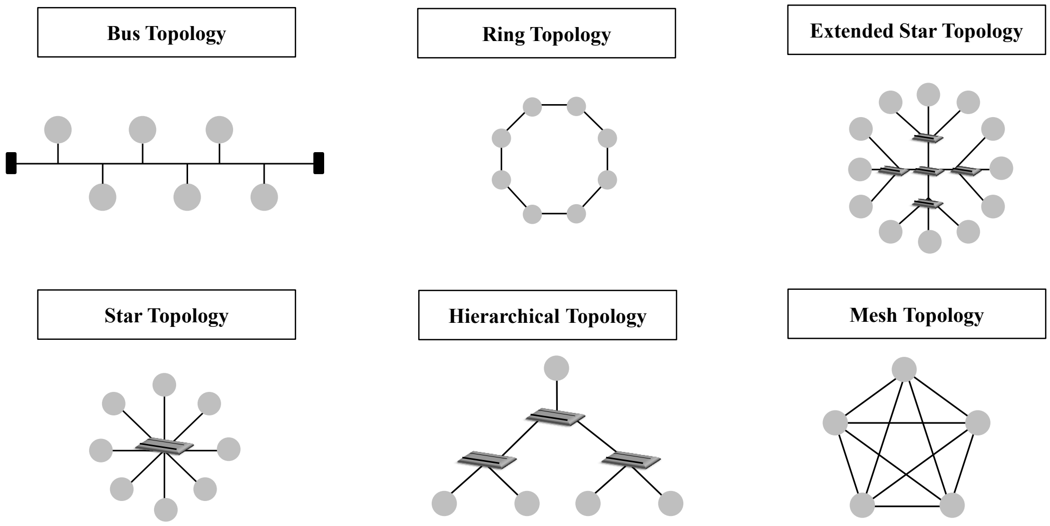


Figure 12: Physical Topologies. [10]

Datalink connection in Ethernet was improved to some variety of physical communication media such as twisted pair cable, wireless and optical fiber. Ethernet provides various data transmission rate for example: 10 Mb/s, 100 Mb/s (Fast Ethernet), 1 Gb/s (Gigabit Ethernet), 10 Gb/s, 40 Gb/s and 100 Gb/s are developed. [11]

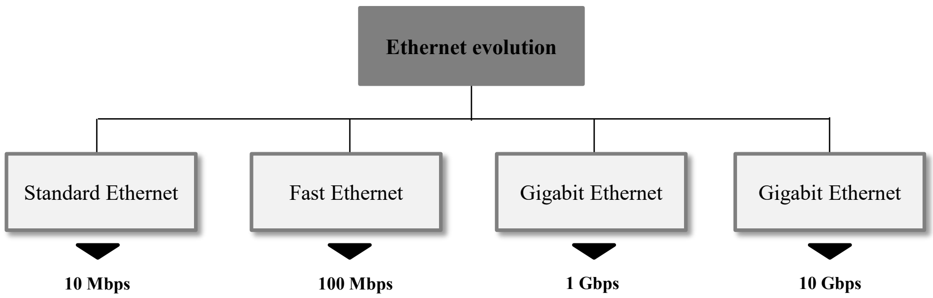


Figure 13: Ethernet evolution diagram.[11]

2.5 Access Network

Access-network is a kind of network which physically connects an end-user to the immediate edge router. The optical network has two types of access-network :
1- Active optical network (AON)
2- Passive optical network (PON)

2.5.1 Active optical network (AON)

AONs were developed based on point to point (P2P) network structure, where each user is allocated its own fiber that the fiber connection will be ended on optical access node, moreover, AONs use electrical equipment in their networks such as electrical switch and router.[12]

2.5.2 Passive optical network (PON)

PONs were deployed according to one point to multipoint (P2MP) to provide broadband access, in addition to the structure of PONs that did not use electrical power.
Nowadays with the help of fiber, ISPs provide large bandwidth for serving high bit-rate media for customers, but with increasing requests for higher bandwidth, the traditional fiber capacity should be increased, because of that reasons FSAN working group have introduced passive optical networks (PONs) which maintain traditional telephone system, VoIP and multimedia.

Cost-effective and power consumption play the main role in deploying PONs.
PONs have to work mode:

• Downstream: uploading data from user side to network.
• Upstream: downloading data from network. [13]

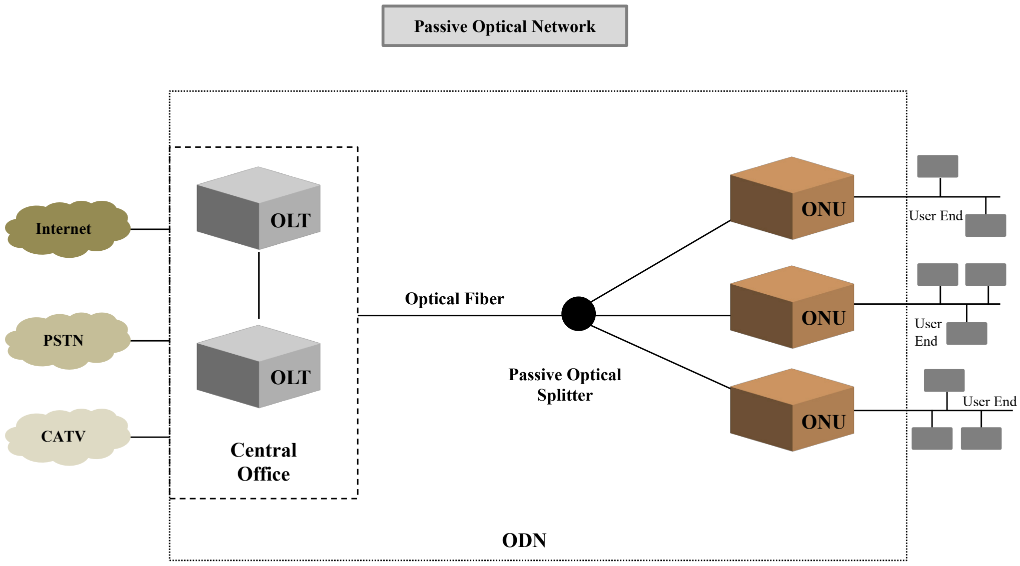


Figure 14: Passive optical network architecture.

The PON architecture is shown in figure 14, it includes three main sections:
1- OLT (Optical Line Terminal)
2- ONU (Optical Network unit)
3- ODN (Optical Distribution Network)
- The OLT operates as an interface between the access network and backbone network; moreover, it performs the implementation of MAC protocols.
- After OLT until end-users is defined as Optical Distribution Network (ODN) which conforms to some optical splitters and WDM filters that distribute received optic signals from OLT toward end-points, along the ODN only passive optical elements are permitted.

2.5.3 TDM PON

According to the performance of the TDM, it allows each client to use their single portion of wavelength and assigns a high-bandwidth in fiber link to share data. TDM-PON utilizes the TDM technique for merging received traffic from OUNs into upstream and downstream links. This technique is more common because of lower support costs and reliability.

2.5.4 PON generations

During recent years the Full-Service Access Network (FSAN) in collaboration with ITU and the Ethernet in the First Mile alliance cooperated with IEEE, introduced some PON standards according to bit-rate which their generation have developed, these institutes have worked based on increasing data transmission rate form, so different technologies have used PON:

- ATM PON
- Broadband PON
- Ethernet PON
- Gigabit PON
- 10G EPON (NX-EPON)
- XG-PON
- TWDM-PON [13]

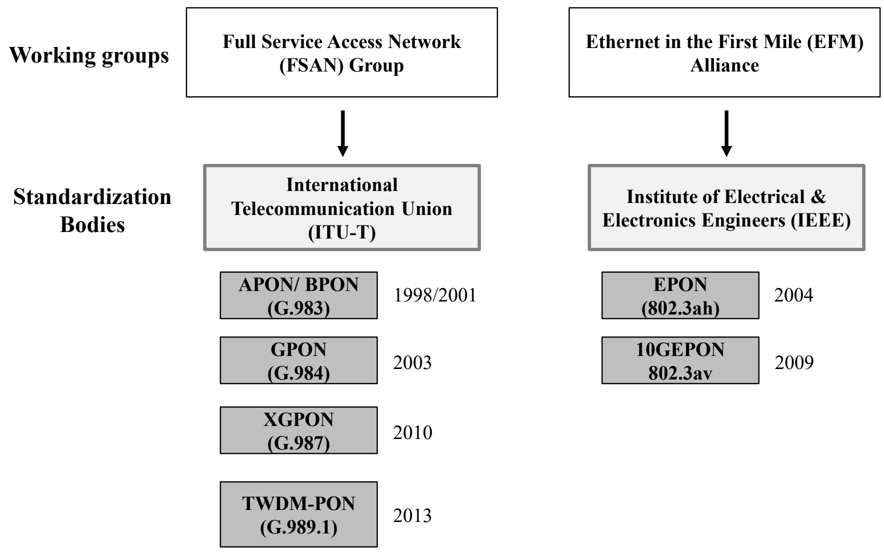


Figure 15: Hierarchy of multipule generation of PON.[12]

2.5.4.1 EPON

Ethernet passive optical network is a point to multi-point standard has developed for gaining large bandwidth in Ethernet, this standard's goal is providing low-cost Ethernet network and finding a solution for enough bandwidth demands for some services in Ethernet such as video demands, the voice on IP, video on IP and gaming. It provides symmetric 1.25Gbps bandwidth both upstream and downstream in 20km distance.

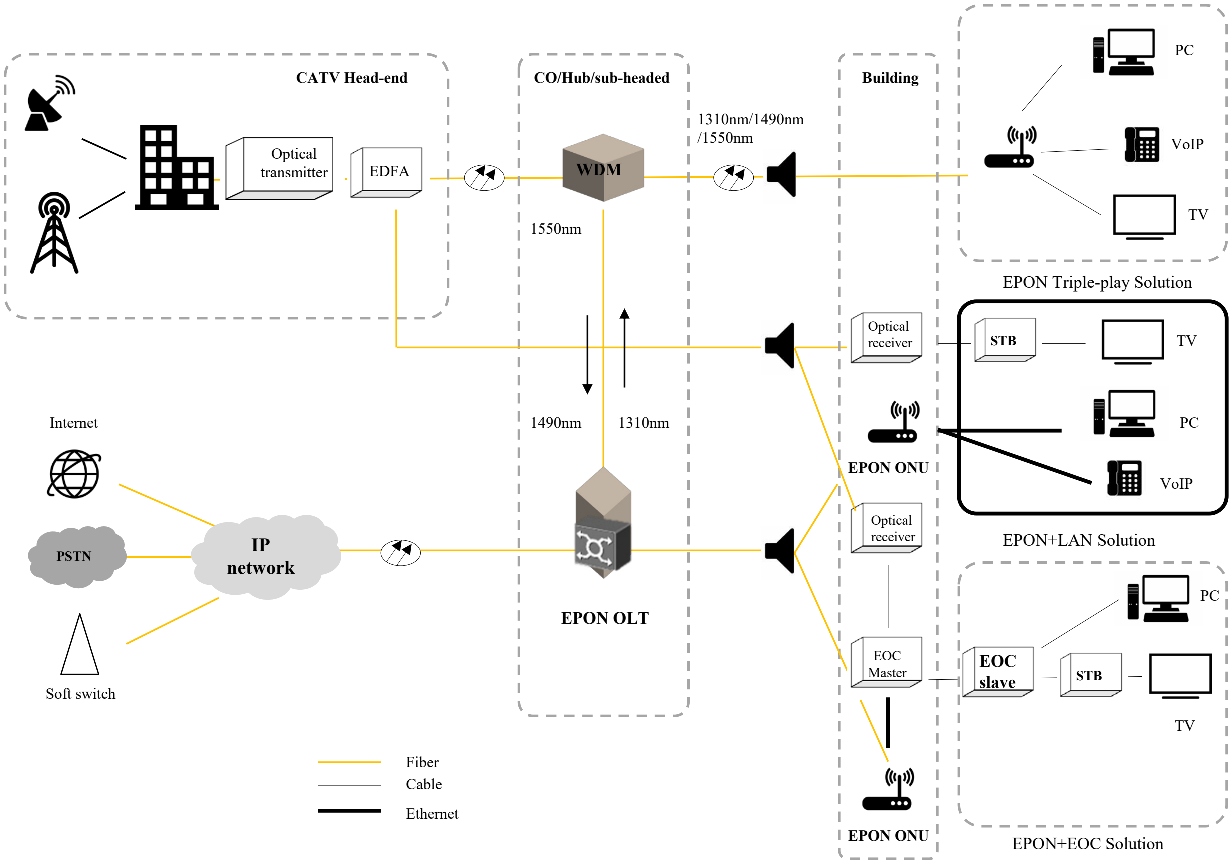


Figure16: EPON architecture.

In upstream (from ONUs to OLT), multiple ONUs send traffic on single fiber towards OLT, so my collision occurs in link, for avoiding collision OLT spreads fiber link capacity by using upstream bandwidth arbitration mechanism, here is some point to point connections over a single fiber, TDM protocol divides bandwidth of link to multiple sub-band to avoid the collision.

In downstream (from OLT to ONUs), the data are broadcasted to end-points, in this situation ONU should listen to a channel, so each ONU consumes energy to stand awake, running an effective energy management mechanism (EMM) to schedule the sleep mode period to ONUs will reduce energy consumption.[14-15]

For more information about the cycle of awake-sleep scheduling, mechanism refers to Improving Energy Efficiency in Upstream EPON Channels.[16]

2.5.4.2 GPON

ITU-T G.948 series defines GPON standards that maintain different bit rate, in both upstream and downstream links. The first one is 622 Mbps or 1.244 Gbps in both up or down, the second one, 2.488Gbps in downstream and 1.244Gbps in upstream.[13]

2.5.4.3 NX-GPON

The most recent generation of PON standards is the next generation PON2 (NG-PON2). The important benefits of NG-PON2 include:

- Development of the aggregation rate to 40Gbit/s in downstream or upstream.
- Splitting ratio up to 256 users
- The distance of transmission between 40-60 km

2.5.4.4 XGPON

The most important challenge in deploying PON networks is the power consumption, in the next generation of PON network this matter should be considered. So for overcoming this challenge, Green NG-PON is deployed. The goals are an exploration of design methods to reach minimum power consumption and satisfying QoS needs.

Energy-saving techniques:
1- Hardware-based
• New OUN architecture [17]
• Optical noise reuses [18]
2- Software-based
• ONU shedding
• ONU sleep [19]
• ONU dozing
• ALR (adaptive link rate)
• Shutdown wavelength [20-21]

2.6 ATM

Asynchronous transfer mode was designed in the 1990s, the goal was to combine voice, media, and data in an integrated system. The ATM widely used in broadband access links inside telephone networks.
It is a data link layer protocol according to transferring the fixed-length cells of data. Because in ATM all cells do not follow the same rule for transmission bits, when the bits receive they are sent, so cells act in a different time, in fact, cells do not have constant relation with the master clock, at the result this protocol is called Asynchronous.
ATM is a connection-oriented technology, it means any cell carries the information of destination, by virtual-circuit identifier on its header, which permits to establish a connection in the path.[10]

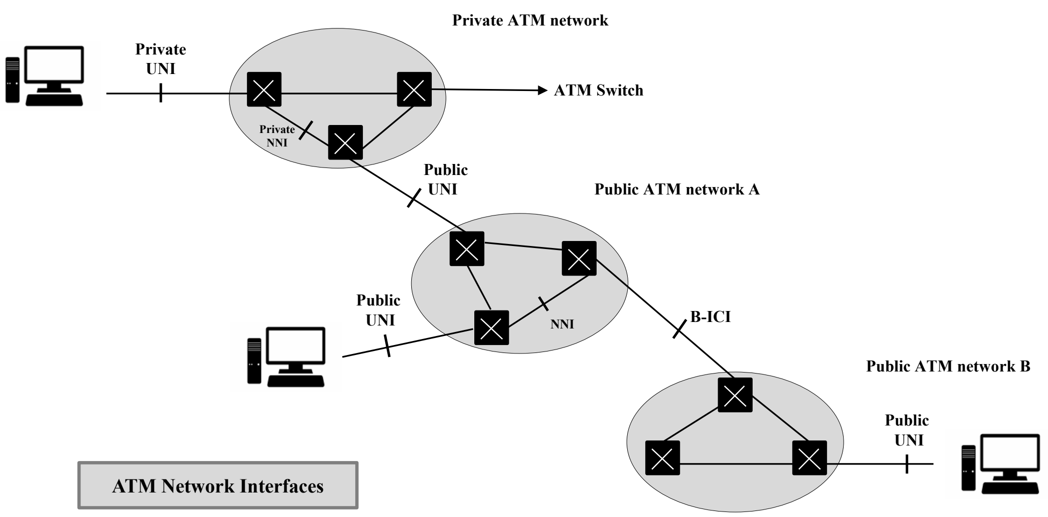


Figure17: ATM based network.

User-Defined Interface (UNI) is used for transmitting data from ATM users to ATM networks, also Network to Network Interface (NNI) between two ATM switches.
ATM collaborates with both circuit and packet switching, data is segmented to a 53-byte cell, five bytes for header and 48 bytes payload. The header includes routing information. ATM provides QoS guarantees such as delay and bandwidth, the cell flows are generated according to source required bandwidth with using multiplexing techniques. Another benefit of ATM is that performing switching in a local-area environment unlike other LAN technologies the same as Ethernet, token ring, this feature makes to satisfy QoS requirements. The ATM technology can deploy low-cost high-speed switches, because of fix packet-size.

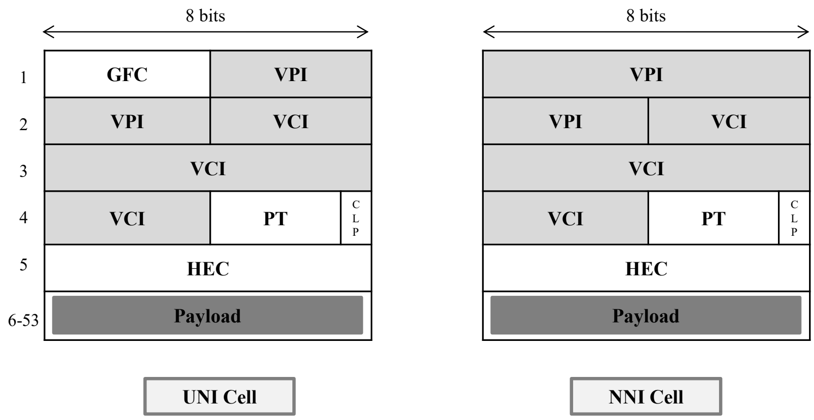


Figure18: ATM cell.

VPI or Virtual Path Identifier: 8 bits on UNI, 12 bits on NNI.
VCI or Virtual Circuit Identifier: 16 bits.
PT or Payload Type: 3 bits.
CLP or Cell Loss Priority: 1 bit.
HEC or Header Error Control: 8 bits. The HEC constitutes a CRC on the 5 ATM.
In ATM each connection is established in a virtual channel and is allocated a unique identifier. As mentioned before the first aim of using ATM was to provide QoS requirements to guarantee cell loss, cell delay, and jitter, ATM hires a combination of traffic shaping and admission control to provides those guarantees.[6]

Chapter 3

Standards of Physical and Optical layer

Introduction

Optical networks offer some facilities to solve the weakness of electrical networks and the constraint of the capacity in traditional networks. The optical fiber provides much higher bandwidth and bit rate than copper cable (Gbps). Optical networks generally have two generations, the first generation prepared higher capacity and lower bit error rate than copper cables which is utilized for transmission, while all switching and other network equipment are supporting in the electric domain such as SONET/SDH. In the second generation of optical networks all routing, switching and so on are handled by the optical domain.
From a cost point of view, transmission data with a higher rate over a single fiber is very economical than transferring a lower rate in multiple fibers, this fact has created multiplexing techniques which was a revolution in growing transmission capacity on a single fiber. According to the work environment, in the both optical or electrical domain, multiplexing techniques are provided such as: TDM, OTDM, WDM and DWDM.
Each optical network has several types of equipment to route, amplify, add-drop and regenerate the signal over the path that is able to support data transmission based on network policies. So in order to achieve a better understanding of the network, the functions of the network were divided into different layers. Certain categories of functions are performed by each layer and prepare some services to the upper layer. Hence, this chapter is considered layer one and optical layer standards and protocols and their relation and functionalities.[6]

3.1 Interface to Optical layer

The direct transmission services in wavelength cause the problem in managing network, so network operators utilize framing standards to simplify this problem. For instance, SONET and SDH features are used to present a framing standard format for optical transmission, the header of the frame contains some information such as performance monitoring, path trace, and operations, administration and maintenance (OAM) connection.

3.2 SONET/SDH

SONET is the American National Standards Institute (ANSI) standard and generally is used in North America, whereas SDH is the International Telecommunication Union (ITU) standard and is typically used in Europe and Japan.
These standards at first were developed for voice traffic and then are added some features to support data traffic. SONET is a communication protocol is used for Synchronization Optical Network, also SONET is an interface to switching from electrical to the optical domain.[8]
Moreover, this interface is used for multiplexing which provides the capability to use time-division multiplexing, where for each time slot one circuit is assigned, then slots are packed into a bigger frame.
SONET/SDH has deployed in backbone networks that had higher adaptation with constant bit rate (CBR) connections and it uses time-division multiplex techniques to complete some connections in higher rate connection. While SONET/SDH was designed for low rate voice and CBR connection with rate of almost 51 Mb/s, but now maintenances traffic rate up to 10 Gb/s in the transmission link. One of the important capabilities of SONET/SDH is, that can be adopted with layer protocols for working with IP, Ethernet and Fiber link.[6]

3.2.1 SONET network components

SONET is a connection protocol with the ability to transfer multiple digital data simultaneously via optical fiber. As figure 19 shows, SONET includes some elements from source to destination. In source-side first is a multiplexer that multiplies several signals into a single link, then a regenerator is set up in a path to rebuild the signal, after that an add-drop multiplexer add/removes several signals from the different source towards a destination. In the destination side again, a regenerator amplifies signal then in the destination the received signal is demultiplexed to separate wavelengths, this procedure can be established in an inverse direction.

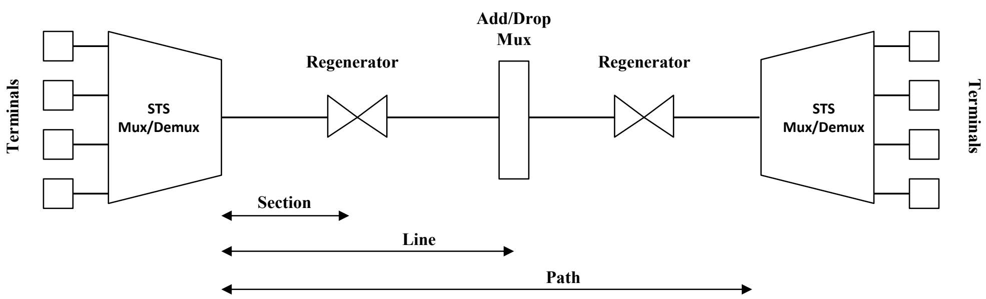


Figure19: SONET architecture.

1. STS Multiplexer
• Performs multiplexing of signals
• Converts electrical signal to optical signal

2. STS Demultiplexer
• Performs demultiplexing of signals
• Converts optical signal to electrical signal
3. Regenerator
• It is a repeater, that takes an optical signal and regenerates (increases the strength) it.
4. Add/Drop Multiplexer
• It allows adding signals coming from different sources into a given path or removes a signal.
SONET is used to convert the electrical signals into the optical signals so that it can travel longer distances.

3.2.2 SONET Connections

• Section: Portion of network connecting two neighboring devices.
• Line: Portion of network connecting two neighboring multiplexers.
• Path: End-to-end portion of the network.

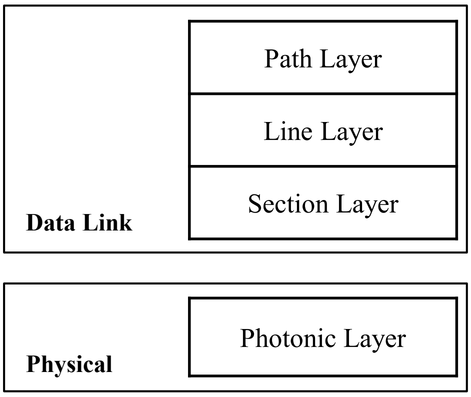


Figure20: SONET Layered model.

SONET includes four functional layers:
1. Path Layer:
• It is responsible for the movement of a signal from its optical source to its optical destination.
• STS Mux/Demux provides path layer functions.

2. Line Layer:
• It is responsible for the movement of the signal across a physical line.
• STS Mux/Demux and Add/Drop Mux provide Line layer functions.

3. Section Layer:
• It is responsible for the movement of a signal across a physical section.
• Each device of the network provides section layer functions.

4. Physical Layer:
• It corresponds to the physical layer of the OSI model.
• It performs transmission of digital signal over fiber.[22]
Each of the layers has its own header bytes in the SONET frame. For carrying packet over SONET, some framing operation is required to realize the procedure of packet comes from a different layer.

3.2.3 Advantages of SONET

The advantages of SONET are:
1- Multiplexing simplification:
In asynchronous multiplexing, each terminal in the network runs its own clock, however, it is specified a clock rate for the signal, so the result will have a major difference between signal clock rate and others.
In synchronous multiplexing, because all the clocks are synchronized with a signal clock rate, it will decrease the cost of multiplexing.
2- Management: this standard has wide management information for managing networks, contains performance monitoring, identification of connectivity and traffic type, identification of failures between nodes.
3- Interoperability: because different vendors use different optical interfaces and emphasis to optimize their products, so that is difficult to establish a connection between vendors. SONET/SDH provides optical interface standards for collaboration between vendors.
4- Network availability: the SONET/SDH was derived to collaborate with particular network typologies and special protection techniques to enable high availability services, therefor after failure the service restoration time with SONET/SDH is less than 60 ms.[6]

3.2.4 ATM over SONET

ATM can executes on top of several interfaces in this case, ATM over SONET used to map ATM cells into PSE (Synchronous Payload Envelope is SONET frame). Cells are scrambled after back to back placing. The scrambling possess is essential to be sure the SONET signal to permit line rate clock recovery at destination by having sufficient transitions.[22]

3.2.5 IP over SONET

IP over SONET/SDH or packet over SONET/SDH (PoS) was first deployed in 1996 at 155 Mb/s, where large bandwidth demand was increased, after ATM that was designed for aggregating voice and data traffic on high rate, now IP over SONET/SDH as new approach which provided new technology can be used in backbones, so it has become the main protocol standard to build large IP backbones. Networks all over the world with this standard could transfer data with 10 Gb/s and 40Gb/s rate.[23]

3.2.5.1 Protocol stack of IP over SONET/SDH

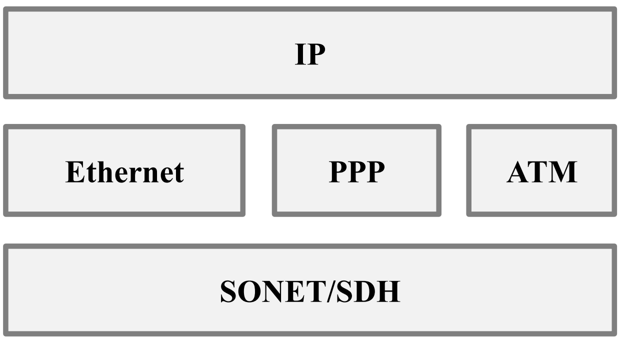


Figure21: Protocol stack of IP over SONET/SDH. [24]

According to figure 21, basically the protocol stack of packet-switched optical architecture, which is deployed in three layers, each layer utilizes different technologies. Basically, IP is packet-based switching, which is located on the top of a circuit-switched SONET/SDH optical network. Between IP and SONET/SDH layer, there are an ATM, Ethernet, and Point-to-Point protocol layers.[24]

Here two scenarios will appear:
1- First scenario: IP over ATM then SONET
The ATM was deployed because of some efficiency properties:
• Cheaper than Ethernet
• Very flexible
• High QoS
• With IP over ATM service provider can offer VPN
2- Second scenario: IP over SONET directly
To implement IP over SONET directly, the point-to-point layer two protocols were defined by IETF.
The path of encapsulation can provide a QoS degree offered by ATM while using IP over SONET directly creates some security and reliability problems in the network.

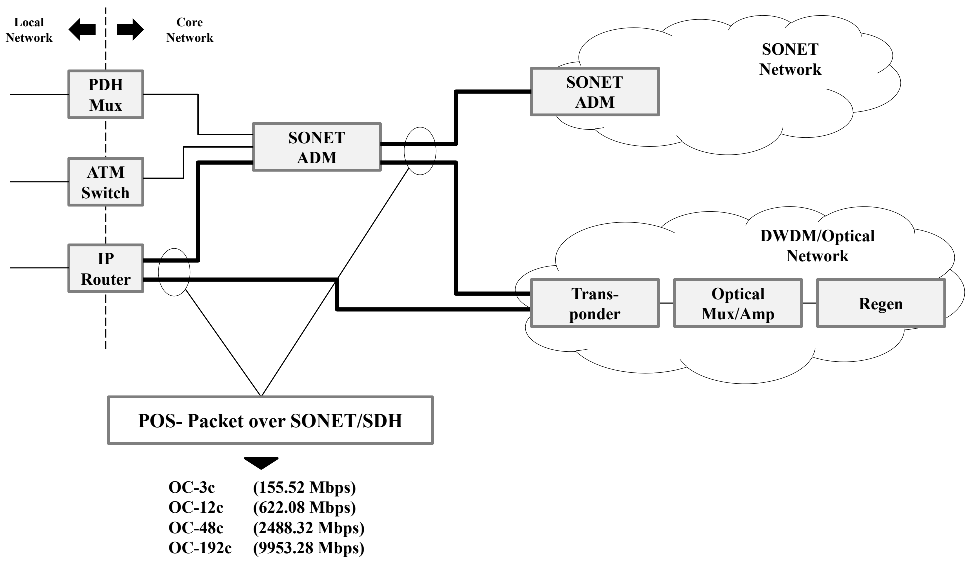


Figure22: The diagram of IP Packet over SONET.

This diagram demonstrates the network model of Packet over SONET, as is shown the packet is transmitted from the IP router toward the SONET switch which different optical carrier (OC) rate. Along the path, the IP packet will be encapsulated and gets each layer header to arrive in the destination.
The path for the IP packet encapsulation is:
1- IP
2- PPP
3- Optical carrier (OC) over SONET/SDH which is described in IETF RFC 1619.
The first data is segmented to IP datagram which contains 20 byte IP header. IP datagram is encapsulated into Point-to-Point packets, framing information is added to PPP encapsulated IP data-gram by high-level data link control (HDLC). Between frames exist gaps that are filled by flags. When any flags are found in data the octet stuffing protocol will run, the octet value 7E is employed to show state and end of the frame, the output data is scrambled and mapped synchronously by octet into SONET/SDH.[23]

3.2.5.2 Advantages of IP over SONET

Using IP over SONET has some benefits promises:
1- Simplicity
2- Bandwidth efficiency
3- Being scalable
4- Fault-Tolerant (with Sprint's fiber network)
5- 1:1 redundancy
6- Only one infrastructure should be managed. [23]

3.3 OTN & WDM networks

• Multiplexing & WDM
• EDFA
• OADM
• OAMP for WDM
• Flex-grid networks
• OTN

3.3.1 Multiplexing Techniques

The cost is an important reason for multiplexing demand, so that transmission data with a high bit rate in single fiber is more economical than sending in multiple links.
Basically, there are two fundamental methods for enhancement transmission capacity on fiber link:
1- TDM
2- WDM

3.3.1.1 TDM
Time-division multiplexing, in this way two or more signals are transmitted at the same time in a single fiber, the time domain is separated into several time slots with a fixed length.

3.3.1.2 WDM
Wave division multiplexing is a technique that aggregates some number of carriers into a single optical fiber, here bandwidth of transmission link is divided into some sub-bands with different wavelengths. WDM is integrated from frequency division multiplexing. In these approaches, any sub-carriers occupy separate wavelengths, so it makes to prevent interference between signals. WDM enhances the capacity of transmission by using high-speed network devices such as optical switches, optical carrier (OC) and optical cross-connects (OXC).

3.3.2 WDM technology

As it explained, WDM technology increases the bandwidth capacity of the fiber-optic link by employing optical fibers to multiplex and demultiplex N laser wavelength into one aggregated fiber. EDFA plays an important role in WDM systems, for reducing loss and number of regeneration amplifiers in expanded optical networks. [26]
WDM Network elements:
1- Optical line terminal (OLT)
2- Optical line amplifier
3- Optical add-drop multiplexer (OADM)
4- Optical cross-connects (OXC) [26]

3.3.2.1 OLT

The optical terminal contains wavelength multiplexers, demultiplexers, and transponders. Transponder converts the incoming signal from the client to an appropriate signal for transmission on the WDM link and an incoming signal from WDM to a feasible signal towards to client.
The OLT has the transponder that adopts the incoming signal from a user with a feasible signal for transmission over the WDM link by converting the incoming signals. When the client signal has a suitable format that can be directly transmitted on a WDM link, the transponder is not required. In reverse direction again OLT converts the optical signal into an appropriate signal which is usable for the client. Some parameters such as bit-rate, distance or loss between clients and transponders affect on the selecting interface between them, more popular interface is SONET/SDH. [26]

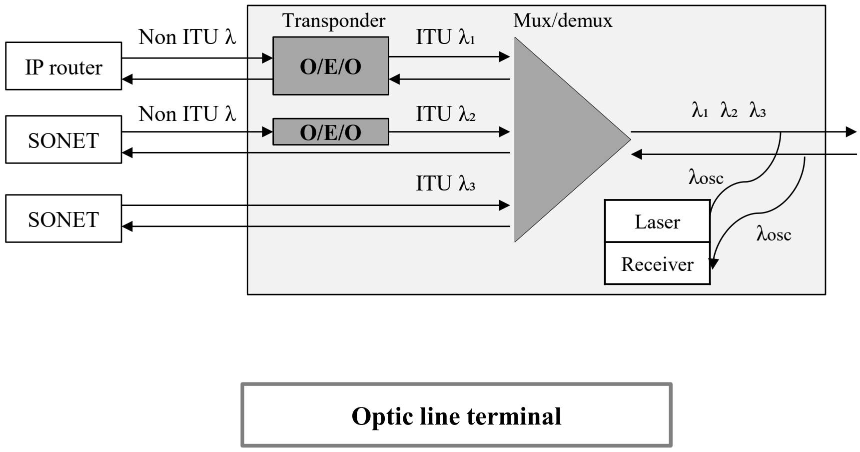


Figure23: Block diagram of an Optical line terminal. [6]

3.3.2.2 Optical line amplifier

It is deployed for regenerate the signal among optical fiber link, it is set up in periodic intervals in defined distance.

3.3.2.3 EDFA

One of the major approaches in optical transmission was the development of ebrium-doped fiber amplifiers (EDFA).
This key provided cost-effective wave division multiplexing systems (WDM). Early EDFA regenerated the signal every 40 km periods, after it deployed up 80 km, while now EDFA systems permit to optical signals to transmit 500 km and upper without regeneration the signal.[8]

3.3.2.4 OXC

This is a network element which needed to organize more complicated mesh topology and wide number of wavelengths. OXC can use in optical and electrical switches. OXC enables switches and mesh topology in wavelength routing and reconfigurable optical networks.
The functionality of OXC are:

- Service provisioning
- Protection
- bit-rate transparency
- Performance monitoring
- Wavelength conversion
- Multiplexing and grooming

3.3.2.5 ROADM & OADM

It is an optical add/drop multiplexer that provides cost-effective tools for routing traffics in metro and long-haul networks. The traffic which is passing through the node can be in the optical domain between east and west links.[8]

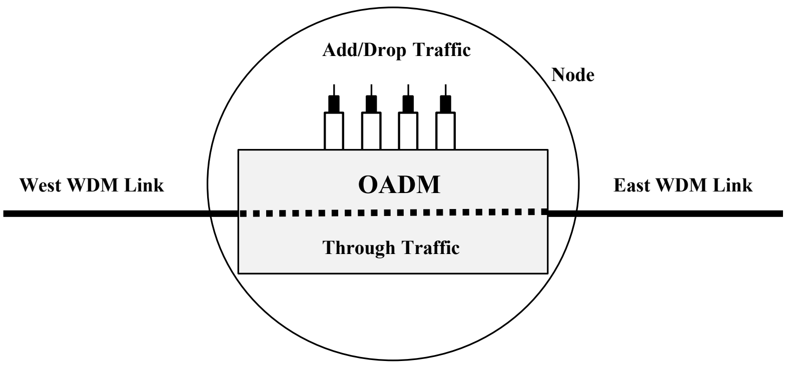


Figure24: Optical Add/Drop multiplexer. [8]

OADM has some architecture such as parallel, band-drop, serial, and modular. It can be employed in two methodologies; the first one is fixed and the second one is the reconfigurable mode. In the fixed mode, any operation is done in an outline scheme that can be reorganized manually.
In reconfigurable OADM, the network configures OADM, it means that the channels are assigned as add/drop or pass-through a node by the network, this method is more complex but it can remove all manual intermediation, decreases unessential optoelectronic altering and reduces the cost in the network.

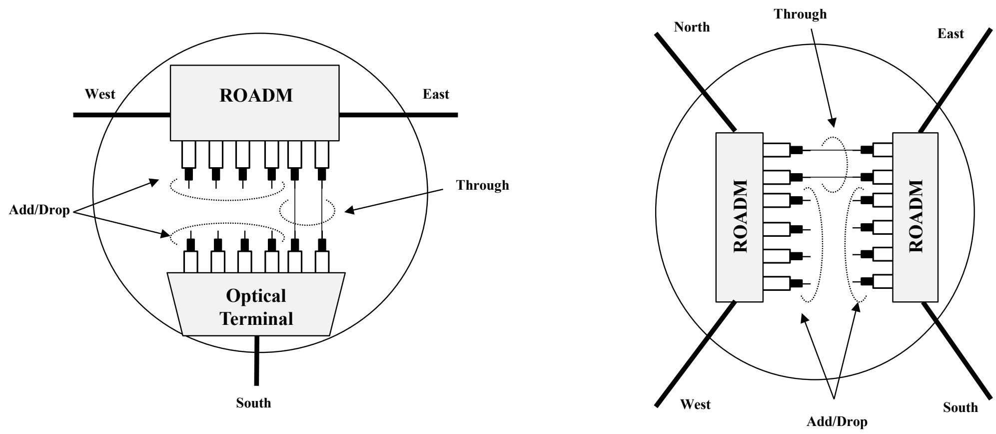
3.3.2.5.1 Re-configurable OADM

1- Partly reconfigurable
2- Fully reconfigurable

In partly reconfigurable architecture, in spite of choosing the channels to add/drop, there is a predetermined matrix between add/drop and through ports that make constraints to wavelength allocation.
Fully reconfigurable architecture puts out the tools to select channels as add/drop because there is a connection between add/drop and via ports that actives flexible wavelength allocation, such that a channel needs more bandwidth, it will be permitted to carriers to be flexible in selecting the wanted wavelength.[26]
While the ROADM is able to be reconfigurable, the amount of add-drop cannot invade in a given threshold, the common threshold is 50% of the maximum wavelength of fiber, the upper mount of the threshold will be add-drop.[8]

3.3.3 Multi degree ROADMs

As mentioned, ROADM enables dynamic add-drop or represents a tunnel of WDM channels at network nodes without optical-electrical-optical (O-E-O), so the results are cost-effective. However, the first generation of ROADM was degree 2 that has supported line or ring architecture, next ROADMs to able to support high-degree nodes that are mandatory for design and extension of future optical networks.[8]



a

Degree-three node with one reconfigurable optical add/drop multiplexer (ROADM) and one optical terminal.

b

Degree-four node with two ROADMs.

Figure25: Multi degree ROADMs. [8]

In WSS-based ROADM each degree of ROADM requires a wavelength selective switching (WSS) switch for each direction, so by increasing node, the cost will increase.
ROADMs have a significant effect on reconfigurable capabilities and cost-saving. As mentioned, ROADMs maintain dynamic traffic, run new services, and save capital expenditure besides the operational expenditure. While the limited number of a wavelength which allocated to nodes decreases the cost, but it reduces the capabilities of reconfiguration. Limit reconfigurability makes a new constraint that arises in wavelength allocation, which is called wavelength termination constraint.[27]

3.3.3.1 Properties of ROADMs

1- Cascadability: it refers to the number of ROADMs that a signal can be routed before decadence of the signal.
2- Automatic Power Equalization: the power levels which enter in each node are not equal, unequal power level also integrated from inappropriate amplifier gain, for providing better system efficiency, it is essential to balance this power level periodically by ROADM automatically.
3- Colorless: the capability to entering a transponder of a wavelength into another slot of ROADM. It comforts operations.
4- Directionless: means the ability of an add-drop transponder to access any link which enter/exit the ROADM
5- Multicast: some ROADMs maintain to send a signal to multiple destinations.[8]

3.3.3.2 Limitations of ROADMs

The first generation of the WSS based ROADM is low cost, but WSS architecture is not flexible in the next phase of optical switching, early generation according to one WSS in each direction raised some limitations :
1- Fixed wavelength allocation to particular ports.
2- Fixed direction allocation for multiplexers.
3- Divisions add/drop structure because of wavelength conflicts.
In an assignment for comparison between two models of ROADM:
- limited ROADMs (L-ROADMs) can add-drop only a subset of wavelength and cost less than fully model.
- Fully ROADMs (F-ROADMs)

This result was provided:
- Applying ROADMs makes higher flexibility in reconfiguration capability and decreases the cost of optical networks
-Employing a limited range of wavelengths reduces cost and it is possible to decrease flexibility in reconfigurability.
-While F-ROADM can add-drop any wavelength from the spectrum, but L-ROADM is able to add-drop wavelengths among a limited sub-portion.[27]
Today upgrade ROADM (NG-ROADM), is expected from the next generation of ROADM will solve this limitation by providing below features:
• Colorless functionality
• Directionless
• Contentionless (in wavelength)
• Grid less (flexible grid) [28]

3.3.4 Flex-grid networks

The grid is a new architecture that prepares more capabilities to implement some services in the network, moreover gird users were designed to compensate the weakness of traditional networks in service providers. Because of the mentioned demands, the transport network requires to derive from DWDM systems towards elastic optical networks, according to Flex-grid transmission and switching technologies.

The grid architecture permits resources to maintain a large number of services and brings some facilities in the network such as scalable, reliable, re-configurable, and secure mechanism also allows the optimizing of bandwidth utilization. The Flex-grid network concentrates on the architecture of the network which supports variable and dynamic spectrum to enhance spectral efficiency and decreases the cost. This type of network against WDM which is using fixed 50 GHz and flexible 12.5 GHz based on ITU-T standards.[29-30]

3.3.5 OTN

"The optical transport network (OTN) protocol defined by the ITU-T (Recommendation G.709) has become the backbone of service provider long haul and metro networks".[31]
The OTN flexibility has permitted to maintenance transparent transport for both constant bit rate and packet-based WDM signals and is modified to decrease the number of devices and operational costs for service provider networks. OTN is deployed according to concepts of SONET/SDH, and able to handle all kinds of traffics including SONET/SDH. also OTN standard has provided high adaptation with 40Gb/s and 100Gb/s DWDM systems. Moreover, the OTN has developed for multiplexing and encapsulation in networks, first OTN has presented standard-based operation, administration, management and provisioning (OAM&P) functionality within encapsulation procedure which puts up payload bytes for OAM&P to gain information about path and link during optical connection.
"Second, OTN has also defined a TDM-based mechanism for aggregation and switching lower rate payloads within a higher rate optical channel" [32]

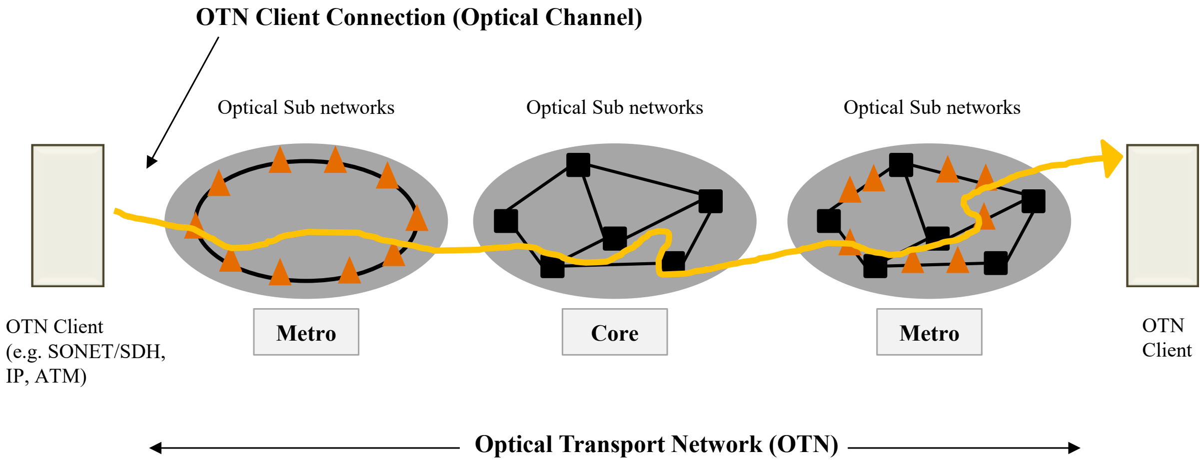


Figure26: OTN architecture.

3.3.5.1 Layers within the Optical Layer

In OTN standard several optical channels can be transported at the same time, where each channel is mapped to a particular wavelength, for transmitting each optical channel, a digital frame is required which is confirmed by payloads and header fields.
As shown in figure 27, the client data is mapped into the payload unit, also it has network information on its header. Optical channel payload, optical channel data unit, and optical channel transport unit allocates to the electrical domain. The optical payload unit encapsulates the received signal from the client with interface standards such as SONET/SDH and runs rate synchronization. The OTU includes the forward error correction (FEC) too.

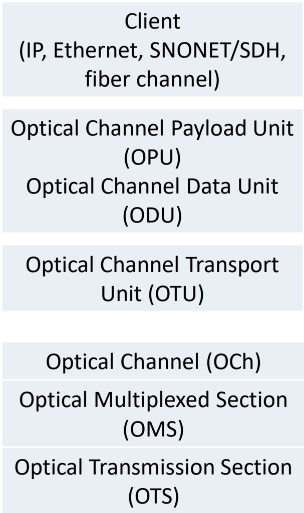


Figure27: Sub-layers within the Optical Layer. [6]

3.3.5.2 OTN layers and containment relationships

According to figure 28, the ITU-T in G.709 defines some interface for OTN which is using in sub-networks of OTN:

- Optical transport hierarchy (OTN)
- Frame structures
- bit rates
- The functionality of overhead in support of multi-wavelength optical networks.
- Format for mapping client signals. [33]

The OTH maintains the operation and management status of different architecture of optical networks such as point-to-point, ring, and mesh.

- For creating the optical channel payload unit, the OH should be added to the client signal.
- After adding OH to OPU the optical data unit (OPU) will be created
- By the combination of OH and FEC, the optical transport unit (OTU) is formed.
- Added OH to optical channel is transmitted by a color.
- Optical channel by adding OH can be enabled to manage several colors in OTN.
- After all of the steps, the optical multiplex section (OMS) and optical transmit section (OTS) are built.[34]

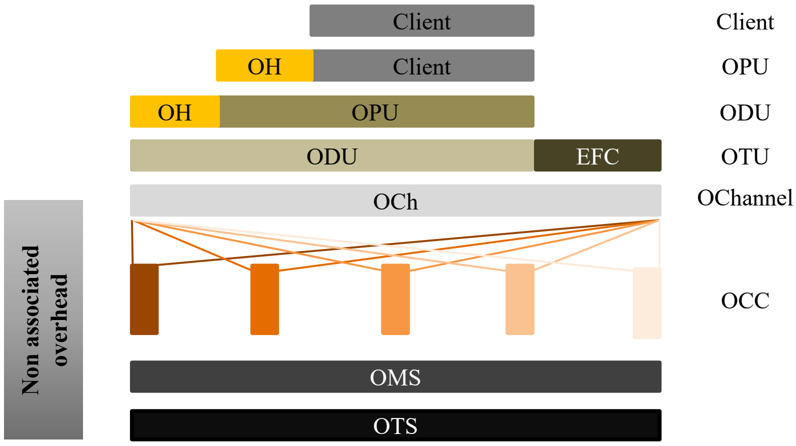


Figure28: OTN sub-layers relationship.

3.3.5.3 Comparison OTN with SONET/SDH

In comparison with SONET/SDH, OTN prepares benefits such as more impressive multiplexing and switching of high-bandwidth services, improved monitoring capabilities, and better forward error correction (FEC).
OTN and SONET/SDH using circuit switching protocol, while IP and Ethernet are packet-based. In packet-based routing may occur loss, latency, and delay. [8]

OTN line rates compared with SONET/SDH line rates			
OTN	Line Rates	SONET/SDH	Line Rates
OTN1	2.666 Gb/s	STS-48/STM-16	2.488 Gb/s
OTN2	10.709 Gb/s	STS-192/STM-64	9.953 Gb/s
OTN3	43.018 Gb/s	STS-78/STM-128	39.813 Gb/s

Figure29: Comparision of OTN and SONET/SDH line rates. [6]

3.3.5.4 Advantages of OTN

OTN has been designed for transferring IP and Ethernet packets over fiber according to the traffic policy specially SONET/SDH. The optical transport network is called digital wrapper because of its categories signals from a client in overhead information for operations, administration, and management. It has the following capabilities:
- Forward error correction (FEC)
- Management
- Protocol transparency
- Asynchronous timing

3.3.5.4.1 Forward error correction (FEC)

OTN has designed for transmission high data rate in long paths, so for long-distance transmission, the noise is outstanding and becomes a problem when is expecting for low bit error rate. FEC plays an important role in achieving a low error rate; already FEC has been implemented on SDH.
FEC can correct an error in each data block up to 8 bites and detect errors at most 16 bites in a block.

3.3.5.4.2 Management

As know SONET/SDH maintenances monitoring and managing the signal at its layers, this feature contains signal identification, bit error rate measurement and communication alarm information. OTN provides a structure to monitoring end to end connections.

3.3.5.4.3 Protocol transparency

OTN prepares a constant bit rate service. It can transfer all types of packet traffics such as IP and 10 Gb Ethernet as well as SONET/SDH frame. OTN line rate is 7% higher than the SONET/SDH line rate because of its FEC information.

3.3.5.4.4 Asynchronous timing

OTN has an asynchronous mapping of client signals into OTN frames where the clock creates the frame that can be a free-running oscillator. For calculating mismatching between OTN frames and client signal, the OTN payload floats within frames.[6]

3.4 IP over WDM

For satisfying QoS demands, we need to implement high bandwidth and increase the service speed. IP over WDM (optical layer) is a method that able to carrying IP packet in a high-speed optical network. For the implementation of IP over WDM several architectures have been prepared.[35]

3.4.1 IP over WDM paradigm

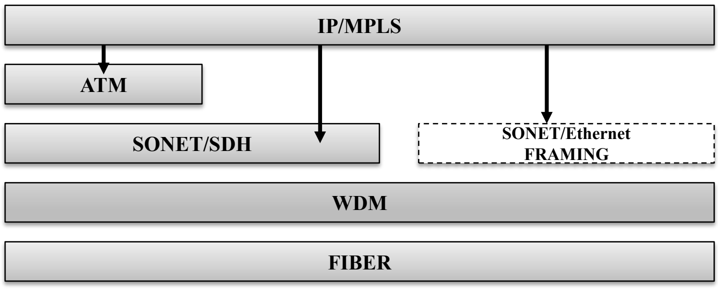


Figure30: IP over WDM parafigm.

As demonstrated in figure 30:
• IP over ATM over SONET/SDH over WDM
• IP over SONET/SDH over WDM
• IP over WDM

The IP packet encapsulation in the first and second methods was considered in SONET/SDH part. In IP over WDM directly methodology IP packet should be mapped over WDM.

3.4.1.2 IP over WDM directly

In IP over the optical layer directly, IP routers are connected to optical layer terminals (OLTs). Three ways are defined, so differences depend on managing traffic passing within intermediate nodes and provided a degree of activity in an optical network:
1- IP router directly linked to OLTs, in this case, routers, handle passing traffics at intermediate nodes.
2- IP second method likes to the first method, with a small difference, that connecting patch cables between back to back WDM handle passing traffic.
3- The third approach implies OXCs to handle pass-through traffics.

3.4.1.3 Approaches comparison

There are three approaches:
1- In the first approach, because expensive routers port are required to handle all the traffics, it has the highest cost.
2- The second one is low cost, because of handling traffics without additional tools or up router ports, also the light-path does not have dynamically configurable capabilities in the result of the inflexible network.
3- In the third approach, OXCs are used to manage traffics. While in cost point of view they have higher costs rather than others, but light-path can be set up dynamically in a result of a flexible network.

3.4.2 Switching methods in optical networks

In order to transmit IP packet over WDM in all over methods, need to use switching techniques:
1- Light-path (lambda) switching, is a traditional circuit switching, is used for mapping IP over SONET/WDM method.
2- Optical burst switching based on bursts (sequence of a packet in the path) for direct IP packet over WDM [35]. WDM uses in the circuit switching.

3.4.2.1 Optical circuit switching

The circuit switching is derived from concepts of O/E/O switching node, in this switching, the method is established end to end connection between source and destination, each connection has its fixed path. The cross-connects will create a circuit by performing adjusting between the electrical and optical domains, so data can route within a core network to be sent destination. If some failures occur during the path, data can not reach other nodes. For solving this problem optical packet switching is introduced. [36]

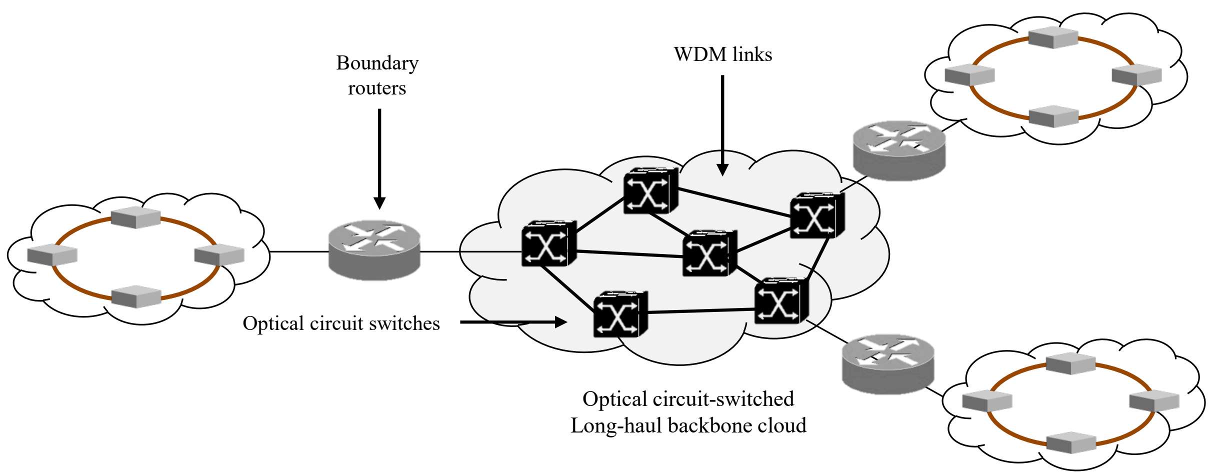


Figure31: Optical circuit switching.

3.4.2.2 Burst switching

The optical network employs an optical burst switching technique. The edge nodes can save and process IP packet, while internal nodes are transmitting this mechanism arrival packets are stored in edge routers to make bursts, so bursts are gathered based on destination and class of service then controller packet will inform to optical wavelength for coming bursts.
Two categories of burst switching:
1- With offset: data burst is postponed at source then sent.
2- Without offset: data is sent at the same time when the controller burst (OBH) is sending through the path.
The OBS (optical burst switching) mechanism is same as MPLS that uses a label for transmission.[37]

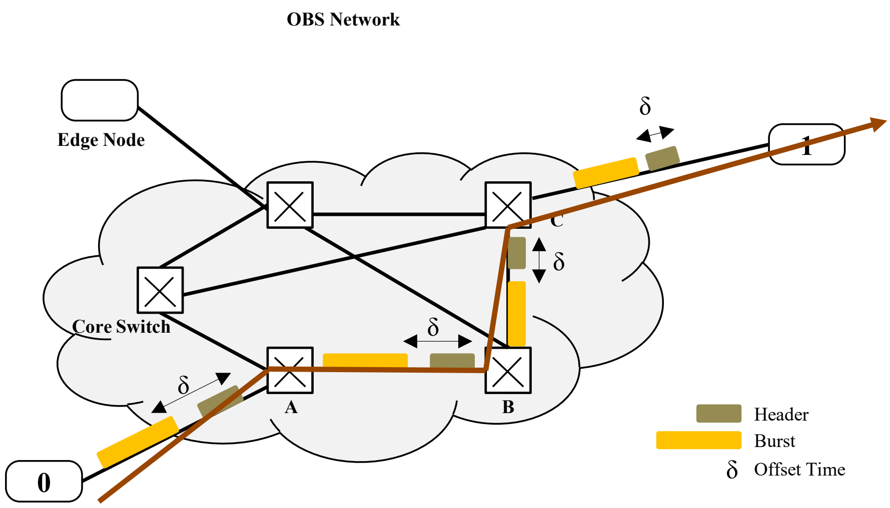


Figure32: Brust switching.

3.4.2.3 Label optical switching

LOSN was designed for WDM-based IP backbones that employ MPLS protocol. The ingress edge routers connected to the WDM network for routing packet toward the core network, the packet gets access to the core network by label switching router. The Light-paths are established by optical circuit switching in WDM backbone and for each path, a label is allocated. Any stream of IP packet among WDM backbone gets a label which is attached to the packet header.
As explained, there is not IP routing inside the WDM network, labeled packets are forwarding by intermediate LSRs, ingress LSR allocates label to newly-arrived label and routes it, in other side Egress is responsible for delivering a packet to specified access-network. Label-switching optical network (LSON) resolves bottleneck problem in ingress LSR. [38]

3.4.2.4 Packet encapsulation

label switched paths could be mapped to the WDM network, this network is circuit-based switching that makes point-to-point protocol feasible for encapsulation IP over WDM. Optical cross-connects within the WDM network can be reconfigured, multi-protocol label-switching control (MPLSCP) acts same as link control protocol that performs enabling and disabling label switching in the point-to-point link. The IP packet is labeled by MPLS protocol according to interface points then encapsulated in PPP, after that HDLC header will be added to the PPP frame.[39]

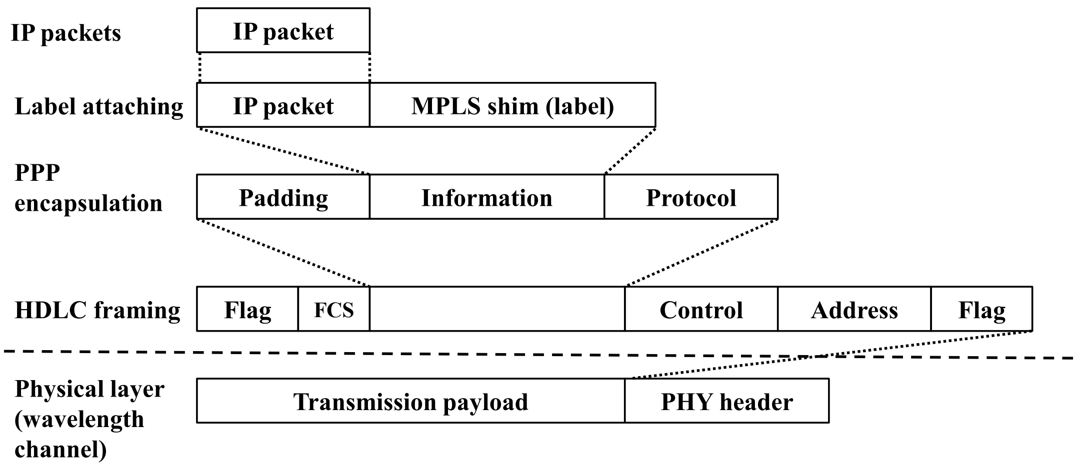


Figure33: IP packet over WDM.

3.4.2.5 IP over WDM network layers

IP over WDM network has layers:
• IP layer: the edge router collects data traffic from access-network.
• Optical layer: is responsible to provide light-path between routers.[40]

3.4.2.6 Implementation methods of IP over WDM

There are two methods to implement IP over WDM:
1- Light-path non-bypass: all the light-paths arrive at a node should be bringing to end.
2- Light-path bypass: in contrast, the light-path bypass method permits IP traffic, whose destination is not in an intermediate node, to directly bypass the intermediate router via cut-through light-path.[41]

3.4.2.7 Advantage of IP over WDM

IP over WDM networks reduce energy consumption by decreasing the number of electrical routers and substitute with bypassing light-path in the optical layer. A light-path is formed from optical connections which find the path for delivering IP packet over the optical network to destination, this connections also called optical cross-connects (OXC).

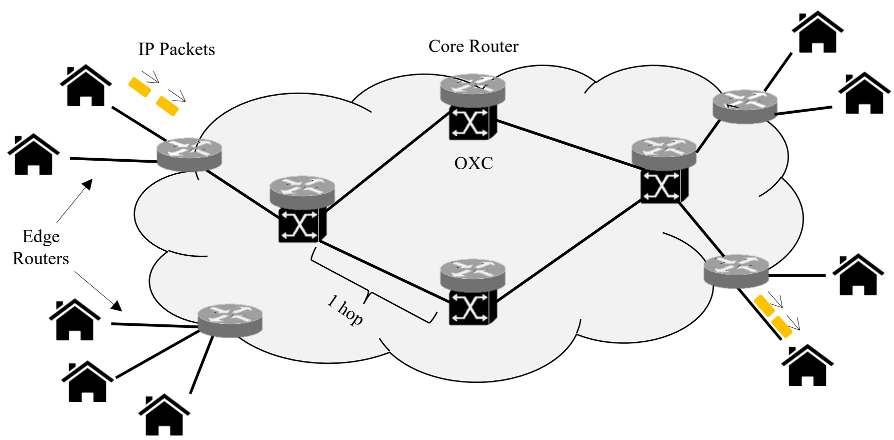


Figure34: WDM Network.

Figure 34 shows an IP over the WDM network, by following the packet the procedure of sending a packet from source to destination will appear that, the client sends an IP packet into the access-network, the edge router find a path for it to enter core-network. The core-network is responsible for routing the packet to destination address among core WDM network, the routers through a core-network run the WDM technique.

3.5 IP over OTN

As described in the OTN networks section, with increasing and appearance some applications, the demand for large bandwidth and high QoS guarantees are growing, the optical transmission network is a new generation of transmission technology which provides high-speed transmission based on optical. OTN is the next and upgraded version of SONET/SDH that merged advantages of SONET/SDH with DWDM. According to some benefits of OTN, also interaction with the IP layer, implementation of IP over OTN is necessary. [42]

3.5.1 IP over OTN architecture

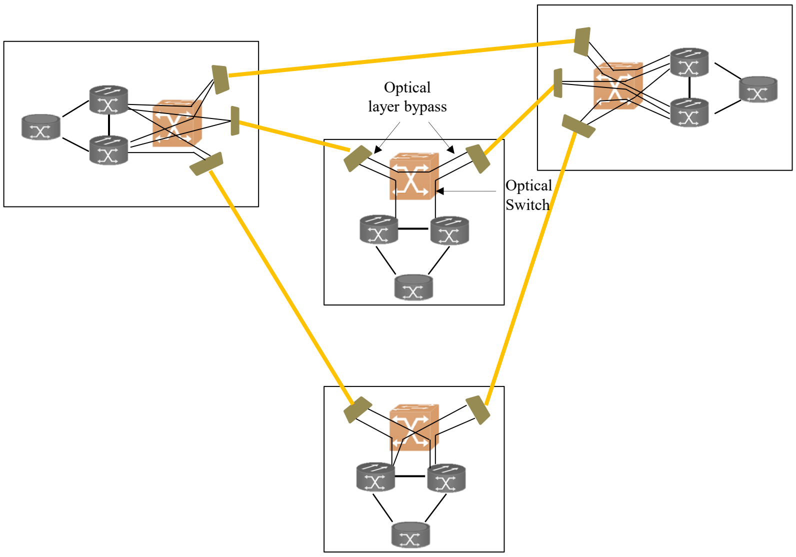


Figure35: OTN Network.

In IP/WDM architecture, core routers are connected directly over point-to-point WDM link, while in IP over OTN, core routes are connected among reconfigurable optical backbone (optical switch), includes optical cross-connects (OXC) interconnected in a mesh WDM network. In IP over OTN architecture, the optical cross-connects is an intermediate equipment which connects IP routers from different interfaces (point of presence) which have IP routers. [43] In IP/OTN architecture all routers connect to optical switches using Ethernet interfaces which according to the link requirements have 10/40/100G.

3.6 Comparison IP/OTN with IP/WDM

1- IP over OTN is more scalable than IP over WDM, because of using more scalable OXCs in the core of the network.
2- IP over OTN is much flexible to the traffics changing
3- IP over OTN, the optical transport layer provides restoration services in fast and scalable method, while restoration in IP over WDM is reached by IP routing that is slow and may drive network to a unstable condition.
4- IP over OTN is more cost-effective than IP over WDM [43]

Chapter 4

Network Control layer

Introduction

As the networks have developed in size and intricacy several factors in network performance will be outstanding, so new methodology in networks is implemented based on simplicity the architecture, cost-effective, improve service time and simplify management.[44]
The network control layer refers to enhancement network management which contains management of optical and electrical domains by improving traffic engineering and Ethernet services. This approach uses software-based development to control the hardware.
Software-defined networking is a new method that was explored based on decoupling control-plane and data-plane, the SDN manages the routing and network configuration.[8]
Besides the appearance of controlling paradigms, some network equipment were developed that they are able to reconfigure by SDN. For instance, service providers can initialize re-configurable ROADM remotely.[47]
Several protocols and standards are presented for connection between control-plane with data plane and application layer which will be discussed during this chapter.

4.1 ASON Networks

In recent years the number of internet clients was increased, as the result, high bandwidth demand is increasing, for responding to this request, a network that is able to cover all over the world is required and automatically switched networks (ASON) provide this facility. ASON is an optical transport network with dynamically connection capability; this ability is performed by the control plane. [46]

The ITU-T Automatic Switched Optical Network (ASON) standard introduced the set of Control plane components that are used to manipulate transport network resources in order to provide the functionality of setting up, maintaining, and releasing optical connections. [47] ASON has the capability to handle the complex process, by configuration control-plane of ASON before transmission of the data, there is not any operation manually for preventing time consuming and errors.

ASON logical architecture contains three planes:
1- Control plane
2- Transport plane
3- Management plane

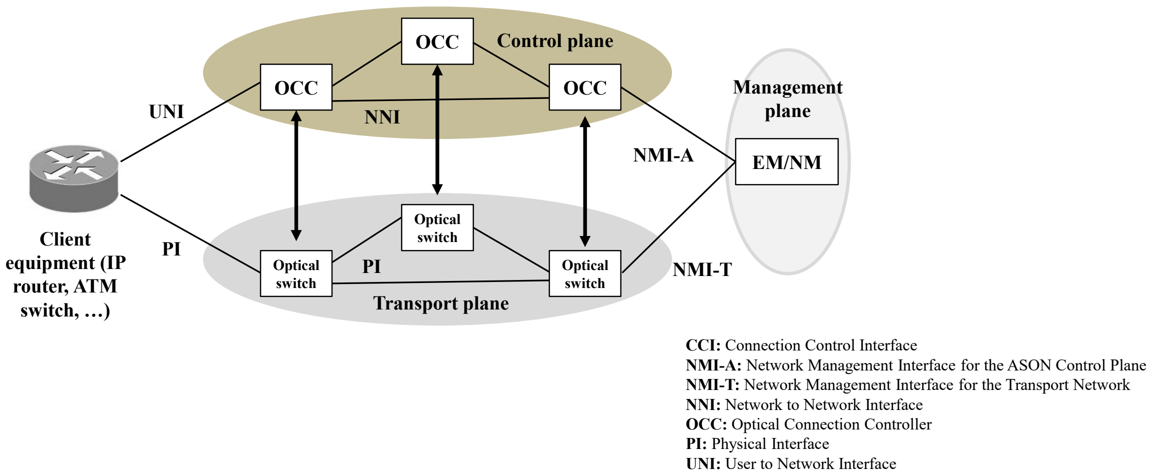


Figure36: ASON architecture.

The transport plane includes a number of optical or other types of switches, which are performing switching data in the network. These switches are connecting with physical links. The control plane is responsible for managing resource connections in the ASON network. It contains some of the optical connection controllers (OCC) that interconnected via the network to a network interface (NNIs).
The management plane performs the managing of the control plane. Also it is responsible for configuration control plane resources, routing area, and transport resources in the control plane. The management plane includes network Management Entity that is linked to an OCC in the Control plane via NMI-A plane and to one of the devices via NMI-T.
In fact, The management plane handles both other planes in a centralized manner. Optical networks are using a centralized network management system (NMS) that performs configuration, accounting, and security. [3]

4.1.1 Advantages

1- Fast provisioning
2- Easier network operation
3- Higher network reliability
4- Scalability
5- Simpler planning and design [46]

4.2 GMPLS

GMPLS was developed the MPLS functionality with the elevation of traffic engineering and quality of service (QoS). GMPLS is generalized multi-protocol label switching that prepares the united control plane for both packet-based switching and circuit-based switching. GMPLS defined the interface switching capability (ISC) for connecting different types of switching. GMPLS presents five layer hierarchy of switching:

1- Packet switching (PSC)
2- Layer two switching capability (LSC)
3- Time-division multiplexing capability (TDM)
4- Lambda switching capability (LSC)
5- Fiber switching capability (FSC)

The basic idea of GMPLS is the enhancement of traffic engineering with aggregation connection between two interfaces with different switching methods. The GMPLS presents a hierarchy label switched path (LSP) region. Where a LSP can traverse different LSP region by creating a tunnel over LSP server, LSB is basic service in GMPLS that establish end to end connection between similar interfaces. For example, TDM can traverse in a Lambda-based LSP for transmission over wavelength network.
GMPLS is defined a link management protocol to manage and support the health of control and data plane between neighbors nodes. [48]

4.2.1 Main building blocks of GMPLS architecture

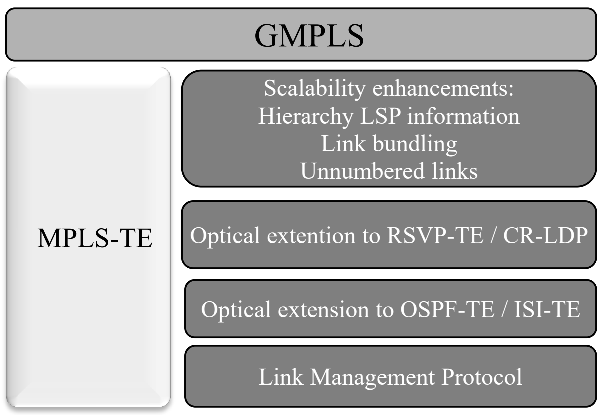


Figure37: GMPLS main block.

In the multi-layer networking scheme same as GMPLS emphasis on separation of the control-plane and the transport-plane, so it is required a protocol to map between them and handle the connection. Link management protocol (LMP) behaves the same as an interface between control and transport planes. LMP is an IP based protocol which contains a deployment of Resource Reservation Protocol-Traffic Engineering (RSVP-TE) and Constraint-Based Label Distribution Protocol (CR-LDP) signaling protocols. [48]
GMPLS for building intelligent network employs two useful routing protocols, first the OSPF and the ISIS, also two signaling protocols, RSVP and CR-LPD. [49]

4.2.2 GMPLS Peer Model Deployment

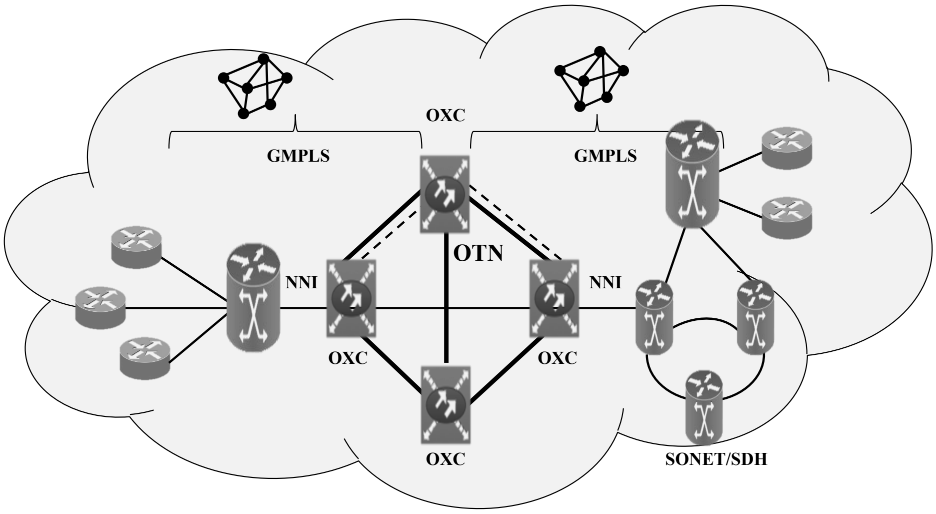


Figure38: GMPLS Peer Model Deployment.

GMPLS develops MPLS by improving traffic engineering and the QoS abilities of a packet-based network, also enables virtual label-switched from router label network toward optical packet-based networks.
The Peer model includes the OXC and SONET/SDH switches, network to network interface (NNI) and the OTN network. Here IP/MPLS layer gets a permit from NNI to operate as a full peer of optical transport layer where IP routers recognize the entire of network by passing among optical cross-connects with the help of SONET/SDH. [49]

4.2.2.1 Advantages of GMPLS Peer Model

1- This model makes fast provisioning and optical path chosen between optical and electrical paths.
2- Single administrative domain:
The single administrative domain makes challenges for full peer model recruitment; this can be huge problem when there are multiple administrative groups for each service provider domain. For more details refer to Cisco Segmented Generalized Multiprotocol Label Switching for the IP. [49]

4.2.3 GMPLS Overlay Deployment Model

It can also called user to network interface (UNI), the router operates same as a client to the optical network and gets connection only with optical nodes which is an adjacent node.

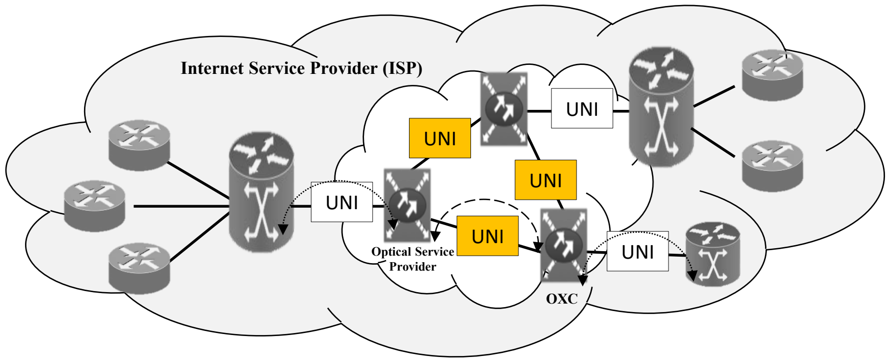


Figure39: GMPLS Overlay Deployment Model.

• Two administrative domain:
  1- optical service provider: is responsible for interconnection elements and optical routing
  2- internet service provider: is a electrical domain which provides internet for end users.
• No exchange of routing and technology information between optical and IP networks.

The goal of this model is to present a signaling message to provide a path from POP in the IP domain to an Optical domain or vice vera.[49]

4.2.4 S-GMPLS model

Cisco has developed this model to compensate the weakness of two previous models. In this model border router has connection with the optical network and other routers, in fact, border router supports both optical topology and routing and it is as interface between optical and electrical domain.
S-GMPLS implies capabilities of the peer while considering the separation of optical and electrical domain which provides choice for any service providers to select among optical, electrical or combination of them. This approach permits the optical region is deployed with less or no reconfigurable routers. [49]

4.2.5 GMPLS based IP over OPN

The GMPLS was designed to unify the network control plane functions contains both IP based networks with optical based ones. One of the important functionality of GMPLS encompasses merging the multilayer traffic engineering functions into a single control plane instead of accomplishing them in individually in each layer of physical, optical, MPLS. This aspect of GMPLS is related to an optical network which contains time division multiplexing and optical cross-connects that can be controlled by GMPLS control-plane.
In the designing of cross-layer, the integrated IP and Optical mechanisms are used to improve the network through put and resource utilization, also the quality of transmission during light path for routing IP traffic, noise effects in non-linear directions and propagation delay should be taken into account.
In GMPLS technology by combination of IP/MPLS packet switching and wavelength switching, the new designed backbones are required to handle optical and IP traffic in end to end connections along light path. [50]

4.3 Software Defined Networking (SDN)

The SDN is an architecture that makes network will be quick and flexible. Consider an IP network, the router in the network according to some policy performs a routing protocol such as OSPF, it means each router makes a decision to route data automatically without network collaboration, so in this type of network, control plane and data plane are coupled. SDN is a new paradigm that has a control plane and data plane separately and network control logically is centralized. The IP routers and Ethernet switches in the software-defined-networking model be able to control with software which runs in the control plane. The SDN in wide brings the capability to enable network discovery, routing, traffic engineering (TE) and recovery, especially in wide networks. [8]

4.3.1 SDN architecture

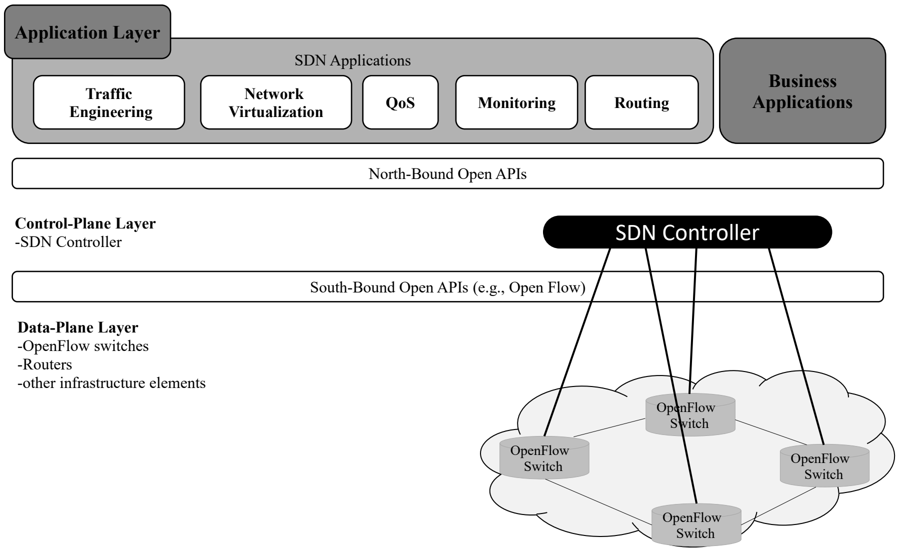


Figure 40: SDN layered model.

The SDN architecture constructed with three layers:
1- Infrastructure layer (Data plane layer)
2- SDN control layer (control plane layer)
3- Application layer

4.3.1.1 Infrastructure Layer

The infrastructure layer provides a possibility for data-plane to forwarding traffics in virtual or actual hardware. The data-plane includes some network devices which communicate with control-plane through SBI. In traditional networks routing and switching decisions made by infrastructure that each element according to its policies which initialized by vendor routed traffics automatically, hence, traditional network devices were not reconfigurable in a flexible way. After the appearance of SDN, moved all of the controlling procedure out of infrastructure and created a centralized controlling scheme for network nodes. [51]

4.3.1.2 Control Layer

Control layer is responsible for managing policies and routing traffics in network and translating requests of the applications onto instructions for network devices. SDN controller is designed for managing networks, son it has logically control on switching, routing, L2 VPN, L3 VPN, firewall rules, DNS, DHCP and clustering.

For the implementation of these services are required some Application Programmable Interfaces (APIs) to communicate with the application layer. [8]
Two types of interfaces are used in control plane for upper and lower layer connections:
1- Northbound interface: is a tool to communicate with the upper layer by means of some protocols.
2- Southbound interface: is a meant for communication with lower infrastructure layer of network elements by southbound protocols such as Openflow, Netconf, Ovsdb and etc.

4.3.1.3 Application Layer

It is a platform to develop new applications for obtaining information about network topology, state and statics. Several kinds of the application can be developed for managing, network monitoring, troubleshooting, policies and security such as SDN application.
Figure 41 demonstrates SDN orchestrator and SDN controllers:

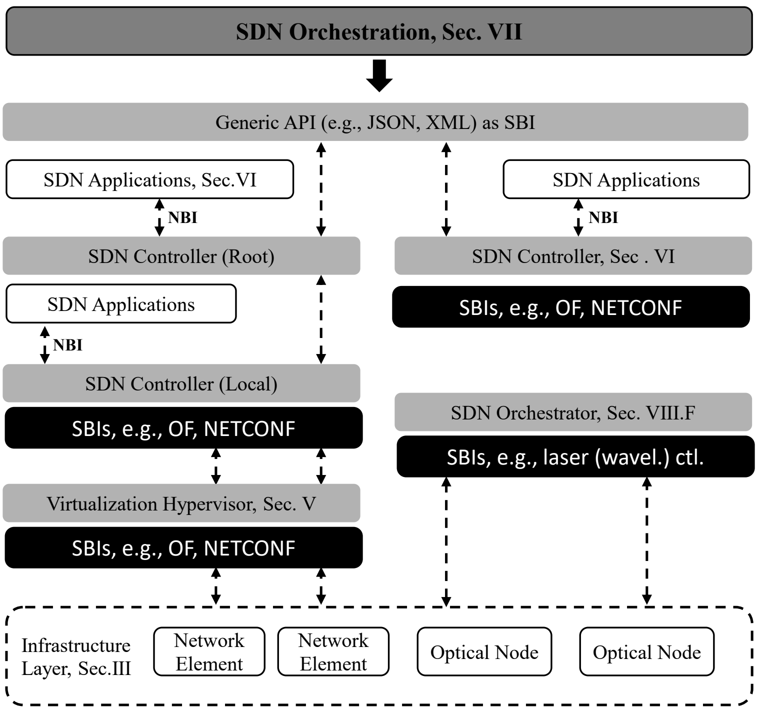


Figure 41: The SDN orchestrator and controllers.

According to figure 41, there are two interfaces in this architecture:
1- Northbound interfaces (NBIs): is a logical and programmable interface, commonly refers to application layer.
REST: Representational State Transfer is an API which is a software architectural style that is responsible for maintaining flexibility, interoperability and scalability.
2- Southbound interfaces (SBIs): is a logical interface which connects to control plane, some important protocols here:
• Open-flow
• Path computation element protocol
• NETCONF protocol
• Border gateway protocol link state distribution [51]

4.3.2 Advantages of SDN

As described in SDN architecture, Control Plane and Data Plane are separated, so it brings some benefits:
1- First it permits the control software to perform more easily, without controlling each device individually. This feature allows introducing new services and innovations to control plane.
2- Second, because SDN provides applying policies on groups of devices, it decreases cost implementation.
3- Third, the SDN paradigm provides a capability to network virtualization, where several logical networks are mapped into single physical network to communication, computing and storage resources.[8] [51]

4.3.3 SDN controlled optical network infrastructure layer

1- Transceivers
Software-defined optical transceivers are optical transmitters and receivers which can be controlled by SDN to send and receive a wide range of optical signals.

2- Space Division Multiplexing (SDM) – SDN
SDN controls space division multiplexing by controlling the physical layer to obtain flexible bandwidth and programmable SDM optical network.

3- SDN-Controlled Switching:

• Switching elements
- ROADM: this switch is formed ROADM network that statically wavelength channels that route traffic along a pre-configured path. This network in SDN based model is controlled by the SDN controller for routing traffic by the add-drop mechanism.
- Open Transport Switch (OTS): is an OpenFlow-enabled optical virtual switched design.
- Optical White Box
- GPON Virtual Switch: This is designed to make GPON switch fully programmable with the SDN control interface.
- Flexi access network node.
• Switching paradigms

4- Optical Performance Monitoring

• The Cognitive network infrastructure: involves the collection of monitoring information in a controller, Executing control algorithms and charging the software adaptation with control decision by SDN.
• Wavelength Selective Switch (Amplifier control): ROADM uses WSS for add-drop wavelength channel for routing within an optical network. The non-ideal filter effects decease Optical SNR. Also, the EDFAs amplifier has been deployed to remove attenuation from the optical fiber and ROADM, moreover by employing SDN the OSNR in the EDFA will increase.[8] [51]

4.3.4 SDN Control Layer

1- Controlling optical transceivers with OpenFlow:
The new generation of optical transceivers employs digital signal processing techniques which permit many parameters of transceivers could be software-controlled. These parameters include wavelength, modulation scheme, and symbol rate, which are controlled by OpenFlow.

2- Controlling Optical Circuit Switches with OpenFlow:
OpenFlow enables circuit switching by adding circuit switching flow table entries.

3- Controlling Optical Packet and burst switches by OpenFlow:
The optical packet-based switches use OpenFlow tables to explicit forwarding table and its computation that would be removed from the SDN controller to make easy the designing of complex optical packet switches. [51]

4.4 SDN based EPON (optical access network)

The passive optical networks (EPON and GPON) are currently used in access-network, the EPON is performed a central office (optical line terminal, OLT), passive optical splitters and one terminal (OUN) for each user gets access to network.

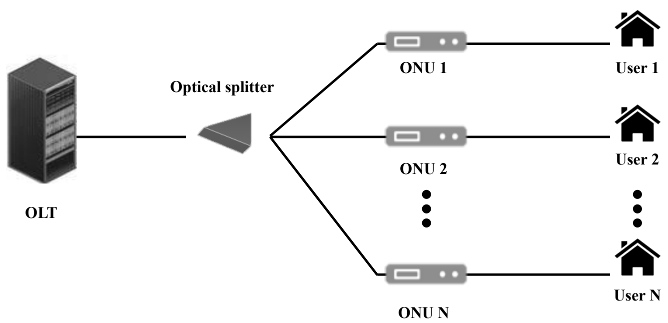


Figure 42: SDN based EPON.

The SDN is a new paradigm for network management which can be emplacement on PON networks with centralizing network controller, for providing QoS, minimizing power consumption and resilience. [52]

4.5 OpenFlow

The OpenFlow is an interface protocol which operates between the control plane and the infrastructure plane, it provides the ability to accessing the data plane of various network elements (switches and routers), and so the OpenFlow permits to the software controller to program network elements. It activates the software to control the traffic flow based on some predetermined policies (software enabler). [8]

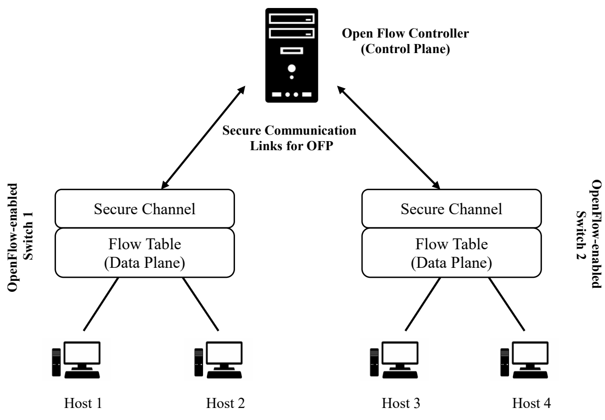


Figure 43: The OpenFlow diagram. [53]

While in the traditional networks when a packet reaches to switch, the switch performs the destination addressing process finding and forwards it to the dedicated link, but in the OpenFlow network all procedures of finding a destination and controlling are done by centralized OpenFlow controller. Each switch is responsible for data forwarding only by accessing its own flow table. According to the OpenFlow network architecture, a switch includes a flow table and a secure channel for communicating with the OpenFlow controller by hiring the OpenFlow protocols.

4.5.1 Flow table

A flow table has three fields:
1- Matching field (packet header): Which is used to match the arrived packet with the flow table.
2- Counters: Counts the number of packets and tracking them after matching.
3- Actions: Performs the particular task which is set up by controller. [53-54]
When a packet arrives to an OpenFlow switch, the switch begins the matching process from first flow table, after completing the process, the packet will go to the next pipeline. If the matching is successful the particular actions are performed by OpenFlow controller and the counters get updated.[68]

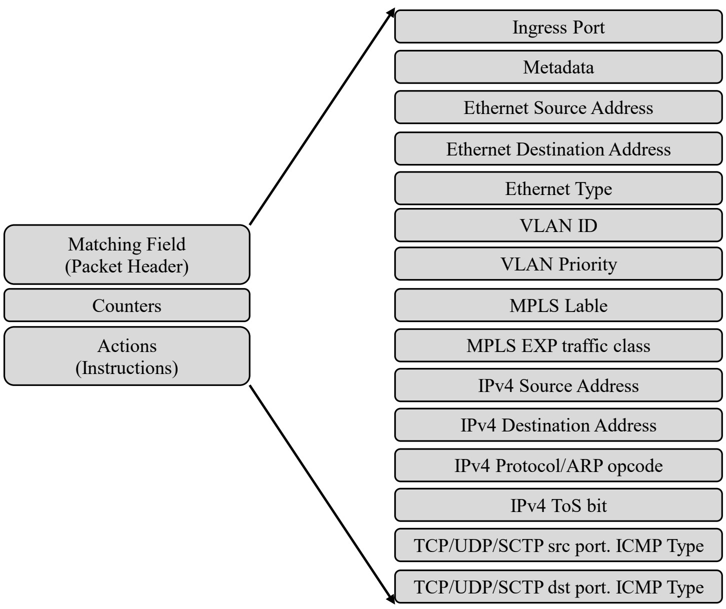


Figure 44: The Flow table.

4.5.2 OpenFlow switch types

The OpenFlow logical switch includes one or more flow tables and group tables, which are responsible for forwarding and searching packets, and also OpenFlow consists one or more open-flow channels for the external controller.
The controller uses the OpenFlow switch protocol to add, update, and delete flow entries from flow tables.[55]
OpenFlow switches come in two types:
1- OpenFlow-only: supports only the openFlow operation, all packets are processed by the OpenFlow pipeline.
2- OpenFlow-hybrid: maintains both OpenFlow operation and Ethernet switching operation, traditional L2 Ethernet switching, VLAN isolation, L3 routing (IPv4 routing, IPv6 routing, etc.), ACL and QoS processing. [56]

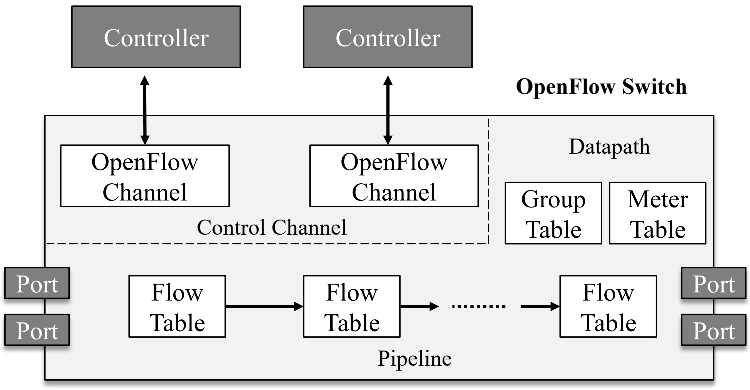


Figure 45: Main components of an OpenFlow switch. [57]

4.6 Integrated OpenFlow and GMPLS control-plane

The OpenFlow technology is expected to integrate the control and management of both optical domain and packet switched domain, so it beside of SND provides a framework to develop new protocols. For combination of the optical and packet switched domain as unified control -plane should deploy GMPLS for optical and OpenFlow for packet switched. The software defined packet over optical networks is enabled as an overlay model in whole network for inter-networking of OpenFlow and GMPLS. In this case the optical circuit-switched is controlled by the GMPLS control plane, while the packet switched domain by OpenFlow protocol and both control-plane communicate with an UNI interface. [57]

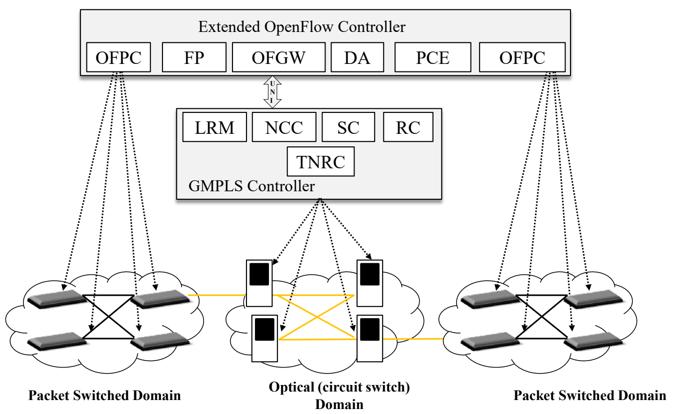


Figure 46: Integrated OpenFlow and GMPLS control-plane.

The GMPLS control plane uses the ASON model and it encompasses:
• NCC: Network Connection Controller which handles connection requests
• SC: Signal Controller that performs RSVP-TE protocol to pick up GMPLS signaling
• RC: Routing Controller is responsible for compromising the OSPF-TE protocol and path computation algorithms to calculating end to end route.
• TNRC: Transport Network Resource Controller that establishes a connection between the controller and network devices.

When a user sends a request for data to L2 switches in packet-switched domain if the OpenFlow switches not able to find flow path in the packet switched domain, it forwards the flow to the extended OpenFlow controller, the controller finds the destination address and asks from GMPLS via UNI to establish an optical path between Client and server domains. The GMPLS will return the acknowledge message for established LSP between source and destination. The extended OpenFlow controller updates flow tables of backbones in client and server domains and supports the light-path identification. [57-58]

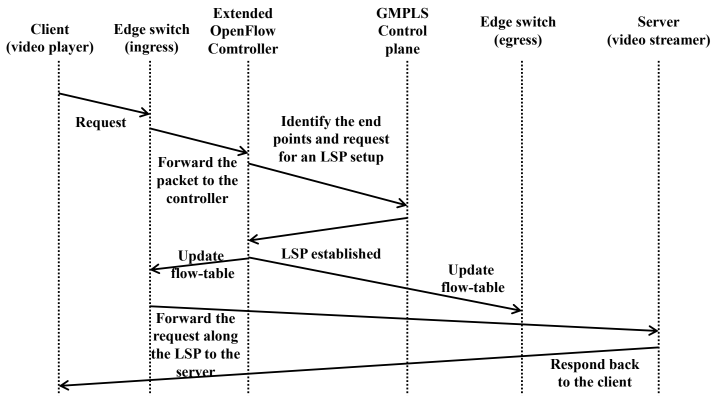


Figure 47: Timing sequence diagram for the experimental demonstration scenario.

4.7 YANG model

YANG is a data modeling language that is utilizing the Netconf protocol to manipulating the model configuration and state the data. YANG and the Netconf provide a facility to control and manage networks automatically and support APIs for control and management of elements.[59]

YANG provides a description of network's nodes and their interactions. YANG is data modeling language is used to model, configure and manipulate data by NETCONF protocol. Several YANG models are specified for network handling, also this model can be used to manage single optical channel interface parameters in DWDM and routing wavelength in wavelength switched optical channels.

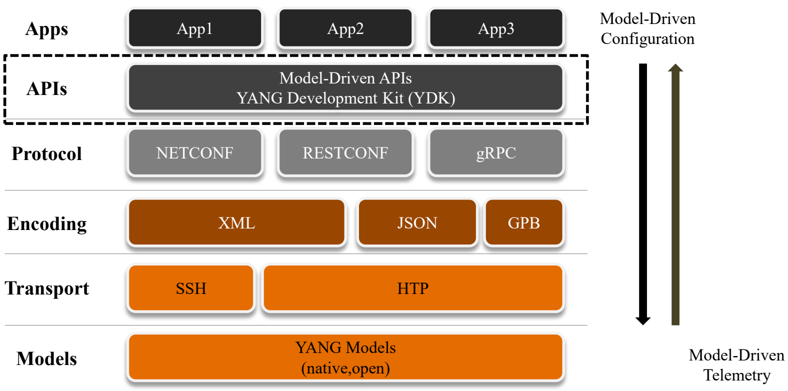


Figure 48: YANG model.

YDK is YANG development kit, it is a tool which developed by Cisco to provide adaptation with YANG model. This model is determined and implemented, a network management system (NMS) can choose a particular encoding (XML or JSON) and particular protocol (Netconf or Restconf) for transmission. [61]

Considering data plane technologies in SDN, new sliceable transponders are emerged to handle demands of operators to support variable bit rate (BER), optimizing spectral efficiency, multiple modulation formats and forward error correction (FEC). These technologies increase the scalability of the network, permit to resource optimizing and dividing bandwidth according to demands.
YANG employs NETCONF protocol to model and describes network elements for managing and controlling them. In the NETCONF connection session is established between controller (client) and device (server) by sending "Hello" message. [59]

4.8 Network Configuration protocol (Netconf)

Netconf is an IETF network management protocol, and emerging as SDN protocol which provides a secure methodology to control data-plane devices (router, switch) and manage functionalities. The Netconf brings some mechanisms to install, configure, manage and delete states and information of network devices. [62]

YANG model is divided into three parts:

1- Definition of the channel list
2- Configuration of the switching matrix
3- Operation parameters and notification boundaries [63]

The data model is defined in several YANG modules:
a) Network topology: includes a special network topology model which defines all nodes, edges, graphs of paths in the network and the termination points in topology.
b) L3-unicast-igp-technology: uses the general network topology model in Network layer Unicast IGP topology.
c) OSPF- topology: defines a model for OSPF topology by developing L3-unicast-IGP.
d) ISIS-topology: determines a model for ISIS topology.
e) TED: specifies a model for the traffic engineering database. [64]
The YANG model is used in dynamic optical network technologies:
• Wavelength switched optical networks (WSON)
• Flexi-grid DWDM networks.

There are two YANG models in optical networks:
1- Optical Traffic Engineering Database (TED): the module provides all the information required to demonstrate an optical node, optical transponder and the optical link.
2- Media – channel: this module presents the entire path from source transponder toward the destination with all nodes are among path.
Firstly, the model should configure the available optical channels in network, because of the frequency grid the first option is using YANG model.

4.9 Open ROADAM

The reconfigurable optical Add/Drop multiplexers (ROADMs) were designed with the software inside them that can be used to plan, manage and support the system. today's ROADM networks have more internal connections. In the SDN world, the connection between ROADMs elements should be without human interference, so they should be completely remote configurable among the open interface. [62] [69]

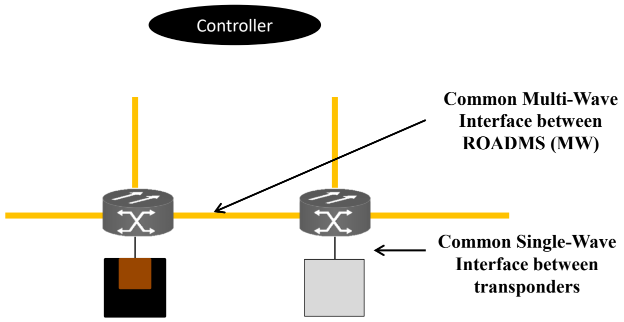


Figure 49: Common Netconf/Yang APLs between all components and Controller.

4.9.1 Open ROADAM architecture

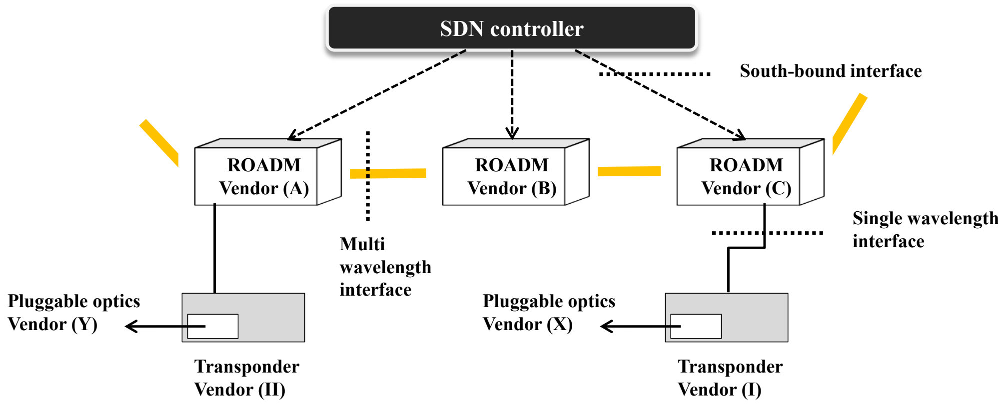


Figure 50: Open ROADAM SDN based architecture. [62]

The Open ROADM technology is coupled with optical layer and software control, it means one side ROADMs in the optical switch, transponders and pluggable module (Hardwares) and another side Netconf/YANG model for software controlled network merged together for providing services in short time and rapidly.[69]

4.10 Network Virtualization

The Network Virtualization (NV) is a procedure to merging hardware and software resources and network functionalities into a single software-based controller.

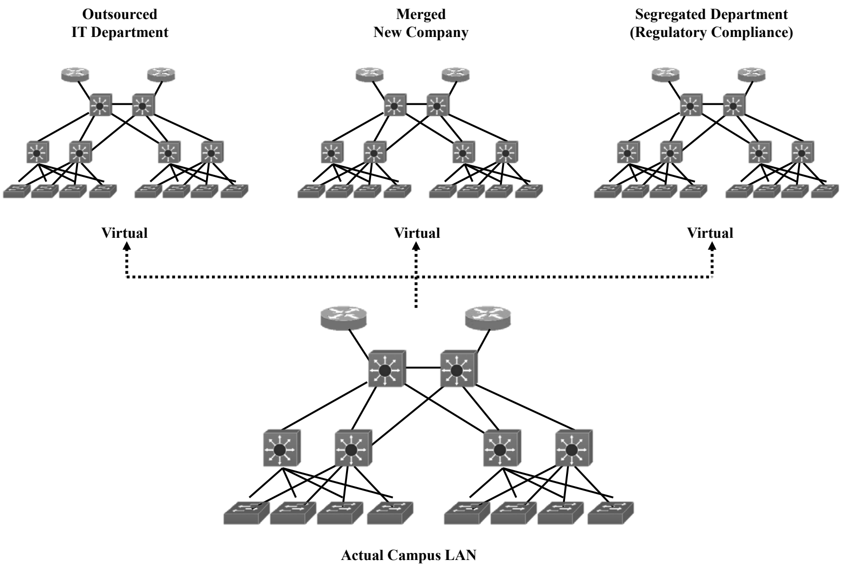


Figure 51: Network Virtualization diagram.

The optical networks specially the WDM networks are ideal options for network virtualization because of the large bandwidth and QoS guarantees. [65]

The NV is extended as important concepts of server and storage virtualization to network, is expected as a key enabler technology for cloud computing services. The network virtualization platform takes action as an intermediate between cloud user and physical resources.
The two outstanding requirements for large network virtualization are bandwidth and bandwidth granularity of connection, to permit a large number of cloud computing application with different bandwidth demands which both will be provided by flexible-grid optical networks. [66]

4.11 Hybrid SDN model

The combination of traditional IP network architecture with SDN is called the Hybrid model, this model provides an environment where both legacy and SDN nodes work together. In other words, in the Hybrid model, the centralized and decentralized paradigms collaborate and communicate with each other to manage, control, configure and improve the performance of network. [4]

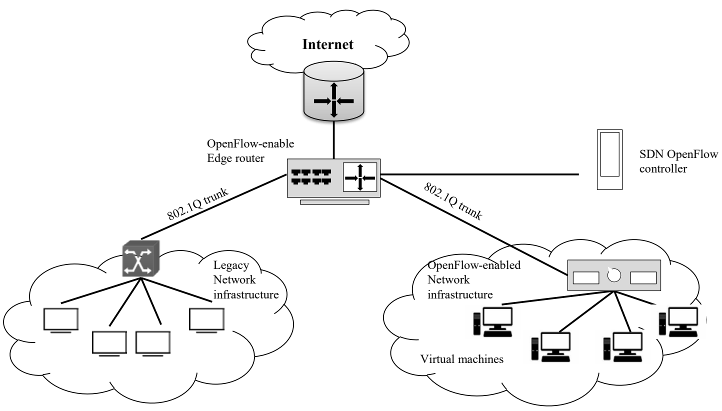


Figure 52: Hybrid SDN model.[67]

The main bases of the Hybrid model are:
1- Coexistence:
- Only at data-plane; both the legacy and the SDN exist, but the legacy network is managed by a distributed control-plane.
- On control-plane; centralized SDN and decentralized legacy control have the main role.
- Both control and data-plane exist and collaborate.
2- Communication;
- Communication at data-plane only: The SDN and the legacy contact each other with some protocols.
- Communication at control-plane only: when the legacy tries to route a connection by routing algorithm, the SDN controller understands it and handles to find a path.
- Both control and data-plne; they have interaction with some protocols.
3- Crossbreeding [4]

Chapter 5

SDN based Optical Networks

Introduction

As mentioned in the previous chapter, SDN is a new methodology which is separated control-plane and data-plane based on centralized management. With the help of the central SDN controller can support the whole of the network, also control and manage routing and switching procedures to satisfy QoS, traffic load and etc. which effect global optimization of network performance. The SDN controller employs a forwarding model that includes forwarding function same as f(map) as an input of the controller. When the entire network by mapping becomes available to the controller, it enables the controller to route traffics in an appropriate manner. After the implementation of packet switching, the switching information will be broadcasted to switches by the controller. Hence, the control-plane and data-plane are decoupled completely, they use an interface protocol for communication which called OpenFlow. The application layer of SDN architecture contains several applications which negotiate with the SDN controller by application programming interface (API). [65]
SDN presents a glance of fundamental network infrastructure for the network managing, controlling and monitoring applications of each separated layer, according to figure 41 in chapter 4 which demonstrates the layering model of SDN architecture comprises an application, control, and transport layer based on ONF description. The ONF has introduced OpenFlow protocol for the southbound interface between control and infrastructure layer. The Southbound and Northbound interfaces are presented as interconnecting interfaces within SDN layers.
In the modern information technology scheme, the optical network has an incredible role where it uses some switching characteristics which are not performing in a flexible manner according to controlling and management, so a new paradigm of SDN based optical is introduced. Software-defined optical networks try to increase the flexibility of the optical network in supporting and management areas. [51]

5.1 SDN structure

SDN architecture has three layers as shown in figure 41 in chapter 4, now is considered deeply according to each layer functionality and features.

5.1.1 Infrastructure Layer (data-plane)

The infrastructure layer provides a possibility for data-plane to forwarding traffics in virtual or actual hardware. The data-plane includes some network devices which communicate with control-plane through SBI. In traditional networks routing and switching decisions made by infrastructure that each element according to its policies which initialized by vendor routed traffics automatically, hence, traditional network devices were not reconfigurable in a flexible way. After the appearance of the SDN, moved all of controlling procedure out of infrastructure and created a centralized controlling scheme for network nodes. [51]

5.1.1.1 Infrastructure sub-layer

Infrastructure layer has two sub-layers:
5.1.1.1.1 Network infrastructure:
This sublayer contains network devices such as routers, switches and etc. in the SDN model some devices are removed because of the central control unit.
5.1.1.1.2 Southbound interface:
As mentioned before, the SBIs are responsible to establish a connection between the infrastructure layer and the control layer. OpenFlow as the most common protocol is used to support the pipeline of flow tables.
Some SBIs protocols are:
1- OpenFlow
2- Path computation element protocol (PCE)
3- NETCONF
4- Border gateway protocol link-state (BGP-LS)[70]

5.1.2 Control layer (Control-plane)

In the SDN model, the network devices should be managed, so the control layer executes element configuration via Southbound interfaces. In order to manage network effectively, the controller can send a request to the infrastructure for achieving a set of information about flow statistics, topology information, link status and so on.[51]
In fact the control layer is responsible for handling traffic, also it prepares a backup from controllers when a failure occurs, it has the ability to recover the network.

5.1.2.2 The Control layer's sub-layers

The control layer includes three sub-layers:
1- Network Hypervisor
2- Network Operation system
3- Northbound Interface

5.1.2.2.1 Network Hypervisor:

Network Hypervisor permits to some virtual machines get access to the installed hardware resources over the same clould infrastructure, it makes the number of physical recources in network to decrease, at result, the cost will reduce. (network virtualization)

5.1.2.2.2 Network Operation system:

As the SDN inherently was designed in centralized logical control manner, so it requires a Network Operating System to prepare common development environment for network engineers.

5.1.2.2.3 Northbound Interface:

The SDN utilizes NBI APIs to communicate with the application layer. The Northbound provides a software environment. Among the northbound SDN application interfaces REST is more common than others.

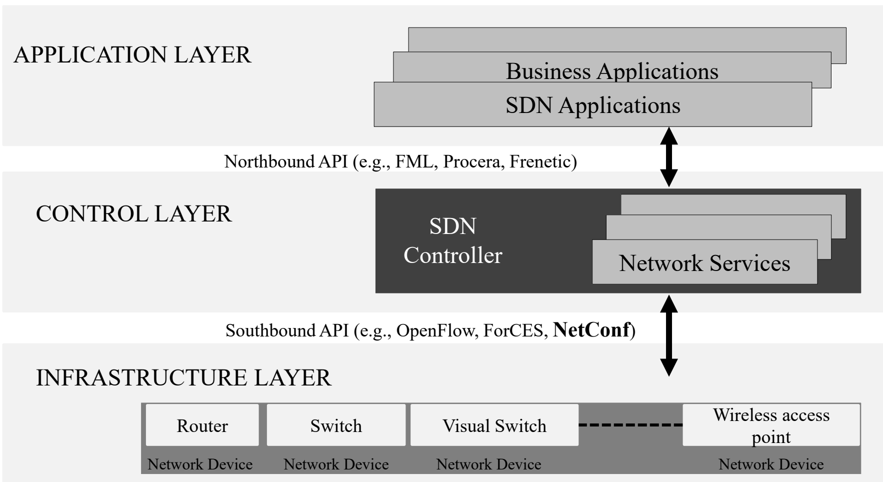


Figure 53: SDN Layering model. [74]

5.1.3 Management Layer (Application plane)

This layer includes network application and services that manage control plane to discover network function over physical or virtual infrastructure. The Application layer has three sub-layers:

5.1.3.1 language based virtualization:
This layer prepares abstraction of network modules while supporting network structure.

5.1.3.2 Programming languages:
Programming languages are used to present abstraction of network.

5.1.3.3 Network applications:
This layer defines a logical algorithm which is using by lower layer, also presents the business demands.

5.2 SDN based Optical Networks

As it discussed in the previous chapter, the high bit rate is one of the most important features of optical networks which had incredible role in deploying optical networks, also optical networks have low level of attenuation so, means the demand for the regeneration point along path will be decreased, it makes the number of required amplifiers between source and destination be lower. moreover, distortion of broadcasted signal inside the fiber path is low, so that regeneration of signal frequently does not require. [70]

5.2.1 SDON -IP Architecture

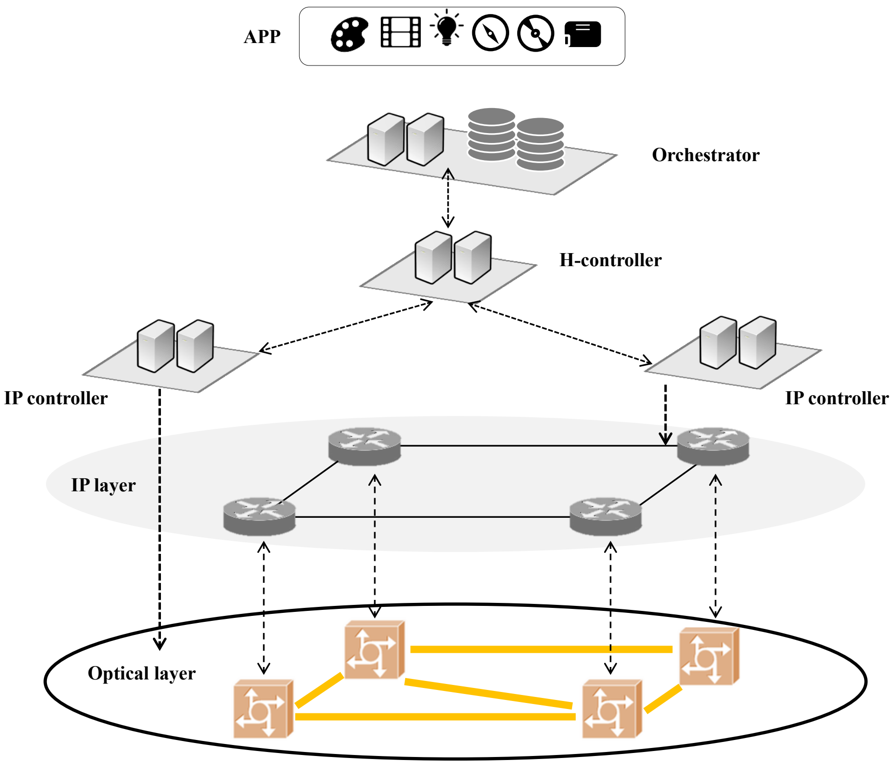


Figure 54: SDN-based IP and optical network.

In addition, with growing traffic value and emerging sophisticated networks, managing and controlling new emerged network requires a mechanism which performs in a flexible bandwidth access manner. In other words, the service provider should proper services more dynamic, adaptable via intelligent control methods. Also, optical networks have some problems in service expansion for instance in route availability, path computation, resource usage and so on, now to provide private networks demands when using optical transport, optical networks are not able to handle alone, so according to mentioned challenges SDONs network are developed.[73] Because optical networks is implemented in different network architecture with a huge coverage, so managing this network needs higher cost and time. Hence, by the properties of the SDN can tackle this constraint.[70]

5.2.2 Advantages of SDON:

1- With the developing integrated network technologies, a different type of services and network resources are using in heterogeneous networks, so interconnection, management between a variety of recourses create problems, with the help of SDON can solve these problems. SDON presents protocols such as OpenFlow to build a unified controlled architecture heterogeneous network between access and core network.
2- The SDON by carrying out service on demand and plug-in-use can satisfy client's requirements, which provides to use network elements in a flexible way and clients can achieve the services faster.
3- The virtualization is a very efficient technique in managing and controlling some network resources, the SDON enables virtual management which controls all of OTN devices in the whole network by utilizing an open centralized resource platform.
Every year the control and management technology is growing, here is shown two developed generation and future SDON mechanism:

	Early technology	Developed technologies	Current technology
Properties	Network management centralized configuration.	Distributed control.	SDN control.
	Feasible to simple network such as ring and link networks.	Appropriate to sophisticated network topology such as Mesh.	Supports programmable and flexibility based networks.
	Have fixed type of network.	Re-configurable optical and electrical layer.	Open standards and open interface applications maintain network layers.
	Manual configuration.	Implement distributed control plane for optical network.	Multi-layer heterogeneous networks are enabled by cloud centralized control.
	Sudden services handling is difficult.	Quick serving, dynamically recovery.	Open control management provides valuable network layer for user.
	Using software initializing in path computation.	Path computation element is used for dynamic path computation.	Network virtualization is used for path computation.

Table 03: Evolution of Optical Network Control Technology.[73]

However, the SDN based optical network reduces power consumption, but also SDON reduces complexity of network with a flexible control plane and decrease the operation expenditure (OPEX) or the capital expenditure (CAPEX).

5.3 Challenges on SDON:

One important challenge arises in using many degrees of flexibility to provide better services to clients, in SDON. While With the presentation of network virtualization in the optical network (VONs), it is possible to divide large size network into slices and each slice is controlled by SDN, but in dynamically created VONs the variety of demands make the number and intricacy of SDN controllers increase. In addition, because everyday customers demands are growing according to variety and they will be unpredictable, so by emerging new demands new challenges will be arisen for service providers to satisfy customers requirements.[71]

Challenges in SDN's optical extension:

5.3.1 Analog nature of optical layer:

Because the optical layer nature is different from others (layer 1, 2, 3 are electrical), so the optical layer communicates with the physical aspects of light which is an analog problem.

5.3.2 Vendor's proprietary equipment:

Each vendor, produces its own equipment with specific parameters and properties, so it is essential to define a SDN controller configuration standards which all of vendors tools can adapt to them. [72]

5.4 South-bound Interfaces and protocols

1- OpenFlow

2- NETCONF/RESTCONF protocols and YANG modeling

5.4.1 OpenFlow

The OpenFlow protocol was introduced to use in the southbound interface for communication between control and data-plane. OpenFlow is used in electronic switches which are famous for Openflow switch, OpenFlow employs switches to handle received packets based on OpenFlow tables, so with programming, the network can modify or change flow tables.

The same procedure could not happen directly to circuit switching elements, and in particular case in ROADM, because of lack of packet structure. however, flows within the optical circuit are able to match based on header values, so OpenFlow can handle the SDN model for optical network controlling with unified management of circuit-based and packet-based electrical networks.

5.4.2 NETCONF/RESTCONF protocols and YANG modeling

This protocol was presented by IETF as a tool to configure network equipment and compensate for the weakness of the SNMP protocol. the NETCONF protocol employs Extensible Markup Language (XML) for data serialization and permits the network operators to alter, modify static and configure run time in network elements.

The YANG is a data modeling language where is implemented via NETCONF protocol. As a disadvantage of web services and growing the benefits of application programming interfaces via HTTP connections, a group of NETCONF concepts was moved RESTful concepts which made to appear RESTCONF protocol.[75]

The YANG community tried to divide between Internet Engineering Task Force (IETF) and OpenConfig, the basic difference concentrates on the role of YANG data stores and the methods on how to encapsulate the difference among the wanted and efficient state of tools in the network:

1- OpenROADM
2- Open device
3- OpenConfig

5.4.2.1 OpenROADM

The OpenROADM is a multi-source agreement (MSA) standard that presents optical accomplishable YANG models. In fact, the aim of OpenROADM is to create an environment by APIs in YANG modeling language on optical functions in which this environment is multi-vendor, interchangeable and inter workable. [75] The OpenROADM is implemented to define a white-box model of ROADM for optical devices which is using by the control-plane, is called the OpenROADM controller. The OpenROADM provides a network view that includes a summary of particular vendors devices, that can be utilized for path computation of service instantiation.[76]

4.5.2.2 Opendevice

An Open Line System is an area in the Optical domain where the network can progress toward an automated fiber network, each OLS includes several optical elements such as ROADMs. Optical line system vendors have developed the optical line systems with software programmable features for management, so Open Line System interfaces do these tasks. Hence single standard interface does not deploy in all vendors, so it requires a translator for parameters to interpret them in correct way integration. The Infinera optical SDN controller communicates with different vendors tools using mediators where they are essential to interpret vendor's particular open model parameters. Figure 55 demonstrates the software components and interfaces which are used for aims of the demonstration. The mediator is utilized for converting between the Lumentum network device YANG model and the OpenDevice YANG model. Both OpenDivice and OpenOLS are YANG models that define clear sight of what they should display. [77]

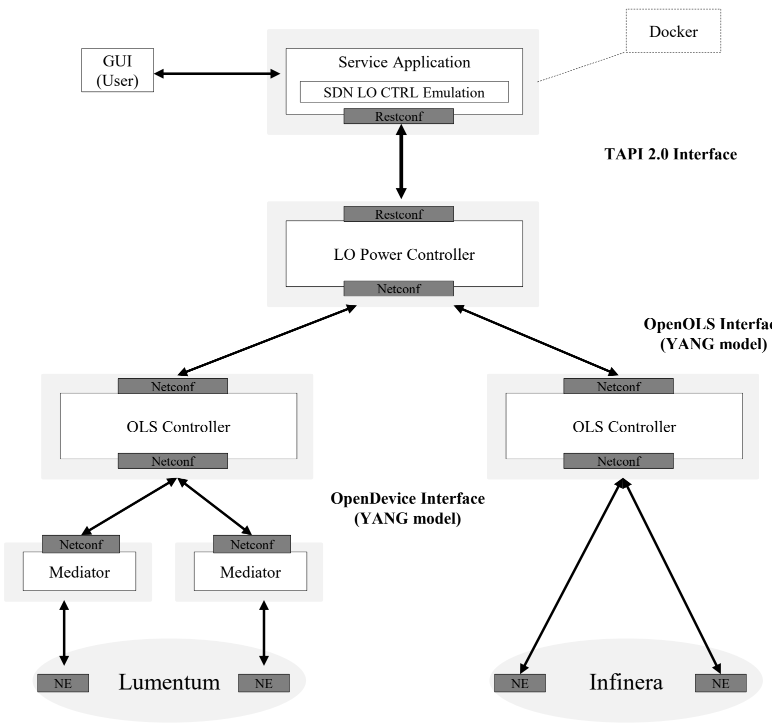


Figure 55: Software components and interfaces. [74]

5.4.2.3 OpenConfig

The OpenConfig began as a project to deploy a common data model with respect to vendors, this data model is able to use for configuration and monitoring network devices. The OpenConfig comprises some data modelling for vendors from different technologies that are obtained according to demands and use cases.
The main goal of OpenConfig defines a set of standards for managing network elements, by controlling APIs. Also, OpenConfig presents multiple models for optical devices such as an amplifier, switch and etc. [75]

5.5 Summary on SBIs protocols

However, the OpenFlow is provided appropriate schemes in the early stages of SDONs, but nowadays, vendors are more interested to use YANG modeling of combination with NETCONF/RESTCONF protocols.
OpenFlow based on the concept is simpler to implement in theory, but according to available tools, it can not be deployed easily, also it did not deploy to support optical demands, while NETCONF and RESTCONF can maintain optical domain perfectly. [75]

5.6 Quality of Transmission in SDON networks

For satisfying dynamic traffic demands and maintain grown traffic, the optical networks use DWDMs that for the rising capacity of DWDM uses higher-order modulation formats where it needs higher optical to noise ratio in destination to satisfy the quality of transmission. However, a clear way to increase OSNR in DWDM is to decrease noise figure by substitution optical elements which have a high noise figure, but this methodology will increase capital expenditure (CAPEX). On the other hand, with manipulating reconfigurable optical add-drop multiplexer (ROADM) spectrum modifying algorithms and adaptive local amplifier operation point optimization can increase OSNR.
So, global performance optimization algorithms are underlying in improving OSNR to obtain higher channel capacity without sharp ramping up CAPEX costs, hence using SDN makes to have a simple global network view, monitoring and enabling to utilize SDN applications to improve QoT.
The procedure in implying SDN over DWDM is such that using SDN in deploying wavelength selective switch (WSS) based ROADMs. [78]
Therefor, ROADMs based on WSS and optical amplifiers commonly based on the ebrium doped fiber amplifiers (EDFA) which can have global performance improvement if they are configured. The globally configured ROADMs can provide better OSNR, also this mechanism completely related to achieving higher network capacity and lower noise figure. [79]

Chapter 6

Conclusion

During the time, some new protocols are presented to develop both optical and electrical networks based on flexibility and providing QoS demands. In the early years by introducing communication and invention transferring voice by the telephone, new methods and standards were invented. In the networking field, higher improvement has occurred when the OSI layering model was explored. By seeking in layering model new protocols were presented according to each layer properties. Basically in this thesis is concentrated on layer zero until layer three so the protocol maturation of these layers along time is considered. With increasing the number of clients in the network, the new kind of networks was required to cover all customers, so according to geographical coverage, the network size was grown from LAN toward WAN, beside the network for serving customers should be allocated unique address in the network so Internet Protocol was established. The first version of Internet Protocol was IPv4 that can support many clients according to different classes categorized; in after years the IP technology world was developed and presented IPv6 which will satisfy a huge number of users in the future.
For the increasing quality of delivered service to clients in access-networks new standards were developed which they could communicate such as the interface between layers or specially dedicated for layer two, for instance, ATM and Ethernet. Moreover in finding destination of each transmitted packet over network new paradigms were needed, so routing algorithm helps discover network in an efficient manner because the final goal of network was delivering data with high quality so new and essential algorithms were developed to decrease collision and latency in network also route the path in messy and huge networks. Hence the generation of routing algorithms was grown according to their features and which environment they are using, nowadays BGP and OSPF or combination of them with different versions are using in various IP networks. In addition, for efficiency data routing some switching techniques over different physical and logical topology were deployed to increase the rate of data transmission.

After fiber invention, all attention of the network designer was concentrated on using fiber for increasing the capacity of transmission link and providing high bite rate in data transferring. For increasing capacity several wavelength multiplexing techniques have been utilized, so new demands made several and useful multiplexing methods were introduced to progress wavelength-division.

With developing fiber technology, new networks type with optical elements has emerged which employed in using access-network. On the other hand, for using optical devices in access-network or utilizing a combination of optical and electrical an interface was required for conversion electrical domain to the optical domain and vice versa. So that, the SONET/SDH standards were extended, these standards simplify multiplexing and synchronized all of the signals which are receiving from multiple sources, also this standard provides high availability services with failure time less than 60 ms.

In multiplexing technology such as WDM, the cost of transmission is very important, therefore for reducing the cost, WDM networks were explored to send multiple channels on a single fiber with high bit rate, so for providing this aim, in WDM network are used some elements to be cost-effective with removing unnecessary devices and replacing them with upgrade versions, this fact especially occurs in amplifiers where with presentation EDFA amplifiers they are substituted. In addition, designers have worked on OADM multiplexer to be able to deploy a multiplexer that can treat in a flexible manner in wavelength allocation, as result ROADM was established to decrease cost.

When each technology is introduced to compensate the weakness of before standard, with arising new demands, the designers try to cover demands with seeking new standard, so WDM and SONET/SDH were progressive but they could not support cost and QoS requirements, therefor OTN networks were deployed with flexibility and cost-effective features. The OTN provides until 100 Gb/s in the DWDM system with low error and can interact directly with the electrical domain.

With the growing value of traffics, the size of networks for supporting and routing traffics is growing, so manage and control very large network manually is difficult also, serving network elements in manual way increases cost and wastes time at result decreases the quality of service. Therefore a new mechanism is required to handle this difficulty, the methodology was considered for the solution which implemented according to the simplicity of architecture, cost-effective, enhancing service time and management. The Software Defined Networks (SDNs) was deployed based on separation control-plane and data-plane with using software to manage network and route traffics on the network. The SDN was introduced for the electrical domain which is using for traffic engineering for routing data efficiently over the network, besides this standard, the network virtualization emerged to control several networks in a single infrastructure.

In addition, after exploration of decoupling control and data plane in control layer, the new way of managing the network was hired and experimented the performance of network-based on cost, time serving and etc., for instance, Integrated OpenFlow and GMPLS control-plane is used in combination of optical and electrical domain for integrated packet-switched and circuit-switched networks.

After deploying SDN in the electrical domain, deploying fully optical infrastructure is very costly, so again the limitations of using optical network yet remained, hence SDON was established in optical networks to reduce the number of optical elements. However optical network approach, because of low latency and distortion, the regeneration points for transmitted signal decrease, but with growing networks, the complicated networks emerged so managing and serving this type of network need a new mechanism to support them as well. So that new challenges arise, for overcoming these challenges ISPs got help from the SDN approach.

The SDN based optical network, defined some southbound protocols to managing the infrastructure layer, at the result by configuration network elements could remove manually functions and emigrate to automatically environment.
Thus, for responding to the demands of customers based on QoS and QoT, the centralized control plane is used in a new generation optical and IP based network. According to traffic size requirements, the control layer is changing during the time, from centralized configuration management toward SND methodology.
However, the SDON approach was deployed to increase flexibility in complicated networks with virtualization of the network, but for maintaining the various types of customer's demands, the whole network should be sliced to control virtually, so this appears new challenges for service providers.
Anyway, the optical network and SDON have their specific bottleneck such as, mapping virtual optical network, abstraction encapsulation of optical networks, how to create a scalable and flexible network, low latency and jitter which vendors and designers are working on. These bottlenecks introduce important challenges in future standards so; the network developers should concentrate bottlenecks to satisfy high Qos and QoT.

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