PERFORMANCE COMPARISON BETWEEN CWDM-PON AND DWDM-PON OVER FTTH TECHNOLOGY

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A project submitted to Dean of Research and Postgraduate Studies Office in partial Fulfilment of the requirement for the degree Master of Science (Information Technology) Universiti Utara Malaysia

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ABSTRAK

WDM-PON secara meluasnya dianggap sebagai satu cara untuk melaksanakan Fiber-To-Home (FTTH) dan menyampaikan akses jalur lebar untuk perniagaan dan pengguna di rumah. Kajian ini mengkaji simulasi awal pelaksanaan WDM-PON teknologi dan membandingkan prestasi rangkaian antara CWDM-PON dan DWDM-PON. Selain itu, senario perbandingan berbeza akan dipertimbangkan untuk menentukan teknologi yang sesuai dari segi tiga kategori utama: wajaran medan modal berlokasi (spatial modal field), ralat bit (BER) dan rajah mata (eye diagram). Secara umumnya, keputusan kajian ini menunjukkan bahawa teknologi DWDM-PON adalah lebih baik berbanding dengan teknologi CWDM-PON dari segi kekuatan jalinan mod (power modal coupling) dan ralat bit (BER).

ABSTRACT

WDM -PON is being widely considered as a means to implement Fiber-To-The-Home (FTTH) and deliver broadband access to business and home users. This research examines a preliminary simulation of the implementation of WDM-PON technology and compares the network performance between CWDM-PON and DWDM-PON. Moreover different comparison scenarios will be considered in order to determine the suitable and reasonable technology in terms of three major categories: weighted spatial modal field, bit error rate (BER) and eye diagram. The result shows that DWDM-PON technology is superior to CWDM-PON technology in term of power modal coupling BER.

ACKNOWLEDGEMENT

With a grace of the almighty (God), this thesis is a culmination of continuous effort where I have been accompanied and supported by many. I am extremely grateful to my supervisor, **Dr. Angela Amphawan** for taking responsibility of my master thesis. Her wide knowledge and logical way of thinking have been valuable for me. Her understanding, encouragement and personal guidance have provided a good basis for the present research.

Most importantly, none of this would have been possible without the love and patience of my parents, my immediate family, to whom this work is dedicated. They have been a constant source of love, concern, support and strength all these years. I would like to express my heart-felt gratitude to my family. My extended family has aided and encouraged me throughout this endeavor. I warmly appreciate the generosity and understanding of my extended family.

I owe my loving thanks to my eldest brother **Mohammed A. Faza**. He had been a role model for me to follow unconsciously when I was a teenager and has always been one of my best counselors. Without his financial support encouragement and understanding; it would have been impossible for me to finish this work. My special gratitude is due to my brothers, my sisters and their families for their loving support. My loving thanks are due to University Utara Malaysia (UUM) for giving me the chance to be one of its students.

Yousef Fazea

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LIST OF ABBREVIATION

AWG	Arrayed Waveguide Grating
BER	Bit Error Rate
BPON	Broadband Passive Optical Network
BR	Back Reflection B
CO	Central Office
CPR	Coupled Power Ratio
CR	Coupling Ratio
CWDM	Coarse Wavelength Division Multiplexing
DEMUX	De-multiplexer
DSL	Digital Subscriber Line
DWDM	Dense Wavelength Division Multiplexing
EPON	Ethernet Passive Optical Network
FTTH	Fiber- To -The-Building
FTTC	Fiber- To -The-Curb
FTTH	Fiber- To -The-Home
FTTx	Fiber- Local Area Network
LED	Light Emitting Diode
MMF	Multi Mode Fiber
MUX	Multiplexer
NRZ	Non-Return to Zero
OLT	Optical Line Terminal
P2MP	Point-to-Multi-Point
P2P	Point-to-Point
PON	Passive Optical Network
PRBS	Pseudo Random Binary Sequence
SMF	Single Mode Fiber
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
VCSEL	Vertical Cavity Surface Emitting Laser
WDM	Wavelength Division Multiplexing

CHAPTER ONE: INTRODUCTION

1.1 INTRODUCTION

Copper cable connection has been sufficient and effective between the central office (CO) and end user for many years. Due to the rapid advance of technology, the traditional network access technology has no longer met the demand on network, which hinders the development of communication technology (Weihua Yu, 2008). According to European Telecommunication Network Operators' Association Press corner (June 24, 2008) and Shinohara (2005) the provided bandwidth and transmissible distance on traditional access networks are subject to twisted pairs. Network managers have been left with no choice but to build up the fiber to the home (FTTH) access network. The delivery of triple play services (video, voice and data) has become a requirement of today's network access (Park et al, 2004). The first/last mile bottleneck in between high capacity network and customer premises of small and medium size can be resolve as well by FTTH (Kitayama et al, 2006).

Fiber structures promise to be suitable for requirements of today and also for a further increase of bandwidth demand in the future (Cheng et al, 2011). Fiber can be a candidate to provide substantially more bandwidth, carry signals further, is more reliable and secure, and has a longer life span than any other transmission medium. Optical fiber till now is the only candidate to provide much more bandwidth than the current access network, and held the signals much farther. Fiber networks come in many types depending on the termination point: premise (FTTP), home (FTTH), curb (FTTC) or node (FTTN). For simplicity, FTTX is commonly referred to by the majority. X stands for the termination point. In the last few years, network operators started installation of Fiber to the building (FTTB) and Fiber to the Home (FTTH) architecture. In a point to multipoint architecture, PON is the most suitable to resolve the first/last mile between the communication infrastructure between carrier and CO, head end or point-of-presence, and business or residential customer premises (green P, 2002; Kitayama et al, 2006). PON technology along with the adoption of WDM technology enhances the transmission efficiency and multiplexing rate by many ways in optical field (Zhuang et al, 2011).

1.2 Problem Statement

Multimedia-rich applications have become part and parcel of today's network (Park et al, 2004). The increase of connected users requires more bandwidth (Elbers, 2010). Optical fiber infrastructure appears as the only candidate to accommodate today's user requirement and further increase the network bandwidth for future demands (Cheng et al, 2011).

In view of the rapidly increasing bandwidth demand from Internet users, legacy networks supporting up to 10Mb/s is no longer able to accommodate the bandwidth increase (Weihua Yu, 2008). Nevertheless, network providers have been undertaking various measures to accommodate the progressive traffic growth (Cho, 2006). Hence, network managers have been left with no clear choice and decision to which FTTH architecture should be considered to accommodate their day's requirements. Despite the high deployment cost of the distinct FTTH base on PON technology and point-to-multipoint (P2MP) architecture (Lee et al, 2006 and Effenberger et al, 2007) WDM-PON has garnered significant attention due to its high bandwidth, high-speed access, large capacity, channel independence, ease of management, format transparency, network security and upgradability (Chang et al, 2009; Pan & Yao, 2010). According to Zhuang et al (2011) WDM-PON is considered as a potential choice for next generation broadband access networks.

1.3 Objectives of this Study

The aim of this project is to model a WDM-PON for FTTH to accommodate rapidly increasing user demands. This research seeks to compare two types of WDM-PON technology, which are coarse wavelength division multiplexing (CWDM) and dense wavelength division multiplexing (DWDM). The specific objectives of this study are to:

I. Design a CWDM-PON and DWDM-PON model.

II. Develop novel CWDM-PON and DWDM-PON Models which multiplex different combinations of LG modes.

III. Analyze the performance of the aforementioned CWDM-PON and DWDM-PON models in terms of their weighted special fields, bit-error rate (BER) and eye diagram.

1.4 Research Scope

This research will be model and compare two types of WDM-PON, which are CWDM-PON and DWDM-PON. This comparison will be based on three performance metrics:

I. Weighted spatial field of the modes of each channel before multiplexing the channels and after multiplexing of the channels.

II. Bit-error rate (BER) of each channel, which indicates the number of received bits of data stream, which have been altered due to noise, interference, distortion or bit synchronization error.

III. Eye diagram of each channel, the most widely open eyes the better signal integrity.

1.5 The Significance of this Study

Notwithstanding, many countries realize the importance of FTTH technology for national economic growth. For consumers, FTTH is viable for delivering triple-play services (video, voice and data) over a single optical fiber link. FTTH is a potential technology for meeting the needs of the foreseeable future, when 3D high-definition television, games, mobile video, iPods, HDTV, telemedicine, remote pet monitoring and thousands of other services pervade the network. This research presents a preliminary simulation of the implementation of WDM-PON to compare DWDM-PON and CWDM-PON from various aspects such as the weighted spatial field, eye diagram and bit-error rate. The research is useful for future deployment of WDM-PON FTTH.

CHAPTER TWO
LITERATURE REVIEW

2.1 INTRODUCTION

Copper cable connection has been sufficient and effective between the central office (CO) and end users for many years. Although legacy network infrastructure employing Digital Subscriber Lines has been effective, the infrastructure will no longer be able to support future traffic demands and hinders the development of communication technology (Weihua Yu, 2008). Network providers unanimously agreed that it would not cater for the traffic increase. The delivery of triple play is a very important consumer requirement (Park et al, 2004). Legacy network employing copper cable will no longer be able to accommodate today's consumer demands from triple play services and further increasing bandwidth in future. Optical fibre is a promising candidate to provide substantially more bandwidth, carry signals further and ensure reliable network services (Elbers, 2010).

2.2 Fibre To The Home

Fibre networks come in many types depending on the termination point. In Fibre-To-The-Home and Fibre-To-The-Building (FTTB), optical fibre is used to the extended path from the operator's switching equipment to at least the boundary point enclosing the home or business. In this architecture, the optical fibre will be terminated before reaching to the home leaving a gap. Another access medium will take over to cover the gap such as copper or wireless and Fibre-To-The Curb (FTTC) or node (FTTN). FTTN is a fibre optical communications cable that extends from the CO’s. Switching equipment to a point further away from the end user than that defined in FTTH or FTTB. This can include Fibre-To-The Curb or Cabinet (FTTC) or some other intermediate point between the CO and the end user. For simplicity, FTTX is commonly referred to by a majority of people for which X stands for the termination point. The question which arises is why FTTH? Many telecoms are realizing that the alternatives for fibre to the home are inadequate for future needs:

- Digital Subscriber Line has already been surpassed in terms of bandwidth (FOA, 2011).
- Wireless communications will not live up to the increasing bandwidth expectations bandwidth (FOA, 2011). Although mobile phones are pervasive, there are applications in wireless communications that are only supported by FTTH.
- Broadband over power lines have not achieved high bandwidth either (FOA, 2011).

Around the world telephone companies, government and even private enterprises are realizing the value of FTTH and as the result millions of homes and business have been connected over fibre each year. The future looks for strong growth of FTTH.

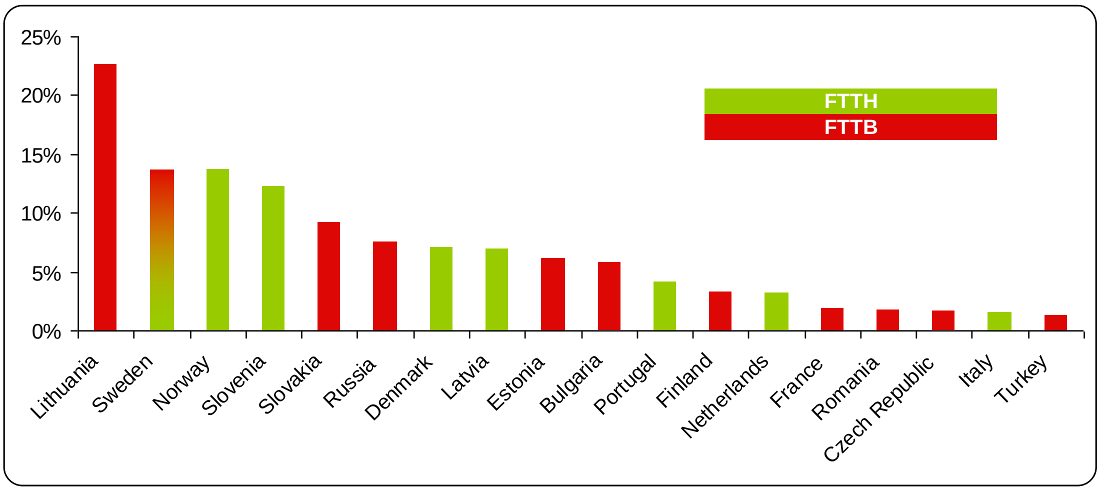


Figure 2.1: Europe ranking (IDATE consoling and research December, 2010)

2.3 FTTH/FTTB Architecture and performance

For the sake of establishing medium-sharing environment to construct FTTH networks, several multi-access structures have been proposed for constituting FTTH access networks (Akhtar, Gallion & Gharaei, 2009; Jer-Chen & Pesavento, 2007). These architectures can be divided into two broad categories.

- Passive Optical Networks (PONs): In this architecture no active electronic in between CO and end end-user.
- Active Optical Networks (AONs): In this architecture, active electronic is required in between CO and end-user.

In a point-to-multipoint architecture, because of its ability to share, passive optical network (PON) is the most suitable and appropriate architecture for providing high bandwidth to end-users.

There are three major point-to-multipoint variants, which have emerged under PON:

- BPON (Broadband PON) based on Asynchronous Transfer Mode (ATM).
- GPON (Gigabit PON) which according to ITU-T recommendations, G.984.x, Gigabit-capable PON is widely deployed in USA and Europe, and
- EPON (Ethernet PON) - According to the Ethernet- First-Mile standard IEEE 802.3ah is broadly deployed in Japan and Korea.

2.3.1 An Active Architecture

There are no much differences between an active and passive optical network. However, there are certain things can be differentiated between those technologies.

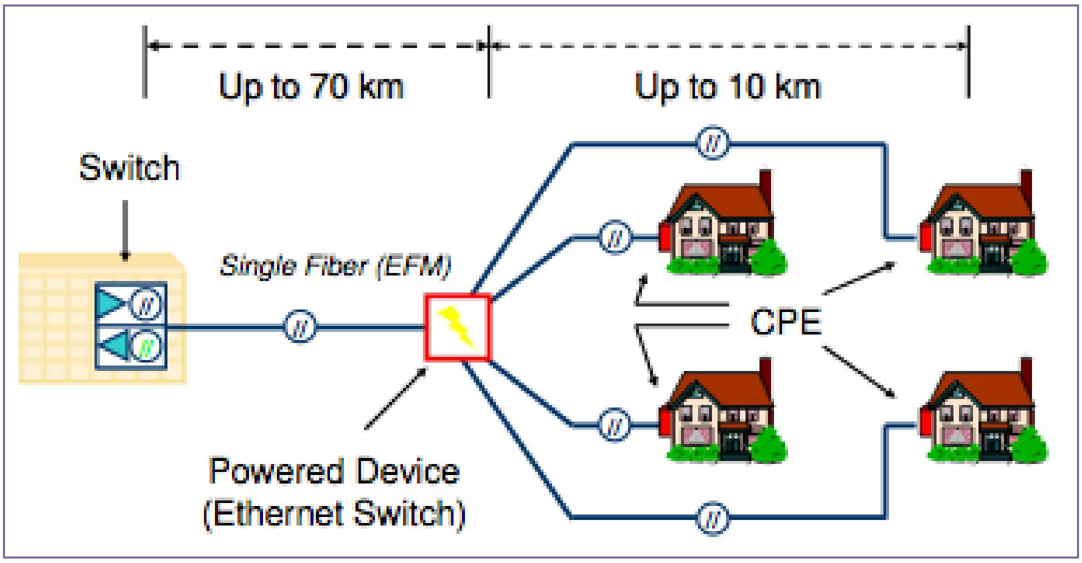


Figure 2.2: Active Architecture (Allied Telesyn, Inc, 2004).

From Figure 2.2 the following may be deduced:

- Active optical network does not use passive splitter but it has hardened Ethernet electronics that provide access aggregation.
- Active optical network does not share bandwidth, which means a dedicated, and bidirectional cable is provided.
- Active optical network support till 80km distance.

2.3.1.1 Home Run Fibre (Point to Point)

Fig. 2.3.1.1 architecture devoted or dedicated fibre from the optical line terminal (OLT) to the Central Office (CO) is connected to an Optical Network Terminal (ONT) at each premise. OLT and ONT are active and powered devices and each is prepared with an optical laser. This kind of architecture is able to cover 80km distance from the CO and each subscriber is provided with a dedicate "Pipe" which provides full bidirectional bandwidth.

Home Run Fibre is a dedicated fibre that is deployed to each premise. Home Run Fibre become less attractive when it comes to deployment cost but it considers as the most flexible architecture therefore in typical upfront planning of an FTTH network, the deployment costs are very high and should be calculated in detail (Mitcsenkov, 2009; Casier, et al, 2008). In conclusion, the fibre cost and network size can make this architecture expensive and inconvenient in many service areas.

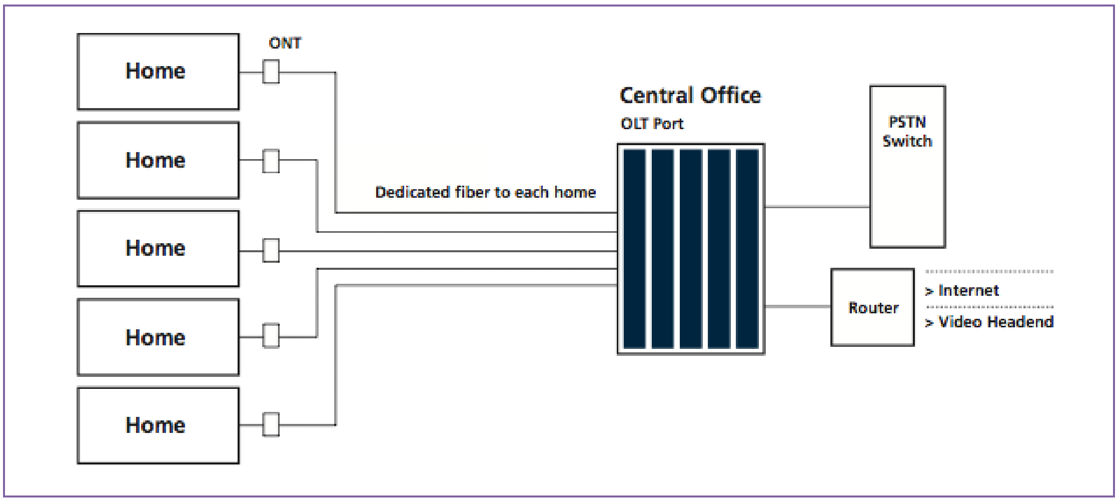


Figure 2.3: Home Run Fibre Architecture. Source :(OCCAM Networks, inc. California May 2005 and Ken Wieland. 2007)

2.3.1.2 Active Star Ethernet (Point to Point)

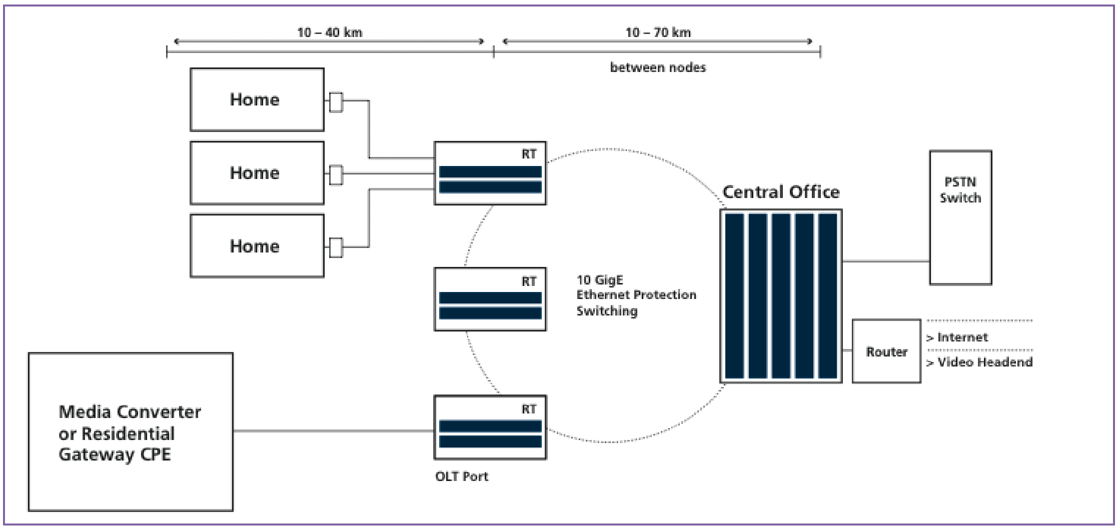


Figure 2.4: Active Star Ethernet Architecture. Source: (OCCAM Networks, inc. California May 2005 and Ken Wieland. 2007)

From Figure 2.4, we can detect that many premises share one feeder fibre through a RN situated between CO and server premises. In Active Star Ethernet (ASE) architecture, tenth to hardened Optical Ethernet electronics such as switches and broadband loop carriers are set up at the RN to provide fibre access aggregation. ASE can also cover distance of 80 km from the RN to each subscriber. On the other hand, RN can cover more than a thousand homes via one devoted distribution link. From RN however each end user is provided with a dedicated “pipe” which has full bidirectional bandwidth. Since many premises share one feeder fibre, ASE architecture principle of work has helped to reduce the amount of fibre required to be deployed as well as to reduce deployment costs. ASE architecture also by offers other benefits such as standardized optical Ethernet technology, which is easier and simpler topologies, support wide range of Customer Premises Equipment (CPE) and provide broad flexibility for future network growth. (OCCAM Networks, inc. California May 2005 and Ken Wieland, 2007).

Table 2.1: Strength and weakness of AON

Strengths	**Weaknesses**
Ethernet technology is leveraged standard	Requires many dedicated fibres.
Devoted fibre	Laser needed for Further distance.
More bandwidth compared to other architecture with flexibility.	OLT or port optic, does not share
Synchronous bandwidth	Power needed
To ease network troubleshooting, some intelligent electronic devices are installed in the network edge of the end user.	Active electronics needed to be distributed in the access network.
Complicated planning is not required	

Covers a distance up to 80 km	
Regarding the end user location, cost can be determined.	
Provides 1Gbps to each subscriber	
Cost can be predicted for new subscriber.	

2.3.2 Passive Optical Network (PON)

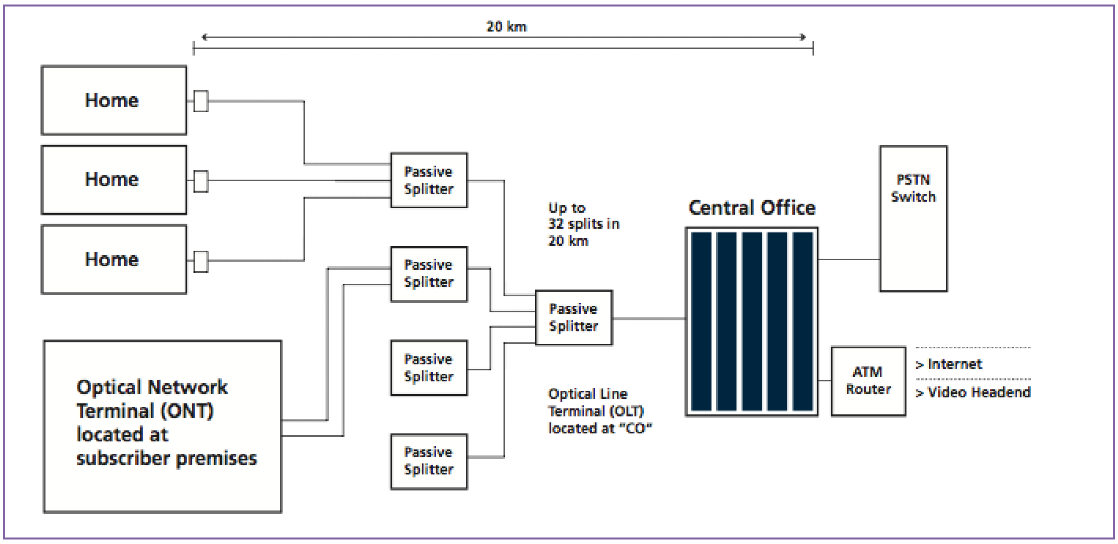


Figure 2.5: Passive Optical Network Architecture. Source: (OCCAM Networks, inc. California May 2005 and Ken Wieland. 2007)

Passive optical networks or point-to-multipoint network are shared-media. From Figure 2.5 we can detect that multiple user share the same bandwidth through device called splitter, which is used for the purpose of dividing the bandwidth from one single fibre to 64 users maximum over distance of 10 – 20 km. Both optical LT and ONT are powered. The idea behind naming this architecture as *passive* was because of all the splitters and equipment between the CO and ONT is passive which means it has no active electronics power.

Table 2.2: PON Technology Types

Technology	Layer 1-2	ONUs per ONT	Upstream	Downstream	Mbps/ONT
APON	ATM	32	622Mbps	1.2Gbps	37.5Mbps
EOPN	Ethernet	32	1.25Mbps	1.25Gbps	78.1Mbps
GPON	Gigabit Ethernet	32	155Mbps	1.25Gbps	19.5Mbps
		64	622Mbps	2.5Gbps	39.0Mbps
			1.25Gbps		
			2.5Gbps		

Table 2.3: PON Strengths and Weaknesses

Strength	Weaknesses
Passive architecture does not require active electronic in the access network	Many subscriber will be affected by a link failure
Less cost deployment compared to Home Run Network because the installed equipment between the CO and ONT are shared between subscribers.	Limited coverage area 20km maximum depending on numbers of splitters (More split less distance).
	Covers only 10 – 20 km maximum which make it limited and depends on the number of splitters (More splitter less distance

	cover)
	Unpredictable incremental customer costs. Cost estimation for new customer unpredictable

2.4 TDM-PON

Figure 2.6 shows a typical TDM-PON architecture. TDM-PON downstream data are broadcasting data to the end user through the splitter, which is located at the remote node. Unlike WDM-PON downstream data are broadcast through single and specific wavelength, which can be shared in the time domain. TDM-PON known by its simplicity to be implemented however the splitter shows splitting losses (Lee, Sorin and Kim, 2006).

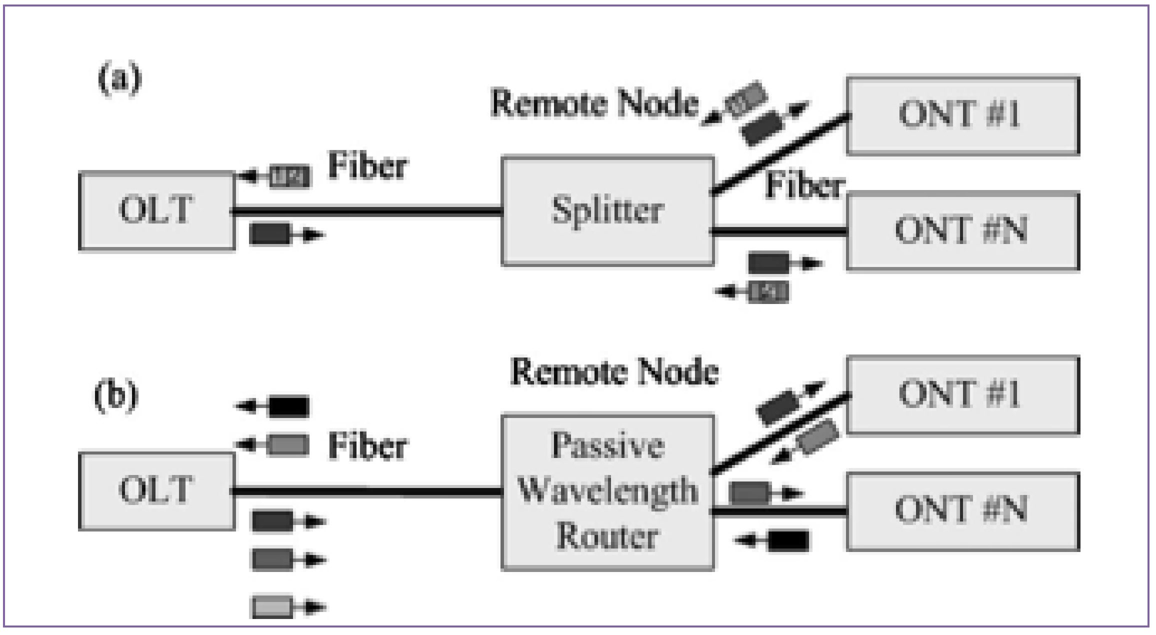
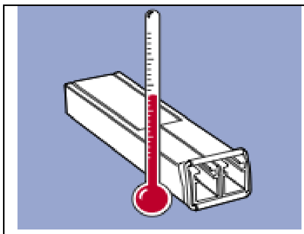
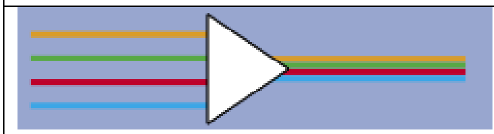
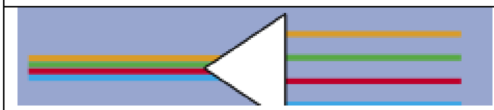
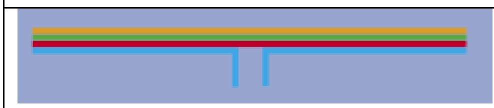
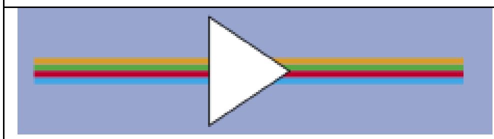


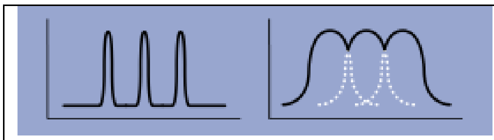
Figure 2.6: PON architecture (a) TDM-PON. (b) WDM-PON

2.5 WDM-PON

Wavelength Division Multiplexing (WDM) is an approach used to transmit data from many sources over one optical fibre at one time where every data channel should transmit over a distinguished wavelength (Amitabha et al, 2005). There are certain concepts should be known before introducing WDM and its types:

Table 2.4: WDM concept

	A digital diagnostics is used to monitor the send and receive power, temperature, voltage and as a warning of threshold (delete – not important for your scope)
	WDM uses a multiplexer to gather all channels of different wavelength to be passed through out one optical fibre
	This is De-multiplexer is the opposite of the multiplexer which separates all channels after it is gathered
	Multiplexer Add and Drop.
	This is amplifier use to regenerate the signals after certain distance

	Dispersion: The spreading of light pulses as they travel over the fibre.

WDM-PON is regarded as a promising candidate to meet the rapidly increasing bandwidth demand from enterprises and households, offering many advantages including large capacity, channel independence, easy management, format transparency, network security and upgradability (Chang, et al, 2009) & (Pan & Yao, 2010). Conventional WDM-PON architectures typically only support virtual point-to-point connectivity and are not suitable for the delivery of broadcast/multicast services (Maier, 2009). However, broadcast/multicast function is crucial to WDM-PONs to meet the exponentially increasing demand of applications, such as IPTV, video-on-demand and multimedia broadcast (Choi et al, 2010). Several architectures have been proposed to simultaneously deliver both point-to-point data to subscribers through WDM-PONs (Moon, Chaio & Lee, 2006). Hence WDM-PON is considered as the next generation broadband access network evolution direction and is the ultimate choice of FTTX (Fibre To The X) (Zhuang et al, 2011).

The approach described in (Moon et al, 2006), which utilizes optical carriers for broadcast video transmission and optical subcarriers for the downlink data transmission, overlays a number of broadcast channels in a WDM-PON". The specifications of 32 ONUs at distance 20 km from OLT are currently allowed. WDM-PON architecture provides scalability network because many wavelength can be supported by one fibre infrastructure. It doesn't experienced power splitting losses.

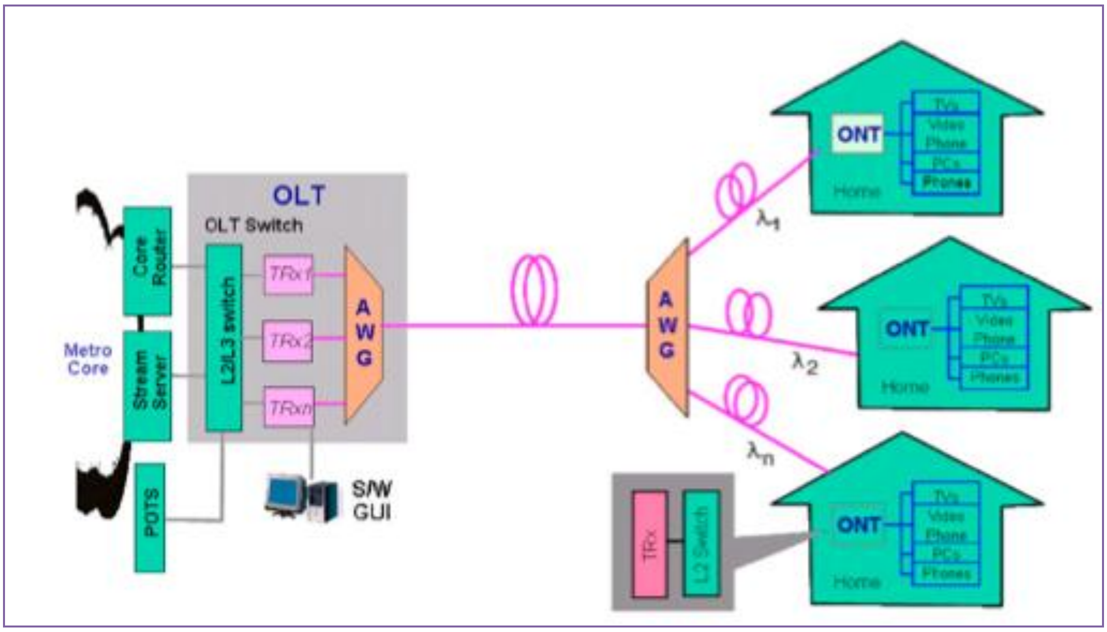


Figure 2.7: Configured WDM-PON Architecture (Amitabha et al, 2005)

From Figure 2.7, the following can be summarized:

- To build a WDM-PON we have to utilize a separate bidirectional wavelength channel from OLT to each ONU, which results, creating P2P link between CO and ONU.
- Different varieties of service can be delivered over the same network due different wavelength can be operated different bit rate.
- AWG Router is used to route the wavelength channels from OLT to ONUs in downstream direction. It is used to allow the reuse of the wavelength channels, which are multiple wavelength of OLT and can be used for transmitting multiple wavelengths to various ONUs.

- WDM de-multiplexer has been utilized by OLT along with receiver array for getting the upstream signal. ONU has its own transmitter and receiver on it's respective wavelength.

In conclusion, the ever-increasing demands of subscribers for high speed bandwidth and robust transport network encourage WDM technology to be used and enhanced to fulfill consumer requirements.

2.6 TDM-PON vs. WDM-PON

From the below Figure 2.8 we can observe that an OLT is connected to several ONU throughout remote node which often contains one or many optical power splitters. The architecture supports 1490nm downstream wavelength channel and 1310nm downstream wavelength channel, which are used to transmit voice signals and data while the downstream 1550nm channel is used for analog video overlay (Girard, 2005). In the case of downstream, the splitter broadcasts all packets to each ONU and each ONU recognize its own packet through the embedded address label in packet's head (Darren et al, 2007) while in the case of upstream, all ONU signals should be multiplexed and sent to OLT. Almost all-commercial PONs of today along with TDM-PON provides high-speed bandwidth rather than the conventional access network (Mohammed, Rashad & Saad, 2009).

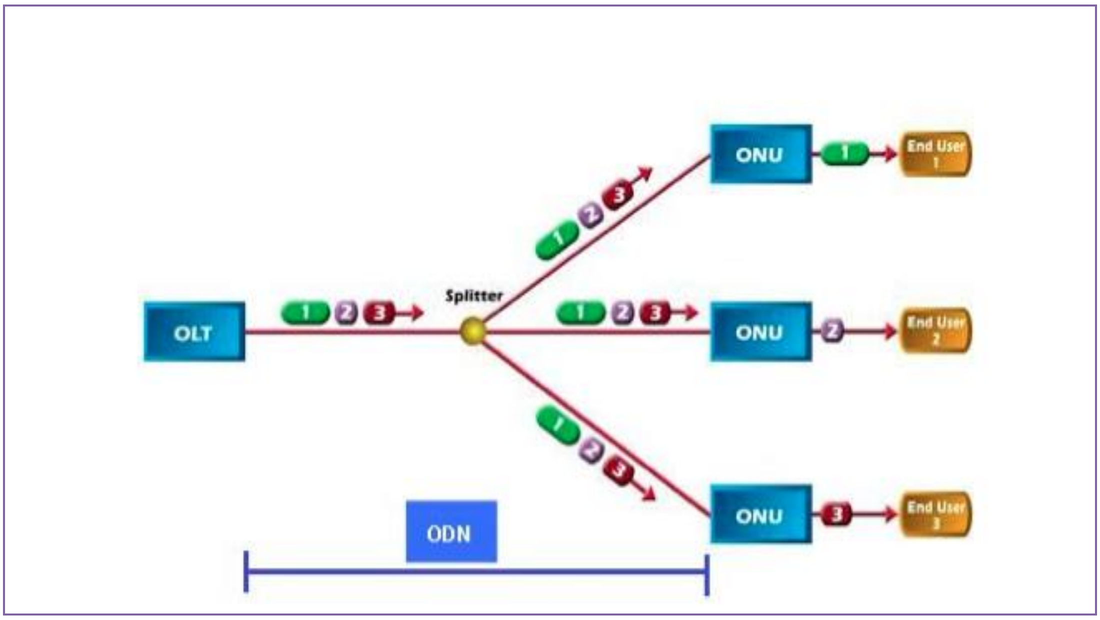


Figure 2.8: TDM-PON basic architecture

Moreover, the use of TDM, which means the use of optical power splitter, results to some security issues and losses of an essential power. Example 2.8 the splitter imposes more than 17dBm insertion lose.

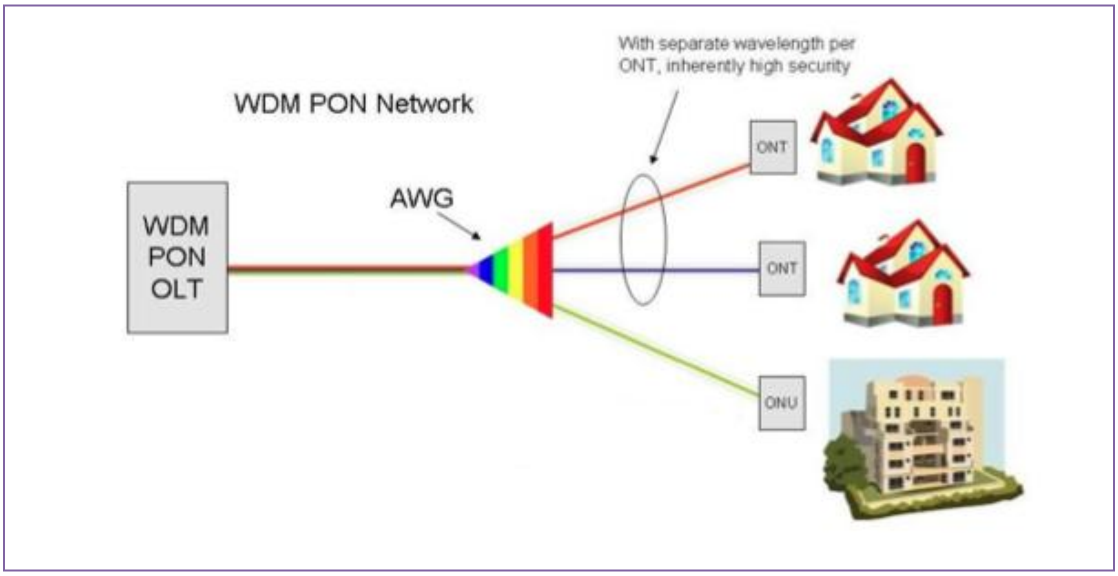


Figure 2.9: WDM-PON Architecture

WDM-PON considered as today and the future promising solution, which has the capability to enhance the performance of the access network for instance: security, power loss, bandwidth and others. Generally, passive wavelength de-multiplexers are used in WDM-PON system by looking to Fig 2.9.   WDM-PON use array waveguide channels (AWG) instead of splitter in the remote node, which avoids large insertion loss that caused by the splitter, which will improve the power budget for the whole system (Woodward & Husson, 2005). WDM-PON still uses a point to other point connectivity but this time using a dedicated wavelength, which is received between the OLT and each ONU.

WDM-PON technology considered to be much more private and secure than TDM-PON technology because of each ONU of WDM only can received it's own signals which we can labialize it as point to point logic architecture. Another point WDM-PON can be easily upgraded from the existing TDM-PON without any changes in ODN.

2.7 Advantages and Challenges of WDM-PON

WDM-PON offers the following advantages:

- The passive ODN between OLT and ONUs enables the high-reliability of a WDM-PON system.
- Higher reliability than other technologies because of its use of passive ODN between OLT and ONU.
- Using AWG instead of traditional splitters devices enable the reduction of insertion loss of the remote nodes as well as improvement of the power

budget, which will increase the transmission distance (Woodward and Husson, 2005).

- More private and secure because each ONU receives its own wavelength.
- Increase the transmission rate by making each ONU operate at maximum full bit rate.
- Provide different connectivity services on each channel
- WDM-PON components considered to be expensive may dropped the near future (Woodward & Husson, 2005).

2.8 WDM-PON Devices Characteristics and Options

Choosing different WDM-PON devices over others has significant differences, therefore the network designer must select suitable wavelength and its spacing based on the chosen device.

Subsection 2.8.1 describes the two major wavelength options—coarse WDM (CWDM) PON and dense WDM (DWDM) PON.

2.8.1 CWDM-PON

Wavelengths such as 1310nm, 1550nm and 1490nm (Amitabha et al, 2005). In the 1980s, the specific transport wavelength 850nm with wavelength spacing of 20-25nm over multiple fibres has been introduced to transport CWDM channels. However CWDM’s optical interface has been standardized and can be found in ITU G.695.

Moreover, cross talk in CWDM is very low because of its wide channel spacing. It has been argued that the total system cost is 40% cheaper for the CWDM-PON compared to DWDM (George, 2004).

The main drawback of CWDM is that the number of channels is limited which means CWDM suffer from lacking of scalability. Other disadvantage is that the shortest wavelength channels experience high loss (Amitabha et al, 2005).

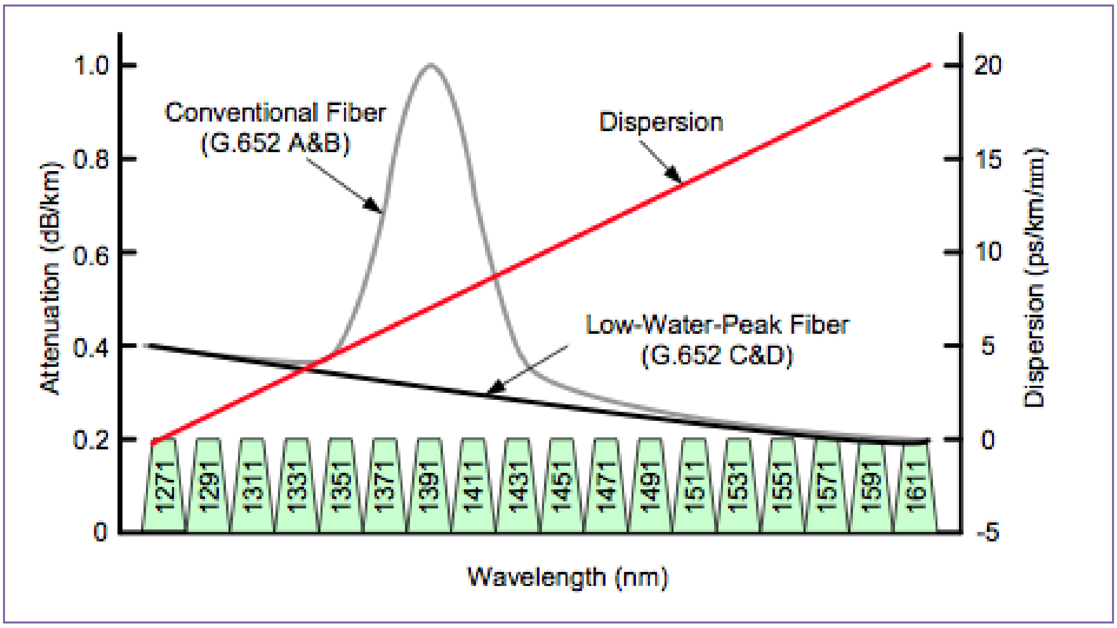


Figure 2.10: wavelength assignment for CWDM (Amitabha et al, 2005)

Basically, CWDM has more than 20 nm while DWDM has far less wavelength spacing than CWDM, usually less than 3.2 nm, and that because of the need to transmit many wavelengths in limited spectrum region. Enough bandwidth to end-user is one of the most expected things out of DWDM-PON and it’s considered as the ultimate PON system. To avoid crosstalk between adjacent channels we should filter each optical source and center wavelength of WDM, monitored and controlled. Therefore in terms of deployment cost, DWDM is consider much expensive and less attractive comparing to CWDM since it needs wavelength tuned devices and temperature control (Amitabha et al, 2005).

2.8.2 DWDM-PON

DWDM based access optical networks can be classified into two categories: DWDM active optical network and DWDM passive optical network.

Basically, DWDM whether active or passive, use the wavelength channel to connect user with the CO. The active DWDM results from applying TDM in each individual DWDM wavelength channel, which is used to provide integrated services (John et al 1998). Many network topologies can be used in active topologies such as star, tree and single star etc. (Song & Wu, 2001). Active DWDM access networks provides high wavelength channel utilization in order to reduce the fibre costs but adds an additional cost and increase the complexity of system management, which leads to high operating costs.

There are several architecture of PON have been proposed for DWDM which are as mentioned single star, double star, and tree, and star-bus topology

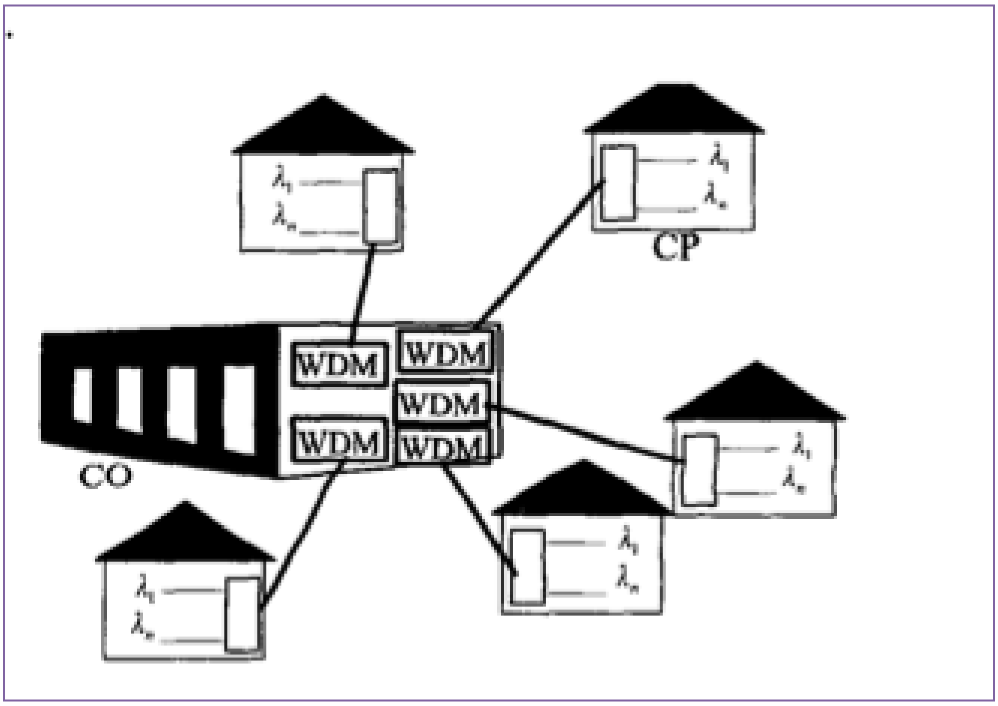


Figure 2.11:DWDM Start Topology (Song & Wu, 2001)

Each home has dedicated fibre shown in Fig. 2.11. Different required services such as voice, video and data are carried out through the channels in the fibre. This architecture is considered easy to install and upgrade (Song & Wu, 2001).

2.9 CWDM-PON vs. DWDM-PON

For CWDM wavelength spacing is wider of 20nm than DWDM and that happens because of the use of non-stabilized laser along with broadband filter while DWDM use narrow wavelength spacing of 0.8 because of the use of stabilized laser. CWDM support less number of channels 17 to 18 channels while DWDM can support to hundreds of channels. However CWDM is more attractive than DWDM in term of deployment cost.

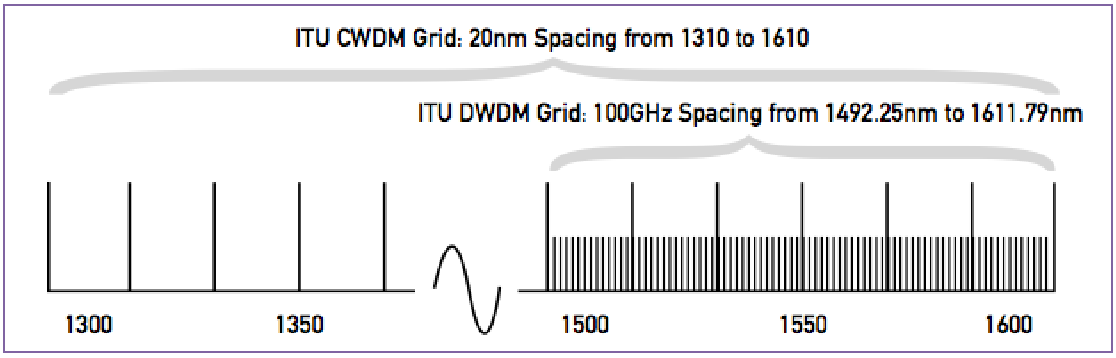


Figure 2.12: Wavelength Spacing of CWDM and DWDM

Table 2.5: Comparison between CWDM and DWDM (Redfern Broadband Networks Inc, 2002)

	Coarse WDM	**Dense WDM**
Channel Spacing	Large, from 1.6 nm (200 GHz) to 25 nm	Small, 200 GHz and less
Number of bands used	O, E, S, C and L	C and L
Cost per channel	Low	High
Number of channels delivered	17-18 at most	Hundreds of channels possible
Best Application	Short haul, Metro	Long haul

2.10 Conclusion

FTTH may be categorized into two main architectures, which are Active Optical Network (AON) and Passive Optical Network (PON). Under the first category, there are many architectures which can be classified such as Home Run Fibre where a dedicated fibre connect subscribers with the Central Office (CO) and Star architecture where it can be either passive or active. In this architecture, many homes share one feeder fibre through remote node, which is referred to as a switch or a splitter and used to connect subscribers with the Central Office.

On the other hand, the Home Run Fibre, Active Star, Passive Star and WDM PON are compared in Table 2.6.

Table 2.6: Comparison AON and PON architecture

Architecture	**Description**	**What's shared**
HomeRun	Dedicated fibre per subscriber (Direct connection between subscriber and meet point	Meet point. Customer chooses how to use fibre and whom/what to connect to.
Active Star	Signals switched at node between user and meet point)	Between meet point and node.
Passive Star	Signals switched at node between user node meet point (virtual bus architecture)	Between meet point and user.
WDM PON	Evolving: dedicated wavelength per… (Service provider, or subscriber)	Depends. Frequency unbundling, maybe.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter explains in depth the methodology that has been used to carry out this research. Basically the main purpose of this chapter is to show the approaches that used executing this research and demonstrating of how the approaches can be delivered to meet the objectives of this research. Section 3.2 provides explanation of used method then followed by explanation in detail of each phase. Section 3.3 explains the method and evaluation of the network performance. Section 3.4 explains the evacuation metrics performance then followed by section 3.5 which indicate the verification and validation of this research. Finally section 3.6 a summary at the end of the chapter.

3.2 Research Operational Framework

3.2.1 Awareness of Problem

In this stage defining the problem and determine the objectives can be deduced by literature research reports, expert interviews, and pre-evaluate relevance. This phase offers a solid and important foundation for the further research process.

3.2.2 Suggestion

Determine the metrics to be used for this performance comparison study. Particularly, in this phase includes the suggestion to produce prototype. The design of the prototype is a creative engineering process. The researcher should identify the requirements of the prototype, because they are the most important things in the methodology. In the other hand, researcher should this study the performance metrics are BER, Eye Diagram, and WDM analyzer.

3.2.3 Development

In this phase, we will develop CWDM-PON and DWDM-PON reference model to be implemented in the propose simulation which is called OptiSystem which allow us later to compare between the two architectures. Before the comparison takes place, suggested variable and parameters should be selected to assist the matrices. in this case, all variable parameter are fixed.

3.2.4 Implementation

After constructing the network model, which is mentioned in phase 3.3. This phase includes the details of simulation's scenarios that will be used to execute and collect performance data, and the result of the execution. During this phase, the problem can be restated as well.

3.2.5 Evaluation

This phase includes the details of validation and verification to the simulation's results that are produced in the previous phase. This study attempts to use different scenarios to indicate clearer picture of the comparison.

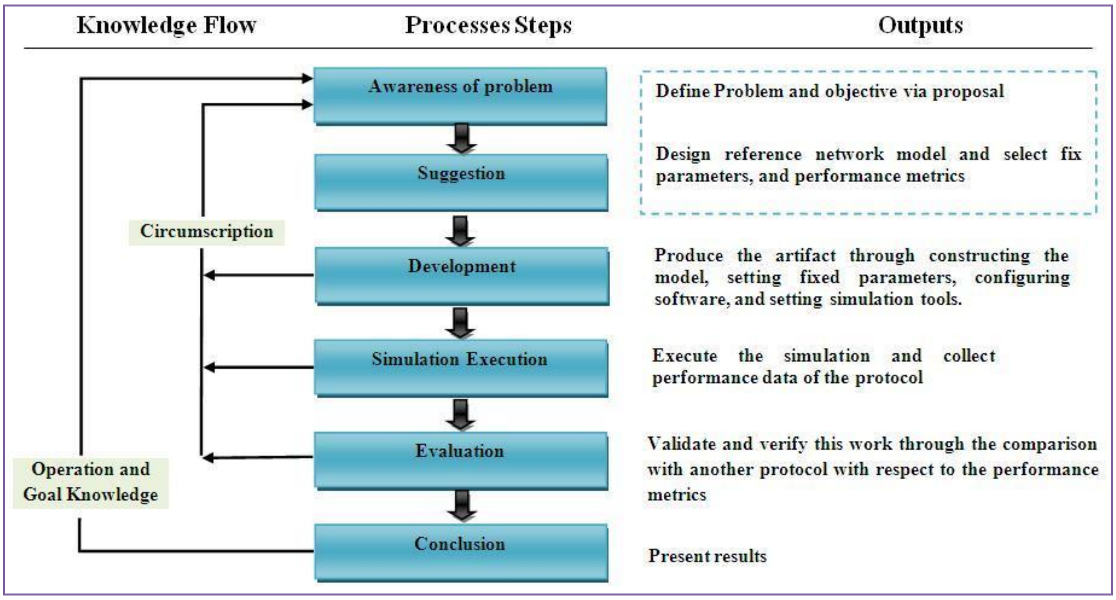


Figure 3.1: Simulation Systematic Study

3.3 Methods used in Evaluating Network Performance

There are many approaches can be used to carry research. According to Egeberg (2006) there are two major approaches in information system depending on the goal of the study, either descriptive approach or prescriptive approach.

The researcher with a descriptive approach is looking for the information about the nature of reality in what concern to the study. The looking for information about the nature and reality in what is concern the study is called Descriptive approach while design science or prescriptive approach concern on improving the performance of a task. Ardakan and Mohajeri (2009) mentioned that, "The steps and outputs of Design Research should be studied as a methodological aspect". Establishing a research base and contributing to increase knowledge through scientific investigation should be done through framework, which is compared five phases. Offermann et al (2009) mentioned that, it has been accepted among many researchers in Information System.

In the other hand, simulation is a popular and powerful tool, which allow network research group to get more insight about specific choice of network parameters, uses them. Hassan and Jain (2004) proposed a systematic study specified for simulation. Offermann et al (2009) mentioned" Many researchers vote for a combination of research perspectives and their respective research methodologies." Since this study includes both systems development and the use of simulation, both the methodology proposed by Vaishnavi and Kuechler (2004) and the systematic study specified for simulation proposed by Hassan and Jain will be combined together to produce the methodology that will be apply to conduct this stud y.

3.3.1 Network Simulator

Network simulation enables the researchers to perform experiments on the operations of the targeted network model without the possibility of disrupting the actual network. Network Simulation generally had been introduced to simulate a real network model in order to perform experiment on the operation of the targeted model without disturbing the real network.

In the other hand, simulation has been defined as discipline of designing mode of theoretical network system, executing and analyzing the executing output using network simulation (Al-Momani, 2010). As mentioned in section 3.2 network simulation has emerged as a main research methodology by many researchers (Lu, Lin, and Chiueh, 2010; Yang, Zhao and Zhang, 2009). The choice of this technique may help to present an accurate study of the network behavior and protocols. Therefore, there are many researchers who take network simulation as their research approach to study network communication, behavior and present their finding after it has been documented in many well-known publications (Pawlikowski, Jeong and Lee, 2002).

There are quite numbers of available network simulators software used in purpose of investigating and optimizing network performance. Some are freely available such as OMNET++, Global Mobile Simulator (GloMoSim), MatLabWDM and the popular network Simulator 2 (ns2) and some are not freely available such as MathLab, OptiSystem and OPTSIM.

3.3.1.1 OptSim Simulation

OptSim is RSoft's has been commercially available since 1998 and is in use by leading engineers in both academic and industrial organizations worldwide.

OptSim simulation used in varies optical connections for instance optimizing all types of broadband optical network such as virtual optical connection. It has a massive database activity and passive components including power, loss, wavelength and other related parameters such as Wavelength spacing, transmission capacity, power level and etc. all the mentioned parameters can be set by the user to optimize system performance.

3.4 Evaluation Metrics

One of the most important and key steps to in network simulation is to select the performance evaluation metrics (Al-Momani, 2010 and Ghazali, 2008). For the comparison of CWDM-PON and DWDM-PON the following performance metrics were used:

- Weighted spatial field of the modes for each channel: which have been used in the past for the measurement of several different parameters such as strain, temperature, pressure, electric and magnetic fields and vibration.
- Bit Error Rate (BER): is the number of received bit of data stream over communication channel that have been altered due to noise, interference, distortion or bit synchronization error.
- Eye diagram: used to provide visual information that can be very useful in the evaluation and troubleshooting of digital transmission systems (Gary Breed, 2005). Eye diagram used to measure signal integrity such as fiber optic transmission, network cables or circuit board can be obtained as well.

3.5 Validation and Verification of OptSim

Verification is very important step, which used to determine that computer model, simulation implementation and their associated data accurately represented. During the simulation process, known input parameters should be used so that the result can be obtained then compared with known output. If the obtained output matches previous work output, we can say our simulation result is valid however if it's fail or some comparison does not match, then the user will be notified and asked to repeat the validation process again.

3.6 Summery

This chapter has presented an approach that has been used to ensure that the entire research objectives can be fulfilled. Since this research includes both system development and the use of simulation, a combination method has been used and applied in this research. The proposed method consisted of five phases started of identifying the research problem and objectives by reading literature review then end by evaluate and validate the produced result with previous known result. In terms of evaluation metrics, this study chooses to use video related metrics, rather than network-based metrics. The video related metrics that have been selected are PSNR, higher video rate, QP stability, and frame loss. In term of study metrics, this research study the evaluation performance of CWDM and DWDM from three performance metrics which are, Weighted spatial field analyzer before and after multiplexer, BER and the Eye Diagram.

CHAPTER FOUR
SIMULATION AND RESULTS

4.1 INTRODUCTION

This chapter presents and compares CWDM and DWDM for FTTH. The comparison between CWDM-PON and DWDM-PON performance were taking place by changing the wavelength spacing, the number of lasers used and the mode configuration. The performance of the CWDM-PON and DWDM-PON were evaluated in terms of the weighted spatial field for each channel, before and after multiplexing, the eye diagram and bit-error rate of each channel.

Section 4.2 presents a novel FTTH model for CWDM-PON and DWDM-PON. Section 4.3 describes the simulation of a novel WDM-PON model which multiplexes odd azimuthal mode numbers on vertical cavity surface-emitting lasers (VCSEL) for CWDM-PON and DWDM-PON individually. The simulation settings for this are presented in Section 4.3.1 and the simulation result is discussed in Section 4.3.2. Section 4.4 describes the simulation of a novel WDM-PON model, which multiplexes continuous azimuthal mode numbers on vertical cavity surface-emitting lasers (VCSEL) for CWDM-PON and DWDM-PON individually. The simulation settings for this are presented in Section 4.4.1 and the simulation result are discussed in Section 4.4.2. Section 4.5 provides a summary of this chapter.

4.2 FTTH WDM Model

The proposed FTTH WDM model was designed and developed in OpSim 5.2 as shown in Fig.1. The transmitter consists of:

- The PRBS block for each channel: used to generate sequences, which are offset from one another. This ensures that each of the signals is not propagating the same bit value at all time points.
- The signal generator for each channel: through it we can choose the needed modulation format for instance (NRZ, RZ and Manchester) and the transmission bit rate.
- The VCSEL for each channel: is a type of semiconductor laser diode with laser beam emission perpendicular from the top surface, contrary to conventional edge-emitting semiconductor lasers (also in-plane lasers) which emit from surfaces formed by cleaving the individual chip out of a wafer.

Attenuation and power modal coupling have been taken into consideration. At the receiver, the signal is analyzed using a BER tester. The aggregate multiplexed VCSEL spatial signal is also examined. The five VCSELs signals are then combined using a wavelength division multiplexer.

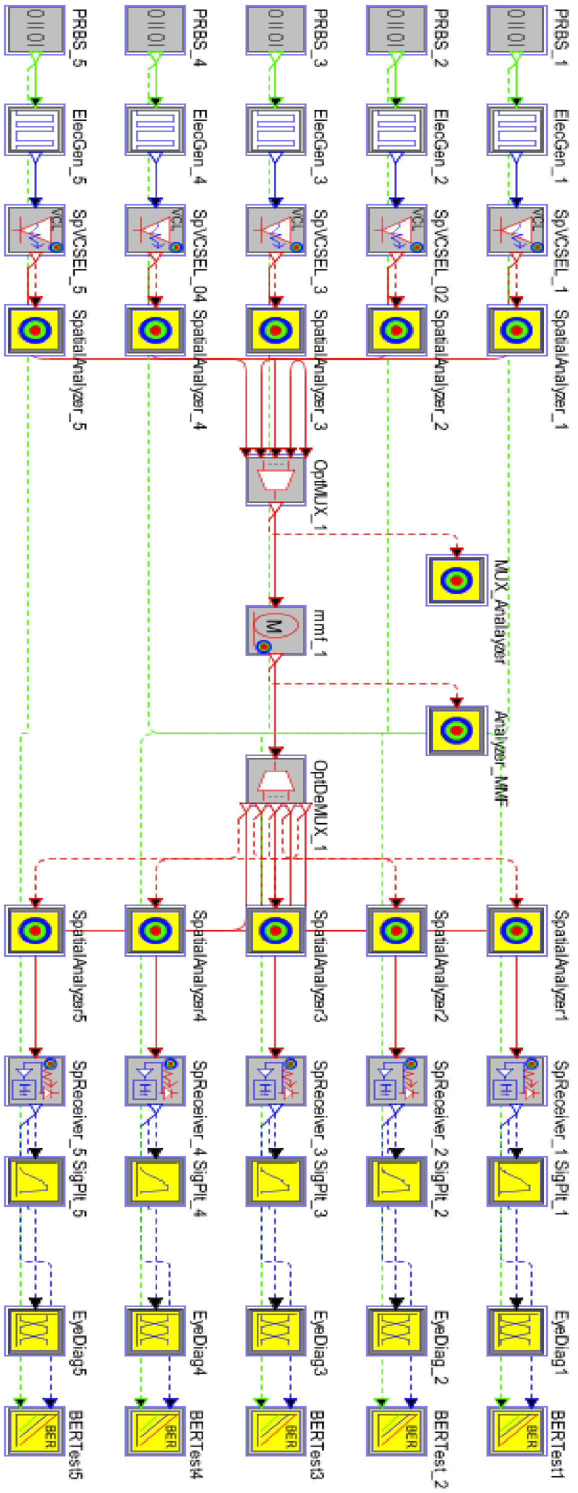


Figure.4.1: WDM-PON Model

4.3 WDM-PON with multiplexing of odd-numbered azimuthal modes on VCSELs

4.3.1 Simulation settings

The model consist of five vertical cavity emitting lasers (VCSELs) which lase at five wavelengths, λ_1 to λ_5 between 1546.92nm and 1553.33nm based on the ITU grid, separated by 1.6 nm with a center wavelength of 1550.12 nm are used for DWDM-PON and between 880nm – 800nm, The five VCSELs are driven by separate PRBS electrical signals to generate sequences which are offset from one another. A Non-Return-to-Zero (NRZ) modulation scheme is used. The VCSELs emit power in the Ex-polarization only. The power from each VCSEL is assumed to be emitted uniformly into 5µ m Laguerre-Gaussian beams. For all odd-numbered VCSELs, radial mode numbers, *m = 0, 1, 2, 3, 4* are excited, while the azimuthal mode numbers, l is fixed. For all even-numbered VCSELs, radial mode numbers, *m = 6, 7, 8, 9, 10* are excited, while the azimuthal mode numbers, l is constant. Azimuthal mode numbers, *l = 1, 3, 5, 7, 9* are used, where each VCSEL excites a single distinct azimuthal mode number. The transverse modal electric fields are calculated analytically based on the wavelength of each VCSEL. The power-coupling coefficient between the output field of each VCSELs and each transverse modal field of the MMF is calculated as follows:

$$c_{lm} = \int_0^{2\pi}\int_0^{\infty} E_{in}(r,\phi)E_{lm}^{*}(r,\phi)\; r\;\; dr\; d\phi \qquad (1)$$

Where E_{in} is the incident electric field on the multimode fiber (MMF) and E_{lm} is the transverse modal electric field for LG_{lm}. The total incident spatial electric field at the MMF input from each VCSEL may be described as:

$$E_{in}(r,\phi,t) = E_{in}(r,\phi)E_{in}(t)$$
$$= \begin{cases} \sum_{l=1}^{2n-1} \sum_{m=0}^{4} c_{lm} E_{lm}(r,\phi) E_{in}(t), & \text{for } n = 1,3,5 \\ \sum_{l=1}^{2n-1} \sum_{m=6}^{10} c_{lm} E_{lm}(r,\phi) E_{in}(t) & \text{for } n = 2,4 \end{cases} \quad (2)$$

Where n=1, 2, 3, 4, 5 is the VCSEL number. The total incident spatial electric field for each VCSEL is shown in Fig. 4.2 DWDM-PON.

DWDM-PON Fig. 4.2 (a) indicates VCSEL 1 at $\lambda_1=1553.33$ nm which emits *LG* mode of *l=1* and *m=0,1,2,3,4.*

Fig. 4.2 (b) indicates VCSEL 2 at $\lambda_2=1551.72$ nm which emits *LG* mode of *l=3* and *m=6,7,8,9,10.*

Fig. 4. 2 (c) indicates VCSEL 3 at λ_3=1550.12 nm which emits *LG* mode of *l=5* and *m=0,1,2,3,4.*

Fig. 4.2 (d) indicates VCSEL 4 at λ_4=1548.52 nm which emits *LG* modes of *l=7* and *m=0,1,2,3,4.*

Fig. 4.2 (e) indicates VCSEL 5at λ_5 = 1546.92 nm which emits *LG* mode of *l=9* and *m=6,7,8,9,10*}.

Eventually, Fig. 4.2 (e) illustrates the total incident electric field after the multiplexer, incident at the MMF input.

The total incident spatial electric field for each VCSEL is shown in figure Figure. 4.3 CWDM-PON as well.

CWDM-PON Fig. 4.3 (a) indicates VCSEL 1 at $\lambda_1=800$nm which emits *LG* mode of $l=1$ and $m=0,1,2,3,4.$

Fig. 4.3 (b) indicates VCSEL 2 at $\lambda_2=820$ nm which emits *LG* mode of $l=3$ and $m=6,7,8,9,10.$

Fig. 4. 3 (c) indicates VCSEL 3 at λ_3=840nm which emits *LG* mode of $l=5$ and $m=0,1,2,3,4.$

Fig. 4.3 (d) indicates VCSEL 4 at λ_4=860nm which emits *LG* modes of $l=7$ and $m=0,1,2,3,4.$

Fig. 4.3 (e) indicates VCSEL 5at λ_5 =880nm which emits *LG* mode of $l=9$ and $m=6,7,8,9,10\}$.

Eventually, Fig. 4.3 (e) illustrates the total incident electric field after the multiplexer, incident at the MMF input.

The five VCSELs signals are then combined using a wavelength division multiplexer. The total incident fields at the MMF input from the five VCSELs are then combined, as shown in Fig.4.2 (f) and Fig.4.3 (f). The signal propagates through a multimode fiber. Dispersion, attenuation, and power modal coupling have been taken into consideration. At the receiver, the signal is analyzed using a BER tester. The aggregate multiplexed VCSEL spatial signal is also examined.

4.3.2 Simulation results

At the receiver, the following important performance metrics are investigated:

I. Weighted spatial field of the modes for each channel, which is the total spatial fields of all the modes excited within the channel.

II. Eye diagram of each channel: This provides visual information from an oscilloscope to measure signal integrity.

III. Bit-error rate (BER) of each channel, which indicates the number of received bit of data stream over communication channel that have been altered due to noise, interference, distortion or bit synchronization error.

The weighted spatial field of modes present at the de-multiplexer output is depicted in Fig. 4.4 and Fig. 4.5. It is an evident that the spatial field no longer resembles the original input spatial fields. Fig. 4.4 and Fig. 4.3 has been affected severely by power modal coupling. A typical eye diagram is given in Fig. 4.6 The BER for all channels are given in Table. 4.1. This demonstrates that less number of channels are required to achieve a transmission speed of 40Gbps for a DWDM system compared to (Kaman et al., 2005; Patnaik & Sahu, 2010).

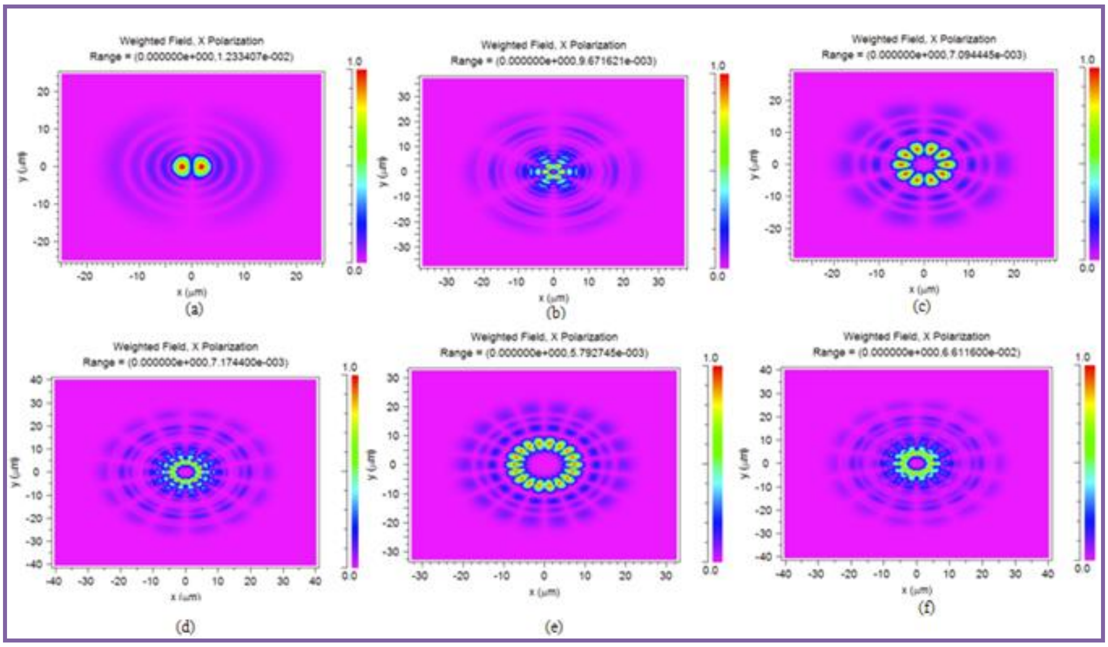


Figure 4.2: (a) to (e). Total incident electric field each DWDM-PON VCSEL. (f) Total spatial electric field of (a) to (e) after the multiplexer, incident on the MMF input

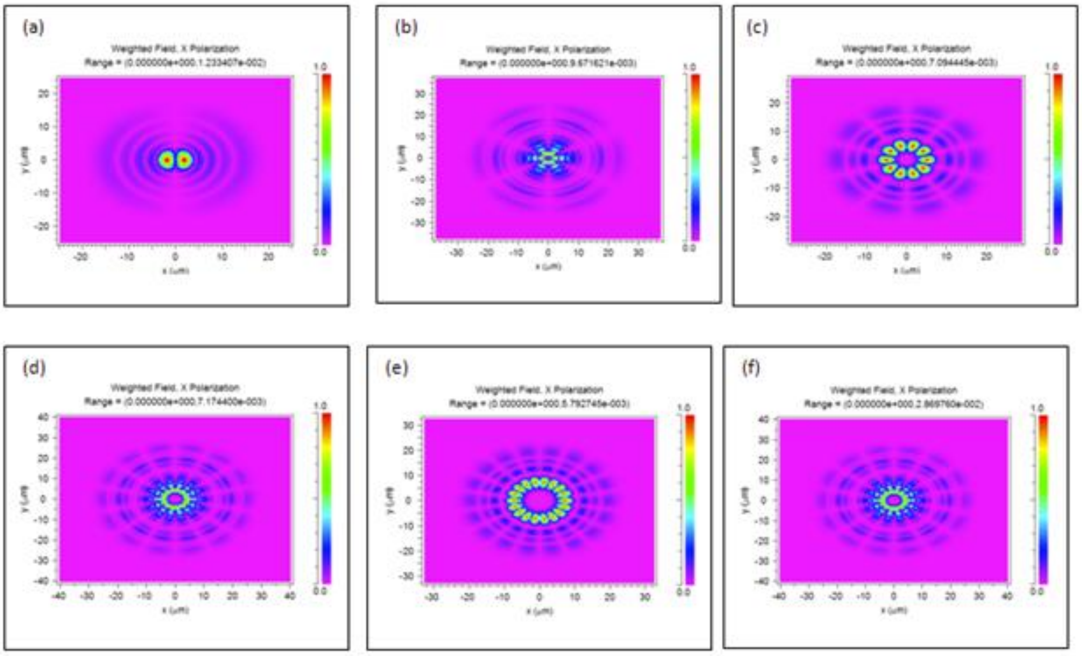


Figure 4.3: (a) to (e). Total incident electric field each CWDM-PON VCSEL. (f) Total spatial electric field of (a) to (e) after the multiplexer, incident on the MMF input

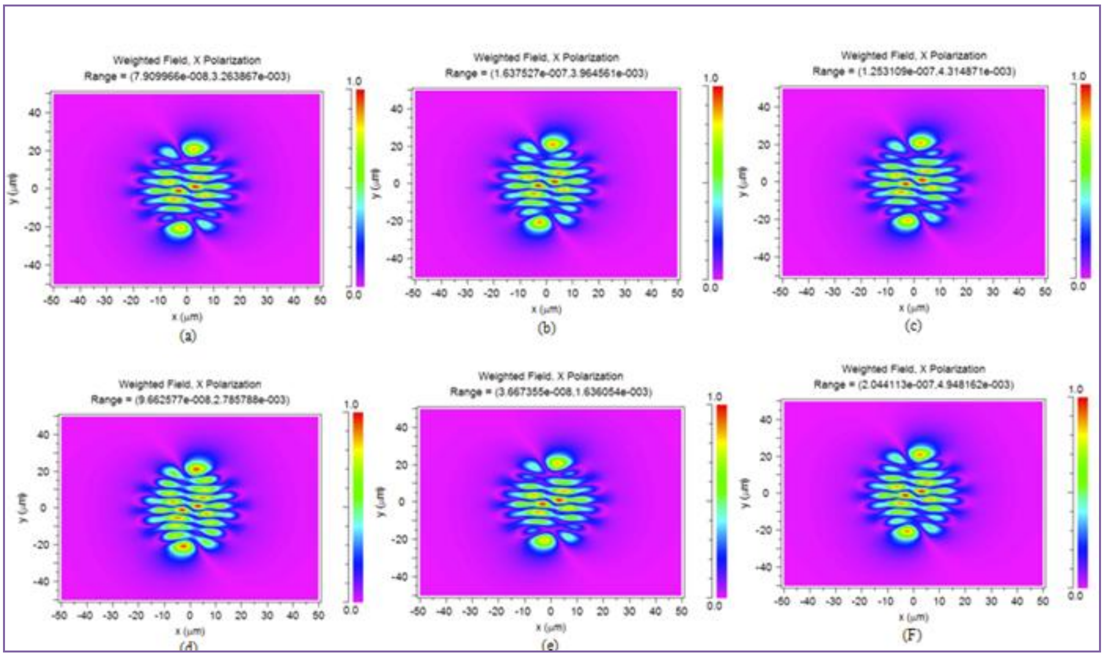


Figure 4.4: (a) to (e). Total spatial electric field for each DWDM channel after the de-multiplexer. (f) Total spatial electric field of (a) to (e) after the multiplexer.

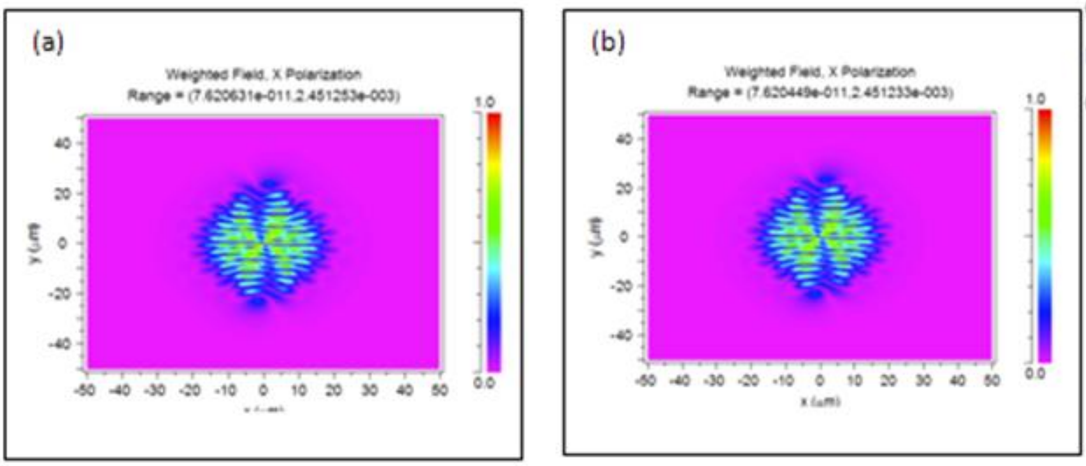


Figure 4.5: (a) to (e). Total spatial electric field for each CWDM channel after the de-multiplexer. (b) Total spatial electric field the multiplexer.

Table 4.1: (a) BER for all channels in DWDM system. (b) BER for all channels in CWDM system

Channel	BER	Channel	BER
1553.33e-9	4.9815e-010	800-9	1.0000e+000
1551.72e-9	8.5945e-011	820-9	2.7103e-006
1550.12e-9	8.8517e-011	840-9	1.0000e+000
1548.52e-9	4.9815e-010	860e-9	1.9022e-006
1546.92e-9	8.8972e-011	880e-9	1.0000e+000

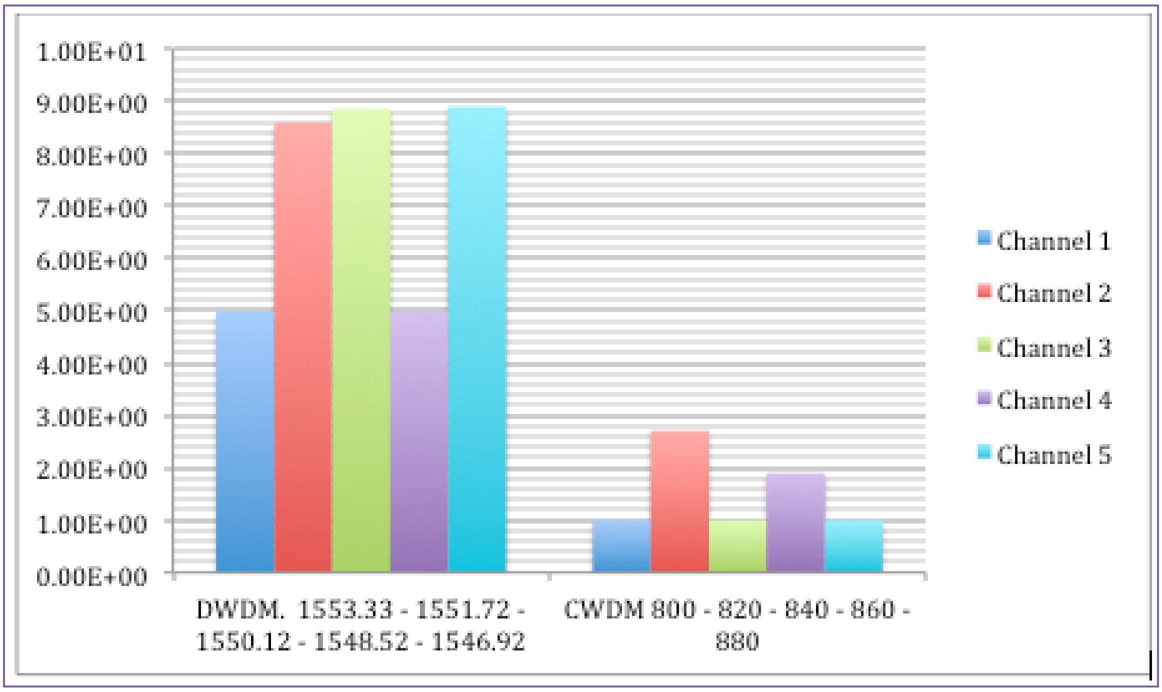


Figure. 4.6. Bar graph of comparison of BER for DWDM and CWDM channels

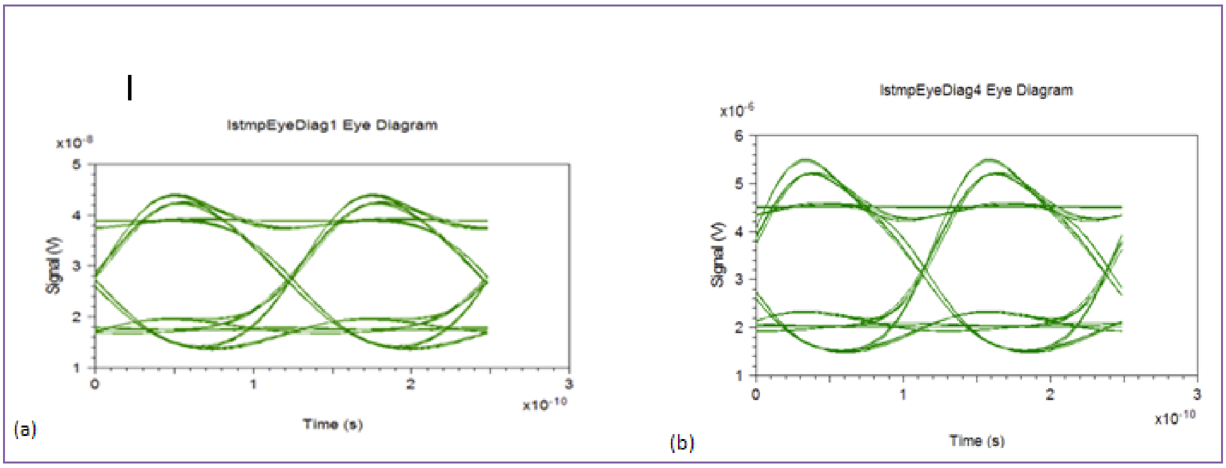


Figure 4.7 :(a) DWDM BER Diagram and (b) CWDM BER Diagram

Fig. 4.7 (a) indicates the very acceptable eye shape with given references of BER e-010 and e-011 which means if the eye margins for given references BER closer to zero the perfect the eye which means the perfect decision can be made while Fig 4.6 (b) indicates the unacceptable eye shape for given references BER either 1 or e-06 which means the eye margin for given references is not closer to zero.

4.4 WDM-PON with modal multiplexing of continuous azimuthal modes on VCSELs

4.4.1 Simulation settings

In this sitting the following parameters remain unchanged from the previous settings in Section 4.3:

- Number of VCSELs.
- Wavelength Spacing.
- PRBS electric signal
- Modulation format

However, the azimuthal mode numbers used on the VCSELs are continuous. The radial mode numbers, *m = 0, 1, 2, 3, 4* are excited, while the azimuthal mode numbers, *l* is fixed. Azimuthal mode numbers, *l = 1, 2, 3, 4, 5* are used, where each VCSEL excites a single distinct azimuthal mode number. The transverse modal electric fields are calculated analytically based on the wavelength of each VCSEL. The power-coupling coefficient between the output field of each VCSELs and each transverse modal field of the MMF is calculated as follows: m

$$c_{lm} = \int_0^{2\pi}\int_0^{\infty} E_{in}(r,\phi)E_{lm}^{*}(r,\phi)\ r\ \ dr\ d\phi \qquad (2)$$

Where E_{in} is the incident electric field on the multimode fiber (MMF) and Elm is the transverse modal electric field for LG_{lm}. The total incident spatial electric field at the MMF input from each VCSEL may be described as:

$$E_{in}(r,\phi,t) = E_{in}(r,\phi)E_{in}(t)$$
$$= \sum_{l=1}^{n}\sum_{m=0}^{4} c_{lm}E_{lm}(r,\phi)E_{in}(t), \qquad \text{for}\, n = 1,2,3,4,5 \qquad (2)$$

Where $n=1, 2, 3, 4, 5$ is the VCSEL number. The total incident spatial electric field for each VCSEL is shown in Fig. 4.8 DWDM-PON.

DWDM-PON Fig.4.8 (a) indicates VCSEL 1 at λ_1=*1553.33*nm which emits LG mode of *l=1* and *m=0,1,2,3,4.*

Fig. 4.8 (b) indicates VCSEL 2 at λ_2=*1551.72*nm which emits LG mode of *l=2* and *m=0,1,2,3,4.*

Fig. 4.8 (c) indicates VCSEL 3 at λ_3=*1550.12*nm which emits LG mode of *l=3* and *m=0,1,2,3,4.*

Fig. 4.8 (d) indicates VCSEL 4 at λ_4=*1548.52*nm which emits LG modes of *l=4* and *m=0,1,2,3,4.*

Fig. 4.8 (e) indicates VCSEL 5at λ_5= *1546.92* nm which emits LG mode of *l=5* and *m=0,1,2,3,4.}.*

The total incident spatial electric field for each VCSEL is shown in Fig. 4.8 CWDM-PON as well.

CWDM-PON Fig. 4.9 (a) indicates VCSEL 1 at λ_1=*800*nm which emits LG mode of *l=5* and *m=0,1,2,3,4*

Fig. 4.9 (b) indicates VCSEL 2 at λ_2=*820* nm which emits LG mode of *l*=*5* and *m=0,1,2,3,4*

Fig. 4.9 (c) indicates VCSEL 3 at λ_3=*840* nm which emits LG mode of *l*=*5* and *m=0,1,2,3,4*

Fig. 4.9 (d) indicates VCSEL 4 at λ_4=*860* nm which emits LG mode of *l*=*5* and *m=0,1,2,3,4*

Fig. 4.9 (e) indicates VCSEL 5at λ_5= *880* nm which emits LG mode of *l*=*5* and *m=0,1,2,3,4*

Eventually, Fig. 4.9 (f) illustrates the total incident electric field after the multiplexer, incident at the MMF input.

The five VCSELs signals are then combined using a wavelength division multiplexer. The total incident fields at the MMF input from the five VCSELs are then combined, as shown in Figure. 4.8 (f) and Figure. 4.9. The signal propagates through a multimode fiber. Dispersion, attenuation, and power modal coupling have been taken into consideration. At the receiver, the signal is analyzed using a BER tester. The aggregate multiplexed VCSEL spatial signal is also examined.

4.4.2 Simulation Results

At the receiver, the following important performance metrics are investigated:

a) Weighted spatial field of the modes for each channel

b) Bit-error rate (BER) of each channel

c) Eye diagram of each channel

The weighted spatial field of modes present at the de-multiplexer output is depicted in Fig.4.8 and Fig. 4.9. It is evident that the spatial field no longer resembles Fig. 4.10, (f) and Fig. 4.11, and has been affected severely by power modal coupling. A typical eye diagram is given in Fig. 4.13. The BER for all channels are given in Table 4.2. This demonstrates again that that less number of channels is required to achieve a transmission speed of 40Gbps for a DWDM system compared to (Kaman et al., 2005; Patnaik & Sahu, 2010).

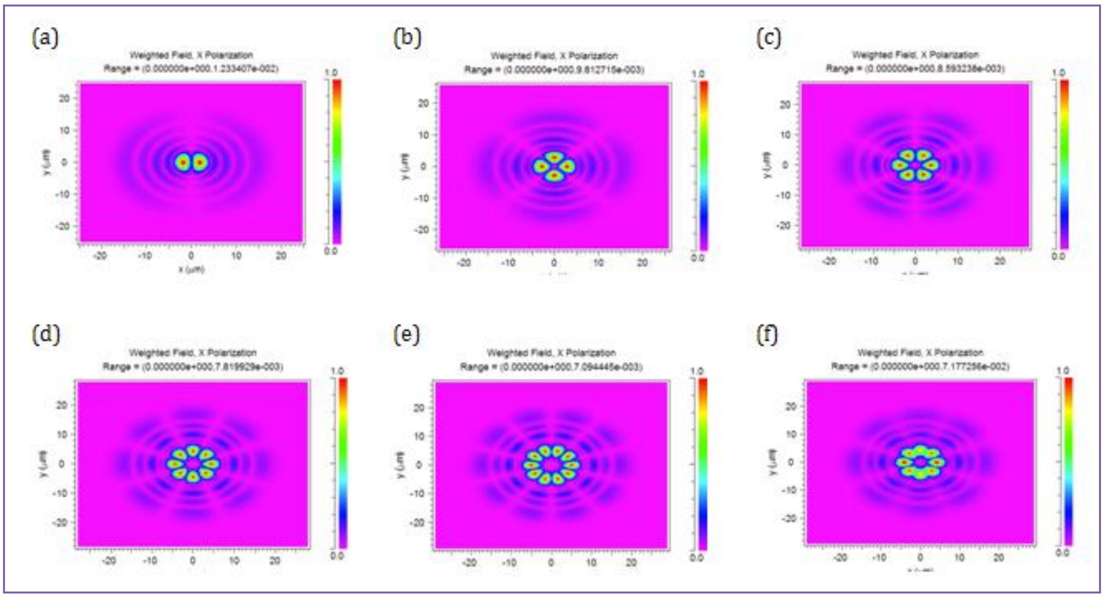


Figure. 4.8: (a) to (e). Total incident spatial electric field for each DWDM VCSEL. (f) Total spatial electric field of (a) to (e) after the multiplexer, incident on the MMF input.

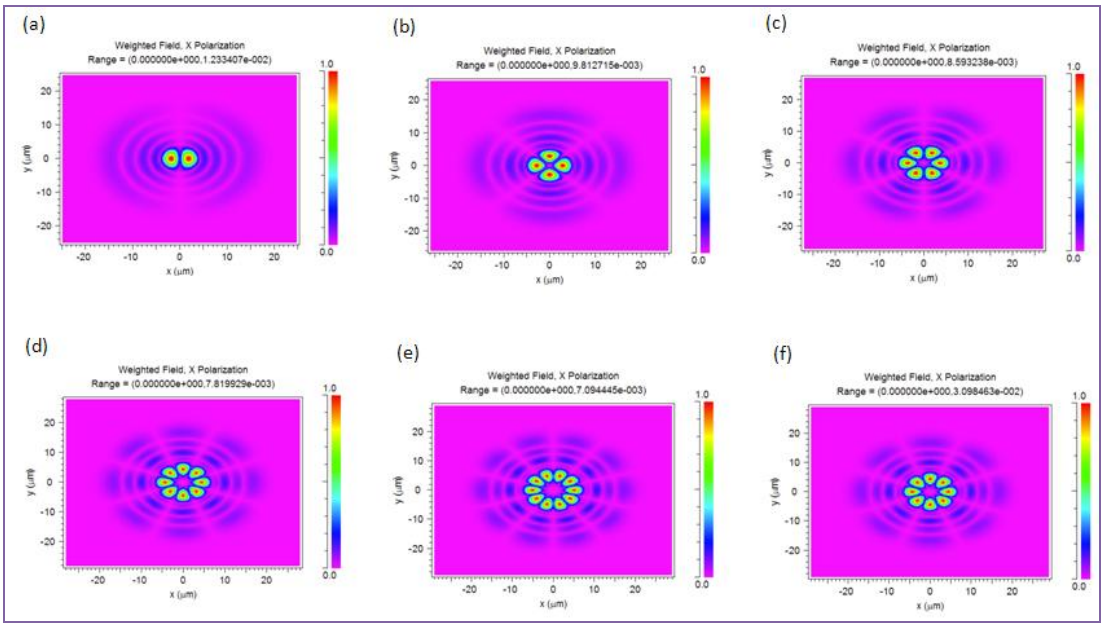


Figure. 4.9: (a) to (e). Total incident spatial electric field for each CWDM VCSEL. (f) Total spatial electric field of (a) to (e) after the multiplexer, incident on the MMF input.

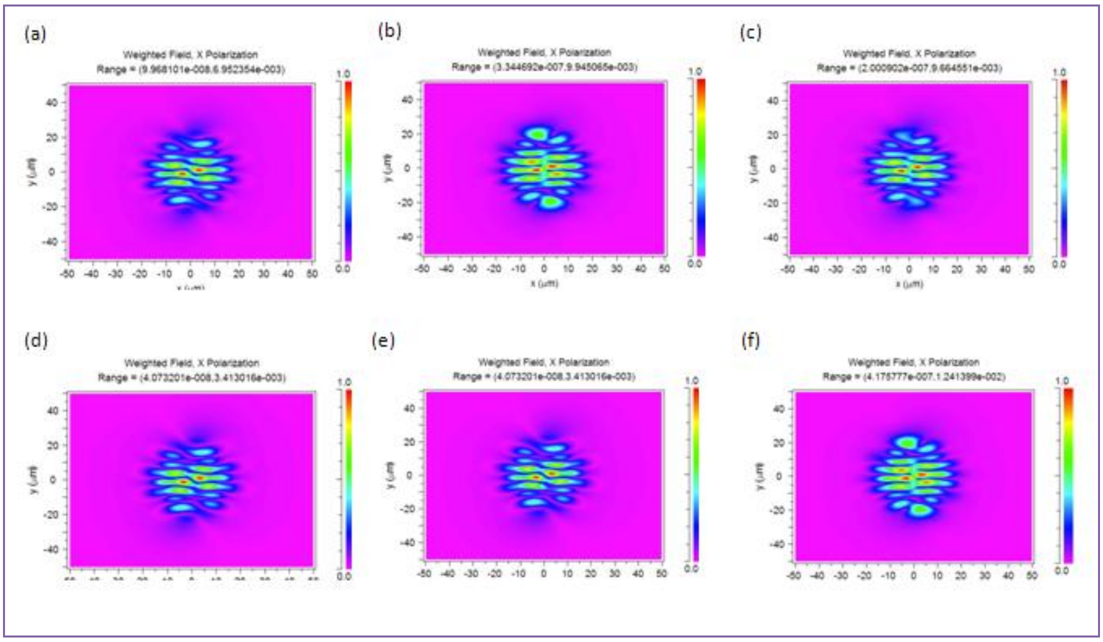


Figure.4.10: (a) to (e). Total spatial electric field for each DWDM channel after the de multiplexer. (f) Total spatial electric field of (a) to (e) after the de-multiplexer.

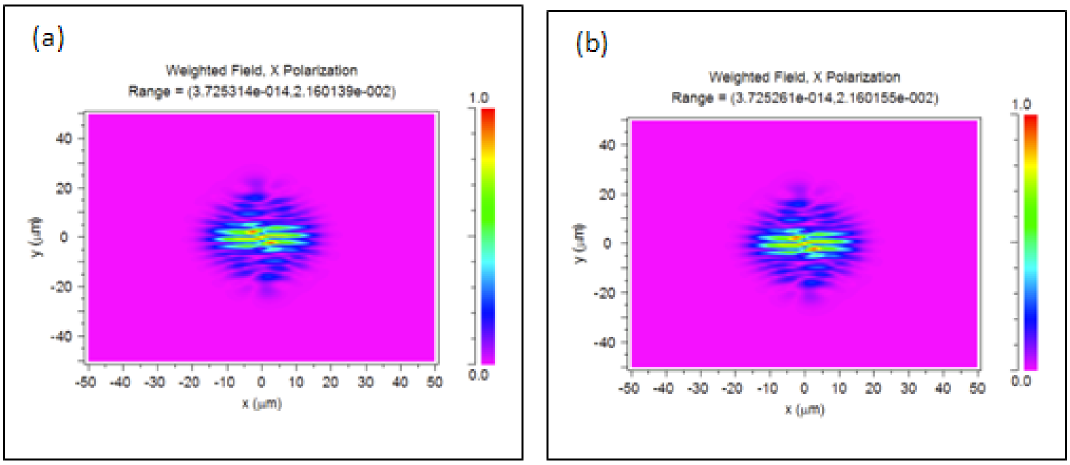


Figure. 4.11 :(a) to (e). Total spatial electric field for each CWDM channel after the de multiplexer. (f) Total spatial electric field of (a) to (e) after the de-multiplexer.

Table 4.2: (a) BER for all channels in DWDM system. (b) BER for all channels in CWDM system

(a)

Channel	BER
1553.33e-9	1.1352e-012
1551.72e-9	9.8385e-012
1550.12e-9	1.7875e-012
1548.52e-9	9.3521e-011
1546.92e-9	1.0977e-012

(b)

Channel	BER
800e-9	1.0000e+000
820e-9	3.5619e-007
840-9	1.0000e+000
860e-9	2.1533e-007
880e-9	1.0000e+000

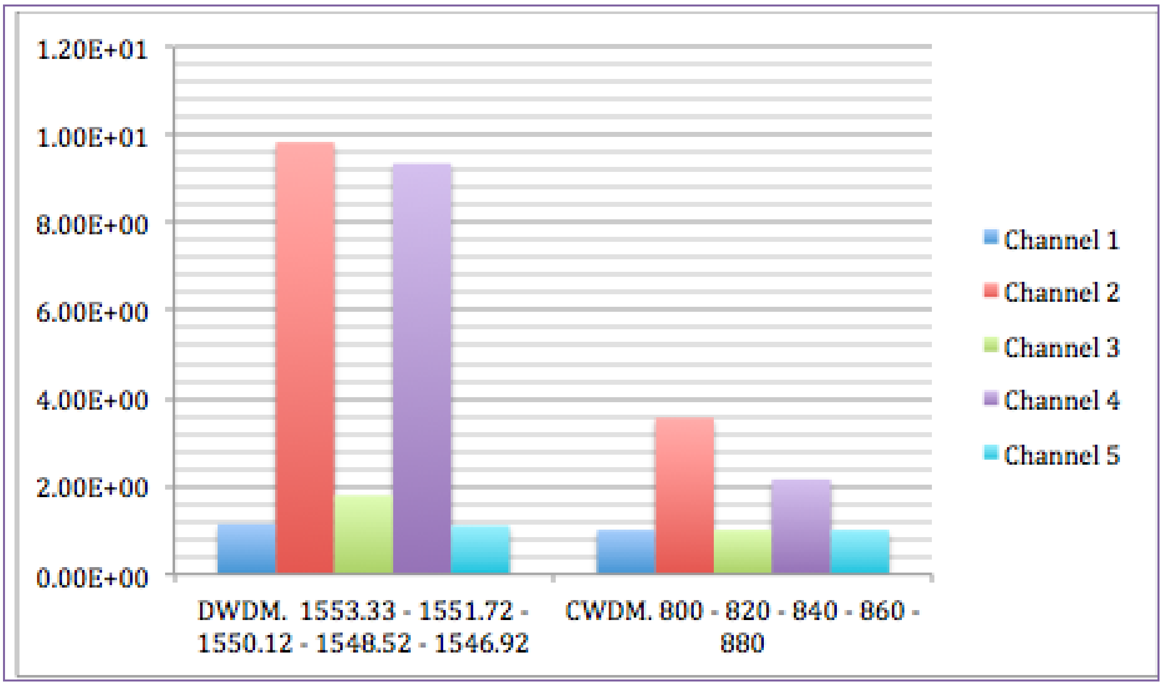


Figure. 4.12: Bar graph of comparison of BER for DWDM and CWDM channels

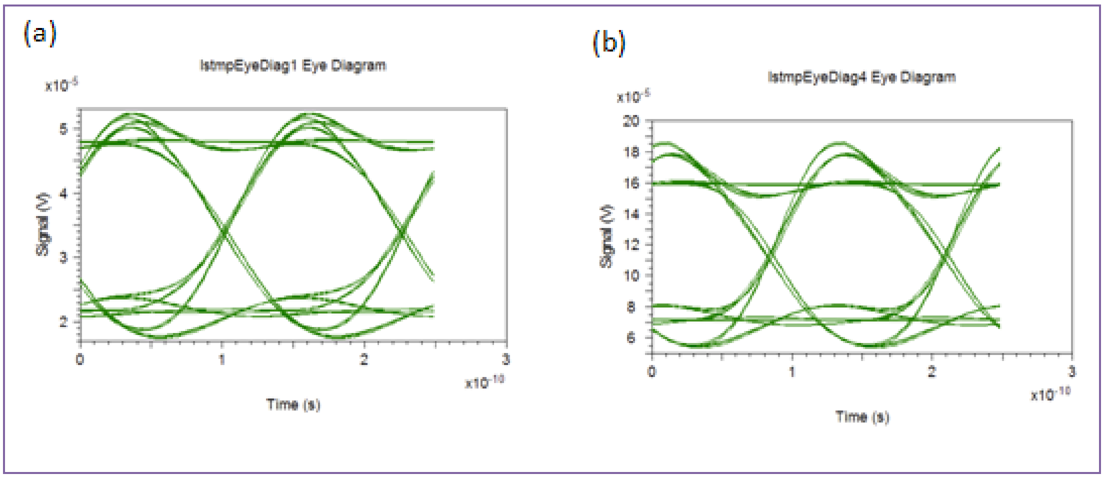


Figure 4.13: (a) DWDM BER Diagram and (b) CWDM BER Diagram

Fig. 4.12 (a) indicates the very acceptable eye shape with given references of BER e-011 and e-012 which means if the eye margins for given references BER closer to zero the perfect the eye which means the perfect decision can be made while Fig

4.12 (b) indicates the unacceptable eye shape for given references BER either 1 or e-07 which means the eye margin for given references is not closer to zero.

4.5 Summary

In this chapter, a 25-channel WDM-PON model has been designed at a center wavelength of 1550.12nm for DWDM and 840nm for CWDM in OptSim 5.2. A transmission speed of 5 x 8Gbps for both CWDM-PON and DWDM-PON has been achieved, using five VCSELs separated at 1.6nm DWDM and 20nm CWDM. Five Laguerre-Gaussian modes have been multiplexed on each VCSEL, providing a total of 25 channels on the DWDM-PON.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSIONS

Due to rapid advancement in online multimedia-rich applications, consumer demands have increased significantly over recent years Legacy networks using copper cables will not be able to accommodate Future bandwidth requirements. FTTH is regarded as a promising candidate to meet the rapidly increasing bandwidth demand from enterprises and households, offering many advantages including large capacity, channel independence, easy management, format transparency, network security and upgradability. This research was conducted to study the performance of CWDM-PON and DWDM-PON over FTTH.

CWDM-PON and DWDM-PON models over FTTH were simulated using OptSim version 5.2. A novel contribution is the incorporation of modal multiplexing in both the CWDM-PON and DWDM-PON models. The performance of CWDM-PON and DWDM-PON were compared by changing the wavelength spacing, the number of lasers used and the mode configuration. The performance of the CWDM-PON and DWDM-PON were evaluated in terms of the weighted spatial field for each channel, before and after multiplexing, in order to determine the amount of power modal coupling; the eye diagram and bit-error rate of each channel. Explain the results achieved (in terms of number of channels, total speed achieved for the different scenarios).

5.2 Limitations

There are some limitations so many limitation and challenges has been faced through out this project however here are the common and most challenging point.

- **Simulation Limitation**: The execution of this research depends on commercial simulation environment, which is not provided by School of Computing, College of Arts and Sciences. MatLab Simulation was the first proposed to execute this research, using a MatPlanWDM. However, major limitations such as setting the wavelength spacing and the transmission bit rate discourage future use of this software. OptiSystem was the second proposed simulation. The limitations discovered include the inconsistency in the result with gradual increase of the input, and also lack of support for different FTTH services. Hence the use of this software was discontinued.

5.3 Contribution

A novel contribution is the introduction of modal multiplexing in the CWDM-PON and DWDM-PON models.

5.4 Future work

An experimental testbed of the CWDM-PON and DWDM-PON could be implemented to determine feasibility issues. In addition, different bit rates and modulation schemes for the channels could be investigated.

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