Analysis of In-band Transmission of Baseband and Broadcast Signals for Next Generation WDM-PON

By

(Shamima Nasrin Rumi)

A thesis submitted as the requirements for the degree of Master of Engineering in Electronics and Communication Engineering (ECE)

Department of Electronics and Communication Engineering (ECE)
Khulna University of Engineering & Technology(KUET)
Khulna 9203, Bangladesh

December 2017

Declaration

This is to certify that the thesis work entitled "*Analysis of In-band Transmission of Baseband and Broadcast Signals for Next Generation WDM-PON*" has been carried out by Shamima Nasrin Rumi in the Department of Electronics and Communication Engineering (ECE), Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis or any part of this work has not been submitted anywhere for the award of any degree or diploma.

Shamima Nasrin 31.12.17

Signature of Candidate

Approval

This is to certify that the thesis work submitted by Shamima Nasrin Rumi entitled "*Analysis of In-band Transmission of Baseband and Broadcast Signals for Next Generation WDM-PON*" has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of Master of Engineering in the Department of Electronics and Communication Engineering (ECE), Khulna University of Engineering & Technology, Khulna, Bangladesh in December 2017

BOARD OF EXAMINERS

1. ______________________
Dr. Pallab Kumar Choudhury (Supervisor)
Professor,
Department of Electronics and communication Engineering
Khulna University of Engineering & Technology (KUET)

2. ______________________
Dr. Md. Faruque Hossain Member
Professor and Head,
Department of Electronics and communication Engineering
Khulna University of Engineering & Technology (KUET)

3. ______________________
Prof. Dr. Sk. Shariful Alam Member
Professor
Department of Electronics and communication Engineering
Khulna University of Engineering & Technology (KUET)

4. ______________________
Dr. Monir Hossen Member
Associate Professor,
Department of Electronics and communication Engineering
Khulna University of Engineering & Technology (KUET)

5. ______________________
Dr. Md. Saifuddin Faruk Member (External)
Professor
Department of Electrical and Electronic Engineering
Dhaka University of Engineering & Technology (DUET)

Acknowledgement

I would like to offer my foremost appreciation to my supervisor Prof. Dr. Pallab Kumar Choudhury for his support, encouragement and guidance through the course of this work. He introduced me to the world of optical access networks and integrated photonics. I am so fortunate to have such a great advisor who truly taught me how to identify and solve research problems. His knowledge, passion and excellent personality were inspiring, and his flexibility and accommodating approach paved my way for research.

I gratefully acknowledge Professor Dr. Md. Faruque Hossain for serving as head at department of ECE, KUET and giving valuable feedback during this thesis work.

Beyond the professional environment, I would like to thank my parents, firstly for trusting me and giving me the opportunity to continue my university studies, and, secondly, for being an example of strength to adversity. My warmest regards to my parents, for their understanding, support and love during all these times and to all the members of my family and friends, for so many good moments.

Abstract

This research was conducted to deal with the problem of finding cost-effective solutions for Fiber-to-the-Home (FTTH) network deployment. In the FTTH network, the transceiver at the user premises and the deployment of fiber at the last mile are the major barriers.

A novel approach is demonstrated for the ultimate solution to ensure large bandwidth, wavelength independency, easy upgradability and excellent network security. A single wavelength can be shared by both the baseband and broadcast data where the system utilizes the subcarrier multiplexing (SCM) signals for broadcasting service and finally combined with baseband data to modulate a single optical source. This approach simplifies the design of optical line terminal (OLT) and meets the future bandwidth demand.

In this project work, a wavelength reuse bidirectional WDM-PON is proposed for the transmission of both baseband and broadcast data in single wavelength. Broadcasting signals are generated in different radio frequencies (RF) to meet the diverse applications in both residential and commercial networks. Since the broadcast signals are placed in-band to the baseband data, the propose system does not require additional bandwidth dedicated for broadcast transmission. Moreover, the combined signal is received by a single photodiode and recovers the corresponding data without any wavelength specific optical or electrical filter. Beside this, wavelength reuse architecture ensure maximum utilization of available wavelengths and simplify the 'colorless' operation of upstream/downstream transmission.

Contents

LIST OF TABLES

LIST OF FIGURES

Nomenclatures

ASE	Amplified Spontaneous Emission	
AWG	Array Waveguide Grating	
BER	Bit Error Rate	
BLS	Broad-band Light Source	
CO	Central Office	
CW	Continuous Wave	
DBR	Distributed Bragg gratings	
DFB	Distributed Feedback Laser	
DSL	Digital Subscriber Line	
EAM	Electro-Absorptive modulator	
EDFA	Erbium-Doped Fiber Amplifier	
EIN	Excess Intensity Noise	
FP-LD	Fabry-Perot Laser Diode	
FSR	Free Spectral Range	

FTTB	Fiber-to-the-Building	
FTTC	Fiber-to-the-Curb	
FTTH	Fiber-to-the-Home	
FWHM	Full-Width Half-Maximum	
ITU	International Telecommunication Union	
LD	Laser Diode	
MAN	Metro Area Network	
NF	Noise Figure	
NRZ	Non Return to Zero	
ONU	Optical Network Unit	
OLT	Optical Line Terminal	
OSA	Optical Spectrum Analyzer	
PON	Passive Optical Network	
PRBS	Pseudo-Random Bit Sequence	
P2MP	Point to Multipoint	
P2P	Point to Point	
QW	Quantum Well	
RIN	Relative Intensity Noise	
RN	Remote Node	
RSOA	Reflective Semiconductor Optical Amplifier	
SMSR	Side-Mode Suppression Ratio	
SNR	Signal to Noise Ratio	
TDM	Time Division Multiplexing	
VOA	Variable Optical Attenuator	
VCSEL	Vertical Cavity Surface-Emitting Laser	
WDM	Wavelength Division Multiplexing	
WiFi	Wireless Fidelity	
WiMAX	Worldwide Interoperability for Microwave Access	

CHAPTER I

Introduction

1.1 Introduction

The access network, also known as the "first-mile network," connects the service provider central offices (COs) to business and residential subscribers. This network is also referred to in the literature as the subscriber access network, or the local loop. The bandwidth demand in the access network has been increasing rapidly over the past several years. Residential subscribers demand first-mile access solutions that have high bandwidth and offer media-rich services [1]. Similarly, corporate users demand broadband infrastructure through which they can connect their local-area networks to the Internet backbone as illustrated in Fig.1.1

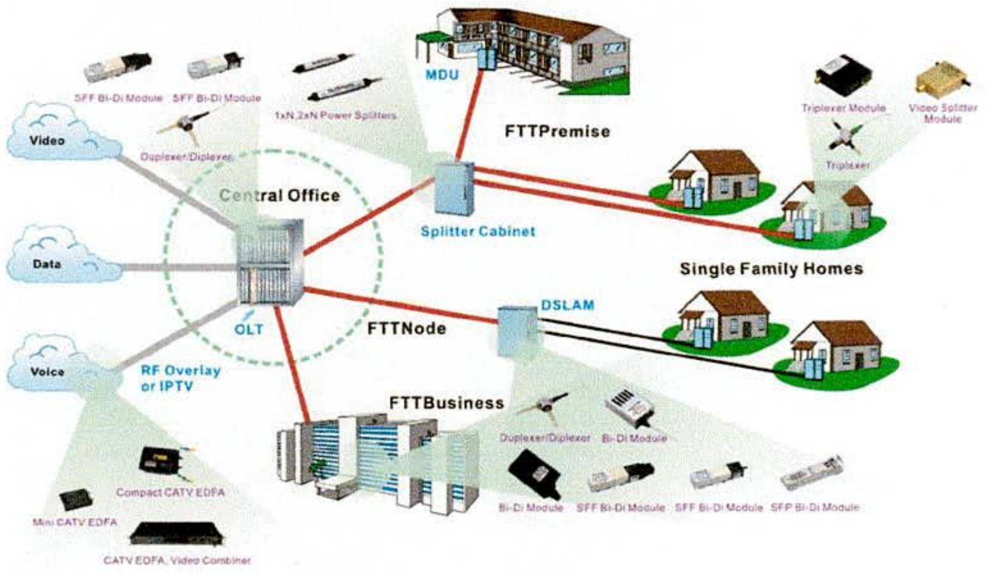


Figure 1.1: The access network

The predominant broadband access solutions deployed today are the digital subscriber line (DSL) and community antenna television (CATV) (cable TV) based networks. However, both of these technologies have limitations because they are based on infrastructure that was originally built for carrying voice and analog TV signals, respectively; but their retorted versions to carry data are not optimal.

For future broadband access, wavelength division multiplexing passive optical network (WDM-PON) is regarded as the ultimate solution that ensure large bandwidth, wavelength independency, easy upgradability and excellent network security To meet the growing bandwidth demand from diverse services such as IPTV, video-on-demand and multimedia broadcast, a converge WDM-PON with both unicast/baseband and broadcast/multicast data has been attracted much attention in recent years

1.2 Motivation

In recent years, the passive optical network (PON) is considered to be an ultimate solution in access technology to meet ever increasing bandwidth demand especially for high speed broadband services [2] and the wavelength division multiplexed passive optical networks (WDM-PONs) are considered as a promising candidate to provide broadband access for the next generation networks, since WDM-PONs have a number of excellent features including wide bandwidth, large split ratio, extended transmission reach, aggregated traffic backhauling and simplified network architecture. However, at present the WDM-PONs is not regarded as a cost-effective solution, as the cost of the wavelength selective optical components and frequency-stable transmitters is still very high. So reducing the cost of WDM-PON [3] will be the key challenge for their deployment. To make the WDM-PON system more cost effective and easily manageable, the optical network unit (ONU) should have the capability to reuse the downstream signals by re-modulating it with the upstream data. To ensure future bandwidth demand use of single wavelength for both baseband and broadcast services can be most effective for in-band transmission. Hence, in this paper, a wavelength reuse bidirectional WDM-PON is proposed for the in-band simultaneous transmission of both baseband and broadcast data in single wavelength.

1.3 Thesis Objectives

The major objectives of this research work are as follows:

a) Development of simulation model for wavelength reused bi-directional WDM-PON.

b) Propose new architecture for WDM-PON with in-band transmission of Baseband and Broadcast data.

c) Measurement of different performance metrics that have the significant influence on practical deployment of such Hybrid in-band WDM-PON system.

d) Compare the advantages and complexity of propose method to the existing wavelength re-used WDM-PON system.

1.4 Thesis Outline

In chapter I, the basic background information is described followed by motivation and thesis objectives.

Chapter II focuses necessary theoretical information towards our architecture. These include optical access networks and methods to deploy FTTH in user premises. The advantages of PON, WDM-PON and their scope in future research field. It also includes Hybrid network, in-band signal transmission process and their advantages for optical fiber transmission.

In chapter III, Encoding process of 8b10b line coding is analyzed with necessary spectrum.It includes advantages and disadvantages of different modulation formats to design cost sensitive ONU to reach high data rates with fewer components.

Chapter IV demonstrates the simulation environment that carried out optical system design simulation tool VPITransmissionMaker-9.7®. System setup schematics are illustrated with necessary parameters.

In chapter V, in-band Transmission of Baseband and Broadcast Signals are analyzed for next Generation WDM-PON. Broadcasting signals are generated in different RF to meet the diverse applications in both residential and commercial networks. Since the broadcast signals are placed in-band to the baseband data, the propose system does not require additional bandwidth dedicated for broadcast transmission. The system performance is measured in terms of BER and EVM for baseband signals and RF signals respectively.

Finally chapter VI includes the summary of the thesis and also proposes some topics for further work.

REFERENCES

[1]. Amitabha Banerjee, Youngil Park "Wavelength-division-multiplexed passive optical network(WDM-PON)technologies for broadband access"Vol. 4, No. 11 / JOURNAL OF OPTICAL NETWORKING

[2]. K. Grobe, and J. P. Elbers, "PON in adolescence: from TDMA to WDM-PON," IEEE Commun. Mag. vol.46, no. 1, pp.26-34, 2008.

[3]. E. Wong, "Next-generation broadband access networks and technologies," *J. Lightw.Technol.*, vol. 30, no. 4, pp. 597-608, 2012.

CHAPTER II

Optical Access Networks

2.1 Access Networks: An Overview

An access network is the network between Central Office (CO) and end users and is traditionally called last-mile networks. They are also called first-mile networks in recent years as they are the first segment of the broader network seen by users of telecom services [1] .The "last mile" is the most expensive part of the network because there are far more end users than backbone nodes [2]. Example of access networks are i) twisted copper pairs connecting to each individual household ii) residential coaxial cable drops from CATV service providers. Wi-Max is another type of access technology which uses radio waves for last-mile connectivity. Traditionally, optical fibers have been widely used in backbone networks because of their huge available bandwidth and very low loss. However, until the beginning of this century, fiber has not been used as the technology of last-mile connection.

The most widely deployed "broadband" solutions today are Digital Subscriber Line (DSL) and Cable Modem networks. Although broadband copper-based access networks provide much higher data rate than 56 Kbps dial-up lines, they are unable to provide enough bandwidth for the tremendous growth of Internet traffic, emerging services such as Video-On-Demand, High Definition Television and interactive gaming, or two-way video conferencing. These Copper-based access technologies are close to their bandwidth limit, and provide only few Mb/s per user over a short distance. These technologies generate a bottleneck at the gateway of the backbone to the access networks, shown schematically in Fig. 2.1. In this place there is often a lot of traffic causing to slow down or stop.

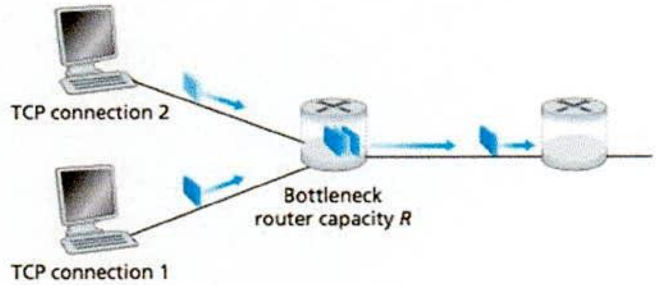


Figure 2.1: Multiple Connections share a common bottleneck to the access networks

Access network contrasted with the core network, (for example the Network Switching Subsystem in GSM) which connects local providers to each other. The access network may be further divided between feeder plant or distribution network, and drop plant or edge network. When the architecture of access network is based on wireless or wired (optical fiber) optical link is called optical access network and also shown below in Fig. 2.2

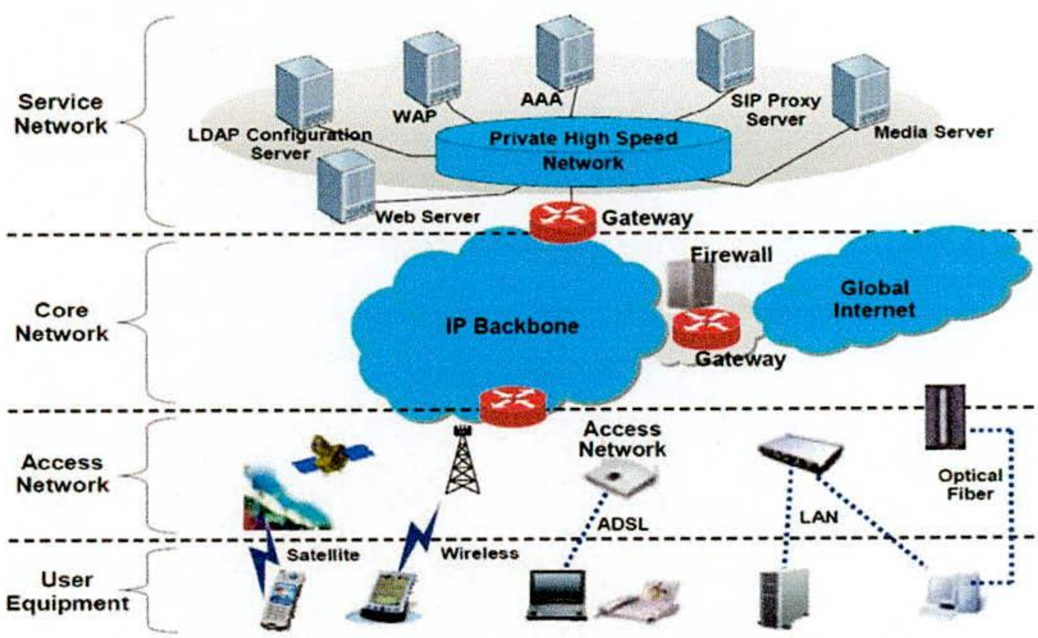


Figure 2.2: A typical optical networking architecture

We can identify three ellipses representing the core network, the edge network, and the access network. The long-haul core network interconnects big cities, major communications hubs, and even different continents by means of submarine transmission systems. The core networks are often called the wide area networks (WANs) or interchange carrier networks. The edge optical networks are deployed within smaller geographical areas and are commonly recognized as metropolitan area networks (MANs) or local exchange carrier networks. The access networks represent peripheral part of optical network and provide the last-mile access or the bandwidth distribution to the individual end-users. The common access networks are local area networks (LANs) and distribution networks. The common physical network topologies are mesh network (often present in core networks), ring network (in edge networks), and star networks (commonly used in access networks).

2.2 FTTx Architectures

An enhancement of the PON supports an additional downstream wavelength, which may be used to carry video and CATV services separately. Many telecom operators are considering to deploy PONs using a fiber-to-the-x (FTTx) model (where x = building (B), curb (C), home (H), premises (P), etc.) to support converged Internet protocol (IP) video, voice, and data services—defined as "triple play"—at a cheaper subscription cost than the cumulative of the above services deployed separately. PONs is in the initial stages of deployment in many parts of the world. In an FTTC system, fiber is connected to the curb of a community where the optical signal is converted into the electrical domain and distributed to end users through twisted pairs. Therefore, an FTTC system can also be regarded as a hybrid fiber twisted pair system. FTTx which brings high-capacity optical fiber networks closer to the end users appears to be the best candidate for the next-generation access network. FTTx is considered an ideal solution for access networks because of the inherent advantages of optical fiber in terms of low cost, huge capacity, small size and weight, and its immunity to electromagnetic interference and crosstalk.

Fiber to the home (FTTH) is the delivery of a communications signal over optical fiber from the operator's switching equipment all the way to a home or business, thereby replacing existing copper infrastructure such as telephone wires and coaxial cable. FTTH is a relatively new and fast growing method of providing vastly higher bandwidth to consumers and businesses, and thereby enabling more robust video, internet and voice services.There are two important types of systems that make FTTH broadband connections possible. The straightforward way perhaps the most expensive one, is with active point-to-point (P2P) Ethernet technologies. Active optical networks rely on some sort of electrically powered equipment to distribute the signal, such as a switch, router, or multiplexer. Such networks are identical to the Ethernet computer networks used in businesses and academic institutions, except that their purpose is to connect homes and buildings to a central office (CO) rather than to connect computers and printers within a campus.

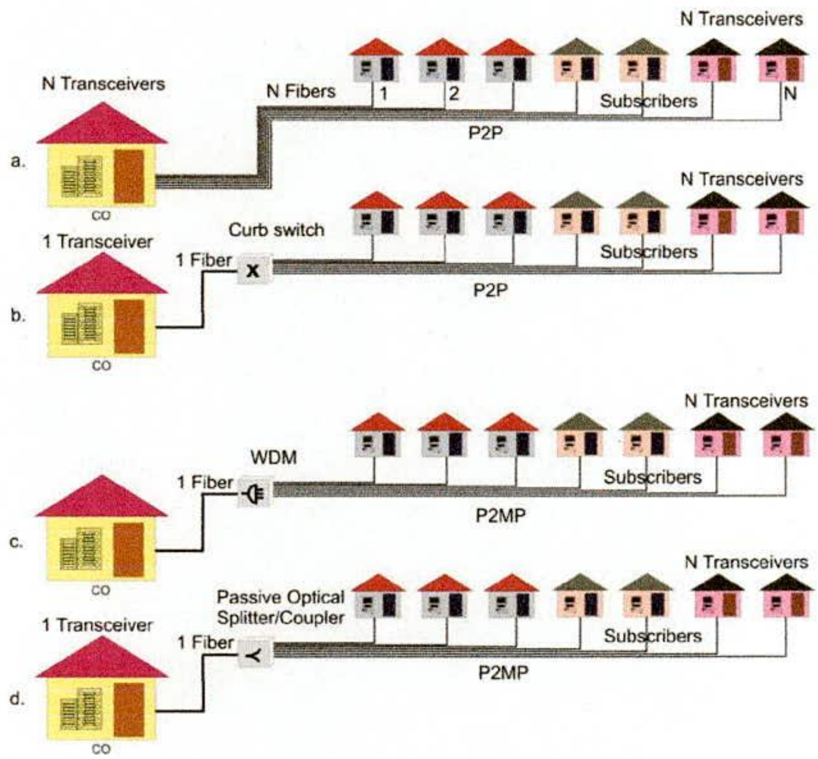


Figure 2.3: Different architectures for fiber-to-the-Home (FTTH)

Fig. 2.3 (a) depicts direct P2P architecture which is simple but expensive due to its extensive fiber deployments. The second architecture in Fig. 2.3 (b) uses a curb switch which reduces the deployed fiber but the curb switch is an active component that requires electrical power as well backup power.

The network topology of the last two architectures Fig. 2.3 (c), (d) are normally referred as passive optical network, where only passive optical devices are used, namely fibers and splitters/couplers or combiners or wavelength multiplexer/de-multiplexer.

2.3 Passive Optical Network (PON)

Passive optical networks are an ultimate broadband access solution for future Internet they bring many advantages such as cost-effectiveness, energy savings, service transparency and signal security over other last/first-mile technologies [3]. A typical design of PON is shown in Fig.2.4

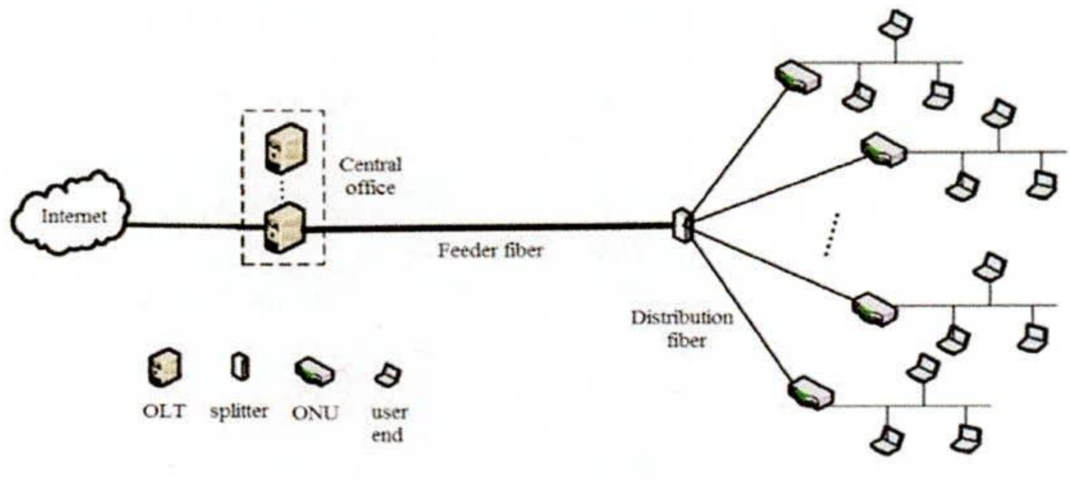


Figure 2.4: PON architecture

Commonly PON has a tree topology. The OLT is located at the service provider's central office. The ONU is located near end users. The optical distribution network refers to the collection of fibers and passive optical splitters or couplers that lies between the optical line terminal and the various optical network terminals and optical network units connects them in the Central Office (CO) sequentially. The capacity of the feeder fiber is shared between all optical network units by means of time division multiplexing technology. Each optical network unit has the capacity according to the bandwidth distribution scheme [4]. Fig.2.4. PON architecture The key interface points of passive optical networks are in the Central office equipment called the OLT for optical line terminal and the CPE, called ONU for optical network unit (for EPON) and ONT for optical network terminal (for GPON). The main difference between optical line terminal and optical network terminal devices is their purpose regardless of their classification. Optical line terminal devices manage maximum up to 128 downstream links and support management functions. Generally, In the Central Office only 8–32 ports to be linked to a single optical line terminal. Therefore the optical network unit devices are much less costly while the optical line terminals tend to be more capable and thus more expensive.

2.3.1 PON Standards

The currently deployed PON systems include ATM PON, Broadband PON, Ethernet PON, Gigabit PON, 10G EPON, and Next-generation PON to provision different data rate. The initial PON specifications are ATM PON is defined by the FSAN committee. APON uses ATM as their signaling protocol in layer 2. In APON downstream transmission is a continuous ATM stream at a bit rate of 155.52Mb/s or 622.08 Mb/s. upstream transmissions are in the form of bursts of ATM cells. Broadband PON as defined in ITU-T G.983 series is a further improvement of the APON system [5]. With the purpose of achieving early and cost effective operation of broadband optical access systems, BPON offers many broadband services including video distribution, ATM and Ethernet access. Ethernet passive optical network is a point to multipoint network topology implemented with passive optical splitters along with many advantages such as fine scalability, simplicity and the ability of providing full service access. Different types of PON and their standards are shown in the given table 2.1

Table2.1. ComparisonBPON, EPON & GPON

	BPON	EPON	GPON
Standard	ITU G.983	IEEE 802.3ah	ITU G.984
Downstream Speeds	622/1244Mbps	1244Mbps	1244 or 2488Mbps
Upstream Speeds	155Mbps or 622Mbps	1244Mbps	155 to 2488Mbps
Downstream Wavelength	1480-1500 nm	1500 nm	1480-1500 nm
Upstream Wavelength	1260-1360 nm	1310 nm	1260-1360 nm
Protocol	ATM	Ethernet	Ethernet and ATM
Voice Support	TDM over ATM	TDM over packet	Ethernet over ATM /IP or native TDM
Video Support	RF overlay (over 1550nm) or IP video	IP video	RF overlay (over 1550nm) or IP video
Number of Splits	32	16	64
Distance	>20 Km	<20km	<60km

2.3.2 TDM-PON

TDM passive optical networks like Gigabit Passive Optical Network and Ethernet Passive Optical Network are now widely accepted as optical access network solutions to distribute reasonably high bandwidth to the customers through an optical fiber network infrastructure [6]. Fig.2.5 shows TDM-PON architecture where Fig.2.5(a) shows downstream link (Broadcasting) and Fig.2.5(b) showsUpstream link (TDM Traffic) for both link a single wavelength channel shared by all the users attached to a time division multiplexing passive optical network, the average dedicated bandwidth assigned to each

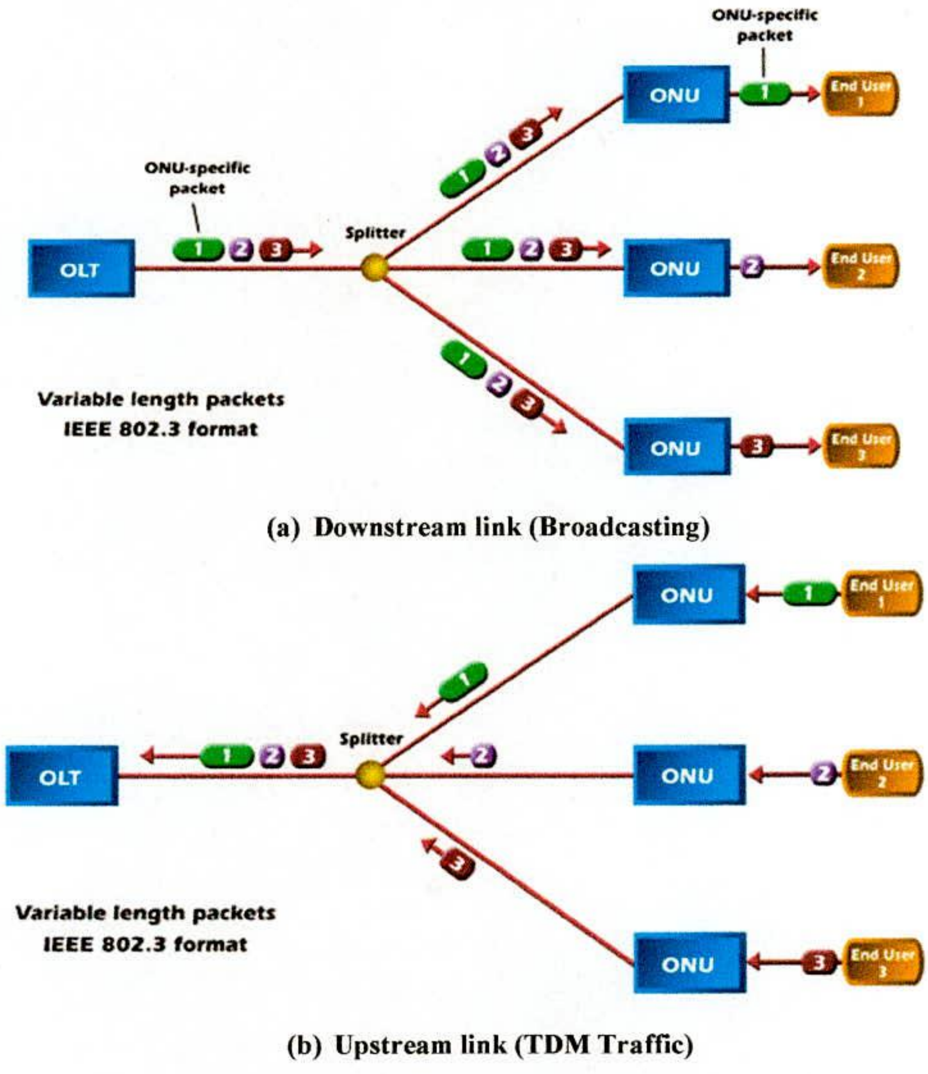


Figure 2.5: TDM-PON architecture

user in either direction is usually limited to a few percent of the channel capacity i.e., a few tens of Mbps [7]. Due to lower maintenance costs and more reliable operation network operators tend to support the TDM-PON scheme. However, the bandwidth provided by one wavelength is shared by the whole optical network units in the network because the time division multiplexing passive optical network architecture provides only limited scope for improving the bandwidth performance. As compare to TDM, in WDM-PON architecture all the optical network units can transmit data independently since each optical network unit is assigned its own dedicated wavelength [8].

However TDM-PONs has some drawbacks which hinder their future-proof application.
These shortcomings can be outlined as follows:

- Security issues due to broadcasting nature of downstream traffic.
- Bandwidth sharing of upstream traffic which diminishes the maximum bandwidth offered by a single wavelength.
- Short coverage reach due to the power split losses associated with the optical splitter.
- Complicated bandwidth allocation protocols.
- Requirement for ranging protocols and timely synchronization between nodes

2.3.3 WDM-PON

Wavelength division multiplexing is the ultimate solution for fast, efficient and secure bandwidth allocation in passive optical networks, and the subject of research proposals for next generation broadband access. WDM-PON was first proposed in WDM-PON systems can eliminate the complicated time-sharing issues in TDM-PON systems by providing virtual point-to-point (P2P) optical connectivity to multiple end users through a dedicated pair of wavelengths. In addition to the advantages of high scalability and flexibility, longer transmission distance can be achieved because of the efficient use of optical power at the remote node. The architecture of a WDM-PON system is shown in Fig.2.6. The big difference in the outside fiber plant is replacing the optical-power splitter in a TDM-PON with an array waveguide Grating (AWG) to de-multiplex the downstream wavelengths and multiplex the upstream wavelengths. In the downstream direction of a WDM-PON, the wavelength channels are transmitted from the OLT to the ONUs on a single fiber using an array of tunable lasers located at the OLT. The wavelength channels are then de-multiplexed by an arrayed waveguide grating (AWG) router located at the passive RN, and a unique wavelength is assigned to each ONU port.

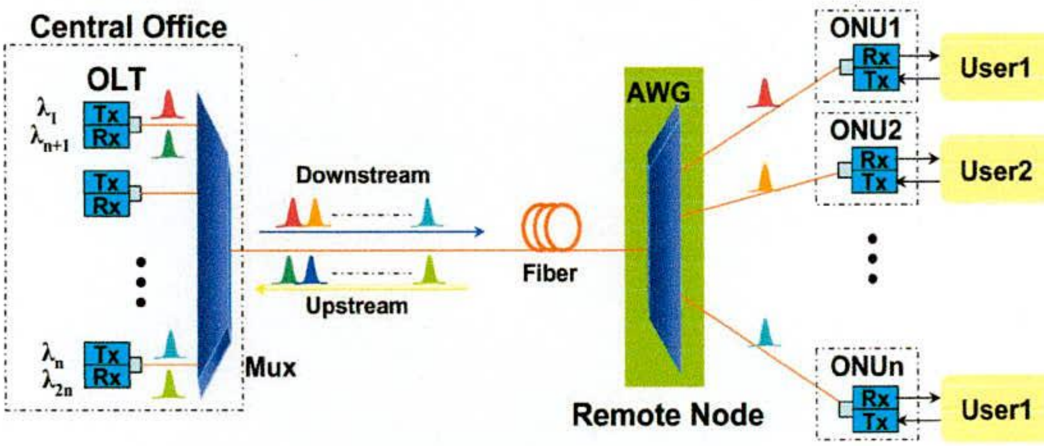


Figure 2.6: WDM-PON architecture.

The AWG ports are periodic in nature, where multiple spectral orders of input wavelength channels are routed to the same output port. This cyclic feature of the AWG allows for downstream and upstream transmission to occur in different wavelength windows. Within each wavelength window, the wavelengths are separated with wavelength spacing's determined by AWG ports. The Wavelength spacing's and wavelength bands are further discussed in the next section.

Cost is the final factor to limit the commercial deployment of WDM-PON systems. To reduce the cost, many research have been conducted on colorless ONUs based on centralized light sources using amplified spontaneous emission (ASE)-injected Fabry-Perot laser diodes (FPLDs), ASE-seeded reflective semiconductor optical amplifiers (RSOAs), and spectrum sliced RSOAs.[9] [10]. Other efforts have been carried out on the reduction of Rayleigh noise or re-modulation noise for longer transmission distance, protection and restoration scheme, architecture design, and wavelength management.

2.4 WDM wavelength allocation

It is very important to allocate upstream and downstream wavelength channels with maintaining standards. The downstream and upstream wavelengths allocated to each ONU are intentionally spaced at a multiple of the free spectral range (FSR) of the AWG, allowing both wavelengths to be directed in and out of the same AWG port that is connected to the destination ONU. WDM allocates operational wavelengths to users in a systematic manner. The wavelength spacing for WDM networks can be categorized as either Coarse WDM (CWDM) with around 20 nm spacing or dense WDM (DWDM) with less than 1 nm. The spectral grid for CWDM is defined in ITU G.694.2, with a wavelength spacing of 20 nm If the full wavelength band from 1270-1610 nm is used, it can house 18 individual wavelength channels seen in Fig. 2.7. CWDM networks have less stringent operational requirements for temperature-controlled environments due to larger spectral range. However, using a conventional single-mode optical fiber for these systems limits the number of available channels due to the presence of water peak attenuation in the 1370-1410 nm range.

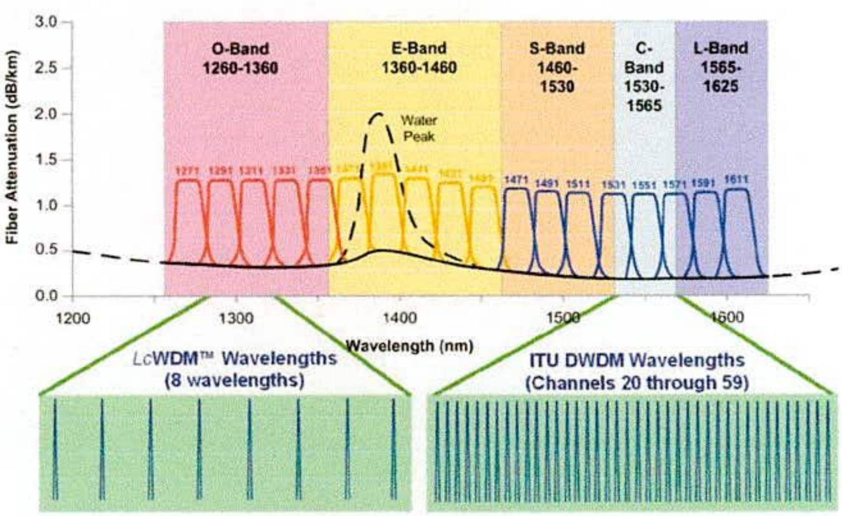


Figure 2.7: CWDM and DWDM wavelength grids based on ITU standards

The wavelength spacing in a CWDM for all wavelength bands is shown in Fig. 2.7. In DWDM, on the other hand, the wavelength spacing can be as narrow as 0.2 nm (25 GHz). Because DWDM can allocate many wavelength channels within a narrow range, it is considered the ultimate solution for WDM-PON. The devices used for DWDM applications need to be controlled for cross talk between adjacent channels and also temperature controlled. Therefore, the DWDM scheme introduces more cost than CWDM. The multiplexing devices must also support the requirements for dense channel spacing with low channel cross-talk. The standardized wavelength spacing for 0.8 nm (100 GHz) channel spacing is shown in Fig. 2.7

2.5 Bidirectional Transmission in PONs

WDM allows bidirectional communication over a single fiber since it is a method of combining multiple laser wavelengths for transmission along a fiber media. This method also increases signal capacity. Bidirectional single-wavelength single-fiber transmission (BSFSW)is the most interesting scheme for application in the access network domain, mainly because of its cost-efficiency in terms of capital expenditure per customer (CAPEX). The share of cost per subscriber for the needed infrastructure and scalability in terms of both number of users and bit rate are fundamental constraints for the development of novel designs.

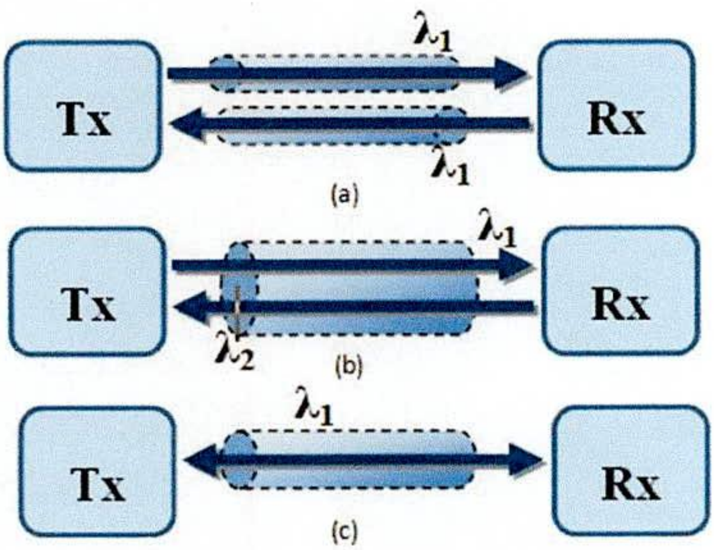


Figure 2.8: Bidirectional options for PON

One of the major barriers of FTTH technologies is the deployment of new fiber infrastructure. The size of the outside plant is then a critical constraint when deploying the access network. The number of kilometers of fiber required and the number of optical fusions needed to connect the ONUs to the OLT depends not only on the network topology but also on the number of fibers used for the transmission. In Fig.2.8 there are represented the basic options for bidirectional transmission. To deploy compact architecture in both directions, it is necessary to deal with general aspects of bidirectional transmission.

A plain option is the two-fiber solution, consisting in one fiber for each direction, Fig.2.8 (a). Even if this is not a cost-effective design, most of the actual commercial technologies for PONs are based on this architecture. The main reason is that optical components employed are less restrictive and inexpensive laser or even LED sources can be employed achieving correct transmission results. Single fiber transmission presents a more efficient solution because only half of the amount of fibers is necessary; as well, the cost for connectors, splices and other network components decrease. Transmission over a single fiber can be implemented using two strategies. The simplest is to transmit down-and uplink data using different wavelength Fig.2.8 (b). Thus, the signals do not interfere with each other, as they are carried in separated frequencies. This option requires sources of different wavelength as well as and optical filters to divide up- and down-link channels. The second alternative consists in using the same wavelength in both directions; Fig.2.8 (c).The last strategy presents a clear advantage for WDM networks, as wavelengths for both directions are now available especially for Coarse WDM (CWDM) networks where the number of wavelength is limited.

2.6 WDM PON architectures

Fig. 2.9 illustrates a typical WDM PON architecture comprising a CO, two cyclic AWGs, a trunk or feeder fiber, a series of distributions fibers, and optical network units (ONUs) at the subscriber premises. The first cyclic AWG located at the CO multiplexes downstream wavelengths to the ONUs and de-multiplexes upstream wavelengths from the ONUs.

The trunk fiber carries the multiplexed downstream wavelengths to a second cyclic AWG located at a remote node. The second AWG de-multiplexes the downstream wavelengths and directs each into a distribution fiber for transmission to the ONUs The downstream and upstream wavelengths allocated to each ONU are intentionally spaced at a multiple of the free spectral range (FSR) of the AWG, allowing both wavelengths to be directed in and out of the same AWG port that is connected to the destination ONU. In Fig. 2.10, the downstream wavelengths destined for ONU 1, ONU 2..., and ONU N, are denoted by λ_1, λ_2 and λ_N respectively.

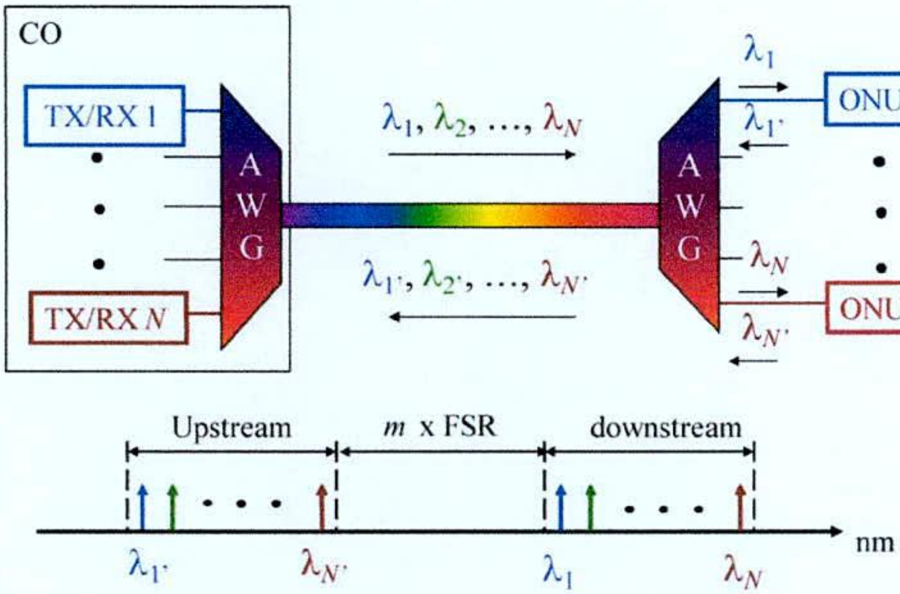


Figure 2.9: Architecture of a WDM-PON. Inset: Allocation of upstream and downstream wavelength channels into two separate wavebands.

Likewise, upstream wavelengths from ONU 1, ONU 2..., and ONU N, that are destined for the CO are denoted$\lambda_{1'}$,$\lambda_{2'}$,........ and$\lambda_{N'}$ respectively. In a typical WDM PON, wavelength channels are spaced 100 GHz (0.8 nm) apart. In systems classified as dense WDM-PON (DWDM), a channel spacing of 50 GHz or less is deployed. Although a WDM PON has a physical P2MP topology, logical P2P connections are facilitated between the CO and each ONU. In the example shown in Fig. 2.9, ONU N receives downstream signals on λ_N and transmits upstream signals on $\lambda_{N'}$. The capacity on these wavelengths is solely dedicated to that ONU. Commonly cited benefits of WDM PON resulting from this unique feature include protocol and bit-rate transparency, security and privacy, and ease of upgradeability and network management.

2.6.1 Tunable laser WDM PON

Fast tunable lasers are widely deployed in WDM-PON. Tunable lasers can also be considered for generating an upstream signal at the ONU. The concept is shown in Fig.2.10. A dedicated tunable laser along with an external modulator is deployed at every ONU node. The laser spectral width is narrower than AWG spacing. Such deployment offers great optical performance and flexibility in terms of wavelength. The number of ONUs supported will be determined by the channel spacing of the AWGs, and the tuning range of the laser. The problem with this scheme is the high cost of a much more sophisticated laser at the source, need for maintenance, and an internal wavelength locker to ensure the laser operates at the correct wavelength channel. It has the benefits of long transmission distances & high bandwidth and Easy scaling of bandwidth, end users & reach.

Since each ONU is assigned a unique upstream wavelength, distinct wavelength transmitters must be deployed at the subscriber premises. The simplest solution is to utilize fixed wavelength transmitters. Long transmission distances and high speed transmission can be achieved with this solution.

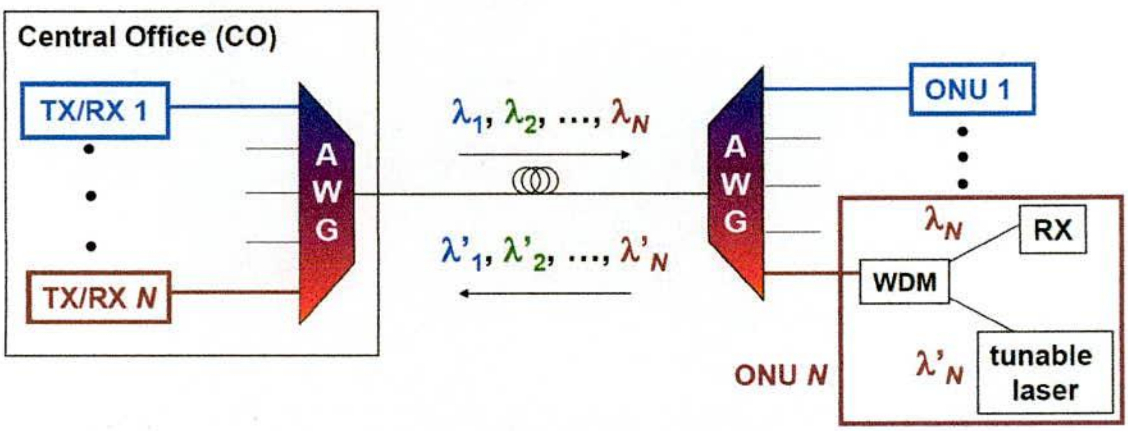


Figure 2.10: Tunable Laser WDM-PON

However, such a network deployment would be cost prohibitive with increased complexity in network operation, administration, and management. Alternatively, identical tunable lasers can be utilized in all ONUs with each laser tuned to the pre-assigned transmission wavelength

[11][12].Potential candidate technologies include tunable distributed feedback (DFB) laser[12]and tunable vertical cavity surface emitting lasers (VCSELs)[13]. The use of tunable lasers avoids the need for centralized light source(s) as compared to other solutions, and subsequently the Rayleigh backscattering penalty from using these CW source(s). However, true colorless feature necessitates prior knowledge of which wavelength each laser has to be tuned to. Also some form of wavelength control must be implemented to ensure that crosstalk is minimized between the wavelength channels during operation and that the wavelength alignment between the AWGs and lasers is maintained. Reducing the cost of tunable DFBs and VCSELs are challenges that are currently being addressed. An additional constraint on tunable lasers for use in a dynamic WDM PON is the tuning speed [14, 15].

2.6.2 Wavelength reuses WDM PON

In wavelength reuse schemes such as those proposed in [16] and [17], the optical source is eliminated altogether in the ONU. Downstream wavelength channels are re-modulated with upstream data, and then sent upstream towards the CO. Fig. 2.11 depicts a WDM PON that uses the wavelength reuse scheme. Aside from carrying downstream signals, the downstream wavelength is used to wavelength seed an RSOA located at the designated ONU. Each RSOA is intentionally operated in the gain saturation region such that the amplitude squeezing effect can be used to erase the downstream modulation on the seeding wavelength [18].

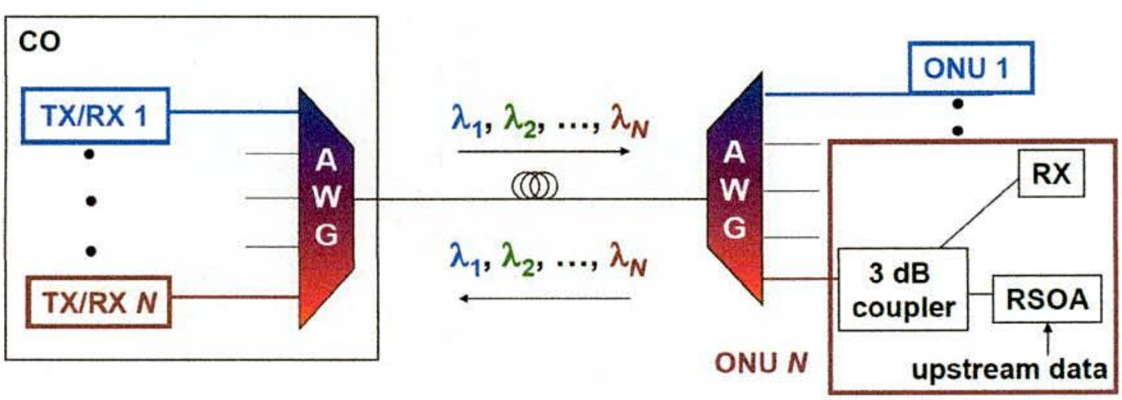


Figure 2.11: Wavelength Reuse WDM-PON

As illustrated in Fig. 2.11, the downstream and upstream wavelengths designated to and from an ONU are identical. The benefits of the wavelength reuse scheme includes the re-modulation ofthe downstream wavelength channel, thereby eliminating the need for seeding sources, is less costly than using tunable lasers, and direct modulation of the RSOA.

However, upstream performance can be severely degraded by the interference between the residual downstream and upstream data at the CO. A solution to minimize residual downstream modulation is to ensure that the upstream and downstream modulation formats are orthogonal. In [19], phase modulation and frequency shift keying modulation are used for the downstream modulation with upstream being modulated with the on-off keying (OOK) format. In another solution reported in [20], data is RF subcarrier modulated onto a carrier and sent downstream towards the ONU. At the ONU, the carrier is filtered and then modulated with upstream data. Therefore, to minimize residual downstream signal, unconventional modulation formats and thereby unconventional transceivers must be used. Recently, line coding approaches such as Manchester coding [21] and DC balanced line coding [22] have been demonstrated to eliminate the DC component on the downstream data to improve upstream performance in a WDM PON.

2.6.3 Coherent injection and seeding WDM PON

In addressing the potential large inventory and cost of wavelength specific sources, researchers have been concentrating on developing cost-efficient and wavelength independent sources termed "colorless" sources. Optical light originating from the CO is fedinto the ONUs to injection- lock Fabry–Perot laser diodes (FP LDs) [23]–[24] or to wavelength-seed reflective semiconductor optical amplifiers (RSOAs) [25]–[28].

As illustrated in Fig. 2.12, the injection- locking or wavelength seeding light may be furnished by CW light from a centralized light source located at the CO. The wavelength seeding scheme is identical to the injection-locking scheme except for the use of an RSOA which amplifies and modulates the incoming continuous wave (CW) light.

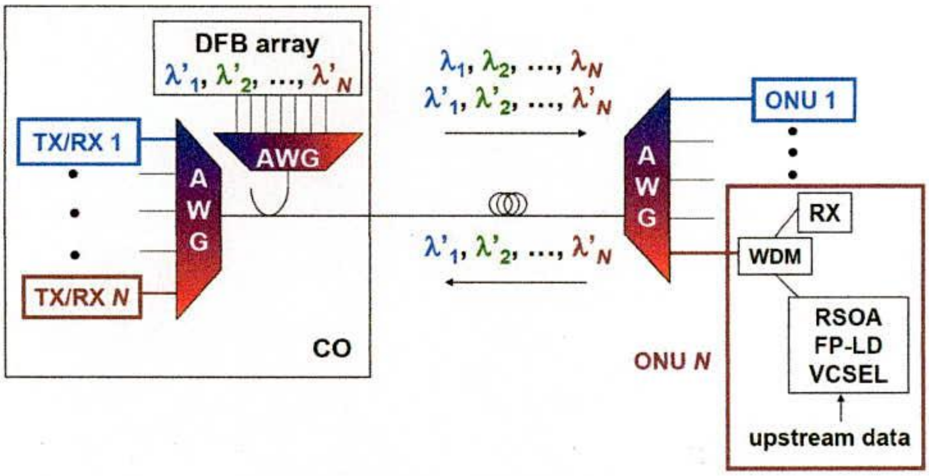


Figure 2.12: Coherent-injection and CW-seeding WDM-PON

As the transmitting wavelength of a colorless ONU is determined externally by the wavelength of the incoming light, all ONUs may be implemented with identical FP-LDs or RSOAs. Fig 2.12 uses DFB laser array that is placed in CO where ONU N receives downstream signals on and transmits upstream signals on .transmits from CO towards ONU N and an reflective modulator use it to modulate the upstream data and sent back to CO.

2.7 HybridTransmission

Hybrid is defined as combination of basebandand RF (broadcast) signal transmission. Hybrid WDM- PON is defined as a PON in which separate wavelength for broadcast services or bysharing a single wavelength for both baseband and broadcast data traffic to establish communication between the OLT and number of ONUs.

2.7.1 Separate wavelengthHybrid WDM- PON

To increase the utility of WDM-PON, it needs to supply diverse services such as video-on-demand and multimedia broadcasting using a minimum number of wavelengths.The Hybrid WDM-PON architecture is shown in Fig.2.13. A CO consists of a distributed feedback laser diode(DFB-LD) array which offers the wavelength from λ_1 to λ_N for downlink. Baseband signals are carrier by wavelength i$\lambda_1$and broadcast (RF) signals are carrier by another wavelength λ_2.

Then the optical signal is transmitted from the CO to the ONUsthrough an AWG at the remote node (RN).

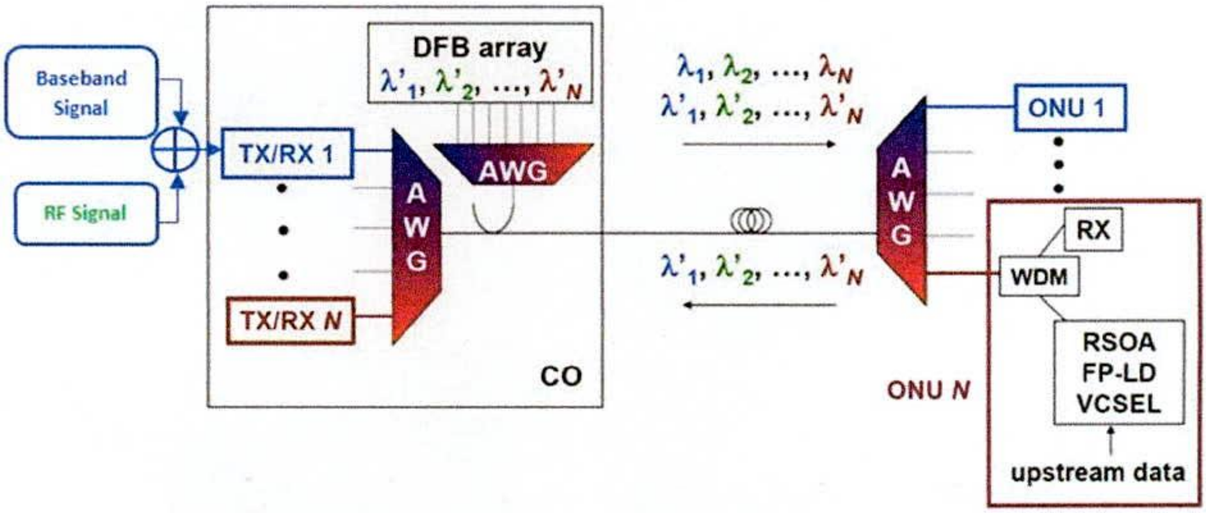


Figure 2.13: Separate wavelength Hybrid WDM- PON

At the ONU side, signal received by colorless ONU is determined externally by the wavelength of the incoming light, all ONUs may be implemented with identical FP-LDs or RSOAs. Fig 2.13 uses DFB laser array that is placed in CO where ONU N receives downstream signals on and transmits upstream signals on .transmits from CO towards ONU N and an reflective modulator use it to modulate the upstream data and sent back to CO.

For each wavelength window, the wavelengths are separated with wavelength spacing's determined by AWG ports but the transmission cost is high. To reduce the cost of separated wavelength we need to build up a architecture by using single wavelength for different service.

2.7.2 Single wavelength Hybrid WDM- PON

For simultaneous transmission of the baseband signal and subcarrier multiplexing (SCM) signals for broadcasting service using a single source.Fig.2.14 shows the schematic diagram of the WDM-PON link. Basic link structure of the WDM-PON scheme is the same as the link structure where RSOA in ONU re-modulates the downstream source as an upstream signal. In CO, the baseband digital signal for downstream data service and the SCM signal for broadcasting service are simultaneously modulated using a single distributed feedback (DFB) LD. A portionof the downstream source containing the broadcasting signal is detected by PD in ONU and electrical filters separate the digital and SCM signals.

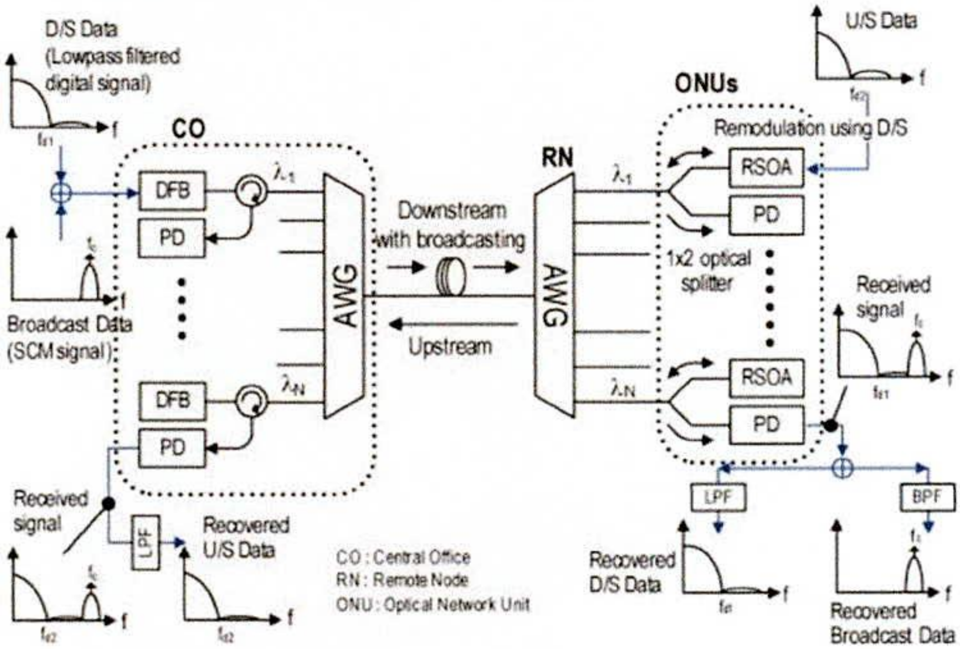


Figure 2.14: Schematic diagram of single wavelength WDM-PON link [29].

The residue of the downstream source becomes injected in RSOA as a seeding source and re-modulated by RSOA with the digital signal for upstream. For an effective re-modulation using an RSOA, an extinction ratio (ER) of the downstream signal should be small enough to be suppressed by a high-pass characteristic of RSOA. Fortunately, since the reduction of ER is required to minimize the signal distortion in simultaneous modulation of the digital and SCM signals using a single LD, generate downstream containing the broadcasting signal suitable for re-modulation of RSOA. The unsuppressed SCM signal in the re-modulation process could be removed by a simple electrical low-pass filtering in CO. Since each transmitter in CO can offer the different broadcasting service, the proposed WDM-PON scheme can provide adaptive broadcasting service satisfying the diverse demands of customers.

The ER of the digital signal in downstream is a key factor to determining the performance of all signals in up/downstream.This cost-effective, colorless WDM-PON overcomes the wavelengthselectivity feature by using RSOAs as optical modulators at both the OLT and the ONUs. Also, the SCM-based broadcasting service can be stably offered without performance deterioration of the digital signals both in upstream and downstream.

2.8 In-Band Simultaneous Transmission

Different approaches have been proposed, where a single wavelength can be shared by both the baseband and broadcast data where the system utilizes the subcarrier multiplexing (SCM) signals for broadcasting service and finally combined with baseband data to modulate a single optical source. Here we want to study about an approach where a wavelength reuse RSOA based bidirectional WDM-PON is proposed for the transmission of both baseband and broadcast data in single wavelength and our thesis work is an extended work of this approach [30].

The proposed wavelength reuse bi-directional RSOA based WDM-PON with in-band transmission of both unicast/baseband and broadcast data is shown in Fig.2.15 (a)

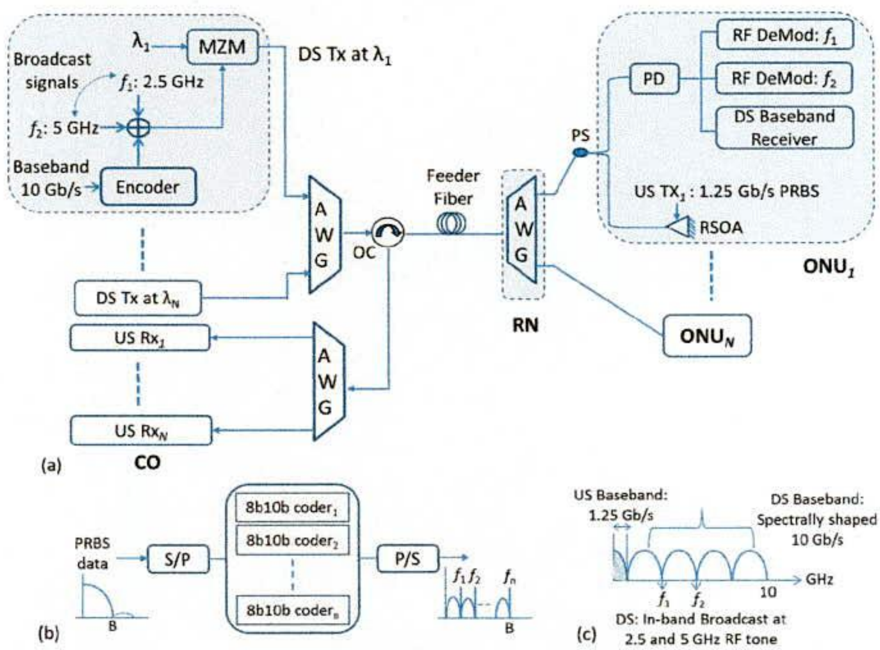


Figure 2.15: a) Proposed architecture of broadcast overlay wavelength reused WDM-PON. b) Encoder for spectrally shaped 8b10b coded signal. c) Bi-directional transmission with spectral separation of downstream and upstream signals.

Fig.2.15 (b) shows the architecture of encoder where incoming PRBS serial data stream is parallelized in *n* blocks, each of which individually encoded to 8b10b data and finally, transmitted again as a serial stream. Fig.1(c) shows the proposed approach of bi-directional transmission with minimized re-modulation noise in 10 Gb/s 8b10b coded spectrally shaped downstream for carrying RF data overlay on baseband signal and 1.25 Gb/s PRBS upstream. Due to the effective suppression of frequency components from DC to 1.25 GHz in 8b10b coded signal, the upstream data with 1.25 Gb/s PRBS can be transmitted over the downstream modulated signal by spectral separation.

Finally, the re-modulated wavelength with 1.25 Gb/s US data is transmitted over the same feeder fiber and received by the PD in CO through an optical circulator. Therefore, the proposed WDM-PON with spectrally shaped downstream baseband signal is not only carrying the in-band broadcast signals but also reduces the re-modulation noise for the transmission of upstream signal with the same wavelength.

REFERENCES

[1]. Cedric F. Lam, Passive Optical Networks Principles and Practice, Ch. 1, pp. 1-17, 2007

[2]. James F. Mollenauer, "Functional Requirements for Broadband Wireless Access Network"', IEEE 802 Broadband Wireless, Access Study Group, March 5, 1999.

[3]. Brigitte Jaumard, RejaulChowdhury, "An efficient optimization Scheme for WDM/TDM PON network planning" Computer Commnications 2013.

[4]. H. Song, B-W. Kim, and B. Mukherjee, "Multi-thread polling:a dynamic bandwidth distribution scheme in long-reach PON", IEEE Journal on Selected Areas in Communications 27, pp.134–142, 2009.

[5]. Cedric Lam, "Passive Optical Network Principles and Practice" Academic press, 2011.

[6]. Goutam Das, Bart Lannoo, Abhishek Dixit, Didier Colle, et.al, "Flexible hybrid WDM/TDM PON architectures using wavelength selective switches" Optical Switching and Networking 9, pp.156–169, 2012

[7]. H. Erkan,G. Ellinas , A. Hadjiantonis , R. Dorsinville , M. Ali, "Dynamic and fair resource allocation in a distributed ring-based WDM-PON architectures"Computer Communications 2012.

[8]. Chuan-Ching Sue, Chia-NungWang,"A novel AWG-based WDM- PON architecture with full protection capability" Optical Fiber Technology 15, pp.149–160, 2009

[9]. R. Sananes, C. Bock, J.Prat, "Techno -Economic Comparison of Optical Access Networks",Proc. ICTON"05, Th.A1.8, Barcelona (Spain), July 2005

[10].K.Iwatsuki, J.Kani, H. Suyuki, M. Fujiwara, "Access and Metro Networks Based on WDM technologies", IEEE J. Lightwave Technol., vol.22, no.11, pp.2623- 2630, November 2004

[11]. G. Jeong, J. H. Lee, M. Y. Park, C. Y. Kim, S.-H.Cho, W. Lee, and B. W. Kim,"Over 26-nm wavelength tunable external cavity laser based on polymer waveguide platforms for WDM access networks," IEEE Photon. Technol. Lett. , vol. 18, no. 20, pp. 2102–2104, Oct. 2006.

[12]. H.Suzuki, M.Fujiwara, T.Suzuki,N. Yoshimoto,H. Kimura, and M.Tsubokawa, "Wavelength-tunable DWDM-SFP transceiver with a signal monitoring interface and its application to coexistence-type colorless WDM-PON," in Proc. Eur. Conf. Opt. Commun.,Sep.2007, paper PD3.4.

[13]. C. Chang-Hasnain, "Optically-injection locked tunable multimode VCSEL for WDM passive optical networks," in Proc. Int. Nano-Op-toelectron. Workshop (i-NOW) , 2008,pp. 98–99.

[14]. Y.-L. Hsueh, M. S. Rogge, S. Yamamoto, and L. G. Kazovsky, "A highly flexible and ef fi cient passive optical network employing dy-namic wavelength allocation," Journal of Lightwave Technology (Volume: 23, Issue: 1, Jan. 2005)

[15]. J.-I. Kani, "Enabling technologies for future scalable and fl ex-ible WDM-PON and WDM/TDM-PON systems," IEEE J. Sel. Topics Quantum Electron., vol. 16, no. 5, pp. 1290–1297, Sep.–Oct. 2010

[16]. N. Deng, C. K. Chan, L. K. Chen, and F. Tong, "Data remodulation on downstream OFSK signal for upstream transmission in WDM passive optical network," DOI: 10.1049/el:20031092, Volume 39, Issue 24, 27 November 2003, p. 1741 – 1743

[17]. L. Xu and H. K. Tsang, "Colorless WDM-PON optical network unit (ONU) based on integrated nonreciprocal optical phase modulator and optical loop mirror," IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 20, NO. 10, MAY 15, 2008

[18]. Y. Katagiri, K. Suzuki, and K. Aida, "Intensity stabilization of spectrum-sliced Gaussian radiation bas ed on amplitude squeezing using semiconductor optical amplifiers with gain saturation, "Electron. Lett.,vol. 35, no. 16, pp. 1362–1364, 1999.

[19]. I. Garces et al., "Analysis of narrow-FSK downstream modulation in colorless WDM PONs," Electron. Lett , vol. 43, pp. 471–472, 2007.

[20]. M. Attygalle, N. Nadarajah, and A. Nirmalathas, "Wavelength reused upstream transmission scheme for WDM passive optical networks," Electron. Lett., vol. 41, no.18, pp. 1025–1027, 2005.

[21]. S. Y. Kim, S. B. Jun, Y. Takushima, E. S. Son, and Y. C. Chung, "Enhanced performance of RSOA based WDM PON by using Manchester coding," J. Opt. Netw.,vol. 6, pp. 624–430, 2007.

[22]. Z. Al-Qazwini and H. Kim, "Line coding for downlink DML modula-tion in lambda-shared, RSOA-based asymmetric bidirectional WDM PONs," in Proc. Opt. Fiber

[23]. H. D. Kim, S.-G. Kang, and C.-H. Lee, "A low-cost WDM source with an ASE injected Fabry–Perot semiconductor laser," IEEE. Photon. Technol. Lett. , vol. 12, no. 8, pp. 1067–1069, Aug. 2000.

[24]. D.J.Shin, D.K.Jung, J.K.Lee, J.H.Lee, Y.H.Choi, Y. C.Bang, H.S.Shin, J.Lee, S.T.Hwang, and Y.J. Oh,"155 Mbit/s transmission using ASE-injection Fabry–Perot laser diode in WDM-PON over 70 C temperature range,"Electron. Lett., vol. 39, pp. 1331–1332, 2003.

[25].D.J.Shin, Y.C.Keh, J.W.Kwon, E.H.Lee, J.K.Lee, M.K.Park, J.W.Park, K.Y.Oh, S.W.Kim, I.K.Yun, H.C.Shin, D.Heo, J. S.Lee, H.S.Shin, H.S.Kim, S.B.Park, D.K.Jung, S.Hwang, Y. J. Oh, D. H. Jang, and C. S. Shim, "Low-cost WDM-PON with color- less bidirectional transceivers," J. Lightw. Technol. , vol. 24, no. 1, pp. 158–165, Jan. 2006.

[26]. M. D. Feuer, J. M. Wiesenfeld, J. S. Perino, C. A. Burrus, G. Raybon, S. C. Shunk, and N. K. Dutta, "Single-port laser-amplifier modulators for local access," IEEE Photonics Technology (Volume: 8, Issue: 9, Sept. 1996)

[27]. P. Healey, P. Townsend, C. Ford, L. Johnston, P. Townley, I. Lealman, L.Rivers, S.Perrin,and R.Moore, "Spectral slicing WDM-PON using wavelength-seeded reflective SOAs," Electron. Lett.,vol.37, pp. 1181–1182, 2001.

[28]. F. Payoux, P. Chanclou, M. Moignard, and R. Brenot, "Gigabit op- tical access using WDM PON based on spectrum slicing and reflective SOA," in Proc. Eur. Conf. Opt.Commun , Sep. 2005, vol. 3, pp. 455–456.

[29] T. Y. Kim, and S. K. Han, "Reflective SOA-based bidirectional WDM-PON sharing optical source for up/downlink data and broadcasting transmission," IEEE Photon. Technol. Lett., vol. 18, no. 22, pp.2350-2352, 2006.

[30] Pallab K. Choudhury "In-Band Simultaneous Transmission of Baseband and Broadcast Signals in Wavelength Reused Bidirectional Passive Optical Network" Optics Communications 355(2015)296-300.

CHAPTER III

8b10b Line Coding and QAM

3.1 Introduction

In order to transfer data over a high-speed serial interface, data is encoded prior to transmission and decoded upon reception. The encoding process insures that sufficient clock information is present in the serial data stream to allow the receiver to synchronize to the embedded clock information and successfully recover the data at the required error rate. The 8b/10b encoding improves the line characteristics, enabling long transmission distances and more effective error-detection. Another topic which is discussed in this chapter is Quadrature Amplitude Modulation or QAM. It is a form of modulation which is widely used for modulating data signals onto a carrier used for radio communications. It is widely used because it offers advantages over other forms of data modulation

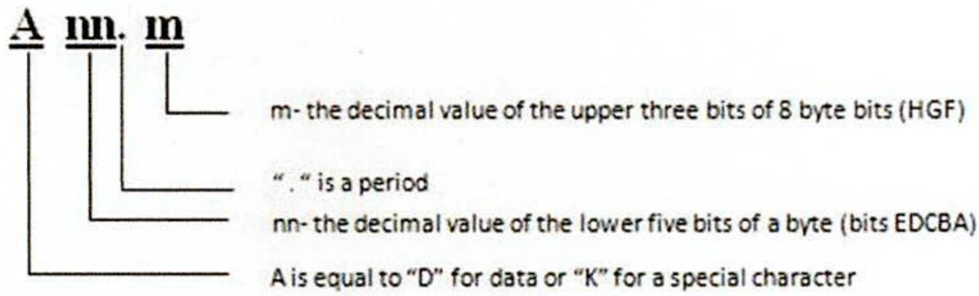
3.2 8B/10B Line Coding

8b10b Line Coding algorithm for encoding data for transmission in which each eight-bit data byte is converted to a 10-bit transmission character. Invented and patented by IBM Corporation. 8b/10b encoding is used in transmitting data on Fiber Channel, ESCON, and Gigabit Ethernet. 8b/10b encoding supports continuous transmission with a balanced number of ones and zeros in the code stream and detects single bit transmission errors.

3.2.1 Encoding Process

The 8b/10b encoding process also provides a number of 10-bit characters conforming to the coding rules which are not required for representing data characters (there are more available code points in the 10-bit space than the corresponding 8-bit data space). These 10-bit characters are available for use as special characters to identify control or management functions. The maximum run length is 5 and the maximum digital sum variation is 6. A single error in the encoded bits can, at most, generate an error burst of length 5 in the decoded domain [1].

It is helpful to recognize the notation structure because you might see it in an error messages. The notation structure is:



The 8b/10b encoder converts 8-bit code groups into 10-bit codes. The code groups include 256 data characters named **D**x.y and 12 control characters named **K**x.y.

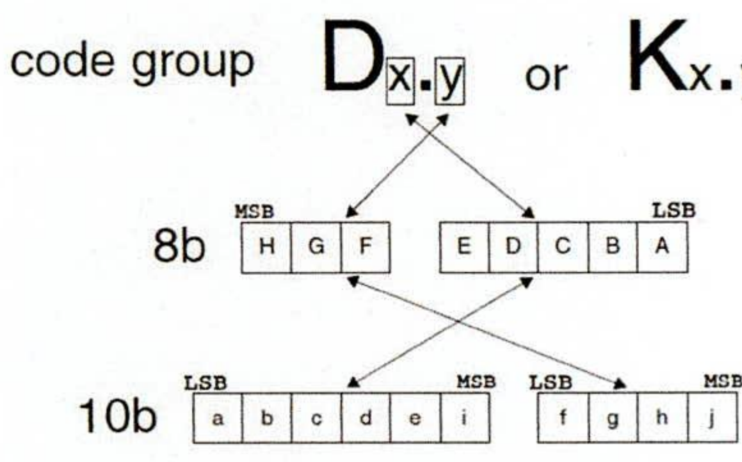


Figure 3.1: Conversion of 8-bit code groups into 10-bit codes

The coding scheme breaks the original 8-bit data into two blocks, 3 most significant bits (y) and 5 least significant bits (x). From the most significant bit to the least significant bit, they are named as H, G, F and E, D, C, B, A. The 3- bit block is encoded into 4 bits named j, h, g, f. The 5-bit block is encoded into 6 bits named i, e, d, c, b, a. As seen in Fig.3.1, the 4-bit and 6-bit blocks are then combined into a 10-bit encoded value.

Using the 8b/10b encoding algorithm adds 25% overhead to each character. Said another way, 20% of the channel is reserved for 8b/10b encoding overhead. This is not the only overhead; however it is the most significant factor.

3.2.2 Signal Spectrum

Transmission code translates each source byte into a constrained 10-bit binary sequence which has excellent performance parameters near the theoretical limits for 8B/10B codes. 8B10B provides a low DC content, as shown in Fig.3.2 [2], maximum run length of 5 and a maximum digital sum variation of 6. In addition, the hardware complexity of the encoder and the decoder are low, less than that of a Forward Error Correction (FEC) code or an electronic equalizer. This is obtained with an implementation based on two smaller and simpler sub-codes (a 5B6B and a 3B4B) that can be easily integrated in a 10 Gbit/s transceiver.

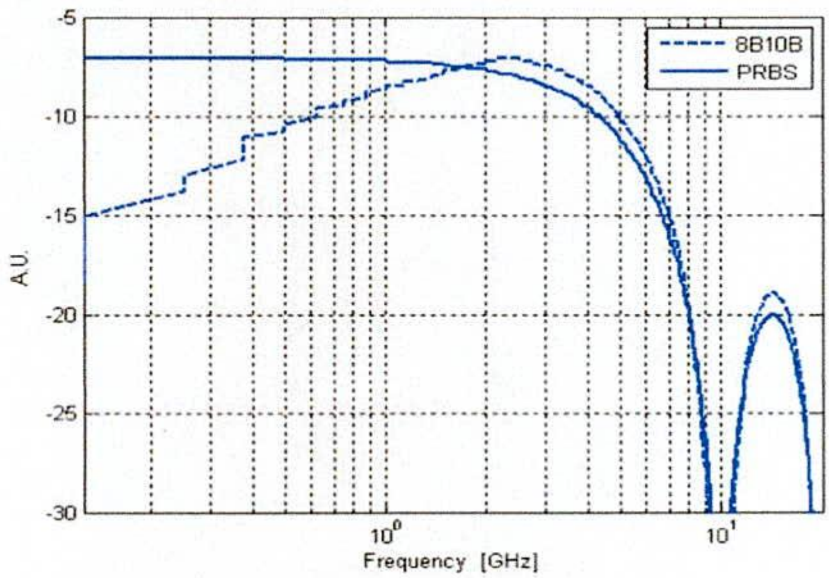


Figure 3.2: Spectra of an uncoded PRBS (solid line) and of a 8B10B coded PRBS (dashed line): the 8B10B coded sequence shows reduced levels at low frequencies.

3.2.3Advantage of 8b10b coding

- 8b/10b encoding enables long transmission distances and more effective error-detection (than traditional parity).
- 8b/10b encoding scheme allows for special control characters.
- 8b/10b encoding is used by many high performance protocols, including: ESCON, FICON, Fiber Channel, Gigabit Ethernet optical links and SSA.

3.2.4 Disadvantage of 8b10b coding

- 8b/10b encoding incurs an overhead of 25% for each character or 20% of overall bandwidth.

3.3 Modulation Techniques

In general telecommunications, modulation is a process of conveying message signal, for example, a digital bit stream or an analog audio signal, inside another signal that can be physically transmitted. Modulation of a sine waveform transforms a narrow frequency range baseband message signal into a moderate to high frequency range pass band signal, one that can pass through a filter.

In electronics and telecommunications, modulation is the process of varying one or more properties of a periodic waveform, called the carrier signal, with a modulating signal that typically contains information to be transmitted. Most radio systems in the 20th century used frequency modulation (FM) or amplitude modulation (AM) to make the carrier carry the radio broadcast. In optical access networks, different modulation formats may be selectively employed depending on the network size and the system settings. To improve the transmission performance of WDM systems, a wide variety of techniques have been proposed.

3.3.1 Analog modulation

In analog modulation, the modulation is applied continuously in response to the analog information signal. The aim of analog modulation is to transfer an analog baseband (or lowpass) signal, for example an audio signal or TV signal, over an analog bandpass channel at a different frequency, for example over a limited radio frequency band or a cable TV network channel.

For a given modulation technique, two ways to simulate modulation techniques are called baseband and passband. Baseband simulation, also known as the lowpass equivalent method, requires less computation. This block set supports both baseband and passband simulation. Since baseband simulation is more prevalent, this guide focuses more on baseband simulation.The modulation and demodulation blocks also let you control such features as the initial phase of the modulated signal and post-demodulation filtering

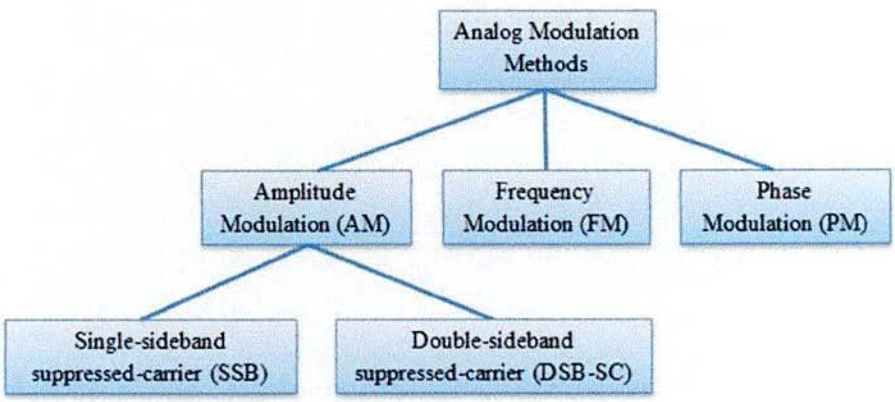


Figure 3.3: Analog Modulation Methods

The Fig.3.3 shows the modulation techniques that the Communications Block set supports for analog signals. As the figure suggests, some categories of techniques include named special cases.

3.3.2 Digital modulation

In digital modulation, an analog carrier signal is modulated by a discrete signal. Digital modulation methods can be considered as digital-to-analog conversion and the corresponding demodulation or detection as analog-to-digital conversion. The changes in the carrier signal are chosen from a finite number of alternative symbols.

The aim of digital baseband modulation methods, also known as line coding, is to transfer a digital bit stream over a baseband channel, typically a non-filtered copper wire such as a serial bus or a wired local area network.

3.3.2.1 Fundamental digital modulation methods

The most fundamental digital modulation techniques are based on keying:

- PSK (phase-shift keying): a finite number of phases are used.
- FSK (frequency-shift keying): a finite number of frequencies are used.
- ASK (amplitude-shift keying): a finite number of amplitudes are used.
- QAM (quadrature amplitude modulation): a finite number of at least two phases and at least two amplitudes are used.

3.3.2.2 Quadrature amplitude modulation (QAM)

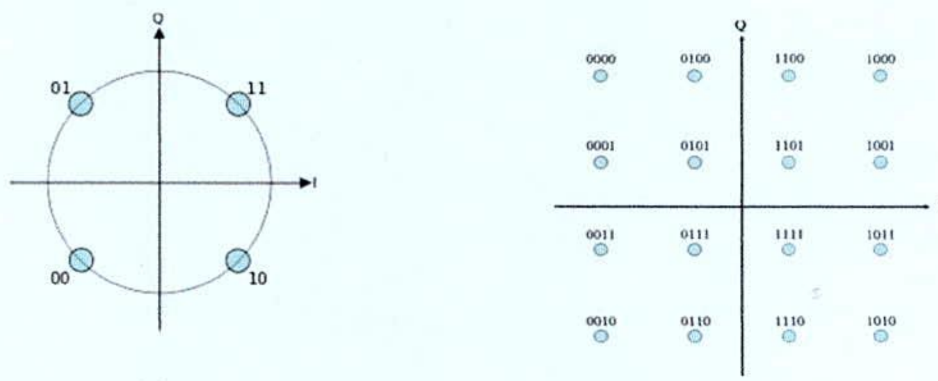
Quadrature Amplitude Modulation or QAM is a form of modulation which is widely used for modulating data signals onto a carrier used for radio communications. It is widely used because it offers advantages over other forms of data modulation such as PSK, although many forms of data modulation operate alongside each other.

QAM is a signal in which two carriers shifted in phase by 90 degrees are modulated and the resultant output consists of both amplitude and phase variations. In view of the fact that both amplitude and phase variations are present it may also be considered as a mixture of amplitude and phase modulation.

Digital formats of QAM are often referred to as "Quantized QAM" and they are being increasingly used for data communications often within radio communications systems. Radio communications systems ranging from cellular technology through wireless systems including WiMAX, and Wi-Fi 802.11 use a variety of forms of QAM, and the use of QAM will only increase within the field of radio communications.

3.3.2.3 Constellation diagrams for QAM

Quadrature amplitude modulation, QAM, when used for digital transmission for radio communications applications is able to carry higher data rates than ordinary amplitude modulated schemes and phase modulated schemes. As with phase shift keying etc., the number of points at which the signal can rest, i.e. the number of points on the constellation is indicated in the modulation format description, e.g. 16QAM uses a 16 point constellation. • The diagrams below show constellation diagrams for a variety of formats of modulation:



(a) (b)

Figure 3.4: Constellation diagrams (a) 4-QAM (b) 16-QAM

When using QAM, the constellation points are normally arranged in a square grid with equal vertical and horizontal spacing and as a result the most common forms of QAM use a constellation with the number of points equal to a power of 2 i.e. 2, 4, 8, 16 . . . . • By using higher order modulation formats, i.e. more points on the constellation, it is possible to transmit more bits per symbol. However the points are closer together and they are therefore more susceptible to noise and data errors.

3.3.2.4 Advantages and Disadvantages of QAM

Advantages

- QAM appears to increase the efficiency of transmission for radio communications systems by utilizing both amplitude and phase variations

Drawbacks

- More susceptible to noise because the states are closer together so that a lower level of noise is needed to move the signal to a different decision point. Receivers for use with phase or frequency modulation are both able to use limiting amplifiers that are able to remove any amplitude noise and thereby improve the noise reliance. This is not the case with QAM.
- The second limitation is also associated with the amplitude component of the signal. When a phase or frequency modulated signal is amplified in a radio transmitter, there is no need to use linear amplifiers, whereas when using QAM that contains an amplitude component, linearity must be maintained. Unfortunately linear amplifiers are less efficient and consume more power, and this makes them less attractive for mobile applications.

REFERENCES

[1] A. X. Widmer and P. A. Franaszek, "A DC-Balanced, partitioned-block, 8B/10B transmission code," IBM J. Res. Dev. 27, 440-451 (1983).

[2] P. Baroni, V. Miot, A. Carena, and P. Poggiolini "8B10B line coding to mitigate the non-uniform FM laser response of direct modulated CPFSK transmitter" (060.2330) Fiber optics communications; (060.2630) Frequency modulation; (060.4510) Optical communications.

CHAPTER IV

Proposed Architecture and simulation setup for In-band WDM-PON

4.1 Introduction

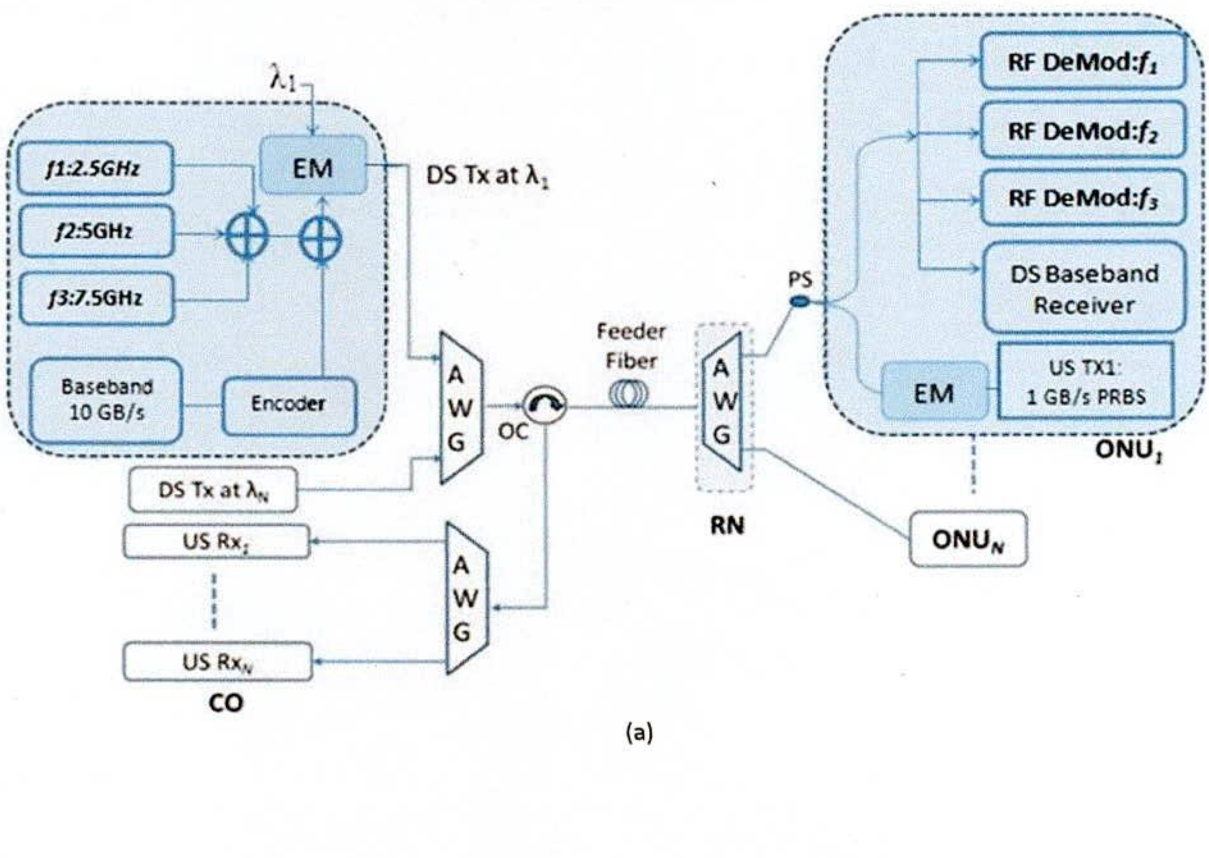
In this Chapter, In-band Transmission of Baseband and Broadcast Signals are analyzed for next-Generation WDM-PON. For future broadband access, wavelength division multiplexing passive optical network (WDM-PON) is regarded as the ultimate solution that ensure large bandwidth, wavelength independency, easy upgradability and excellent network security [1],[2]. To meet the growing bandwidth demand from diverse services such as IPTV, video-on-demand and multimedia broadcast, a converge WDM-PON with both unicast/baseband and broadcast/ multicast data has been attracted much attention in recent years [3][4].The broadcast data over the WDM-PON can be classified by using separate wavelength for broadcast services or by sharing a single wavelength for both unicast and broadcast data traffic. The converge WDM-PON in [4]-[8] utilizes the broadband light sources such as Fabry-Pérot laser diode [4][5], or mutually injected Fabry-Pérot laser diode [6] or ASE source from erbium doped fiber amplifier (EDFA) [7] or semiconductor optical amplifier (SOA) [8] and cyclic property of array waveguide grating (AWG).

As a different approach, a single wavelength can be shared by both the baseband and broadcast data as reported in [9], [10], where the system utilizes the subcarrier multiplexing (SCM) signals for broadcasting service and finally combined with baseband data to modulate a single optical source. This approach simplifies the design of OLT and meets the future bandwidth demand.For the deployment of practical low cost WDM-PONs, the desirable approach is to the use of 'colorless/wavelength independent' ONUs for loopback transmission system with centralized seeding light source [11],[12].In this project work, a wavelength reuse bidirectional WDM-PON is proposed for the transmission of both baseband and broadcast data in single wavelength.The system performance is measured in terms of BER and EVM for baseband signals and RF signals respectively. Error free operation as well as low value of EVM per subcarrier is simultaneously achieved in acceptable receiver sensitivity.

4.2 In-band Transmission of Baseband and Broadcast Signals for Next Generation WDM-PON

Broadcasting signals are generated in different RF to meet the diverse applications in both residential and commercial networks. Since the broadcast signals are placed in-band to the baseband data, the propose system does not require additional bandwidth dedicated for broadcast transmission as reported in [9]. Moreover, the combined signal is received by a single photodiode and recovers the corresponding data without any wavelength specific optical or electrical filter. Beside this, wavelength reuse architecture ensure maximum utilization of available wavelengths and simplify the 'colorless' operation of upstream/downstream transmission.

The proposed wavelength reuse bi-directional WDM-PON with in-band transmission of both unicast/baseband and broadcast data is shown in Fig.4.1 (a).



(a)

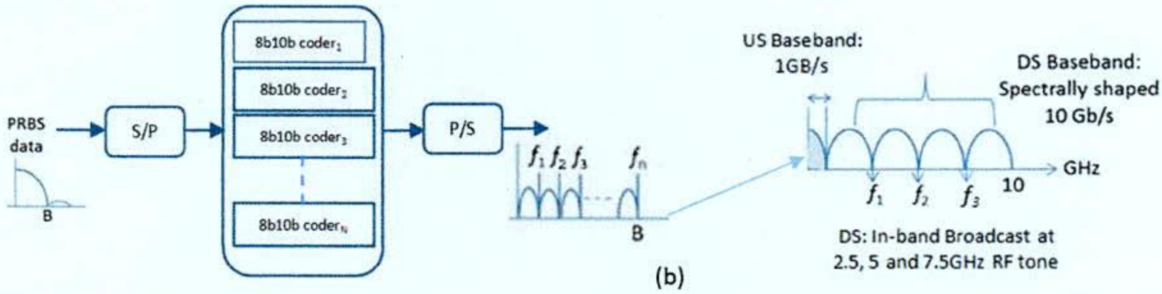


Figure 4.1: a) Proposed architecture of In-band transmission and wavelength reused WDM-PON. b) Encoder for spectrally shaped 8b10b coded signal.

CO: Central Office, EM: Electro absorption Modulator, AWG: Array Waveguide Grating, OC: Optical Circulator, RN: Remote Node, PS: Power Splitter, PD: Photodiode, ONU: Optical Network Unit, S/P: Serial to Parallel, P/S: Parallel to Serial

Fig.4.1 (b) shows the architecture of encoder where incoming PRBS serial data stream is parallelized in n blocks, each of which individually encoded to 8b10b data and finally, transmitted again as a serial stream. Thus, by interleaving n parallel 8b10b coded streams, spectral nulls can be created in B/n frequency positions as shown in Fig. 4.1(b), where the B is the data rate of PRBS data stream. These null frequency positions can be utilized as a RF carrier to modulate with multiple broadcast data for overlay transmission on baseband signal.

4.2.1 Simulation setup

Fig.4.2 shows the simulation setup to evaluate the performance of proposed bi-directional 10 Gb/s wavelength reuse WDM-PON, which is used for the measurement of system BER and EVM performance against receiver input power for both downstream and upstream signals. The transmission system design and analysis are carried out by optical system design simulation tool VPITransmissionMaker-9.7®.

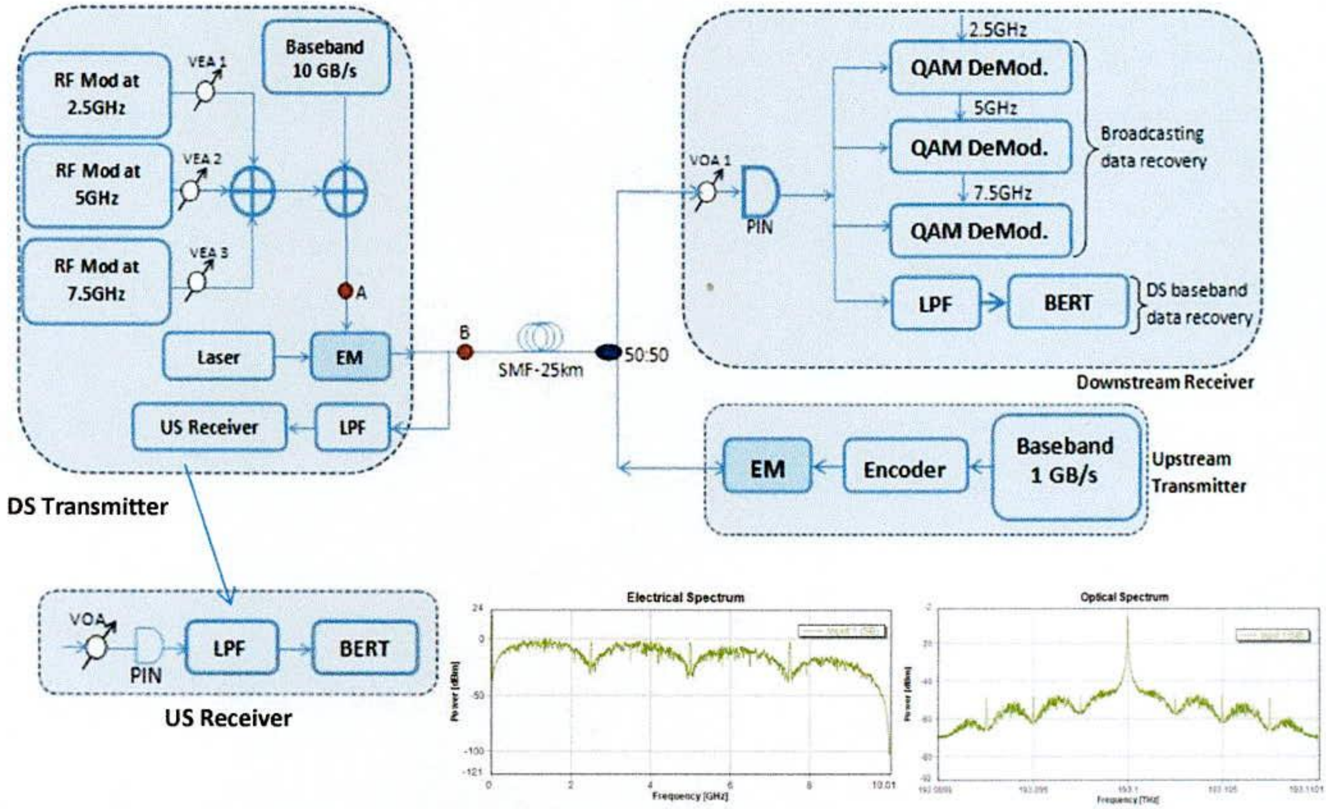


Figure 4.2: Simulation setup for 10 Gb/s baseband with 100 Mb/s broadcast signals in downstream and 1Gb/s re-modulated upstream transmission.

VEA: Variable Electrical Attenuator, SMF: Single Mode Fiber, VOA: Variable Optical Attenuator, LPF: Low Pass Filter, BERT: Bit Error Rate Tester.

In CO, a spectrally shaped 8b10b coded signal is generated at 10 Gb/s with four parallel blocks, which generate multiple frequency nulls at the positions of 2.5 GHz, 5 GHz, 7.5 GHz, and 10 GHz. Among those, frequency positions of 2.5 GHz,5GHzand 7.5GHz are used for RF modulation with 100 Mb/s 16-QAM (quadrature amplitude modulation) broadcast signals. The aforementioned baseband and broadcast signals are then combined by using a broadband RF coupler. RF signal power is varied by variable electrical attenuators (VEA1, VEA2 and VEA3) for effective control on baseband to broadcast power ratio (BBPR). Note that baseband signal power is maintained constant throughout the measurement. A Distributed Feedback (DFB) laser operating at 193.1 THz/1552.52 nm is externally modulated by Electro absorption modulator with the broadcast data overlay on baseband signal as generated before. The downstream optical signal is then transmitted to the ONU over the 25 km standard single mode fiber.

At ONU, the hybrid optical signal is divided by a 50:50 optical splitter, where part of the signal is detected by downstream PIN photodiode. The received in-band hybrid signal is further processed in two QAM demodulators at 2.5 GHz, 5 GHz and 7.5 GHz RF frequencies for EVM analysis of broadcast signals and also, in baseband BER tester. Electrical low pass bessel filter is used for baseband data recovery with the bandwidth of 75% downstream data rate. Variable optical attenuator (VOA1) is used to set different power at the input of downstream receiver especially for BER & EVM measurement.

Another part of DS optical signal is used for the re-modulation with 1 GB/s PRBS upstream signal where an encoder is used for coded that PRBS signal. As the upstream signal is propagated through the same feeder fiber, crosstalk noise may generated by Rayleigh backscattering (RB). To minimize the power penalty induced from RB noise, we maintain a reasonable value of signal to crosstalk power ratio by controlling the power of upstream signal through VOA.

Finally, the re-modulated upstream signal is detected by upstream optical receiver, as shown in Fig.4.2, consists of VOA, PIN photodiode and electrical low pass bessel filter (bandwidth 75% of data rate). Fig.4.2 also show the measured electrical and optical spectrum of in-band broadcast overly on baseband signal at two positions, A and B, in the schematic. The spectrums show the expected shape of 10 GHz 8b10b coded baseband signal with two RF modulated tones at 2.5 GHz, 5 GHzand 7.5 GHz.

4.3 Transmitter

The central office acts as a transmitter which mainly consists of PRBS generator, CW laser,Electrical M-QAM Transmitter,ElectroabsorptionModulator (EA) etc. PRBS generates random bit sequence. A DFB laser produces a continuous wave (CW) optical signal for modulation electrical data where EA acts as an external modulator.

4.3.1 Continuous Wave (CW) laser

This CW module models a DFB laser producing a continuous wave (CW) optical signal. All the parameters are set to default values. The schematic symbol of CW laser in VPI is given as,

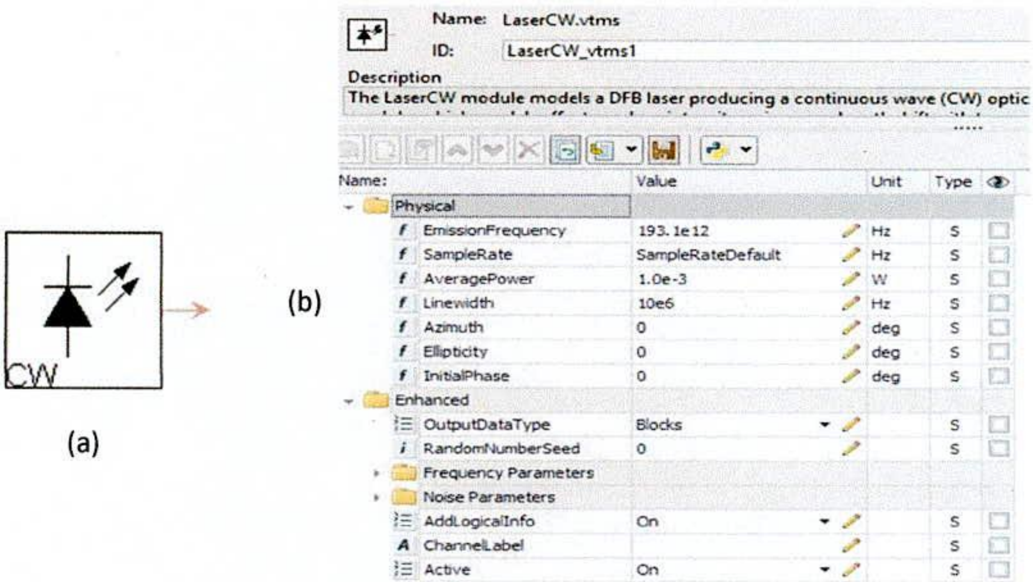


Figure 4.3 (a) CW laser (b) CW laser parameters

4.3.2 Electro absorption modulator

The direct modulation of a laser is cheap and also easy to adapt to low cost applications for moderated distances or transmission rates. However, for advanced applications involving high data rates or long distance links, resorting to external modulation is a good solution.

The output signal **Eout**(t) is given by

$$E_{out}(t) = E_{in}(t).\sqrt{d(t)}.\exp(\frac{j\alpha}{2}\ln[d(t)]) \text{-----------------------------------} (1)$$

Where **Ein**(t) is the input optical signal and α denotes the ChirpFactor which couples the phase and amplitude changes of the optical wave (1) . The power transfer function d(t) is defined as

$$d(t) = (1 - m) + m . data (t) \text{---} (2)$$

Wherem is the Modulation Index and data(t) represents the electrical modulation signal. It is assumed that usually data(t) varies within the limits $0 \leq data(t) \leq 1$ to ensure a power transfer function d(t) larger than zero. If a negative power transfer function d(t) would arise, d(t) is internally clipped up to zero. The power of the output signal $P_{out}(t) = |E_{out}(t)|^2$ is given by

$$P_{out}(t) = P_{in}(t) \cdot d(t) = P_{in}(t) \cdot ((1-m) + m \cdot data(t)) \text{----------------------------(3)}$$

With $P_{in}(t) = |E_{in}(t)|^2$ being the input power of the optical carrier (see Figure 1).

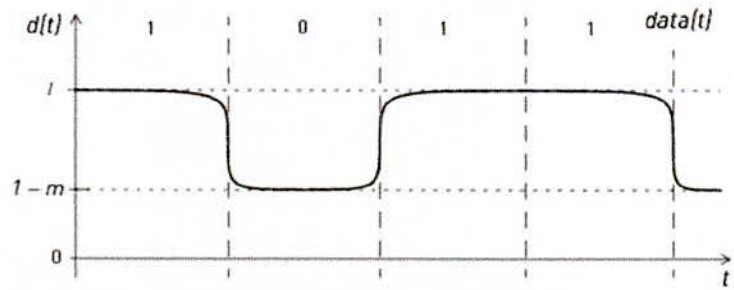


Figure 4.4: An example of the power transfer function of the EA modulator for the rectangular-like modulation signal varying in the range from 0 to 1

If the electrical and optical input signals have different sample rates, the signal that has the lower sample rate is up sampled. An arbitrary polarization state is allowed for the input optical signal. The output polarization is the same as the input one.

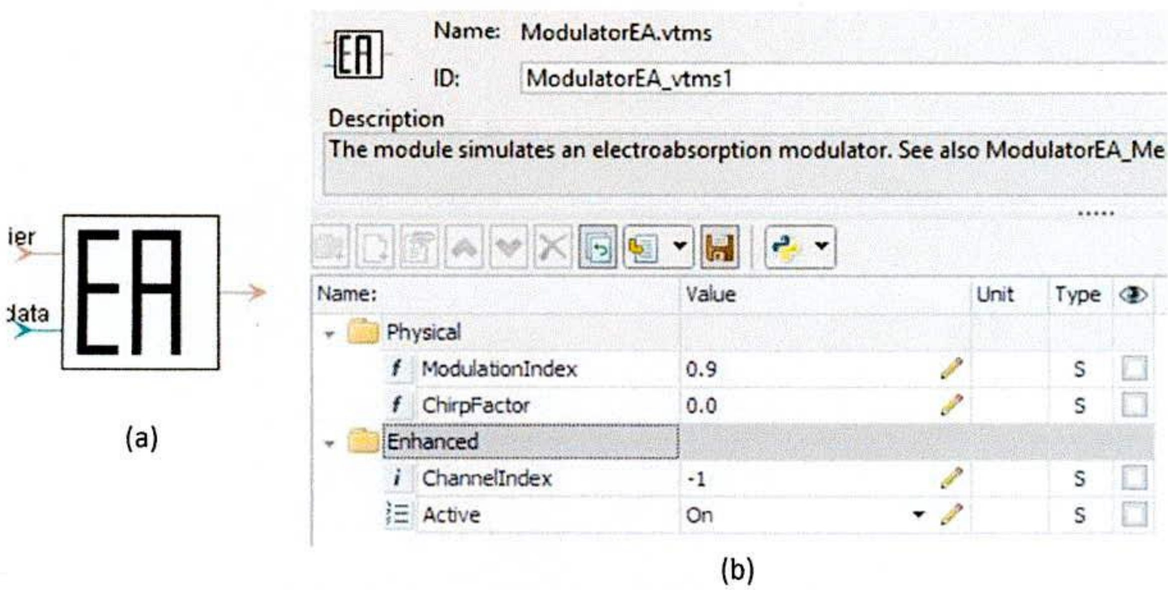


Figure 4.5 (a) EA modulator (b) EA modulator parameter

4.3.3 Pseudo Random Bit Sequence (PRBS)

The module generates many types of pseudo random data sequences, for example PRBS of order N, alternate ones and zeros, predefined sequences, all ones, all zeros. PRBS is usually required when modeling the information source in simulations of digital communication systems.

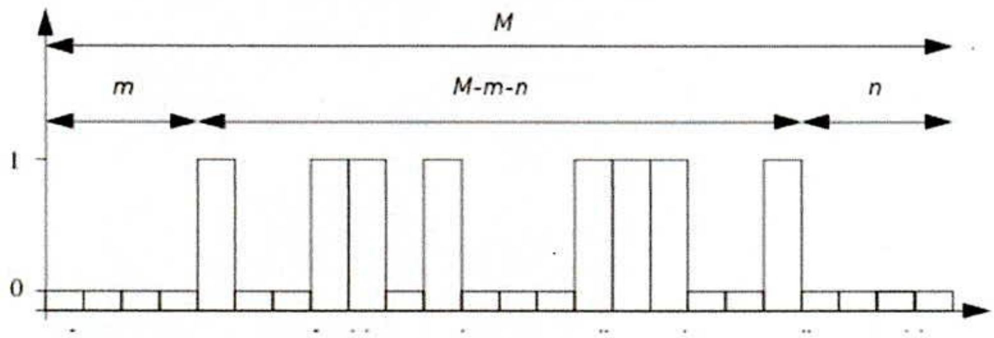
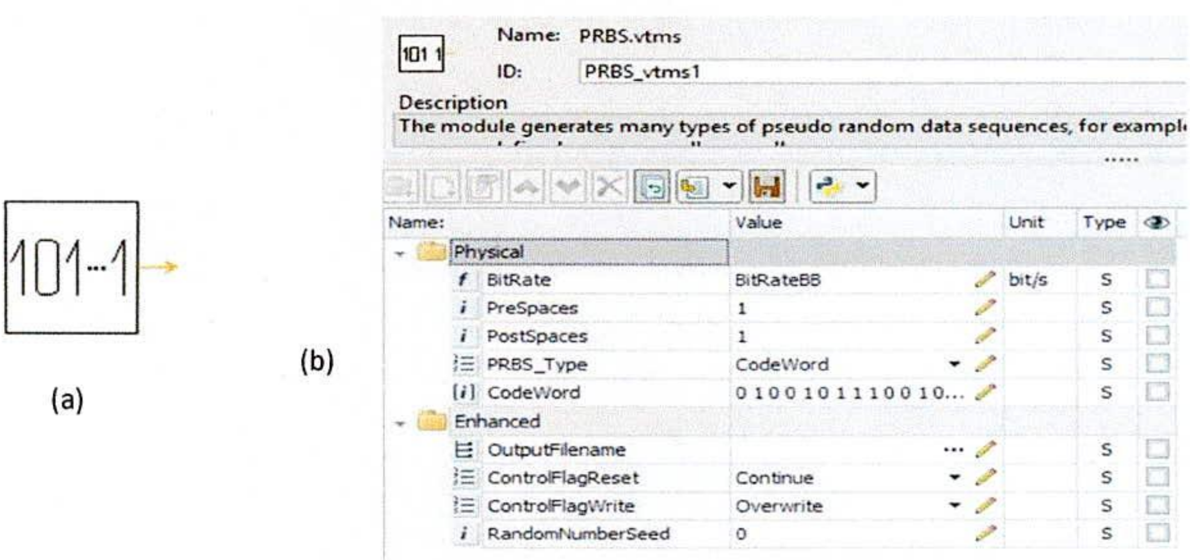


Figure 4.6: A sequence of M bits contains m preceding and n succeeding zero bits

A pseudorandom binary sequence (PRBS) is usually required when modeling the information source in simulations of digital communication systems. The binary sequence can be generated with the use of a random number generator or alternatively can be directly specified by the user or read from a specified file. The PRBS module produces a sequence of M bits (M = Time Window * Bitrate) with the numbers m and n of zero bits (spaces) preceding and succeeding the generated bit sequence of length M−m−n (see Figure 4.6). The numbers m and n can be set by the user via parameters Pre-Spaces and Post-Spaces, respectively. The sequence of generated bits may be saved to or read from a file.



(c)

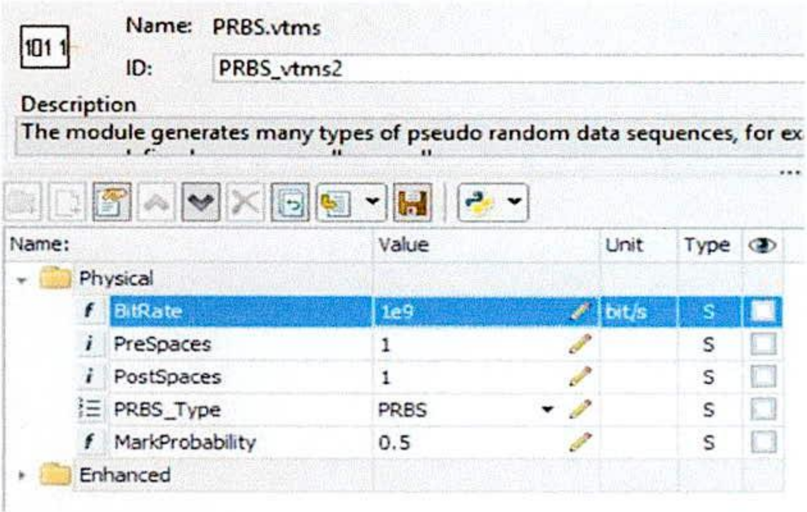


Figure 4.7 (a) PRBS (b) PRBS parameters for DS Baseband Signal
c) PRBS parameters for US Baseband Signal

Here we used two PRBS signal generator .One is used for downstream baseband signal which data rate depends on global parameter. In this model we used codeword type PRBS. Another one is used for Upstream baseband signal which data rate is 1e9 as shown in Fig4.7(c).

4.4 Receiver

Receiver consists of photodiode, low pass filter, and bit error rate taster. Received signal is directly detected by a photo diode, which generates the electrical baseband signal. Low pass filter is a universal electric filter model for simulations and combination filters with the standard transfer functions. BER module estimates the error probability of the baseband signal

4.4.1 Photo detector (PIN)

Photo-detector is usually used to recover electrical signal from Optical carrier. This module is a model of PIN and APD photodiodes. These can be simulated on base of predefined responsively, avalanche multiplication, dark current and noise.

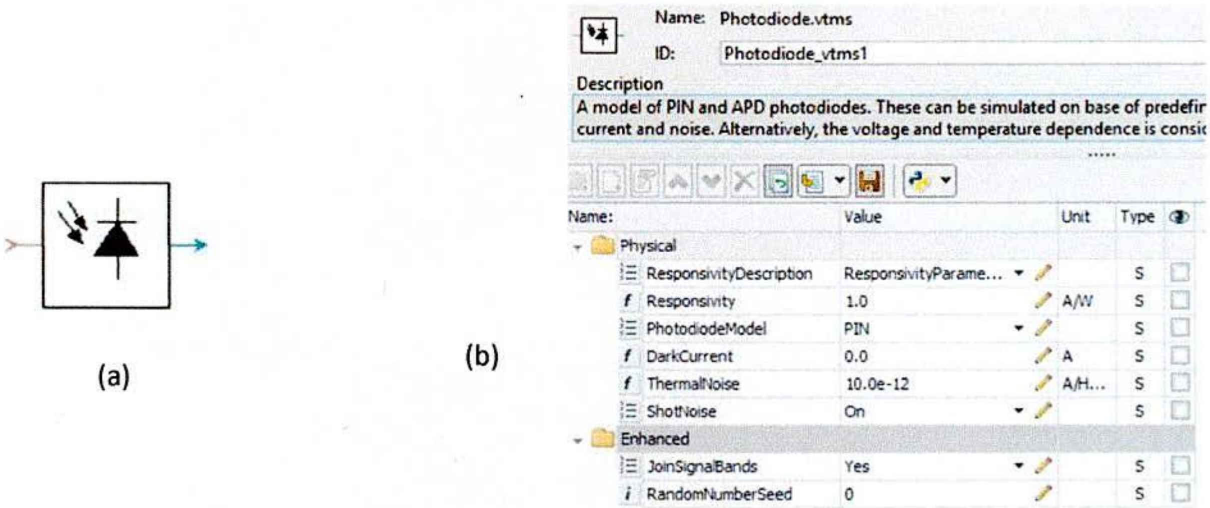


Figure 4.8 (a) Photodiode (b) PIN parameters for Downstream

4.4.2 Low Pass Filter

The Filter El module is a universal electric filter model for simulations of low pass, high pass, band pass, band stop and comb filters with the standard transfer functions: Butterworth, Bessel, Chebyshev, Elliptic, Gaussian, Rectangular, Trapezoid and Integrator. Here we use low pass Bessel filter which bandwidth is the product of 0.75 and data rate of baseband signal.

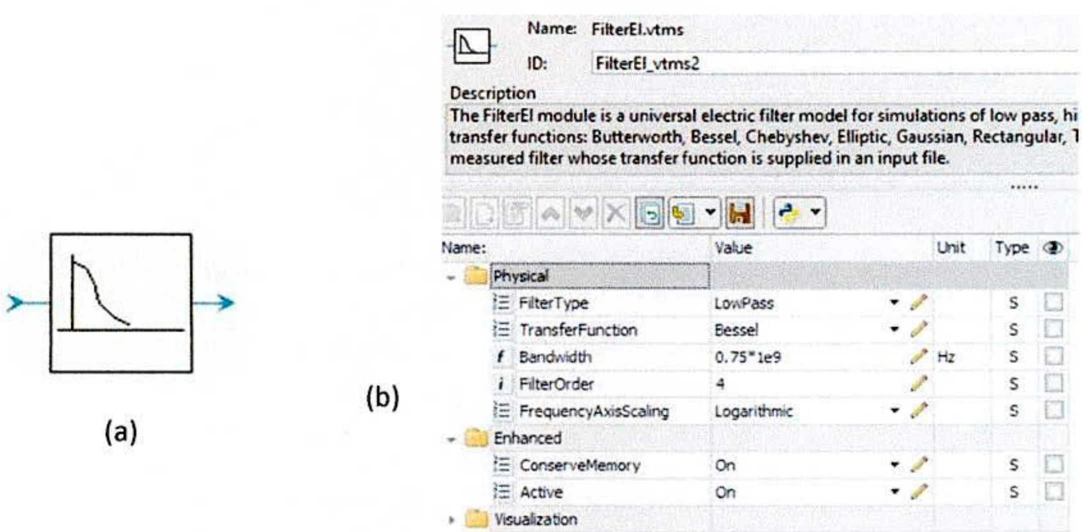


Figure 4.9: (a) Electrical Filter (b) Filter parameters

4.4.3 Bit Error Rate Tester (BERT)

This module estimates the error probability, or bit error ratio (BER) in digital direct detection optical transmission systems.

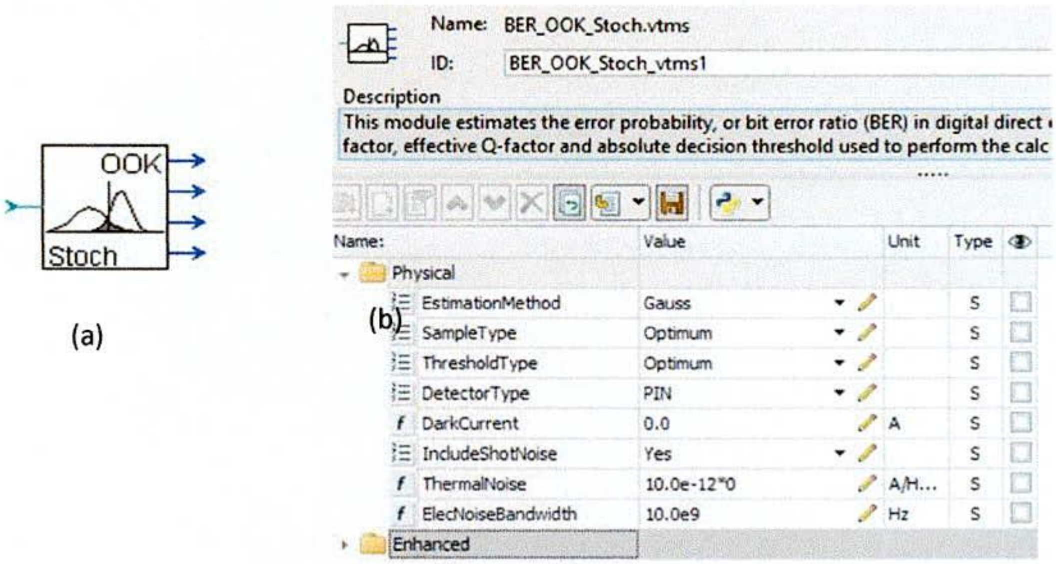


Figure 4.10: (a) BERT (b) BERT parameters for Downstream Receiver

4.5 Channel

In our system design, we used optical fiber as a channel to propagate signal. It can be either single mode fiber or bidirectional fiber.

4.5.1 Universal Fiber

The Universal fiber module for simulation of wideband nonlinear signal transmission in optical fibers, taking into account unidirectional signal flow, stimulated and spontaneous Raman scattering, Kerr nonlinearity and dispersion. In factorial mode, it includes the PMD and polarization dependence of nonlinear effects.

Here we use 25km universal fiber for DS signal transmission which refractive index is 1.47 as shown in Fig.4.11 (b).

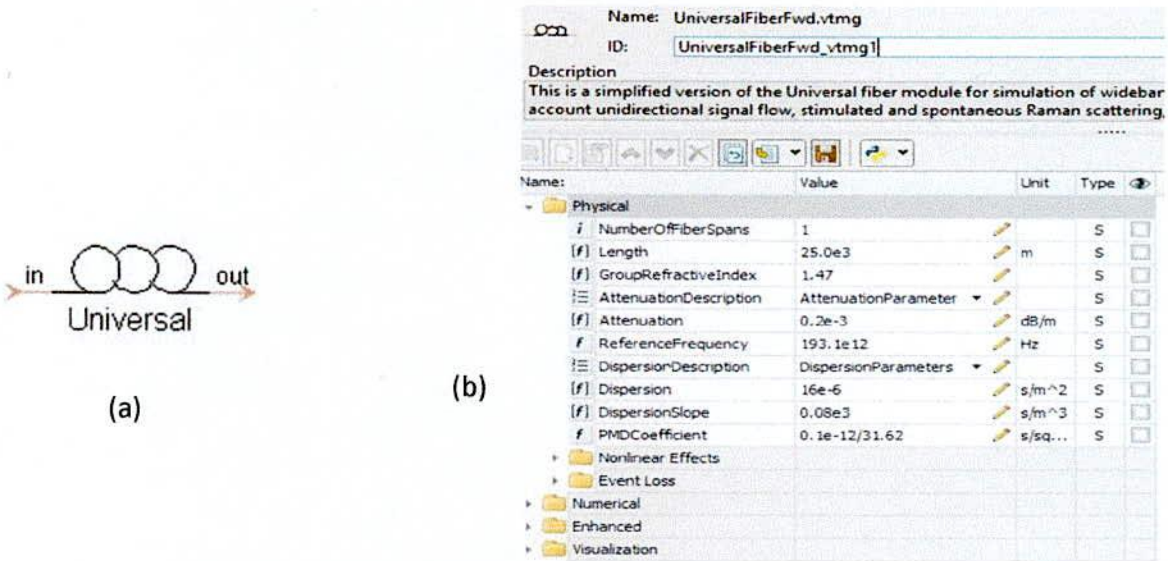


Figure 4.11: (a) Universal Fiber (b) Universal Fiber parameter

4.6 Simulation setup for Downstream

The downstream baseband data in pseudo random binary sequence (PRBS) is placed at the input of encoder, which converts the incoming data stream to 8b10b coded and spectrally shaped such that the frequency nulls can be created in desired positions to carry the broadcast data for simultaneous in-band transmission.The proposed wavelength reuse downstream transmitter of both unicast/baseband and broadcast data is shown in Fig.4.12 (a).

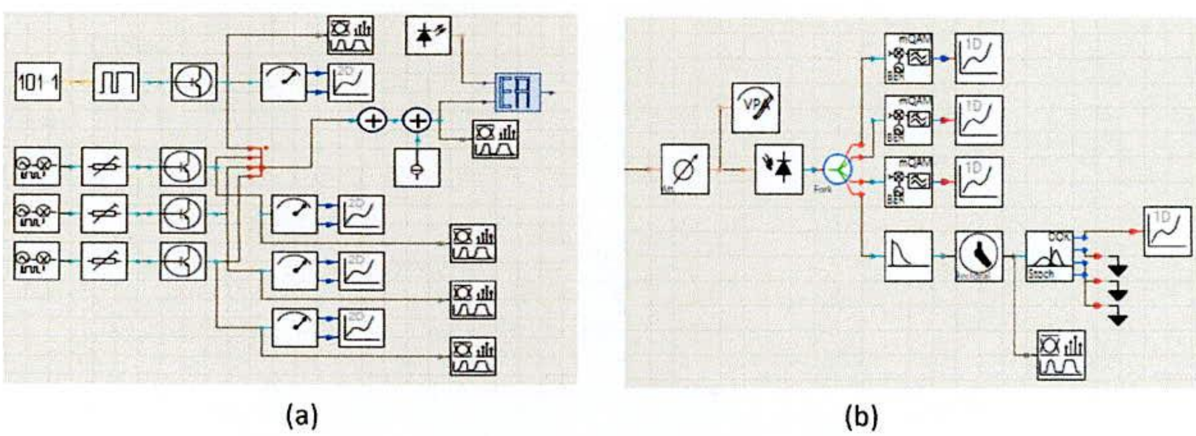


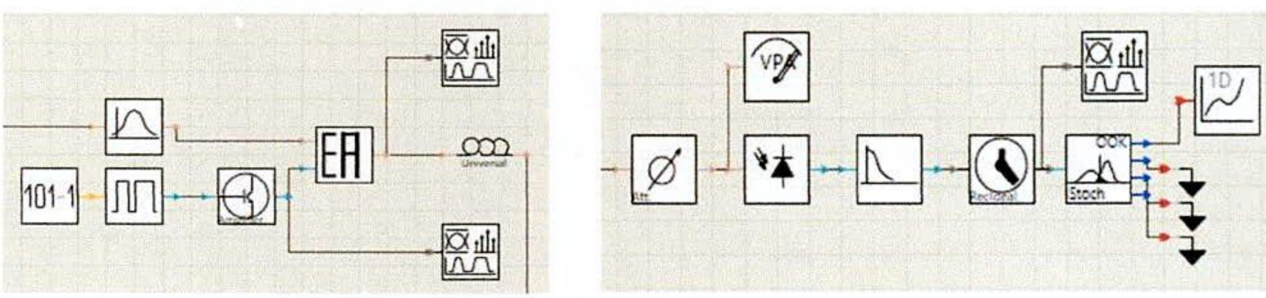
Figure 4.12: (a) Downstream transmitter (b) Downstream receiver

Fig.4.12 (b) shows the simulation environment of downstream receiver wherea portion of the downstream optical signal is received by a single photodiode (PD) to recover the data for both baseband and broadcast signals. Another portion is used as a seeding source for re-modulate the DS wavelength with upstream baseband signal. However, such wavelength reuse architecture based on re-modulation noise and thus need to be minimized for proper operation in re-modulated upstream.

4.7 Simulation setup for Upstream

Another part of DS optical signal is used for the re-modulation through EM modulator with PRBS upstream signal where an encoder is used for that PRBS signal as shown in Fig. 4.13(b).

.Finally, the re-modulated upstream signal is detected by upstream optical receiver, as shown in Fig.4.13(b), consists of VOA, PIN photodiode, electrical low pass bessel filter (bandwidth 75% of data rate) and an analyzer which can measure the BER of the upstream signal. To minimize the power penalty induced from RB noise, we maintain a reasonable value of signal to crosstalk power ratio by controlling the power of upstream signal through VOA.



(a) (b)

Figure 4.13: (a) Upstream transmitter (b) Upstream Receiver

REFERENCES

[1] G.-K. Chang, A. Chowdhury, Z. Jia, H.-C.Chien, M.-F. Huang, J. Yu, and G. Ellinas, "Key technologies ofWDM-PON for future converged optical broadband access networks," IEEE/OSA J. Opt. Commun. Netw., vol. 1, no. 4, pp. C35-C50, 2009.

[2] L.G. Kazovsky,W. T. Shaw, D.Gutierrez,N.Cheng, and S. W. Wong, "Next-generation optical access networks," J. Lightwave. Technol., vol. 25, no. 11, pp. 3428-3442, 2007.

[3] J. Choi, M. Yoo, and B. Mukherjee, "Efficient video-on-demand streaming for broadband access networks," IEEE/OSA J. Opt. Commun.Netw., vol. 2, no. 1, pp. 38-50, 2010.

[4] J.H.Moon,K. M. Choi, and C.H. Lee, "Overlay of broadcasting signal in a WDM-PON," in Proc. OFC, Anaheim, CA, pp. 1-3, 2006.

[5] H. C. Kwon, Y. Y. Won, and S. K. Han, "Noise suppressed Fabry-Perot laser diode with gain-saturated semiconductor optical amplifier for hybrid WDM/SCM-PON link," IEEE Photon. Technol. Lett., vol.18, no.4, pp. 640-642, 2006.

[6] S.-H. Yoo, J.-Y.Kim, B.-I.Seo, C.-H. Lee, "Noise-suppressed mutually injected Fabry-Perot laser diodes for 10-Gb/s broadcast signal transmission in WDM passive optical networks," Opt. Express, vol. 21, no.5, pp. 6538-6546, 2013.

[7] J. Cho, J. Kim, D. Gutierrez and L. G. Kazovsky, "Broadcast transmission in WDM-PON using a broadband light source," in Proc. of OFC, Paper ID: OWS7, 2007.

[8] J. M. Kang, S. H. Lee, H. C. Kwon, and S. K. Han, "WDM-PON with broadcasting function using direct ASE modulation of reflective SOA," in Proc. of OFC, Paper ID: P.160, 2006.

[9] T. Y. Kim, and S. K. Han, "Reflective SOA-based bidirectional WDM-PON sharing optical source for up/downlink data and broadcasting transmission," IEEE Photon. Technol. Lett., vol. 18, no. 22, pp.2350-2352, 2006.

[10] T. T. Pham, H. S. Kim, Y. Y. Won, and S. K. Han, "Colorless WDM-PON based on a Fabry–Perot laser diode and reflective semiconductor optical amplifiers for simultaneous transmission of bidirectional gigabit baseband signals and broadcasting signal," Opt. Express , vol. 17, no. 19, pp. 16571-16580, 2009.

[11] E. Wong, "Next-generation broadband access networks and technologies," J. Lightwave.Technol., vol. 30, no. 4, 2012.

[12] A. Banerjee, Y. Park, F. Clarke, H. Song, S. Yang, G. Kramer, K. Kim, and B. Mukherjee, "Wavelength-division-multiplexed passive optical network (WDM-PON) technologies for broadband access: A review [Invited]," IEEE/OSA J. Opt. Netw., vol. 4, no.11, pp.737-758, 2005.

CHAPTER V

Results and analysis

5.1 Introduction

Results and analysis is the most important part for a research work. In this chapter, in-band propagation of 10GB/s, 5GB/s and 2.5GB/s baseband signals and broadcast signals performance is measured by setting different BBPR ratio. The downstream performance of baseband data is analyzed in terms of BER and the performance of broadcast data is analyzed in terms of EVM for the RF signals. The Upstream performance of baseband data is analyzed in terms of BER.

5.2 Downstream performance analysis for 10GB/s Baseband signal:

Due to the in-band propagation of 10GB/s baseband signal and broadcast signals, the corresponding optimized performance is measured by setting different BBPR ratio as mentioned before. The BBPR is varied from 19 to 23 dB by RF attenuator with the same label for the broadcasting signals, where the power of spectrally shaped 8b10b coded baseband signal is maintained to a fixed value. The performance of downstream 10GB/s baseband signal is characterized by BER in terms of photodiode received power for different BBPR values as shown in Fig.4.1. We optimized the BBPR value to 19 dB, 21dB and 23dBfor BER performance without RF data as illustrated in Fig.4.1. The result indicates 1 dB to 3dB power penalty for BER=10^{-9}, which confirms negligible noise contribution coming from in-band RF tone for BBPR = 23dB. When we reduced the BBPR value to 21dB and 19 dB i.e., RF induced noise power is increasing, it degrades the baseband BER performance and introduce power penalty to reach error free transmission. In particular, the measurement shows that the received power penalty was around 1 and 3 dB for BBPR value decreased to 21 dB and 19 dB respectively to reach BER at 10^{-9}.

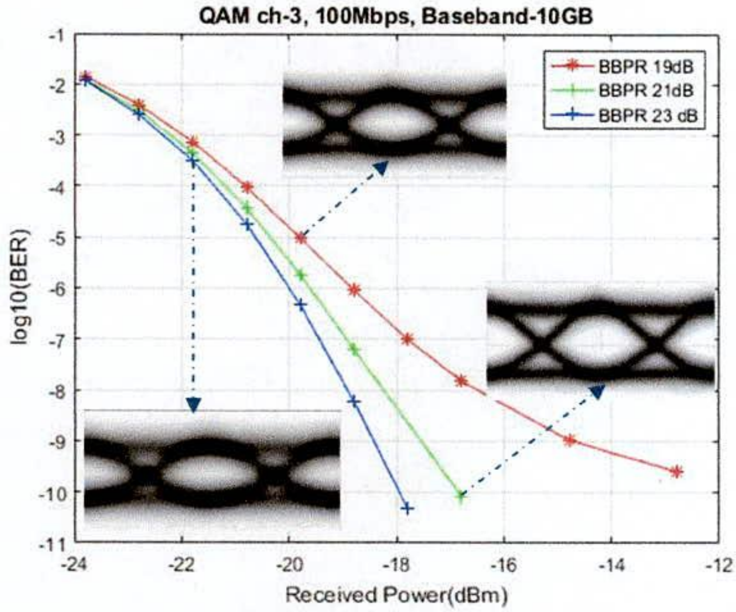
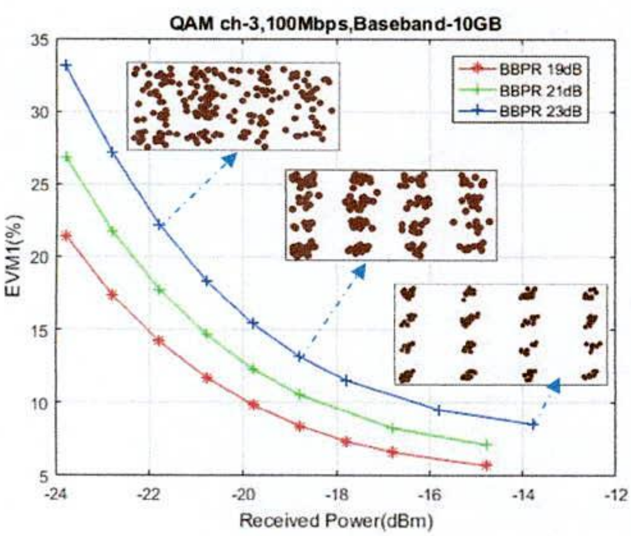
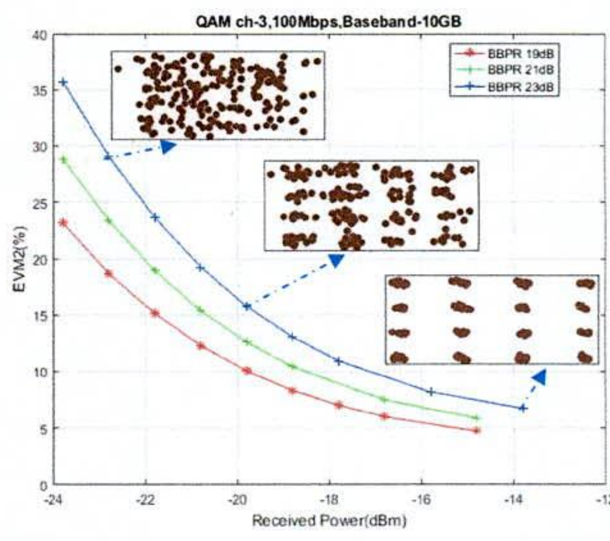


Figure 5.1: Downstream baseband signal BER performance against input power of receiver for different BBPR values over 25 Km fiber.

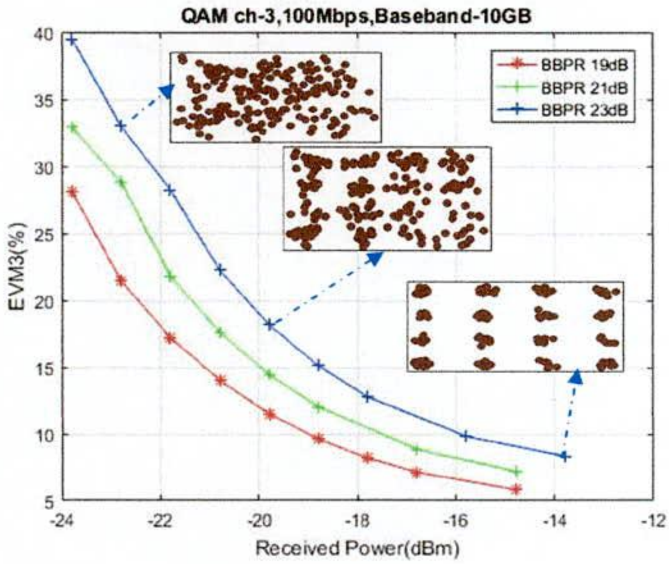
The Fig.5.1 also shows the corresponding eye diagrams at different positions of BBPR value with a fixed received optical power, indicates the contribution of RF signals as a noise source in baseband data reception.



(a)



(b)



(c)

Figure 5.2: EVM performance of in-band broadcast data over 25 Km fiber in terms of receiver input power and BBPR values for RF modulation with carrier frequencies of a) 2.5 GHz b) 5 GHz c) 7.5 GHz

The performance of broadcast data is also analyzed in terms of EVM for both the RF signals of 100 Mb/s 16-QAM modulations at 2.5 GHz, 5 GHz and 7.5 GHz carrier frequencies. Similar to BER analysis, the EVM values are measured by varying the receiver power for several BBPR values as shown in Fig.5.2. As expected, the EVM values of QAM symbols can be improved significantly if the RF signal power is increased (i.e., BBPR value is decreased) along with high received power. In particular, EVM value is decreased from 11.75% to 7% at -18dBm optical input power when the BBPR is varied from 23 dB to 19 dB for 2.5 GHz RF modulated signal as shown in Fig. 5.2(a). The results show that data recovery is further improved with high receive power at photodiode.Fig.5.2(a) also shows the received constellation of 16-QAM modulated signal at different EVM values, which clearly indicates the effect of intermixing noise as produced with high BBPR values.

Fig.5.2 (b) shows that the EVM performance almost samefor 5 GHz broadcasting signal in compare with 2.5 GHz RF signal. Fig.5.2 (b) also shows the received constellation of 16-QAM modulated signal at different EVM values, which clearly indicates the effect of intermixing noise as produced with high BBPR values.

However, according to Fig.5.2 (c), the EVM performance is better in 7.5 GHz broadcasting signal in compare with 5 GHz RF signal mainly due to the presence of high power noise components of baseband signal in this frequency region as justified from the electrical spectrum in Fig.5.2.The received constellation of 16-QAM modulated signal at different EVM values, which clearly indicates the effect of intermixing noise with high BBPR values as shown in Fig. 5.2 (c).

5.3 Downstream performance analysis for 5GB/s Baseband signal:

Due to the in-band propagation of 5GB/s baseband signal and broadcast signals, the corresponding optimized performance is measured by setting different BBPR ratio as mentioned before. The BBPR is varied from 19 to 23 dB by RF attenuator with the same label for the broadcasting signals.The performance of downstream 5GB/s baseband signal is characterized by BER in terms of photodiode received power for different BBPR values as shown in Fig.5.3.We optimized the BBPR value to 19 dB, 21dB and 23dBfor BER performance without RF data as illustrated in Fig.4.3. The result indicates 1 dB to 4dB power penalty for BER=10^{-9}.

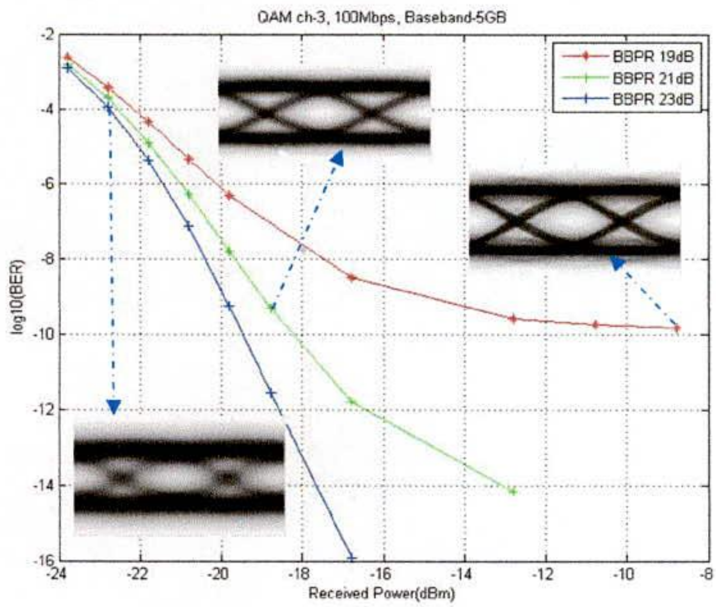
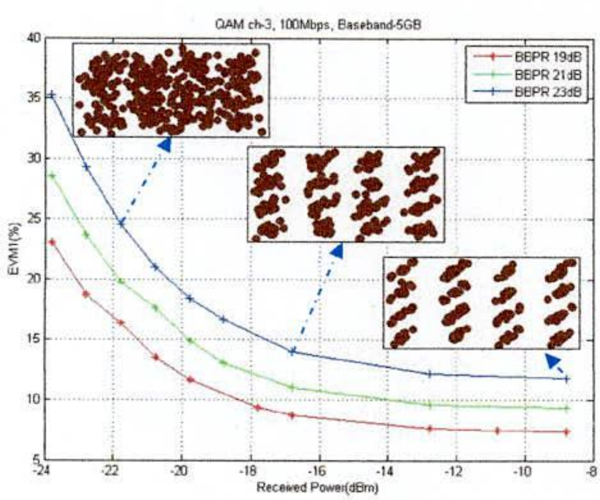


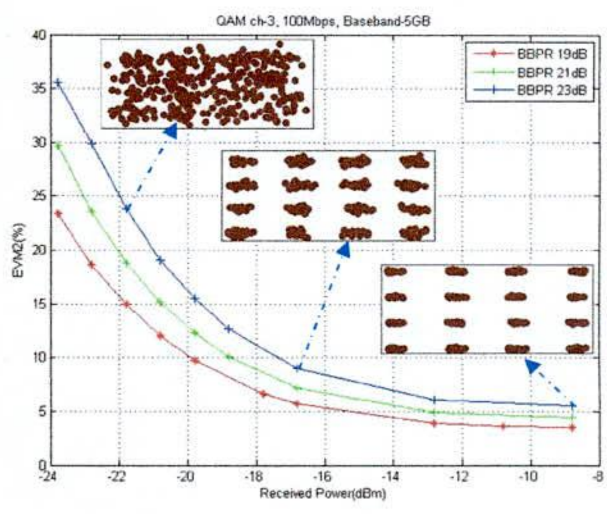
Figure 5.3: Downstream baseband signal BER performance against input power of receiver for different BBPR values over 25 Km fiber.

The Fig.5.3 also shows the corresponding eye diagrams at different positions of BBPR value with a fixed received optical power, indicates the contribution of RF signals as a noise source in baseband data reception. The performance of broadcast data is also analyzed in terms of EVM for both the RF signals of 100 Mb/s 16-QAM modulations at 1.25GHz, 2.5 GHz and 3.75 GHz carrier frequencies. Similar to BER analysis, the EVM values are measured by varying the receiver power for several BBPRvalues as shown in Fig.5.3. As expected, the EVM values of QAM symbols can be improved significantly if the RF signal power is increased (i.e., BBPR value is decreased) along with high received power. In particular, EVM value is decreased from 15% to 9% at -18dBm optical input power when the BBPR is varied from 23 dB to 19 dB for 1.25 GHz RF modulated signal as shown in Fig. 5.4(a). The results show that data recovery is further improved with high receive power at photodiode.Fig. 5.4 (a) also shows the received constellation of 16-QAM modulated signal at different EVM values, which clearly indicates the effect of intermixing noise as produced with high BBPR values.

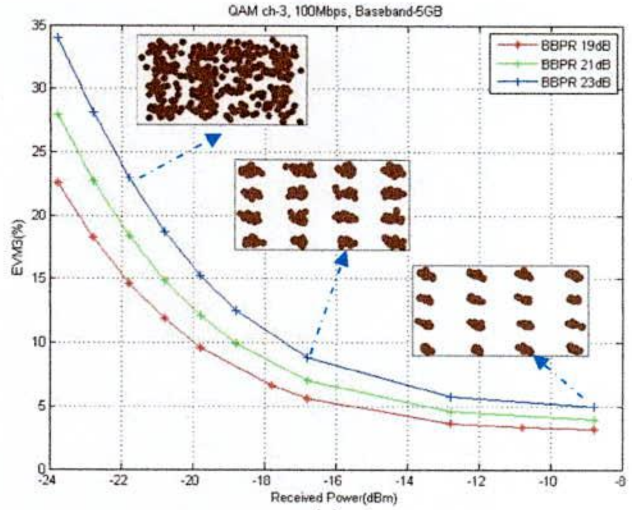
Fig. 5.4 (b) shows that the EVM performance is slightly better in2.5 GHz broadcasting signal in compare with 1.25 GHz RF signal.Fig. 5.4 (b) also shows the received constellation of 16-QAM modulated signal at different EVM values, which clearly indicates the effect of intermixing noise as produced with high BBPR values.



(a)



(b)



(c)

Figure 5.4: EVM performance of in-band broadcast data over 25 Km fiber in terms of receiver input power and BBPR values for RF modulation with carrier frequencies of a) 1.25 GHz b) 2.5 GHz c) 3.75 GHz

However, according to Fig. 5.4 (c), the EVM performance is better in 3.75 GHz broadcasting signal in compare with 1.25GHz RF signal mainly due to the presence of high power noise components of baseband signal in this frequency region. Fig.5.4 (c) also shows the received constellation of 16-QAM modulated signal at different EVM values, which clearly indicates the effect of intermixing noise with high BBPR values.

5.4 Downstream performance analysis for 2.5GB/s Baseband signal:

Due to the in-band propagation of 2.5GB/s baseband signal and broadcast signals, the corresponding optimized performance is measured by setting different BBPR ratio as mentioned before. The BBPR is varied from 19 to 23 dB by RF attenuator with the same label for the broadcasting signals.The performance of downstream 5GB/s baseband signal is characterized by BER in terms of photodiode received power for different BBPR values as shown in Fig.5.5. We optimized the BBPR value to 19 dB, 21dB and 23dBfor BER performance without RF data as illustrated in Fig.4.8.We optimized the BBPR value to 19 dB, 21dB and 23dBfor BER performance without RF data as illustrated in Fig.5.5 The result indicates 1 dB to 6dB power penalty for BER=10^{-9}.The Fig.5.5 also shows the corresponding eye diagrams at different positions of BBPR value with a fixed received optical power, indicates the contribution of RF signals as a noise source in baseband data reception.

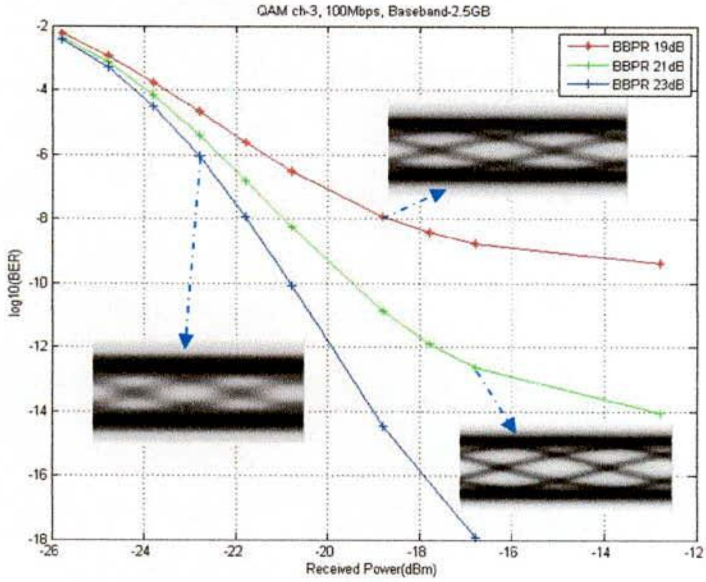


Figure 5.5: Downstream baseband signal BER performance against input power of receiver for different BBPR values over 25 Km fiber.

The performance of broadcast data is also analyzed in terms of EVM for both the RF signals of 100 Mb/s 16-QAM modulations at 0.635GHz, 1.25 GHz and 1.875 GHz carrier frequencies. Similar to BER analysis, the EVM values are measured by varying the receiver power for several BBPRvalues as shown in Fig.5.6. As expected, the EVM values of QAM symbols can be improved significantly if the RF signal power is increased (i.e., BBPR value is decreased) along with high received power. In particular, EVM value is decreased from 21.5% to 14% at -18dBm optical input power when the BBPR is varied from 23 dB to 19 dB for 0.635 GHz RF modulated signal as shown in Fig. 5.6(a). The results show that data recovery is further improved with high receive power at photodiode.Fig. 5.6(a) also shows the received constellation of 16-QAM modulated signal at different EVM values, which clearly indicates the effect of intermixing noise as produced with high BBPR values.

WQAZ

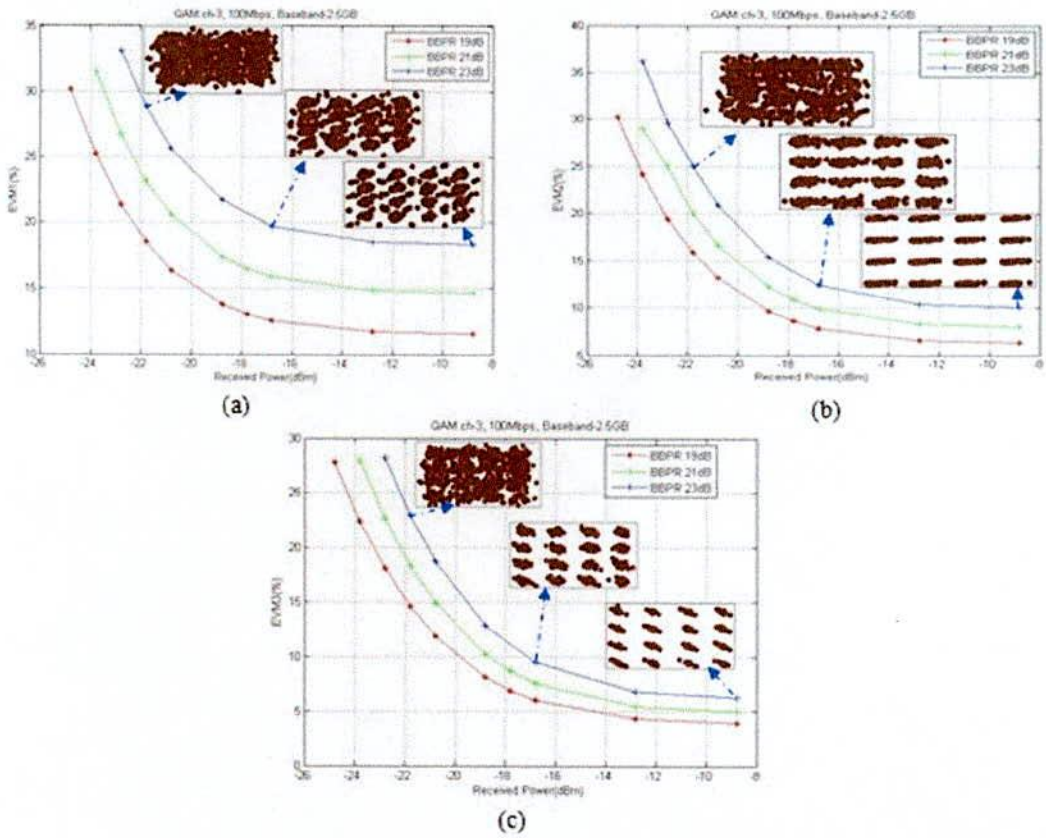


Figure 5.6: EVM performance of in-band broadcast data over 25 Km fiber in terms of receiver input power and BBPR values for RF modulation with carrier frequencies of a) 0.625 GHz b) 1.25 GHz c) 1.875 GHz

Fig.5.6(b) shows that the EVM performance is better in 1.25 GHz broadcasting signal in compare with 0.625GHz RF signal.Fig. 5.6 (b) also shows the received constellation of 16-QAM modulated signal at different EVM values, which clearly indicates the effect of intermixing noise as produced with high BBPR values.

However, according to Fig.5.6 (c), the EVM performance is quitebetter in 1.875 GHz broadcasting signal in compare with 0.625GHz RF signal mainly due to the presence of high power noise components of baseband signal in this frequency region as justified from the electrical spectrum. The received constellation of 16-QAM modulated signal at different EVM values, which clearly indicates the effect of intermixing noise with high BBPR values as shown in Fig. 5.6 (c).

5.5 Overall DS performance analysis

The performance of baseband signal has measured through BER, whereas the broadcast signals characterized by EVM parameters. The BER and EVM parameters are measured in terms of maintaining different level of BBPR values. The receiver power is fixed to -18dBm to confirm that the BER and EVM values are only be varied through the mixing noise of baseband broadcast signals.

Table 5.1: BER and EVM comparison for BBPR value 23dB
This table illustrated for BBPR value 23dB

Baseband signal(GB/s)	**Power (dBm)**	**BER (bit/s)**	**EVM1 (%)**	**EVM2 (%)**	**EVM3 (%)**
10	-18	10^{-10}	11.75	11.75	13
5	-18	10^{-13}	15	11.75	11
2.5	-18	10^{-16}	21.5	14	12

Table 5.1 shows the BER and EVM values for different data rate of baseband signals when the BBPR is fixed at 23dB. Table shows that for this BBPR value the baseband signals shows a good BER performance for every data rate. On the other hand, the EVM performance of in-band RF signals are show low value for 10GB/s baseband signals as it has more spacing in null frequency position compare to 5GB/s and 2.5 GB/s data rate.

Table 5.2: BER and EVM comparison
This table illustrated for BBPR value 21dB

Baseband signal(GB/s)	**Power (dBm)**	**BER (bit/s)**	**EVM1 (%)**	**EVM2 (%)**	**EVM3 (%)**
10	-18	10^{-8}	9	9	11
5	-18	10^{-10}	12	9	9
2.5	-18	10^{-12}	17	11	9

Table 5.3: BER and EVM comparison
This table illustrated for BBPR value 19dB

Baseband signal(GB/s)	**Power (dBm)**	**BER (bit/s)**	**EVM1 (%)**	**EVM2 (%)**	**EVM3 (%)**
10	-18	10^{-7}	7	7	8
5	-18	10^{-8}	9	7	7
2.5	-18	10^{-9}	14	9	7

Table 5.2 and 5.3 indicate that when the BBPR values are decreased, the BER values of baseband are increased, whereas the EVM values of RF signals are improved. The overall performance clarifies that there should have an optimum value of power for both the signals for which both BER and EVM values can be maintain within the required limit.

Table 5.4: Comparison of Received Power for fixed BER (10^{-9})

Baseband signal(GB/s)	**Receiver Power(dBm) for BBPR 23dB**	**Receiver Power(dBm) for BBPR 21dB**	**Receiver Power(dBm) for BBPR 19dB**
10	-18.5	-17.5	-14.7
5	-19.75	-19.0	-14.5
2.5	-21.25	-20.0	-14.0

Here is another table 5.4 show that the required receiver power (dBm) for error free (BER 10^{-9}) in-band transmission. For10GB/s baseband signal required receiver power is -18.5dBm when BBPR value is 23dB. When data rate of baseband signal is decrease then received power is also decrease. But when the BBPR value decrease required received power is increase and introduce -1dBm to -3dBm power penalty for 10GB/s baseband signal.

5.6 Upstream performance

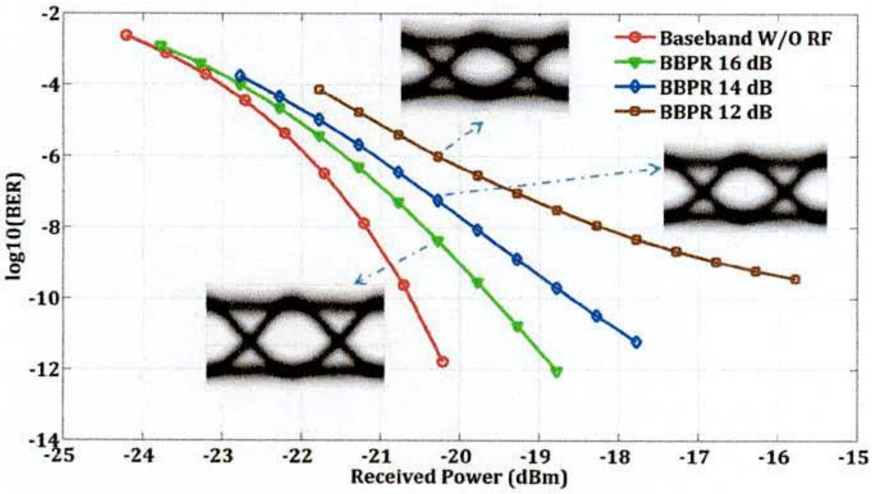


Figure 5.7: Upstream baseband signal BER performance against input power of receiver for different BBPR values over 20 Km fiber.

In compare with CW seed source, the modulated DS signal produces around 1.5 dB power penalty for the BER=10^{-9} caused by unsuppressed DS data on US signal transmission as shown in Fig.5.7. Furthermore, receiver sensitivity is decreased by another 1 dB due to the presence of RB noise when the US modulated signal is transmitted over 20 Km fiber. Fig.5.7 also show the eye diagrams of received signal in US at different received power, clearly indicates the effect of noise coming from re-modulation DS data and fiber induced crosstalk noise.

CHAPTER VI

Conclusion and Future Work

6.1 Conclusions

A bidirectional WDM-PON is proposed and analyzed for simultaneous transmission of broadcast and singles on a single wavelength. In the proposed architecture, the broadcast data is transmitted within the same bandwidth of baseband signal and thus, effectively improves the utilization of network bandwidth. Moreover, wavelength reuse ONU ensures the cost-effective, centralized control and colorless operation of next generation WDM-PON Transmission performance is demonstrated for 10GB/s,5GB/s and 2.5GB/s downstream baseband signal with in-band broadcast signal of 100Mb/s 16QAM data and further re-modulated for upstream 1GB/s signal. The BER and EVM performances are studied in different baseband to broadcast signal power ratio along with input power of optical receiver. Additionally, re-modulation noise and crosstalk induced from Rayleigh Backscattering are also considered and properly minimized for upstream signal transmission. The result shows the successful bi-directional operation of both the signals with low value of BER and EVM, which confirm the feasibility of proposed scheme. Since each transmitter in CO can offer the different broadcasting service, the proposed In-band Transmission of Baseband and Broadcast Signals for Next Generation WDM-PON_scheme can provide adaptive broadcasting service to satisfying the diverse demands of customers.

6.2 Future Work

In this thesis work we can't able to minimize error properly for upstream transmission. In future researchers can investigate new techniques for error free upstream data transmission.
There are several research work can be considered as a future work.

- New architecture for error free (BER10^{-9}) upstream transmission
- Design to transmit more than 1GB/s data through upstream transmitter.
- Different modulation technique and modulator can be used for better performance.