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Wavelength Division Multiplexing Passive Optical Network modeling Using Optical System Simulator

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Abstract

Due to the continuing demand for larger bandwidth, the optical transport becoming general in the access network. Using optical fiber technologies, the communications infrastructure becomes powerful, providing very high speeds to transfer a high capacity of data. Existing telecommunications infrastructures is currently widely used Passive Optical Network that apply Wavelength Division Multiplexing (WDM) and is awaited to play an important role in the future Internet supporting a large diversity of services and next generation networks. This paper presents a design of WDM-PON network, the simulation and analysis of transmission parameters in the Optisystem 7.0 environment for bidirectional traffic. The simulation shows the behavior of optical fiber links when the signal passes through all the components such as optical fiber, splitters, multiplexers then find a good quality of signal in all receivers. The system performance is presented through various parameters such as BER analyzer and the Eye Diagram.

Keywords: *Passive Optical Network (PON), Eye Height, Bit Error Rate (BER), Quality factor (Q).*

1. Introduction

Unprecedented bandwidth requires for emerging web applications override the capacity of conventional VDSL or CATV technologies. The increasing request for bandwidth is driving to new access network architectures to provide the large capacity fiber optic cables very near to the small businesses and indoor homes [1]. Optical fiber communication technology plays an important role in modern telecommunications networks. The FTTx Models -- Fiber to the Home (FTTH), Fiber to the Premises (FTTP), Fiber to the Curb (FTTC), etc. offer the possibility for unmatched access bandwidth to end nodes (up to 200 Mbps per user). The other technologies like VDSL or wireless can adopt access technologies which are aim to provide fiber directly to the home, or very close the home. FTTx models can be considered as the most important application of passive optical network (PON).

PONs use fiber optic cables to provide bandwidth in the broadband access network. PONs can hold-up voice, data, video and bandwidth-intensive services in the broadband user access network where technologies such as CATV and DSL disable to backup due to lack of bandwidth. A point-to-point topology can be used logically to establish optical fiber in the local entrance, with dedicated fiber operats from the telecommunication central office (CO) to each subscriber. In most cases this simple architecture is cost forbidden bacause it requires connector termination space in the CO and significant outside plant fiber distribution.

A PON is a point-to-multipoint (PtMP), bidirectional and high rate optical network with no active components in the signal comming from sender to receiver. In a PON, the downstream transmissions are carry outed from an optical line terminal (OLT) to the optical network units (ONUs). While the upstream transmissions go from ONU to OLT by optical fiber which they separate at a passive optical splitter. The OLT is placed at the local exchange i.e CO and the optical access network is connected to the wide area network (WAN) or metropolitan area network

(MAN), also it is known as long-haul or backbone network. The ONU is placed either at the end-user home or building (FTTH and FTTB), or at the curb, in the case of (FTTC) architecture [2].

Evolutions in PON in latest years contain (EPON), ATM-PON (APON, based on ATM), (BPON, based on APON, with additive support for WDM and larger bandwidth), GPON an growth of BPON, backup various layer two protocols and higher bit rates), and wavelength-division-multiplexing PON (WDM-PON).

Integrating wavelength division multiplexing (WDM) in a PON authorized user to support larger bandwidth with respect to the conventional PON since each wavelength is dedicated to a single subscriber. The WDM-PON offers other advantages such as ease of management and upgradability, strong network security, high flexibility with data and protocol transparency, so that it has been considered by many as a future-proof access technology and an ultimate next-generation FTTH network [3].

Any practical implementation of the optical network should be preceded by a design and subsequent simulation in the simulation software. With these sophisticated tools, it is possible to debug the behavior of the proposed system and thus save a lot of funds.

This paper presents a design of WDM-PON networks, the simulation and analysis of transmission parameters in the OptiSystem 7.0 environment for bidirectional traffic. The rest of the research is arranged as follows: section 2 presents the introduction to Wavelength Division Multiplexing (WDM) passive optical networks. The related works will be in section 3, we present the WDM-PON design and modeling in section 4. Simulation results and discussion will be in section 5. While section 6 contains the conclusion.

2. Related Work

In this part a brief survey of related work on WDM passive optical networks will be present. Most paper consider WDM PON as the most expanded and spreaded access networks because of its unique benefits, such as reliability, transparency against signal format and data rate as well as high data rates. Other papers model and simulate this network. These two approaches are found in [4, 5, 6 and 7].

In [4] B. Kim and B.-Whi Kim introduce different WDM-PON schemes and its applications for the and future-proof and cost-effective access network solutions. They found that the WDM Passive Optical Network (WDM-PON) provides characteristics benefits over TDMA-PON in terms of QoS, security and protocol transparency.
The performance analysis of the hybrid time division multiplexing /wavelength division multiplexing passive optical network (TDM/WDM PON) system using the star topology architecture is presents in [5]. The basic components in Optisystem are introduced and Optisystem software is used to design the fiberoptic communications system also the simulation results are exhibited in [6], which can considered as a good help for understanding of each device of the fiber-optic communications system. [7] Discusses the design of PON and model a new diagram of a bidirectional transmission PON system using Reflective filter Bidirectional and Reflective Semiconductor Optical Amplifier (RSOA) in uplink and downlink stages. A comparison between using RSOA and reflective filter bidirectional has been done on bit error rate in the upstream signal. The new system uses array waveguide grating (AWG) to make multiplexing to the entering signal and increase the capacity then routing it to the users.

3. WDM PON

A WDM passive optical network can be built by employing a different wavelength channel to each ONU from the OLT, for both downstream and upstream directions, as shown in Figure (1). This technique produces a node-to-node connection between the CO and each ONU, which will be different from the point-to-multipoint topology of the orderly PON (TDM-PON). In the WDM-PON of Figure (1), each ONU can utilize the full bit rate of each dedicated wavelength channel. And in order to support multiple varieties of services over the same network moreover, different wavelengths may be work at different bit rates if it desired [8].

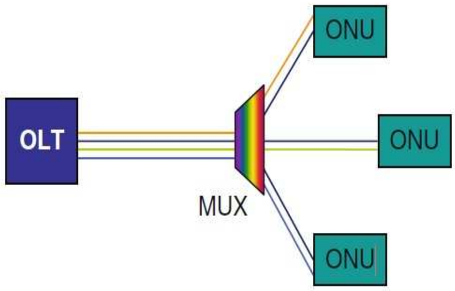


Fig. 1. Wavelength Division Multiplexing Passive Optical Network

It can say that, various groups of wavelengths can be helped to support various separate PON sub networks, all of them working over the same infrastructure for the fiber. In the WDM-PON with downstream direction as showed in Figure (1), passive arrayed waveguide grating (AWG) router will directs the wavelength channels to each ONUs coming from OLT, which is place at a “remote node” (RN), where the passive splitter suppose to be in a TDM-PON. The AWG is a passive optical device with the important characteristic of periodicity, with a cyclic property by which different spectral instructions are routed from an input port to the same output port. This permits the wavelength channels spatial reuse.

At the OLT side, multiple wavelengths are transmitted to the all ONUs through a multi wavelength source. In the upstream transmission, the OLT appoints a WDM demultiplexer connected to a receiver array in order to receive the upstream transmission. Each ONU is set up with a transmitter and receiver for transmitting and receiving on its particular wavelengths. In this case, the upstream and downstream transmissions appear in multiple wavelength windows, coarse WDM (CWDM) is used to separate these windows. In coarse WDM (CWDM) the wavelength spacing is larger than 20 nm [9].

Triple-play PON service (data, voice and video) can be accomplished with CWDM-PON, where the 131 nm wavelength channel is worked for upstream transmission and the 1490 nm wavelength channel is worked for downstream data and voice and 1550 nm wavelength channel is worked for optional video CATV.

An developed application take on 1360–1480 nm CWDM channels for excellent business applications, and three-play services (data, voice and video) are supplied to usual members. The wavelength spacing of Dense WDM (DWDM) is much more lesser than wavelength spacing of CWDM, usually lower than 3.2 nm, because DWDM has been improved to send a large number of wavelengths in a restricted spectrum region in this place an erbium-doped fiber amplifier (EDFA) could be used [10].

A DWDM-PON is suppose to be very advantageous for supplying sufficient bandwidth to large number of users, and it is considered as the extreme PON system. WDM-PON presents the following advantages [11]:

1. WDM-PON offers a very good privacy since each user receives its dedicated wavelength.
2. It has high-reliability properties of PON and low maintenance due to the optical distribution plant is yet passive.
3. In usual PON, if the OLT speed is increased, all ONUs need to be improved at the same time. A problem like this does not exist with WDM-PONs. Since each wavelength in a WDM-PON can run at a different protocol as well as with a different speed.
4. Point to point connections between OLT and ONUs are recognizing in wavelength domain. So there is no point to multi point medium access control required. This greatly facilitates the MAC layer. There will not be distance limitation put by DBA and ranging protocols.

3.1. Characteristics and Options of WDM-PON Device

A WDM-PON designer have to choose the suitable wavelengths also their spacing, depended on if the choice of components may vary safely. Wavelength spacing of 20 nm is taken in this work. Also the transmitter options of WDM-PON have been suggested, we explain receiver options, as they are dependent on both protocols and loss will be explained and different demultiplexers and multiplexers to be located at remote nodes (RNs).

3.1.1. Options of Transmitter

In this paper, Optical sources are categorized to the four groups according to the wavelengths generation way. These are (1) a multiple wavelength source (2) a wavelength-specified source, (3) a sharing source and (4) a wavelength-selection-free source. The sharing source is usable to the ONU, the different-wavelength source is usable to the OLT only and the remaining two are usable to both.

3.1.2. Options of Receiver

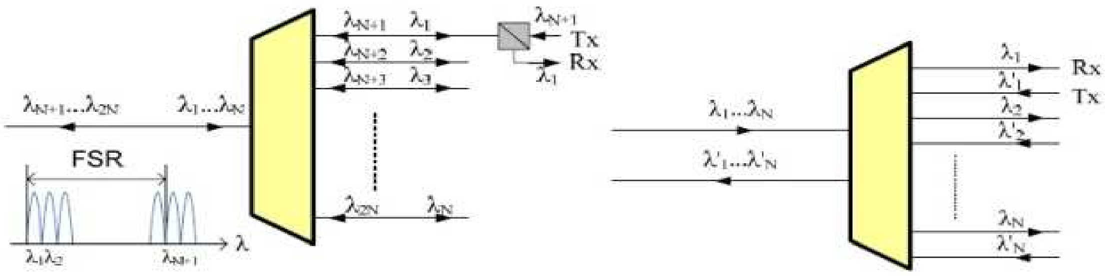
A photo detector (PD) and its following electronics consist a receiver module for signal retrieval. Common PDs are avalanche photodiode (APD) and positive-intrinsic-negative (PIN), which you find various applications depending on the necessary sensitivity. The electronic parts are usually consisting of major amplifier, preamplifier, and clock and data recovery circuits (CDRs) according to the protocol will be worked for each wavelength. Each receiver may be configured in a different way because of each wavelength can operate individually in a WDM-PON [12].

A WDM-PON is flexible to the signals or protocols, since it can accepts any type of signal format. Different types of transmission protocols, like Ethernet, BPON, EPON, SONET and others are use a WDM-PON as they physical layer. In order to satisfy this, the specification required by the selected protocol at the both sides ONU and the OLT receivers should be satisfied.

3.1.3. Options of Remote Node (RN)

The PON remote node (RN) may be consists of either a power splitter or a passive wavelength router. All input signals will be split equally to all output ports by a power splitter, this is need a wavelength filter placed at each ONU. The filter selection depends on important features like: uniformity, operating temperature, insertion loss and return loss. In spite of the splitter is a low-cost, division structure and simple, it needs different center wavelengths optical filters at ONU side. The signal loss happens with a splitter greater than with a wavelength router. The array wavelength grating (AWG) is a very successful device in WDM manufacture. It is very useful to be use in the long distance WDM systems as a demultiplexer /multiplexer device and as an add-drop multiplexer (ADM). It splitting various wavelengths at the same time and routes each particular wavelength to a single output port. It has a cyclic wavelength property which it makes it used as multiplexer and demultiplexer at the same time at RN. This is shown in Figure (2).

There is no need for an additional MAC protocol if every channel in the WDM PON runs separately from all the others. For example, if a wavelength is specified for an EPON channel, then only the MAC protocol of the EPON system can be used because of the other channels are not affected by this wavelength. It is developed to support dynamic capacity allocation and arbitrating the transmission of multiple ONUs. The protocol can assist both dynamic bandwidth allocation (DBA) and fixed slot allocation (FSA), but it best perform on DBA through its two-way messaging support.



(a) **(b)**

Fig. 2. property the cyclic wavelength of the AWG at RN: (a) unidirectional transceiver at ONU (b) bidirectional transceiver at ONU [13].

The loss of insertion of the AWG is about 4–5 dB (whatever the number of channels) is lower than the loss of the optical splitter, which its loss may be more than 0.5–1.5 dB added to the large 1:N splitting ratio loss. But with all these good properties, it is difficult to use the AWG in the RN of a WDM-PON because of the shift in its center wavelength of 0.01 nm/°C, where the RN is located in the sever temperature environment can be varied from -40°C to + 85°C. This temperature reliance due to the silica waveguide index change, which causes a change in the AWG circuit optical length [14].

3.2. WDM-PONS Protocols

Intelligent control containing service-level agreements (SLAs) can be considered as one of the major functions in WDM-PON, for high functionality and high efficiency. The intelligent control functions are composed of QoS control between multiple users and services, resource distribution among users, fault control, connection control including access authority control and multicasting to achieve secure access.

The OLT use a Dynamic Bandwidth Allocation (DBA) algorithm to achieve statistical multiplexing. The OLT complete this when each ONU transmit its bandwidth information to the OLT, then it will allocate the necessary resources based on that information [15].

3.3. WDM-PONS Services

The interchange of data, voice, and video on a one WDM-PON is looked forward to minimize the cost and also extend the new services production. From the viewpoint of services, there was an increasing demand on the Internet, companion with voice over IP (VoIP) and Virtual private network (VPN). These services needed fast bandwidth increasing, QoS for multimedia and high availability of network resources. These novel services will need secure, economic, reliable and much (may be symmetric) bandwidth. So, in the backbone, video networking middleware, scalable multicasting, storage networking technologies and advanced traffic engineering are desired. Having the true assemblage gives the possibility to access these services, and make WDM-PON more promising access technology [10].

4. WDM PON Modeling

Our modeling is performed and analyzed using OptiSystem software. Figure (3) shows the general simulation in OptiSystem software for two transmitters at the OLT with bit rate of 2.5 GB/s. This bit rate will be used throughout the design because if the network is working for this bit rate it will work for all other bit rates. Sequence length is 128 bits and the samples per bit is 64. These will make a total of 8192 samples and are important because it needs a large enough sequences for simulate the network at these high bit rates. Time window is 5.12e-08 with distance of 50 km.

In this proposed model, the two transmitters are transmitted with two different wavelengths 193.1 THz and 193.2 THz with 0.1 spacing. Each transmitter section consists of continuous wave (CW) laser input having power level of 0 dBm. The output of which is modulated by machzehnder modulator using a pseudo random bit sequence with NRZ format. For data transmission, the NRZ format is the most suitable data format can be used. Then the two signals are then combined using 1×2 WDM demultiplexor. All of these output signals of power splitters reach to the users at the receiving end. On the right hand side of ONU receiver should be low pass filter, photodiode, and a PIN photo detector in order to analyze the results [11].

To visualize waveforms, optical spectrum, eye diagrams etc. various measuring instruments like optical spectrum analyzer, BER analyzer and eye diagram analyzer must be used. The Q factor,BER and eye height are the most commonly used performance parameters.

We can defined the Q-factor as the parameter to measure the signal quality for determining the BER. The Q-factor is defined as [16]:

$$Q = \frac{m_{1-} \ m_0}{\sigma_1 + \sigma_0} \quad \text{…(1)}$$

Where m_1 , m_0 are the average value of the receiving signal at sampling instants when a logical 1 or 0 is transmitted and σ_1 , σ_0 are the standard deviations.

The bit error rate is defined as the percentage of error bits divided by the total number of transferred bits during a studied time interval. It is commonly expressed as ten to a negative power. The BER is an indication of retransmission a packet or other data unit when an error is occurred. Knowing the Q-factor, the BER can be estimated by [17]:

$$\text{BER} = \frac{1}{2}\,\text{erfc}\left(\frac{Q}{\sqrt{2}}\right) \quad \text{…(2)}$$

In eye diagram, the best time for sampling of a received waveform is when the height of eye opening as large as possible. Due to amplitude distortion in the signal the height gets reduced. The degree of distortion is defined by the vertical distance between the maximum signal level and the top of the eye opening. It is more difficult to distinguish between 1's and 0's in the signal when the eye closes more. The eye height is given by [17]:

$$E_H = (m_1 - 3\sigma_1) - (m_0 - 3\sigma_0) \quad \text{…(3)}$$

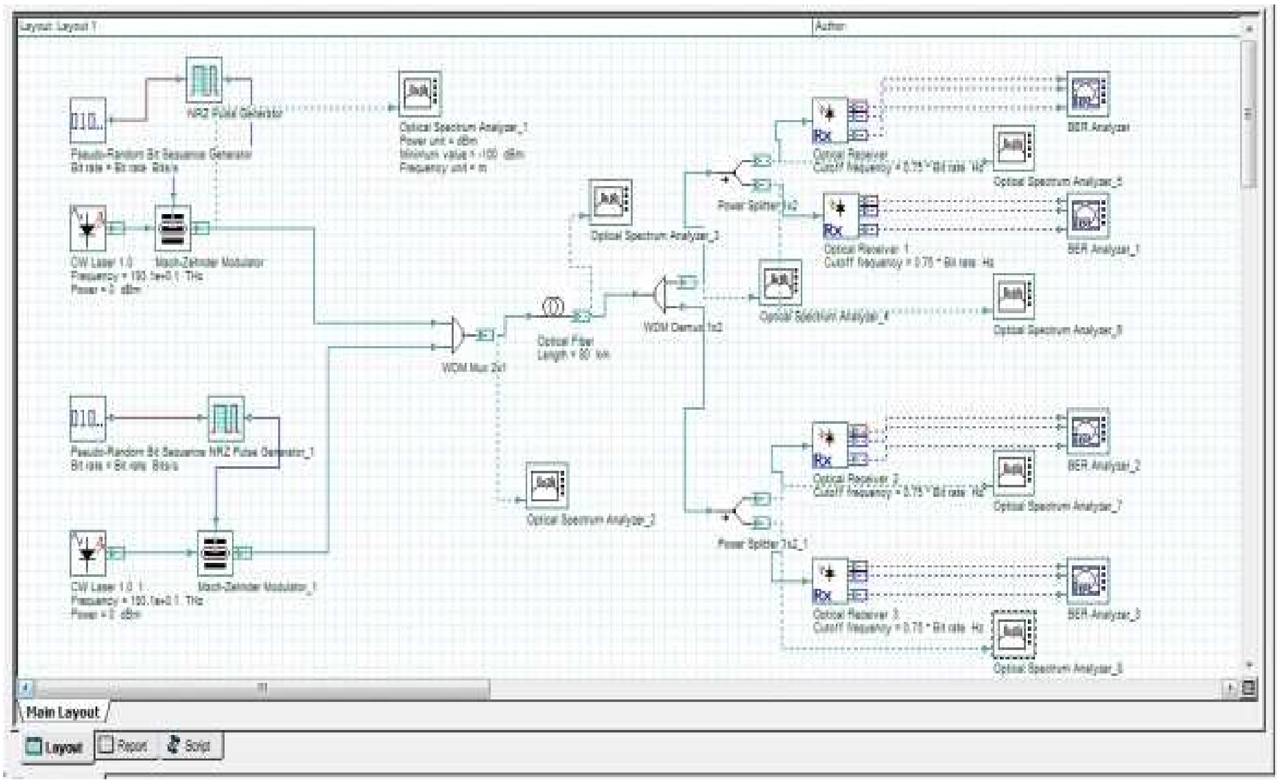


Fig. 3. Simulation Setup for WDM PON system in OptiSystem Software.

5. Results and Discussion

The simulation is done using OptiSystem 7.0. From the results it is obvious that the system implements the basic functions of WDM systems. In the existing experiment, it can be understand by properly fitting the parameters of each component in order to get better experimental results. After the combined, Figure (4) shows the frequency spectrum for the WDM signal. Then after demultiplexing the two channels, Figure (5) shows the frequency spectrum of each channel.

Eye diagram can describe the quality of the received signal. In the absence of noise and for error-free transmission, the eye must be kept some large vertical opening, or otherwise it will exist interference between symbols which will be a reason for errors. When the eye is not fully closed, the interference value between symbols minimize the value of allowable additive noise. Therefore, the higher vertical opening means the greater immunity to noise.

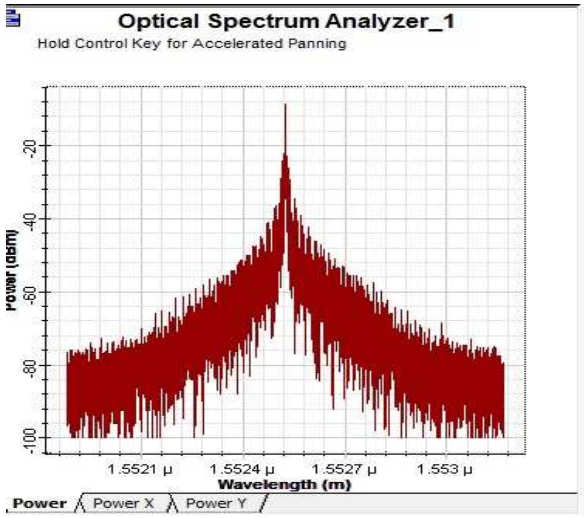


Fig. 4. Multiplexed signal spectrum after the WDM mux.

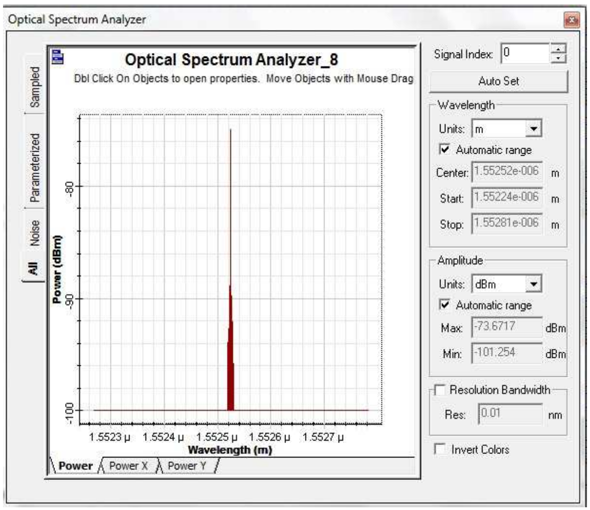


Fig. 5. Spectrum analysis after demultiplexing.

The performance of WDM PON is done using optisystem software. The analysis results is obtained for two cases. In the first case the system performance is tested when distance is 50km with three values of bit rate 10^8, 10^9 and 10^{10} respectively. While in the second case the bit rate is 10^9 but distance is varied as 20km, 50km and 80km respectively. These two cases have been described below:

Case 1- Bit rate is varied

Figures (6), (7), (8) show the WDM passive optical network system eye diagrams after using NRZ modulation format at different data rate 10^8, 10^9 and 10^{10} respectively for the same distance of 50 km. The red line in figure shows curve for quality factor.

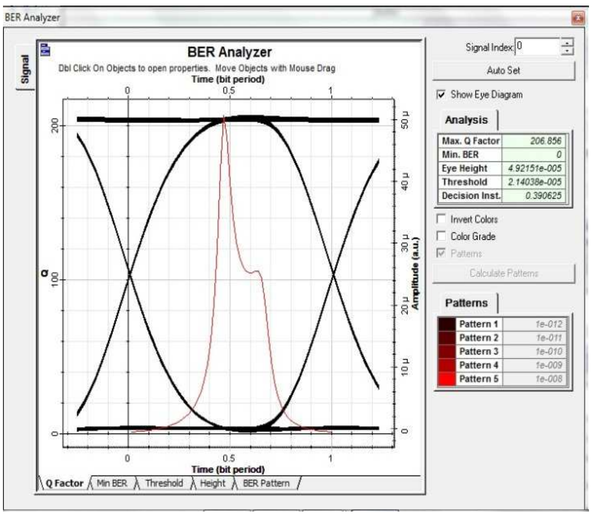


Fig. 6. Eye Diagram of WDM PON at 50 km with Bit Rate 10^8.

It is obvious from the diagram that when the bit rate is increased, the eye height and quality factor decreases and BER increases as shown in Table 1. From graphs also, we observe that the eye height and quality factor is decreasing with the increase in the bit rate.

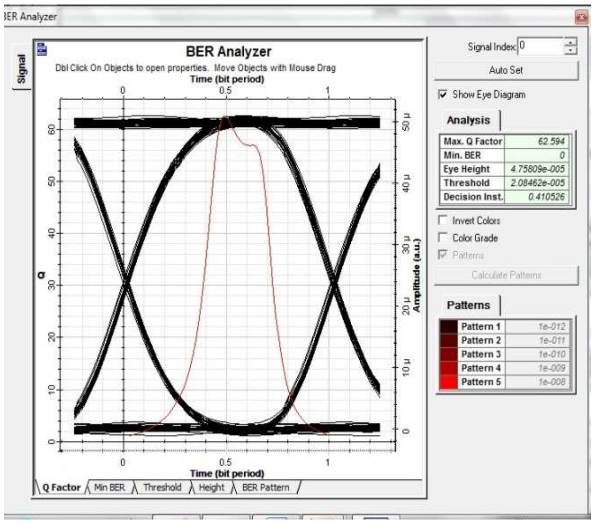


Fig. 7. Eye Diagram of WDM PON at 50 km with Bit Rate 10^9.

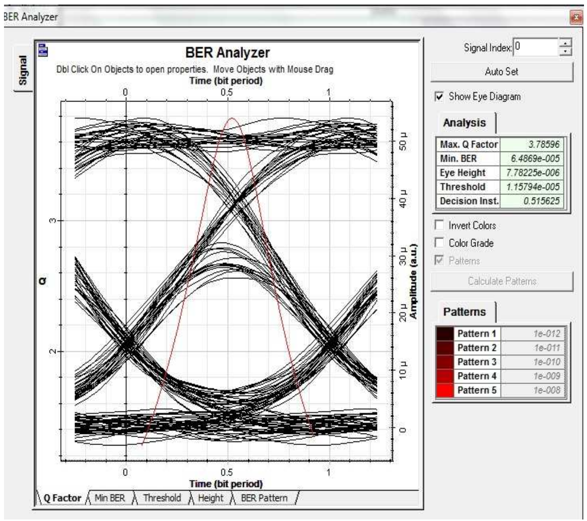


Fig. 8. Eye Diagram of WDM PON at 50 km with Bit Rate 10^{10}.

Table 1
Comparison of parameters for different bit rate.

Bit Rate	Q - Factor	BER	Eye Diagram
10^8	206.856	0	4.92151e-005
10^9	62.594	0	2.75809e-005
10^{10}	3.78586	6.4869e-005	7.78225e-006

Case 2- Distance Varied

Figures (9), (10), (11) show the eye diagrams of WDM passive optical network systems using NRZ modulation format at 20, 50 and 80 km distance respectively. The red line in figure shows curve for quality factor. It is observable from the figures that when the distance is increased for same data rate 10^9 and for two transmitters at OLT, then the quality factor and eye height decreases and BER is increasing.

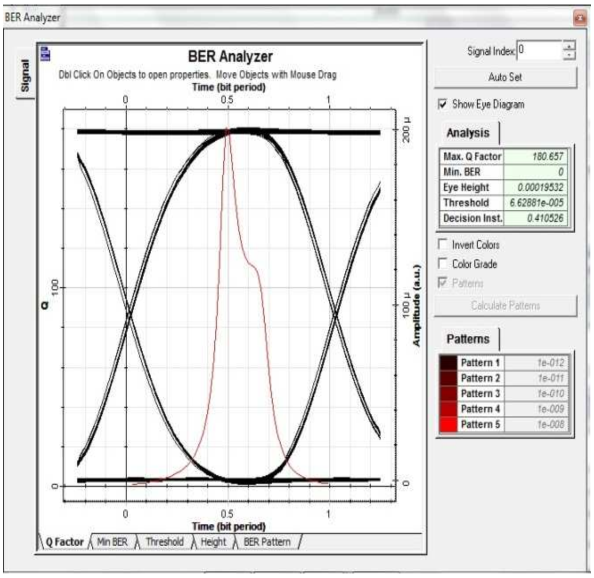


Fig. 9. WDM PON Eye Diagram Bit Rate 10^9 at 20 km.

We observe from the graph that the eye height is decreasing with the increase in the distance. Due to this, the receiver is unable to detect the bit correctly whether it is logical 1 or logical 0. The different values measured are shown in Table 2.

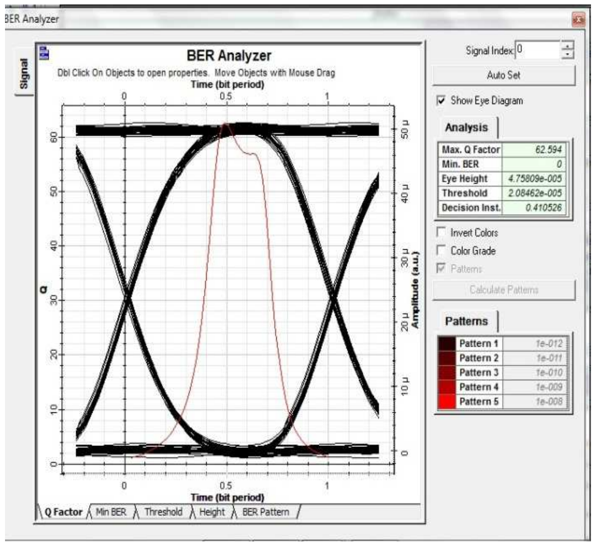


Fig. 10. WDM PON Eye Diagram Bit Rate 10^9 at 50 km.

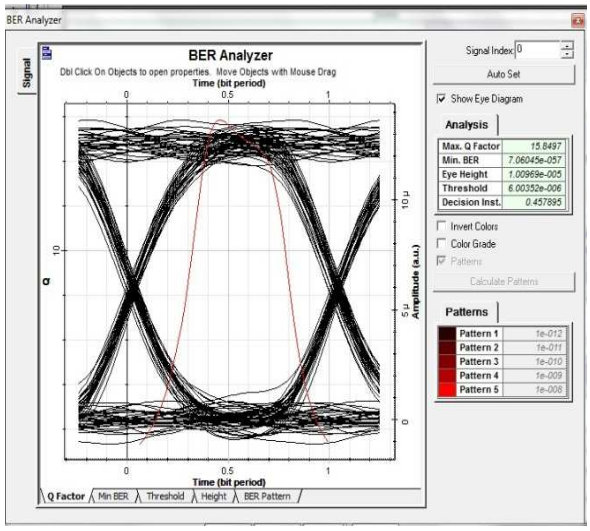


Fig. 11. Eye Diagram of WDM PON Bit Rate 10^9 at 80 km.

Table 2
Comparison of parameters for different distance.

Distance (km)	Q - Factor	BER	Eye Diagram
20	180.657	0	0.00019532
50	62.594	0	4.75809 e-005
80	15.8497	7.06045e-057	1.00969 e-006

6. Conclusion

The optical transmission system presented here has been modeled by using OptiSystem simulator as shown in Figure (4) in order to study the effect of different parameters on the system. The user can transmit the data of different wavelengths through the same fiber. We have analyzed the performance of WDM passive optical network and compared the various parameters in two cases. The first case with varied bit rate and constant distance, and the second case with varied distance and constant bit rate.

The choice of optical fiber as transmission medium allows guaranteeing longevity of the network during the coming years. The logical and physical design of the same establishes optimal conditions for the current implementation of the system but also offer the possibility of future expansion. It has been observed that BER increases with the increase in data rate and distance and the quality factor and eye height decreases. The specified equipment will be valid for migration to future standards as 10GPON, DWDM and other technologies that improve the performance of optical fiber and provide the best possible performance.

List of Abbreviations

ADM	add-drop multiplexer
APD	Avalanche Photo Diode
APON	ATM-PON
ATM	Asynchronous Transfer Mode
AWG	Arrayed Waveguide Grating
CATV	Community Antenna Television
CDR	Clock and Data Recovery
CW	Contiuouse Wave
CWDM	Coarse WDM
DBA	Dynamic Bandwidth Allocation
DSL	Digital Subscriber Line
DWDM	Dense WDM
EPON	Ethernet Passive Optical Network
FTTC	Fiber To The Curb
FTTH	Fiber To The Home
FTTP	Fiber To The Premises
GPON	Gigabit-PON
MAC	Media Access Control
NRZ	Non Return to Zero
OLT	Optical Line Terminal
ONU	Optical Line Unite
PD	Photo Detector
PIN	Positive Intrinsic Negative
PON	Passive Optical Network
QoS	Quality of Service
RN	Remote Node
SLA	Service Level Agreements
SONET	Synchronous Optical Network
TDMA	Time Division Multiple Access
VDSL	Very High bit-rate DSL
VoIP	Voice over Internet Protocol

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نمذجة شبكة نفاذ الكيبل الضوئي العاملة بتقنية الاطوال الموجية باستعمال نظام محاكاة الانظمة البصرية (WDM PON)

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الخلاصة

بسبب الطلب المتزايد لكميات كبيرة من النطاق الترددي اصبح استخدام الاتصال بوساطة الالياف الضوئية وسيلة مهمة ورئيسة في شبكات النفاذ. وبفضل استعمال تقنيات الالياف الضوئية اصبحت البنية التحتية للاتصالات اكثر متانة واكبر سرعة في نقل كميات كبيرة جدا من المعلومات وفي زمن قصير جدا. تعد شبكات نفاذ الكيبل الضوئي المعتمدة على تقنية توزيع الاطوال الموجية واسعة الانتشارفي البنى التحتية للاتصالات السلكية واللاسلكية القائمة ويتوقع لها ان تؤدي دورا مهما في شبكات الجيل المقبل ودعم مجموعة كبيرة ومتنوعة من خدمات الانترنيت.

في هذا البحث تم تصميم شبكة نفاذ الكيبل الضوئي المعتمدة على تقنية توزيع الاطوال الموجية باستعمال نظام محاكاة OptiSystem 7.0. ومن خلال النتائج التي تم التوصل اليها تم استعراض وتحليل ثم تقويم اداء النظام عند مرور الاشارة من خلال الالياف الضوئية وبكلا الاتجاهين، وايضا خلال مرورها بالموصلات الضوئية والمقسم ومن ثم الموزع وصولا الى المستلم. وقد تم تحليل هذا النظام باستعمال اكثر المُعلمات اهمية لتحليل هكذا انظمة مثل قياس معدل الخطأ الحاصل بنقل البيانات (BER) ومخطط العين (Eye Diagram).