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Performance Analysis of an Optical Gigabit Ethernet

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Abstract

The optical fiber is a very attractive communication medium since it offers a large bandwidth and low attenuation, and can therefore facilitate demanding services such as high-quality video transmission and others in computer networks. In this paper, a performance analysis of an optical gigabit ethernet performance using longer wavelength (C-Band) instead of O and E bands, and high Extinction Ratio (Er) value is presented. This performance analysis is represented by decrease the bit-error rate (BER), increase the number of nodes in the network, and increase the backbone cable length. Simulation results show improvement in the performance of the network when using 1550nm wavelength over the 1330nm wavelength for 1Gbps and 10Gbps. In addition, the results are compared for different values of Er where, higher values of Er give better performance. The work is software implemented using optical system simulator packet (OPTSIM 3.6) .

Keywords: Optical Network, Optical communication, Gigabit Ethernet, BER, Extinction Ratio

تحليل أداء إيثرنت جيجا بايت بصرية

الخلاصة:

أصبحت الألياف البصرية من وسائط الاتصالات الأكثر شيوعا والأفضل استخداما نظرا لما تمتاز بها من اتساع وكبر عرض الحزمة ومن قلة الفقدان والتوهين. وبهذا أصبحت هذه الألياف تلبي حاجات وخدمات الإرسال ونقل الصور والفيديو ذات الدقة العالية والحجم الكبير في شبكات الحاسبات. في هذا البحث تم تحليل أداء شبكة الايثرنيت البصرية باستخدام الأطوال الموجية الواقعة ضمن الحزمة (C) بدلا من الأطوال الموجية الواقعة ضمن الحزمة (O , E)، مع اختيار قيم عالية من نسبة الانقراض (Er) والتي تمثل نسبة القدرة المرسلة للبت "1" إلى نسبة القدرة المرسلة للبت "0".

نتائج المحاكاة في هذا البحث بينت تحسن في أداء الشبكة باستخدام الطوال الموجي 1550nm الذي يقع ضمن الحزمة (C) نسبة إلى الأطوال الموجية التي تقع ضمن الحزمة (O , E) وتم اختيار الطول الموجي 1330nm لغرض المقارنة عند قيم 1Gbps , 10Gbps. بالإضافة إلى ذلك تمت مقارنة النتائج لقيم مختلفة من نسب الانقراض حيث تبين أن القيم العالية تعطي أداء أفضل. تم إنجاز هذا العمل باستخدام برنامج المحاكاة OPTSIM 3.6

الكلمات الدالة: شبكات بصرية، إتصالات بصريةة، جيجابيت إيثرنت، نسبة الخطأ في البت، نسبة الانقراض

Introduction

Networks are being converted from copper to optical fiber at an increasing rate. As a result, network designs procedures needs to be adjusted to address the specific requirements of fiber optic cable as a communication transport media. The use and demand for optical fiber has grown tremendously and optical-fiber applications are numerous [1]. Telecommunication applications are widespread, ranging from global networks to computers desktop. These involve the transmission of voice, data, or video over distances of

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less than a meter to hundreds of kilometers using one of few standard fiber designs in one of several cable designs. Optical fibers have two very attractive properties which are : the attenuation is very low, hence large distances can be covered, and the bandwidth is very large. Therefore, optical transmission has taken over in the backbone networks during the last decade and is continuously being deployed closer to the edge of the networks.

Optical gigabit ethernet solutions have become a necessity with the accelerating growth of local area network (LAN) traffic, pushing network administrators to look for higher speed network technologies to meet the demand for more bandwidth.

While most copper systems will support gigabit ethernet, fiber optics provide a much higher degree of flexibly and future bandwidth expansion as opposed to its copper counterparts. Generally, copper will support gigabit and multi-giga transmission rates, but only for very short distances. Copper is affected by electromagnetic interference (EMI) and radio frequency interference (RFI). Fiber optics will support Gigabit and multi-giga transmission for both short and long distances, with immunity to EMI and RFI, making fiber a more suitable solution for a number of applications [2,3]**.** Depending on the fiber type and core size, gigabit ethernet applications supported by fiber optics are now transmitting signal reliably at 10Gbps, up to 80km using single mode systems, and well over that for gigabit and multi-giga transmission rates. While fiber optics provide some clear advantages over copper legacy technology, most systems using fiber today also use copper at the end user point, creating a hybrid system for data transmission. The advantage in utilizing a hybrid system exists by leveraging the bandwidth and preventing the EMI and RFI effects when using fiber optic for the longer length and main distribution legs of the network. Using copper for the very short desktop and non-backbone connectivity allowing a very easily routable and inexpensive connectivity solution without implementing desktop media converters [4,5]**.**

Fiber Optic Network Topologies and Gigabit Ethernet

All networks involve the same basic principle, information to be sent to, shared with, passed on, or bypassed within a number of computer stations (nodes) and a master computer (server). Network applications include local area network (LAN), metropolitan area network (MAN), wide area network (WAN), storage area network (SAN), intrabuilding and interbuilding communications, broadcast distribution, intelligent transportation systems (ITS), telecommunications,… etc. In addition to its advantages (i.e. bandwidth, durability, ease of installation, immunity to EMI/RFI and harsh environmental conditions, long-term economies,... etc.), optical fiber accommodates better today's increasingly complex network, architectures than copper alternatives [6]**.** Fig. 1 shows the interconnection between these types of networks.

Gigabit ethernet standard describes 1Gbps data transmission over both copper-based and optical fiber media. There are two fiber optic standards, namely 1000BASE-LX of 1330nm wavelength and 1000BASE-SX of 850nm wavelength. Gigabit ethernet appeared as the extension to the existing ethernet and fast ethernet standards. Interest in introducing this standard came from the fact that computer speed is increased such that transferring the files among computers and servers became a bottleneck. Moreover, video conferencing demands more bandwidth than the existing local area networks support [7].

The design objectives for gigabit ethernet is to offer 10-fold increase in bandwidth with respect to the fast ethernet standard (100Mbps) to support both full and half-duplex operation and to be compatible with the previous Ethernet standards. To achieve this, most changes have to be made in the physical layer [8,9].

Three different standards are specified depending on the types of media used to transmit data, namely 1000BASE-SX, 1000BASE-LX and 1000BASE-CX [2,8]. The main difference with respect to the previous Ethernet standards are introducing carrier extension and frame bursting. Carrier extension is introduced due to collision detection. Recall that the minimum time to detect a collision is the time, it takes the signal to propagate from one end station to another (Slot Time). But increasing the speed requires proportional decrease in the network span. Keeping in mind that the maximum network span for the ethernet network is 2.5 km, increasing the speed 100 times would limit the span of gigabit ethernet network to about 25 m only [10].

Design Fiber Optic Systems

The first step in designing of fiber optic network or system is making careful decisions based on operating parameters that are applied for each component of a fiber optic transmission system[11]. The system design parameters are listed in Table 1. Transmission distance affects the strength of the transmitter optical output power, which dictates the type of light source used. It impacts fiber type, as a single-mode fiber which is better suited to long distance transmission. Transmitter and fiber type dictate receiver type and sensitivity. Transmission distance also dictates the modulation scheme as some are better for longer distances than others. While designing a system can be complex, several techniques simplify this process. One such technique is used to determine the link's optical loss budget, which evaluates the transmitter output power, the operating wavelength, fiber attenuation, fiber bandwidth, and receiver optical sensitivity [12].

A sensitivity analysis determines the minimum optical power that must be received in order to achieve the required system performance. The receiver sensitivity can be affected by source intensity noise, inherent to the light source being used, fiber noise, inherent to the optical fiber, receiver noise, inherent in the detector used, time jitter, intersymbol interference, and bit-error rate [13,14].

In this paper, an OPTSIM 3.6 simulation software program is used to design, build, and simulate the optical network. The aim of this paper is to analyze the performance of an optical gigabit ethernet under different values of Extinction ratio (Er) and different values of wavelength. This simulation is one of the best software uses for simulating the optical network and optical communications system.

Using this simulation program, different optical communication system or different optical network topology can be simulated. Using this simulation program enables measuring the bit error rate (BER), signal to noise ratio (SNR), optical signal to noise ratio (OSNR), Q-Factor, optical power transmitter and receiver, electrical power transmitter and receiver and Eye diagram. From these measurements, studying, analyzing, and estimating the performance of an optical network system can be done. In addition, it is able to use different kinds of components such as optical transmitter source with different wavelength bands that included laser diode, data source, modulator and driver. Optical receiver included photo detector such as PIN, PN and avalanche photo diode (APD) with different wavelength bands. Also one can use different kinds of fiber optic single-mode or multi-mode. Values and details of all components used in this work are shown in Table. 1 . After choosing the type of optical source, optical receiver, and fiber optic, selection and specification of parameters of these components from the simulation program such as power transmitter, data source, wavelength, type of modulation and code, quantity of Extinction ratio, optical receiver sensitivity, dark current, type of fiber include attenuation and dispersion are made. After implementing the system and running the simulation program, several measurement are obtained such as optical power receive, BER, Q-factor, electrical power receive, OSNR and Eye diagram.

From the received power, the power budget is obtained. The power budget can be defined by the following Equation[8]**:**

$$powerbudget = Ptx / P\min - - - - - (1)$$

Where: Ptx is the power transmitter
Pmin is the minimum power received

From Equation (1), the power budget equals the ratio of the transmitted power to minimum power received needed to perform the required operation under the bit rate transmitted, and BER. From the power budget, the attenuation and total loss permitted in the transmission link will be known, and this total attenuation represents the attenuation in the fiber optic expressed in (dB/km), in addition to the coupling loss resulted from the connection of the node to the link as shown in Equation (2).

$$\alpha_{fiber} L + \alpha_{coupling} N \le powerbudget[dB] (2)$$

Where α_{fiber} is loss in fiber
L fiber length
$\alpha_{coupling}$ coupling loss
N number of nodes

Equation (2) shows that the power budget depends on the length of fiber optic used (segment length L), and number of nodes in the network (N).

In the simulation program, the bit rate, fiber length, wavelength, Er, optical power transmitter and others can be changed. Extinction Ratio (Er), that is defined as the ratio of power to transmit a "1" symbol to the power to transmit a " 0 " symbol, (Eq.3) [8] ia an important factor which affected the performance of optical gigabit Ethernet.

$$Er = P1/P0 \text{ ----------------------------- } (3)$$

The greater the distance between P1 and P0 is the easier for the receiver to distinguish a one from a zero.

Unfortunately, building transmitters with a high Er is more challenging and costly. In practice, transmitters are always on, even when transmitting is zeros, and the higher is P0 (and the lower is P1) the easier and less expensive is the design of the transmitter. Then to get the best performance in the optical communication network Er have to be high.

Simulation and Analysis Results

This section shows the performance of the optical gigabit ethernet using optical system simulator program (OPTSIM 3.6) to build an optical gigabit Ethernet node (transmitter and receiver), as shown in Fig.(2). This figure shows a generic optical networks system from source to destination (physical layers) consisting of an optical transmitter, that consists of an optical source, a modulator, data source, NRZ driver, fiber optic as a communication channel, and an PIN as optical receiver. This system is build using optical simulation package (OPTSIM), and the results are obtaind from this simulator program.

An enhancement improvement in bit-error rate (BER) in optical gigabit ethernet can be obtained by using longer wavelength (C-band 1550 nm) instead of 850nm and 1330 nm wavelength that are used in 1000BaseSX and 1000BaseLX, respectively. Figs. (3& 4) show the optical power transmitted versus maximum number of nodes connected in the network over fiber backbone to achieve the same BER (10e-10) at 1Gbps and 10Gbps at different wavelengths (1330nm, 1550um) on the same quantity optical power transmitted (0dBm). These figures clearly show tat the number of nodes are increased when using longer wavelength on the same value of optical power and in the same fiber optic length (2km). On the other hand the number of nodes will decrease when the bit rate is increased.

Figs. (5 & 6) show the cable length versus maximum number of nodes to achieve the same BER (10e-10) at 1Gbps and 10Gbps, and at different wavelength (1310nm, 1550nm). When the specified transmitted power at (1mw) 0dBm, the number of nodes (users) is decreased when the cable length is increased, but at wavelength (1550nm) more nodes are obtained as comared with that obtained when using wavelength (1310nm).

Fig. (7) shows the bit rate versus maximum number of nodes at wavelength of (1330nm and 1550nm respectively), where BER is (10e-10). This figure shows that the use of 1550 nm is better at high bit rate to increase the number of users connected to the network, or to increase the cable length between the nodes, or to decrease the number of repeater on the network.

Fig.(8) shows typical oscilloscope Eye diagram measurement of Er. From this figure it is evident that high Er gives the clean Eye diagram. This means that the system can easily and clearly detect the transmitted bits, and distinguish between 0 and 1 bits as compared with the lower Er.

Fig. (9) shows the optical power transmitted versus maximum number of nodes at wavelength (1330nm and 1550nm respectively), under different values of Er (5 and 7). This figure clearly shows the advantage of using high Er value on the network performance. Here the number of nodes (users) is increased by four.

Fig. (10) shows the optical power received versus the bit error rate (BER), under different values of Er (5 , 7 and 9), and different wavelength bands. Low values and rapid decrease of BER are obtained for using 1550nm wavelength (C-band) with high Er. One can get BER equal to (10e-18) when using wavelength of 1550nm with Er 9 at power received of 48dBm, while BER equal to (10e-6) when using the same wavelength of 1550nm with Er. 5 at the same power received of 48dBm. Then the high value of the Er is the best for enhancement the performance of optical gigabit ethernet. On the other hand, one can get BER equal to (10e-15) when using wavelength of 1550nm with Er. 7, while BER equal (10e-3) when using the same wavelength value with Er 3 , as shown in Fig. 11**.**

Conclusions

1. The obtained results from this simulations program (OPTSIM 3.6) indicated and showed the advantages and benefit of using longer wavelength (C-Band) 1550nm for

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optical transmitter at 1Gbps and 10Gbps.

2. Extinction Ratio(Er) ia an important affecting factor. It affects the performance of optical gigabit Ethernet. High Er is better than lower Er.

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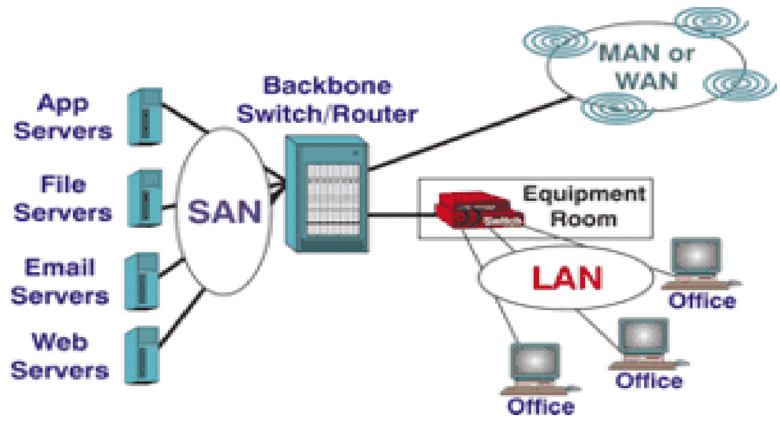

Fig.(1) Interconnection Between Different Network Types

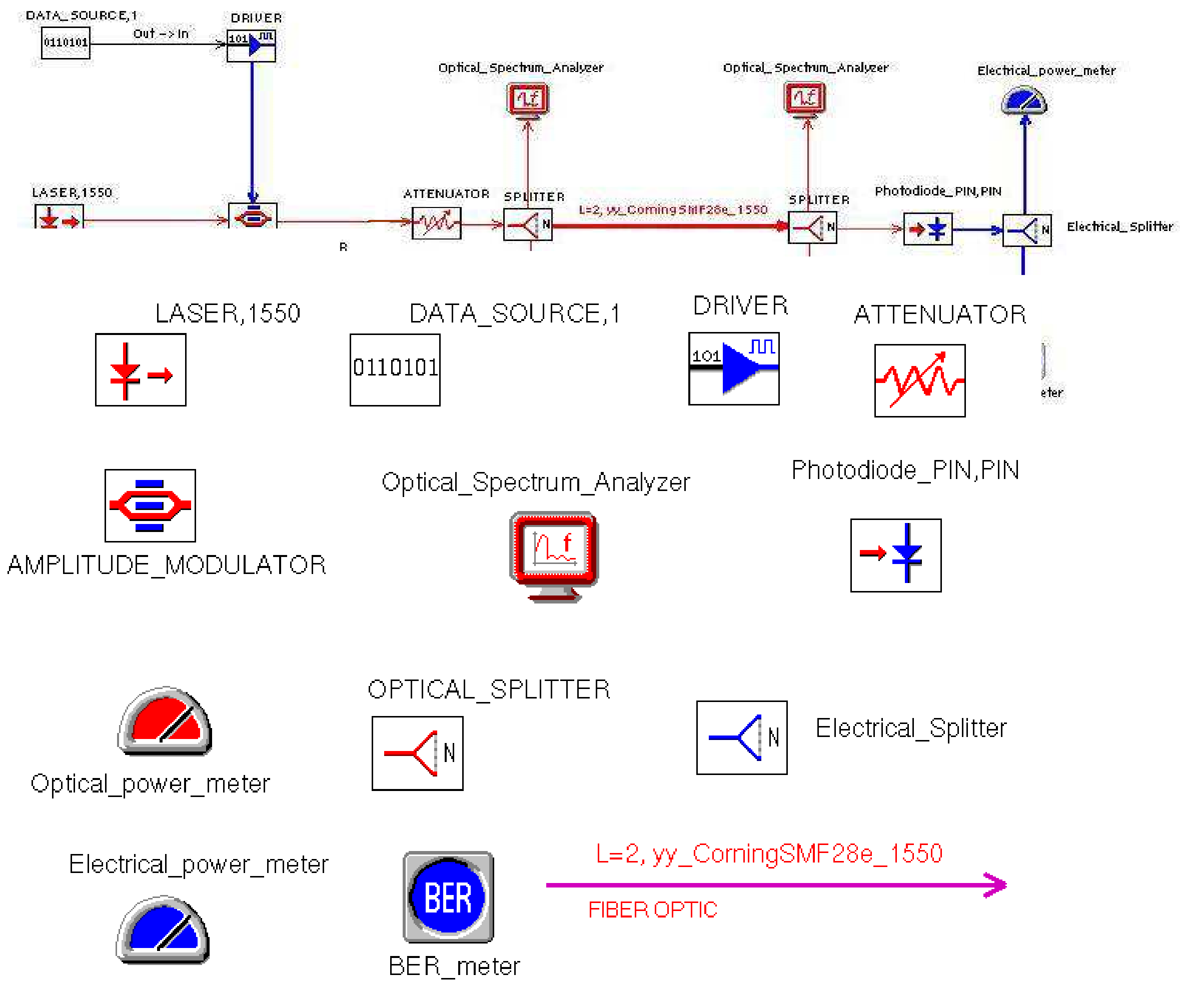

Fig. (2) Connection from a source to a destination (physical layers)

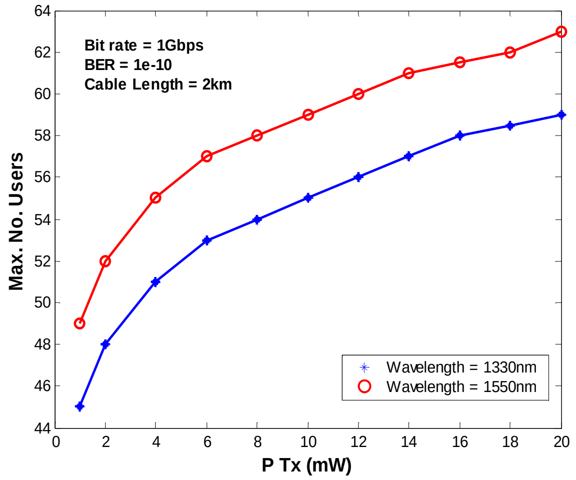

Fig. (3) Power transmitted versus maximumnumber of nodes at 1Gbps

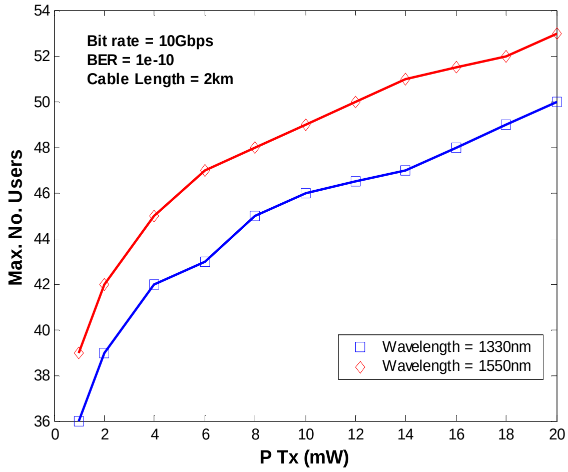

Fig. (4) Power transmitted versus maximum number of nodes at 0Gbps

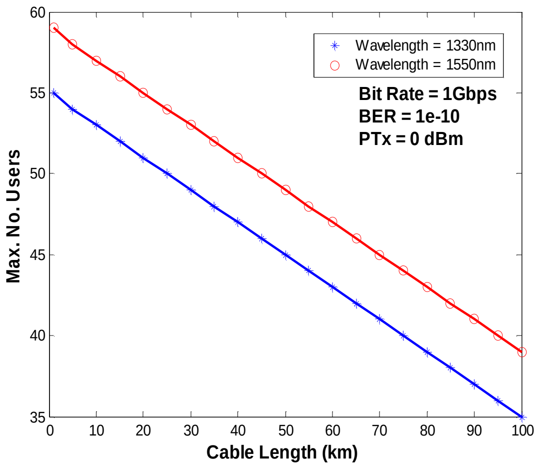

Fig. (5) Cable length versus maximum number of nodes at 1Gbps

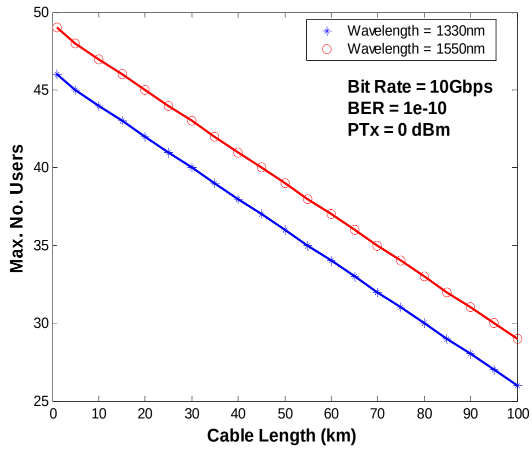

Fig. (6) Cable length versus maximum number of nodes at 10Gbps

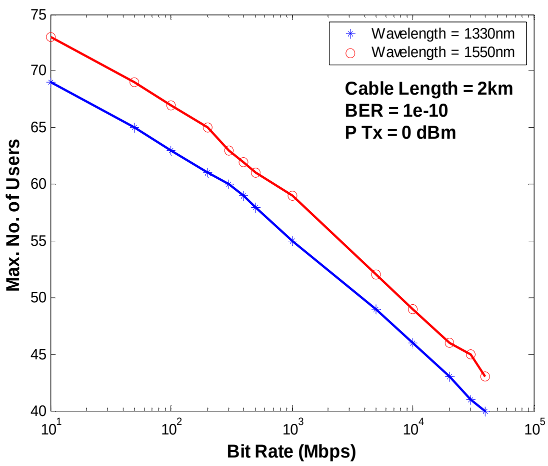

Fig. (7) Bit Rate versus maximum number of nodes

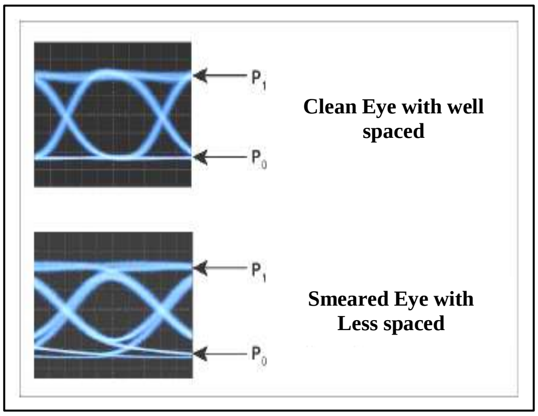

Fig. (8) Typical oscilloscope Eye diagram measurement of Er

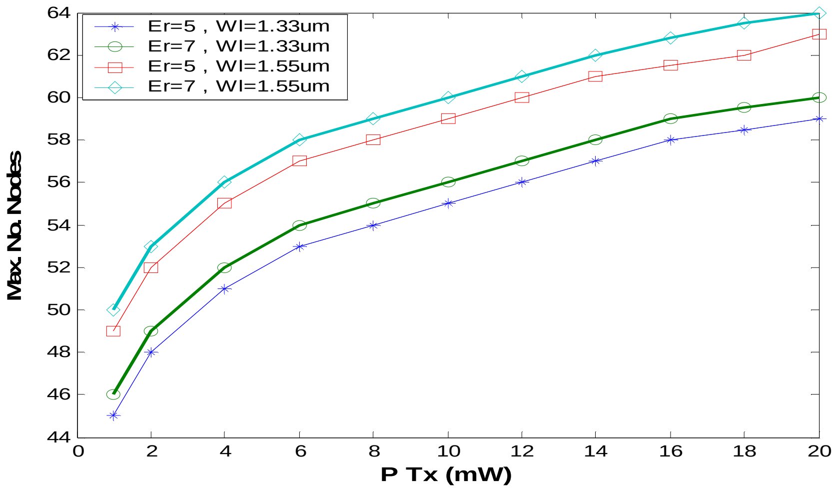

Fig.(9) Power transmitted versus maximum number of nodes at different Er. and wavelength

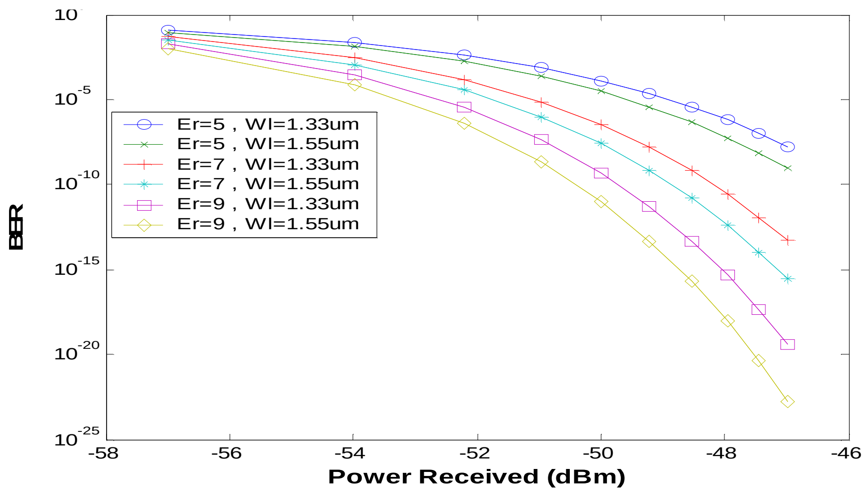

Fig.(10) Power received versus BER at different Er. and wavelength

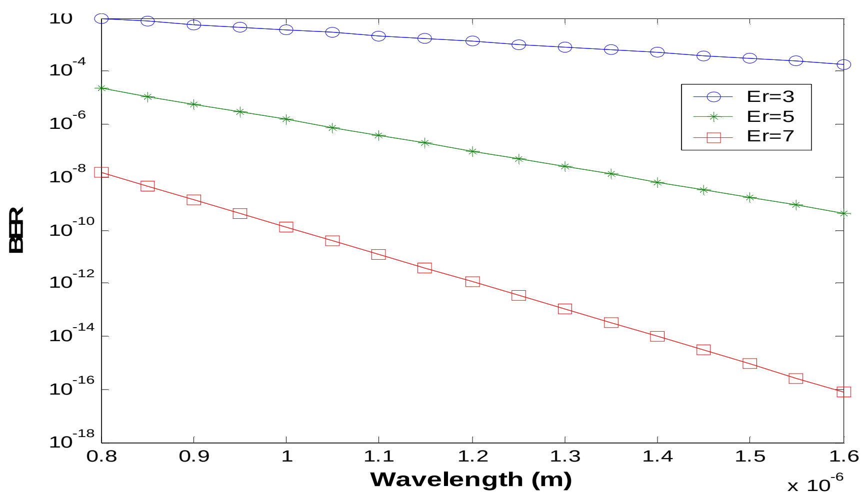

Fig.(11) Wavelength versus BER at different Er.

Table 1: System Design Parameters that are used in Simulation

System Factors	**Values**
Transmission Distance	2 km --100 km
Types of Optical Fiber	Single mode
Fiber Dispersion	0.1 ps/nm/km @ 1550
Fiber attenuation	0.02 dB/km
Operating Wavelength	1330 nm, 1550nm
Transmitter Optical Power	1 mW – 20 mW
Source Type	Laser diode
Receiver Quantum Efficiency	0.8
Receiver Responsivity (at reference frequency)	0.9A/W
Detector Type	PIN diode
Receiver Dark Current	0.15 nA
Receiver Reference Wavelength	1550 nm
Bit error rate (BER)	10^{-10}
Bit Rate	1 Gbps , 10Gbps
Transmitter Laser Line Width (FWHM)	10 Mhz
Channel Coding	NRZ
Receiver Single-Pole Electrical Filtering (-3dB Bandwidth)	2 GHz
Source Reference Wavelength	1550 nm
Extinction Ratio	3, 5, 7 and 9
Number of Connectors or Splices in the System	Depending on number of nodes (users) in the system
Splice Joint loss	0.1 dB