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Simulation and Evaluation of Ethernet Passive Optical Network

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Abstract

This paper studies simulation and evaluation of Ethernet Passive Optical Network (EPON) system, IEEE802.3ah based OPTISM 3.6 simulation program. The simulation program is used in this paper to build a typical ethernet passive optical network, and to evaluate the network performance when using the (1580, 1625) nm wavelength instead of (1310, 1490) nm that used in Optical Line Terminal (OLT) and Optical Network Units (ONU's) in system architecture of Ethernet passive optical network at different bit rate and different fiber optic length. The results showed enhancement in network performance by increase the number of nodes (subscribers) connected to the network, increase the transmission distance, reduces the received power and reduces the Bit Error Rate (BER).

Keywords: Optical Communications, Optical Networks, Passive Optical Network

محاكاة وتقييم شبكة الإيثرنت الضوئية الخاملة

الخلاصة

يدرس هذا البحث محاكاة وتقييم شبكة الإيثرنت الضوئية الخاملة باستخدام برنامج محاكاة (OPTSIM 3.6). حيث تم بناء شبكة إيثرنت مثالية ضوئية خاملة، لغرض تقييم أداء الشبكة باستخدام الأطوال الموجية (1580,1625)nm بدلا من الأطوال الموجية (1310,1490)nm التي تستخدم في المحطة الطرفية الضوئية من جهة و وحدات الشبكة الضوئية من جهة أخرى في معمارية نظام شبكة الإيثرنت الضوئية الخاملة حيث تم تقييم الأداء لقيم مختلفة من البيانات ولمسافات عديدة من الألياف الضوئية . بينت النتائج تحسينا في أداء الشبكة بالزيادة عدد العقد (المستخدمين) في الشبكة، زيادة مسافة الإرسال (طول الكيبل الضوئي)، نقصان في القدرة المستلمة وانخفاض في نسبة الخطأ في البيانات المرسلة.

الكلمات الدالة: الاتصالات الضوئية، الشبكات الضوئية ، شبكة الايثرنيت الضوئية الخاملة

Notations

ATM Asynchronous Transfer Mode
APON Asynchronous Transfer Mode Passive Optical Networks
BER Bit Error Rate
CO Central Office
$D_{chromatic}$ Fiber Chromatic Dispersion
D_{PMD} Polarization Mode Dispersion
DSL Digital Subscriber Line
EFMP Ethernet in the First Mile Passive Optical Networks
EPON Ethernet Passive Optical Network
FTTB Fiber to the Building
FTTC Fiber to the Cabinet
FTTH Fiber to the Home
IP Internet Protocol
L Fiber Cable Length
MPCP Multi- Point Control Protocol
N Number of Nodes
ODN Optical Distribution Network
OLT Optical Line Terminal
ONU's Optical Network Units
OPTSIM Optical System Simulator Program
P2PE Point-to-Point Emulation
Pmin Minimum Power Receive
PONs Passive Optical Networks
POP Post Office Protocol

Ptx Power Transmitter
SDH Synchronous Digital Hierarchy
SNR Signal To Noise Ratio
SONET Synchronous Optical Network
T_{fiber} Fiber Response Time
$T_{receiver}$ Receiver Rise Time
$T_{transmitter}$ Transmitter Rise Time
VSAT Very Small Aperture Terminal
WAN Wide Area Network

Latin Symbols

$\alpha_{coupling}$ Coupling Loss
α_{fiber} Loss in Fiber
$\Delta\lambda$ Fiber Attenuation

Introduction

Over the years, optical networking and communication systems have been seen as one of the attractive solutions to the increasing high data rate in telecommunication systems [1]. Internet and multimedia applications require high gigabit bandwidths over distances of hundred of meters, larger bandwidth, shorter interconnection delays. By using digital fiber optics, signal consistency is guaranteed over the entire transmission path. [2]

The very speed and quality of optical communications systems has itself predicated the development of a new type of electronic communications itself designed to be run on optical connections. Ethernet passive optical network, optical gigabit ethernet, Asynchronous Transfer Mode (ATM) and Synchronous Optical Network (SONET) technologies are good examples of the new type of systems. There are another unique property of fiber optic transmission is its security. Fiber does not radiate any of the signals it communicates the way copper based transmissions do. The main advantage of optical fiber is that it can transport more information longer distances in less time than any other communications medium. In addition, it is unaffected by the interference of electromagnetic radiation, making it possible to transmit information and data with less noise and less error. [3]

Loss budgets and transmission capacity or bandwidth is very important and crucial in single and multi-channel optical system. One calculate loss budget to be sure that enough signal reaches the receiver to give adequate performance. Like wise, you must calculate pulse dispersion, or bandwidth, to be sure the system can transmit signals at the proper speed. The performance of a digital transmission system can be calculated by its bit rate distance product, i.e. the transmitter-receiver spacing that is feasible at the desired bit rate. Many parameters influence this system performance; foremost are the available transmitter power, the required input power at the receiver to obtain the desired bit error rate (BER), and the overall system loss and bandwidth. The received power is naturally related to the power launched into the fiber waveguide by the transmitter and the losses encountered as the optical signal passes through fibers, connectors, and splices. Bandwidth is determined by the fiber and the type of optical source used. The difference between the transmitter power and the receiver sensitivity (at the desired BER) defines the optical link power budget. In order to maintain the specified BER, the insertion loss between the optical source and detector must not exceed the power budget value.

In this paper, a simulator program OPTSIM 3.6 is used to simulation and evaluation ethernet passive optical networks system. Also this paper presented the power budget, rise time budget (bandwidth capacity), fiber optic link length and preference of used wavelength for transmission under condition design, calculate and estimate the maximum number of nodes (subscriber) that can be access or be connected to the network, minimum power required at the receiver. Additional, a performance analysis of ethernet passive optical network at wavelength 1580nm, 1625nm instead of 1310nm, 1490nm respectively is presented.

Fiber Optics System Design

The fiber optic system is similar in concept to any type of communication system. The information source provides an electrical signal to a transmitter, which drives an optical source to give modulation of the light wave carrier signal. The optical source provides the electrical-optical conversion maybe either a semiconductor laser or light emitting diode [4], [5]. The transmission medium consists of an optical fiber cable and the receiver consists of an optical detector. Fig. (1) show the generic optic communication system. [5]

There are many variables enter into optical communications system design, such as light source (transmitter power), coupling losses, response time of the light source and transmitter, signal coding, splice and connecter loss, type of fiber (single mode or multi mode), fiber attenuation and dispersion, fiber core diameter, operating wavelength, optical amplifiers, direct versus indirect modulation of transmitter, receiver sensitivity, bit error rate in digital system, or signal to noise ratio in analog system, receiver bandwidth, number of splices, couplers, and connectors, type of couplers[6],[7]. Many of these variables are interrelated. For example, fiber attenuation and dispersion depend on operating wavelength as well as the fiber type. Coupling losses depend on factors such as fiber numerical aperture and core diameter [8].

However, the main components of any fiber optic system including the following:

1. Transmitter is a key element in any fiber optic system that converts information such as data, image, voice, video and voice over IP, encoded into electrical signals to light signals. The transmitter receives a modulated electrical signal and converts it into a modulated light signal, after which it sends the light signal into the fiber optic cable. Transmitters are design to emit light at different ranges of wavelengths. In this paper, the four bands of wavelength (1310, 1490, 1580, and 1625) nm are selected. The important characteristic of the transmitter that one must know and take in to consideration average power output, operating wavelength range, extinction ratio, optical rise and full time [3],[5].

2. Fiber optic cable, the medium that carries the optical signal from the transmitter to receiver. The important characteristic of the fiber are core size, core refractive index, bandwidth or dispersion and attenuation. The maximum of the link is limited by the dynamic range of the receiver and the properties of the transmitter and fiber [5].

3. Receiver that uses a photo detector to convert the incoming light signal back into an electrical signal. The wavelength designation of the receiver must match that of the transmitter [2]. Important characteristics of receivers are system performance, which is the BER for digital systems or signal to noise ratio (SNR) for analog, saturation and sensitivity, maximum input power, minimum input power, output rise and full time. The bit error rate is the number of errors that occur between the transmitter and the receiver, a typical number is (10e-9) which means 1 error in every 1 billion bits transmitted. Nevertheless, in this paper assume the

BER is (10e-12) to get the best performance. The saturation defines the maximum received power that can be accepted. If too much power was received, the result is a distortion of the signal, causing poor performance. Sensitivity is the minimum power that must be received on an incoming signal. Too weak a signal can cause misread bits or low SNR. These entire characteristic for the transmitter, receiver and fiber optic cable one can get it from the data sheet.

Optical Link Loss Budget and Transmission Capacity Budget

Additionally, the characteristic of the transmitter, receiver and fiber optic, while designing a fiber optic system. There are three major factors to be considered when designing the optical networks or optical communications system. These factors are system loss budget, overall attenuation lost of components, and transmission capacity budget. The system loss budget refers to the tolerance of the fiber optic equipment between the transmit power and the receive sensitivity [9]. The overall attenuation lost of components refers to the combined losses of individual component that links the transmitting and receiving equipment. While the transmission capacity budget refers to the total analog bandwidth or digital data rate, it can carry in channel. Single channel capacity depends on how fast all the parts of the system respond to changes in signal intensity. In practice, transmission speed is mainly affected by properties of the transmitter, fiber, and receiver.

The link budget makes it possible to calculate the link length that will carry signals without a repeater in attenuation-limited systems, or how many connectors and splices can be used at a given distance in dispersion-limited links.

From the power budget, one can know how much power is needed to over come all optical transmission losses and to deliver enough power to the receiver to achieve the desired bit error rate (BER).

The power budget can be defined as [9, 10]

$$powerbudget = \frac{Ptx}{P\min} ---------(1)$$

$$powerbudget(dB) = Ptx[dB] - P\min[dB] \quad ....(2)$$

Where
Pox power transmitter
Pmin minimum power receive

From equation (1), the power budget equals the ratio of the transmitted signal to minimum signal power received needed by the network to perform the required operation under the conditions of 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 nodes (users) to the network through an passive optical splitter. As shown in equation (3).

$$\alpha_{fiber} L + \alpha_{coupling} N \leq powerbudget[dB] \quad ....(3)$$

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

Equation (3) [11], [12], 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 addition, the design should leave some extra margin above the receiver's minimum requirements to allow for system aging, fluctuations, and repairs, such as splicing a broken cable. However, it should not deliver so much power that it overloads the receiver.
On the other hand, the simplest way to calculate transmission capacity budget is form the time response or rise time of the signal in the important components. This corresponds to the rise time of a transmitter, receiver, and dispersion in a fiber as shown in equations (4) and (5). Both analog bandwidth and digital bit rate are related to the time response or rise time.

Transmitter and receiver rise and fall times are listed on data sheets and one can know it. However, fiber response times must be calculated from the fiber length, the characteristic dispersion per unit length, and the source spectral width. To determine the dispersion limitation of the optical fiber link, the system rise time is given by the equation below: [5]

$$T^2_{system} = T^2_{transmitter} + T^2_{receiver} + T^2_{fiber} \quad \ldots\ldots(4)$$

$$T^2_{fiber\,SM} = (D_{chrimatic} \times L \times \Delta\lambda)^2 + (D_{PMD} \times \sqrt{L})^2 \quad \ldots\ldots(5)$$

Where

$T_{ransmitter}$	transmitter rise time
$R_{eceiver}$	receiver rise time
T_{iber}	fiber response time
$D_{ichromatic}$	fiber chromatic dispersion
D_{PMD}	polarization mode dispersion
L	fiber length
$\Delta\lambda$	Fiber attenuation

The power and rise time budget are used to obtain a rough estimate of the transmission distance and the bit rate. We calculate loss budget to be sure that enough power reaches the receiver to give adequate performance. On the other hand, pulse dispersion must be calculates to be sure the system can transmit signals at the proper speed. In reality fiber length (distance) is limited by three things: fiber attenuation, transmitter power and receiver sensitivity (link budget), dispersion.

A passive optical networks technology was designed and builds using optical simulator system software (OPTSIM 3.6) as show in Fig. (2) and Fig. (3). in this simulator the effects of all losses in the optical fiber system were assumed such as:

1. Loss due to variations in the optical coupling to the transmitter output.
2. Loss due to optical connectors that may be in the optical path.
3. Loss due to the optical fiber itself amounts to dB/km of length.
4. Loss at the receiver.
5. Finally, a 3 dB safety margin should be built into all systems.

The system design parameters are listed in Table 1.
In order for the optical network or fiber optic system to work, attenuation lost of components must be lower than system loss budget. If in case the system loss budget is lower, the following design change or improvement to the system may be considered:

1. Minimize losses at splice joints, connector joints.
2. Reduce the number of connectors and joints.
3. Use single mode fiber optic cable instead of multimode fiber optic cable.
4. Use higher wavelength equipment.
5. Place fiber optic repeaters where necessary

Access in Optical Networks

The access network, connects the nodes (subscribers) to the central office to meet the growing traffic demand, service providers expend most of their effort on increasing the bandwidth on their backbone network [13]. But little has changed in the access network. Optical technology is a promising candidate for solving the bandwidth problem in access networks because it can provide at least 10 to 100 times more bandwidth over a larger coverage area. The next wave in access network deployment will bring the Fiber to the Building (FTTB) or Fiber to the Home (FTTH); enabling Gbps speeds at costs comparable to other technologies such as Digital Subscriber Line (DSL) [14].Three optical technologies are promising candidates for the next-generation access networks: point-to-point topologies, passive optical networks, and free-space optics.

a) Point-to-point topologies

Point-to-point dedicated fiber links can connect each subscriber to the telecom central office (CO), as show in Fig. (4). this architecture is simple but expensive due to the extensive fiber deployment. An alternative approach is to use an active star topology, where a switch is placed close to the subscribers to multiplex/de-multiplex signals between the subscribers and the CO. This alternative shown in Fig. (5), it is more cost effective in terms of deployed fiber. A disadvantage of this approach is that the switch is an active component that requires electrical power as well as backup power at the curb-unit location [12], [15].

b) Passive optical networks

Passive optical networks (PONs) replace the switch with a passive optical component such as an optical splitter (see Fig. 6). This is one of the several possible topologies suitable for PONs including tree-and-branch, ring, and bus. PON minimizes the amount of fiber deployed, total number of optical transceivers in the system, and electrical power consumption. Currently, two PON technologies are being investigated: Asynchronous Transfer Mode (ATM) PONs (APON) and Ethernet PONs (EPON). APON uses ATM as its layer-2 protocol; thus, it can provide quality-of-service features. Ethernet passive optical network carries all data encapsulated in Ethernet frames, and can provide a relatively inexpensive solution compared to APON. EPON is gaining popularity and is being standardized as a solution for access networks in the IEEE 802.3ah group [16], [17].

c) Optical wireless technology (free space optics)

Low-power infrared lasers can be used to transmit high-speed data via point-to-point (up to 10 Gbps) or meshed (up to 622 Mbps) topologies. An optical data connection can be established through the air via lasers sitting on rooftops aimed at a receiver. Under ideal atmospheric conditions, this technology can provide a transmission range of up to 4 km. Several challenges need to be addressed for optical wireless technology, including weather conditions, movement of buildings, flying objects, and safety considerations. In this paper, an Ethernet passive optical network technology access is chosen to study.

Overview of Passive Optical Network

There are several technologies such as DSL, cable modems, radio in free band of 2.4 and 5.8 GHz and VSAT, but all of them have numerous drawbacks. Moreover, those technologies cannot meet the upcoming bandwidth requirements for broadband applications.

A Passive Optical Network (PON) is a one important access technology that provide high bit rate, it is a single, shared optical fiber that uses inexpensive optical splitters to divide the single fiber into separate strands feeding individual subscribers[18],[19]. PONS is called (passive) because, other than at the central office (CO) and subscriber endpoints, there are no active electronics within the access network. Using these techniques to create a passive optical infrastructure, Ethernet in the First Mile PON (EFMP) builds a point-to-multi-point fiber topology that supports a speed of 1Gbps for up to 20 km. While subscribers are connected via dedicated distribution fibers to the site, they share the Optical Distribution Network (ODN) trunk fiber back to the Central Office [5, 17].

Ethernet passive optical networks are a low-cost high-speed solution to the bottleneck problem of broadband access network.

One type of PON is the Ethernet Passive Optical Network (EPON) technology; it has many advantages over the traditional broadband access (DSL, Cable Modem etc). One of the major advantages is the architecture of the EPON, which is very simple compared to other access technology. While comparing various access technologies, the main factor of comparison among the technologies should be the ability to utilize the potential bandwidth, which will be achieved by connecting to the submarine cable. Another important point of comparison is the ability to offer converged network applications so that all the services (voice, video and data) can be provided from a single connection. The IEEE ratified EPON as the IEEE802.3ah standard in June 2004 [19, 20, and 21].

EPON is suitable for Fiber-to-the-Home/Building/Business applications, including voice, data and video services. EPON is one type of fiber-based Ethernet access, using a passive optical 1: N infrastructure. An EPON network is a shared network, analogous to hybrid-fiber-coax networks, but with much greater bandwidth (1Gbps). EPON systems are a highly attractive access solution because of cost and performance advantage, resulting from their nature as all-passive networks, point-to-multipoint architecture, and native Ethernet protocol. Point-to-point Ethernet might use either N or 2N fibers, and thus has 2N optical transceivers. Curb-switched Ethernet uses one trunk fiber and thus saves fiber and space in the Central Office (CO). But it uses 2N+2 optical transceivers and needs electrical power in the field. EPON also uses only one trunk fiber and thus minimizes fibers and space in the CO, and also only uses N+1 optical transceivers. It requires no electrical power in the field. The drop throughput can be up to the line rate on the trunk link. EPON can support downstream broadcast such as video. Typical EPON-based systems may include extra features above the IEEE 802.3ah standard, including security, authentication and dynamic bandwidth allocation [12, 22].

The passive elements of an EPON are located in the optical distribution network and include single mode fiber optic cable, passive optical splitters/couplers, connectors and splices. Active network equipments such as the Optical Line Terminal (OLT) reside in the local exchange (central office), connecting the optical access network to an IP, ATM, or SDH backbone. The ONU is located either at the curb (FTTC solution), or at the end user location (FTTH, FTTB solutions), and provides broadband voice, data, and video services. Ethernet-based Passive Optical Network (PON) technology is emerging as a viable choice for the next-generation broadband access network. The PON may also be deployed in protected ring architecture for business application or in bus architecture for campus environments. EPON is typically deployed as a star or star-and-bus topology, using passive 1: N optical splitters, as show in Fig. (7) [22].

The IEEE 802.3ah EPON specification defines Multi- Point Control Protocol (MPCP), Point-to-Point Emulation (P2PE), and two 1490/1310 nm PMDs for 10 and 20 km, required to build an EPON system. An EPON network includes an optical line terminal (OLT) and an optical network unit (ONU). The OLT resides in the CO (POP or local exchange). This would typically be an Ethernet switch or Media Converter platform. The ONU resides at or near the customer premise. It can be located at the subscriber residence, in a building, or on the curb outside. The ONU typically has an 802.3ah WAN interface, and an 802.3 subscriber interface. EPON systems use optical splitter architecture, multiplexing signals with different wavelengths for downstream and upstream as such: 1490 nm downstream, 1310 nm upstream. All transmissions in a PON are performed between an Optical Line Terminal (OLT) and Optical Network Units (ONU's). Traffic from an OLT to an ONU is called 'downstream' (point-to-multipoint), and traffic from an ONU to the OLT is called 'upstream' (multipoint-to point). Two wavelengths are used: typically 1310 nm for the upstream transmission and 1490 nm for the downstream transmission [22], [23].

Simulation and Results Analysis

This section shows the performance of an ethernet passive optical networks using optical system simulator program (OPTSIM 3.6) as shown in Fig. (3), the results that obtained from using the simulation program, are indicated and show the performance enhancement and improvement in ethernet passive optical networks. Fig. (8) and Fig. (9) shows the bit rate versus the number of nodes at 1310, 1580, 1490 and 1625 nm wavelength respectively to achieve BER 1e-12 at same power transmitter (0dBm), These figures clearly show the number of nodes decrease when the bit rate increase on the same value of optical power transmitter and in the same fiber optic length (10km), but at wavelength (1580nm and 1625nm) more nodes are obtained instead of using wavelength (1310nm , 1490nm) that used in Optical Line Terminal (OLT) and Optical Network Units (ONU's), for example at 1Gbps the number of nodes is 39 and 42 in 1310nm and 1490nm respectively , while the number of nodes is 49 and 50 in 1580nm and 1625nm respectively.

On the other hand Fig. (10) and Fig. (11) shows the bit rate versus power received at 1310, 1580, 1490, 1625 nm respectively, these figures shows we need more power at receiver when the bit rate increase to achive the same BER (1e-12) at the same transimtted power (0dBm), but the power needed when using wavelngth (1580nm and 1625nm) less than power needed when using wavelngth (1310nm and 1490nm). Also the improvement in performance in BER is demonstrated in Fig. (12) and Fig. (13) When using the wavelength (1580nm and 1625nm) instead of (1310nm and 1490nm), we need less power to achieve the same BER at the same bit rate and fiber optic length.

Fig. (14) and Fig. (15) shows the fiber optic length versus maximum number of nodes to achieve the same BER (1e-12) at 1Gbps and at different wavelength (1310, 1490, 1580, 1625) nm, when specified transmitted power at (1mw) 0dBm, the number of nodes (users) is decreased when the cable length is increased, but also at wavelength (1580,1625)nm more nodes can connected to network than using wavelength (1310,1490)nm in Optical Line Terminal (OLT) and Optical Network Units (ONU's) as upstream and downstream transmission.

Fig. (16) show the bit rate versus maximum fiber optic transmission distance as determined by attenuation limits on the different wavelength and at the same power transmitter (0dBm), the figure clearly show the fiber optic length (transmission distance) is decrease when the bit rate increase caused by attenuation, the rapid decrease in fiber length when using 1310nm and 1490nm, therefore the way to increase the distance or length of fiber by using the 1580nm and 1625nm.

From the figures one can see the advantage from using (1580, 1625) nm instead of (1310,1490) nm in ethernet passive optical network, these advantage are improvement in BER, increase number of nodes, increase fiber optic transmission distance , increase data rate transmitted, decrease the power received required.

Conclusions

In this research work, a simulation and evaluation of ethernet passive optical network (EPON) using optical network package (OPTSIM 3.6) is presented at different bit rate and at different kinds wavelength (1310,1490,1580,1625) nm . The results indicate that improvement in performance of an ethernet passive optical network when using the (1580,1625) nm instead of (1310,1490) nm, in Optical Line Terminal (OLT) and Optical Network Units (ONU's) as upstream and downstream transmission that used in architecture of (EPON) . The advantage and benefits from using these wavelengths is enhancements in the performance representative by increase the number of nodes, increase bit rate transmitted, increase the transmission distance and decrease the BER. In addition, the results demonstrate how the fiber optic length (transmutation distance) limited by attenuation, but also the performance of (1580, 1625) nm is better than (1310, 1490) nm that used.

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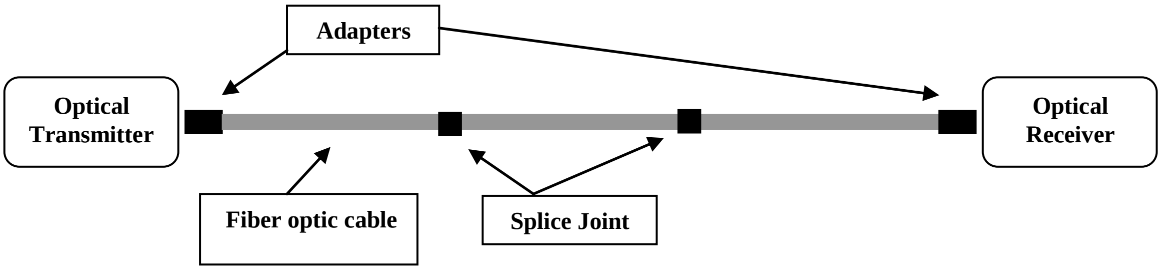

Fig. (1) Generic optic communication system

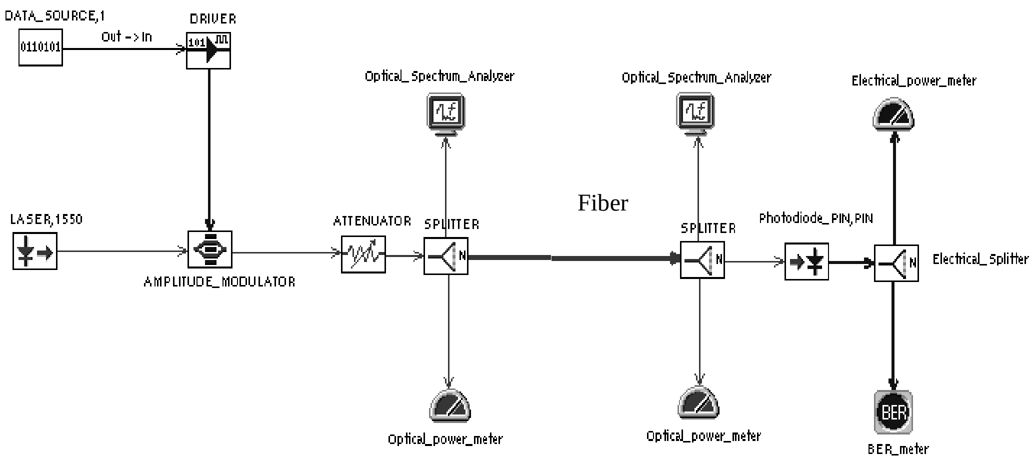

Fig. (2) Typical fiber optic system as point-to-point

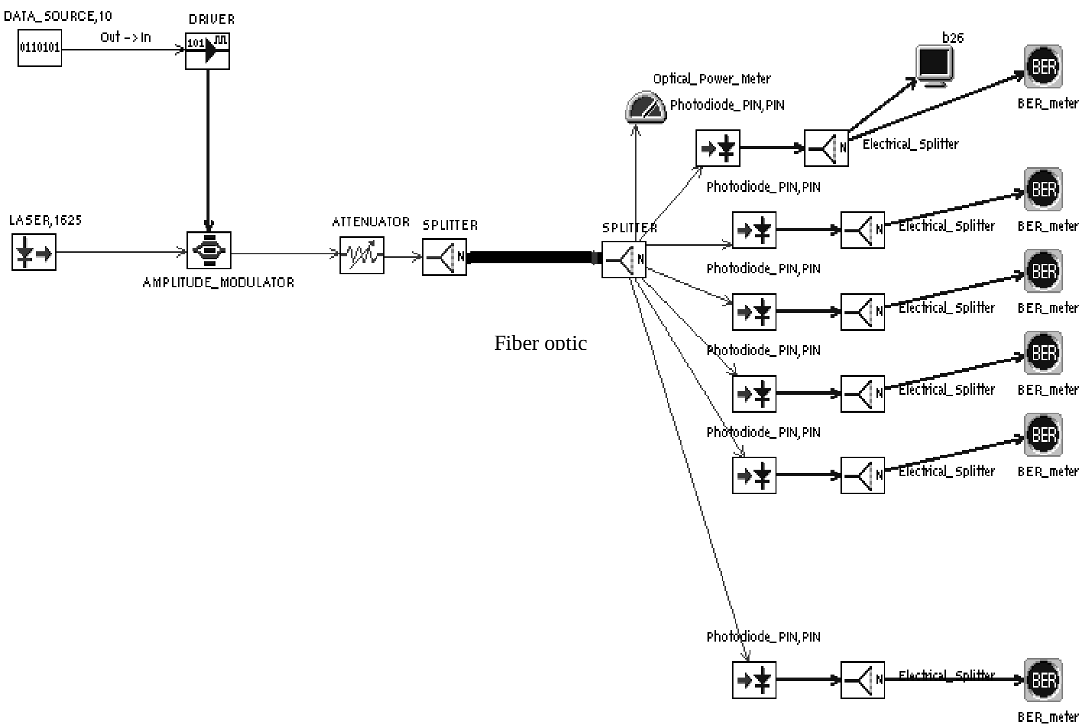

Fig. (3) Ethernet passive optical network system

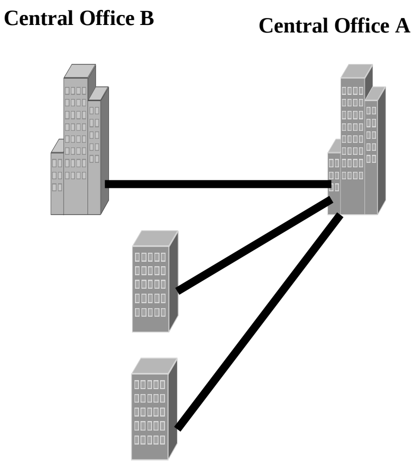

Fig. (4) Point-to-point topology

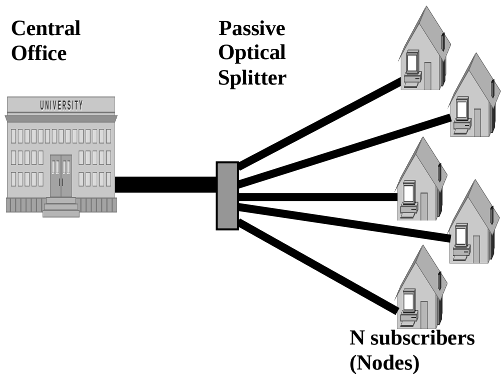

Fig. (6) Ethernet Passive optical topology

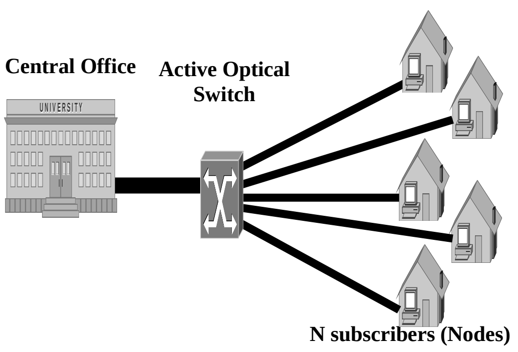

Fig. (5) Active star topology

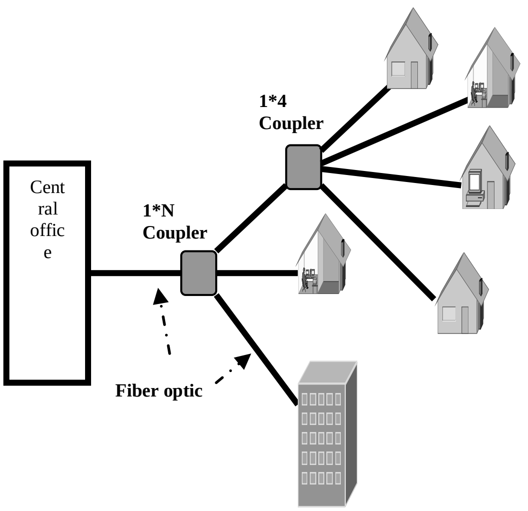

Fig. (7) star-and-bus topology using passive 1: N optical splitters

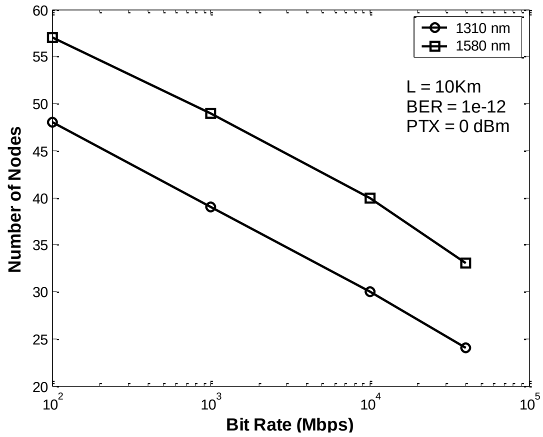

Fig. (8) Bit rate versus number of nodes at 1310nm ,1580nm

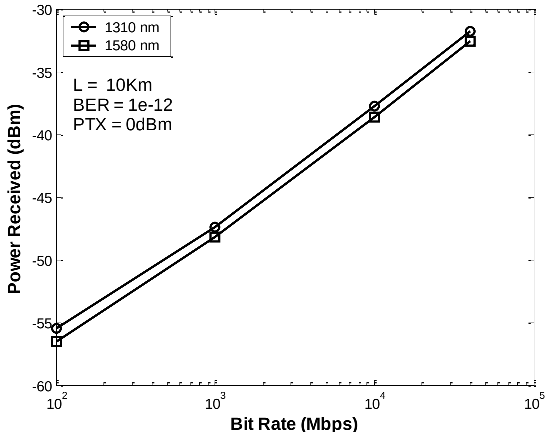

Fig. (11) Bit rate versus power received at 1490nm ,1625nm

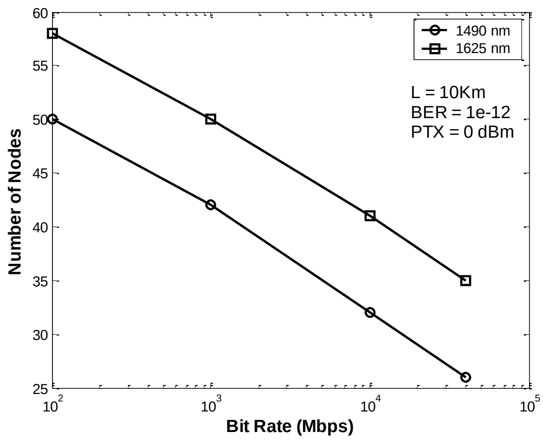

Fig. (9) Bit rate versus number of nodes at 1490nm ,1625nm

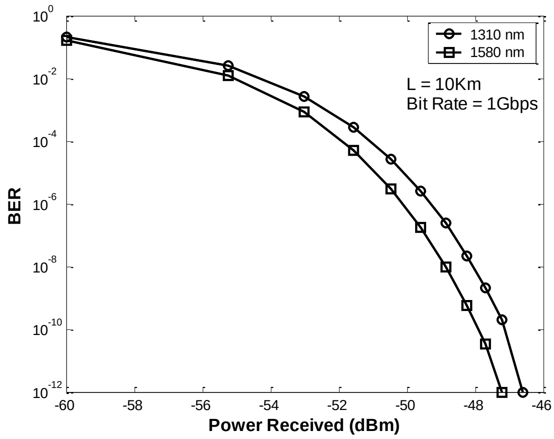

Fig. (12) Power received versus BER at 1310nm ,1580nm

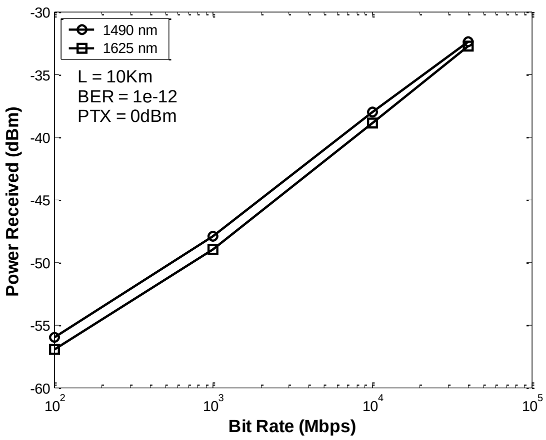

Fig. (10) Bit rate versus power received at 1310nm ,1580nm

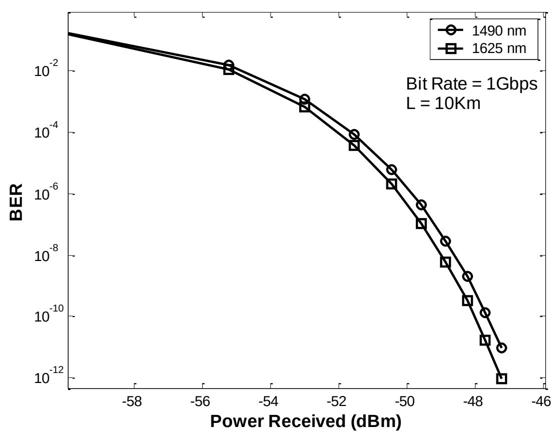

Fig. (13) Power received versus BER at 1490nm ,1625nm

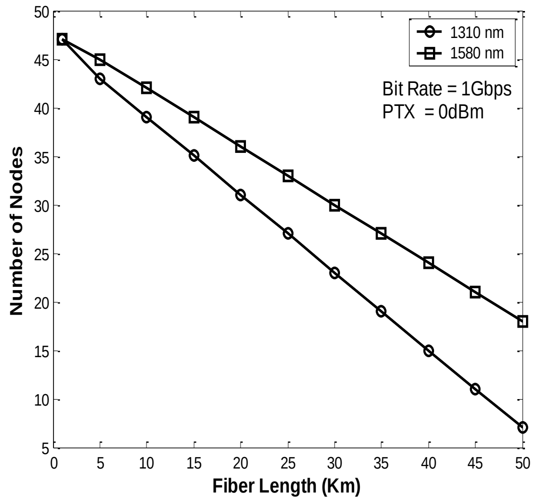

Fig. (14) Fiber length versus number of nodes at 1310nm ,1580nm

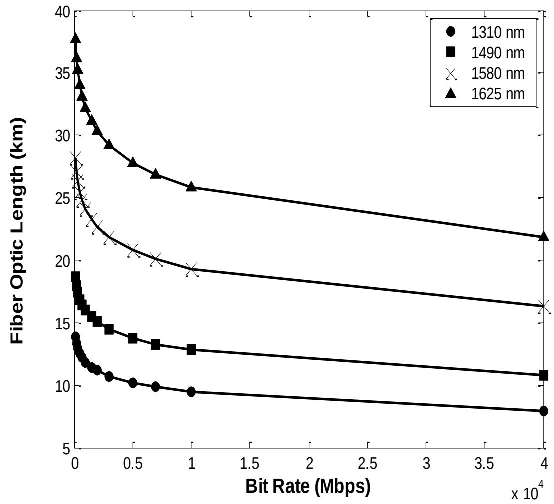

Fig. (16) Bit rtae versus fiber optic lenght at 310nm ,1490nm,1580nm and 1625 nm , as determined

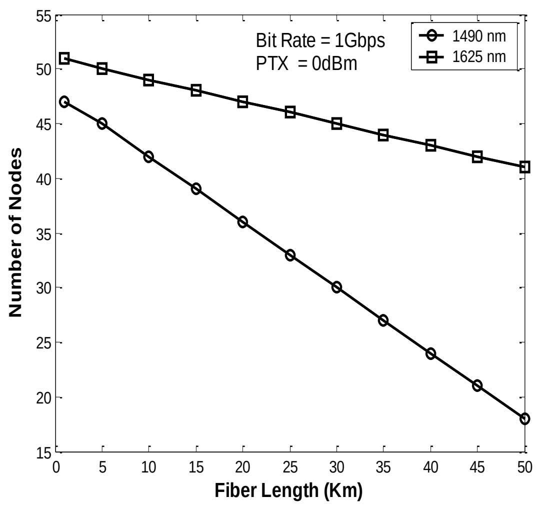

Fig. (15) Fiber length versus number of nodes at 1490nm ,1625nm

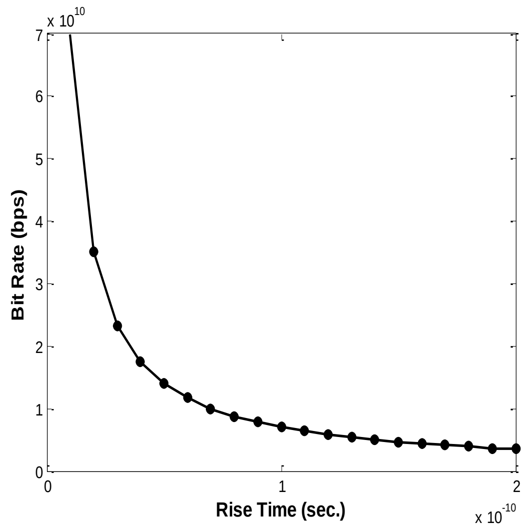

Fig. (17) Rise time versus bit rate

Table (1): System Design Parameters used in Simulation

Bit Rate	100Mbps,1Gbps,10Gbps,40Gbps
Types of Optical Fiber	Single mode
Channel Wavelength	1310nm,1490nm,1580nm,1625nm
Bit Error Rate	10^{-12}
Fiber Dispersion	0.1 PS/nm/km
Maximum transmitted power	0 dB
Adapter loss	1.5 dB
Splice Joint loss	0.10 dB
Transmitter Laser Line Width (FWHM)	10 MHz
Receiver Quantum Efficiency	0.9
Receiver Responsively (at reference frequency)	0.85 A/W
Number of Connectors or Splices in the System	Depending on number of nodes (users) in the system
Receiver Single-Pole Electrical Filtering (-3dB Bandwidth)	2 GHz
Receiver Dark Current	0.1 nA
Fiber attenuation	0.02 dB /km
Fiber Chromatic Dispersion at 1580	18 PS/nm/km
Fiber Chromatic Dispersion Slop at 1580	0.092 $ps/nm^2/km$
Spectral Width (MLM Laser)	1nm
Polarization Mode Dispersion	<0.1 $ps/km^{1/2}$
Source Type	Laser diode
Detector Type	PIN diode
Modulator type	Linear amplitude modulator
Transmission Distance	1 km --50 km