Size-Based Design and simulation of a simple practical Fiber-To-The-Home (FTTH) optical access network

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Abstract

This paper discusses the main parameters for design and simulation of Fiber-To-The-Home (FTTH) with high bandwidths, good quality, less Bit Error Rate (BER) and high value Q-Factor. Also we can connect new users in the main optical fiber network and increase the internet speed given to the users by adding new wavelengths spectrum. We use OptiSystem 7 simulator program to analyze the BER, Q-factor and spectrum output.

Keywords: *Fiber optics communication, Fiber To The Home (FTTH) , Passive Optical Network (PON), Bit Error Rate (BER) and Q-Factor.*

1. Introduction

Day after day, we note the increase of the human demands from daily use of digital communication. This needs to connect between countries and cities to fulfill the needs and demands of internet application, cell phone, telephone system, internet application ….. etc.

Internet applications (HD video, online gaming (3D), online conference, ….. etc.) grow as fast as an exponential equation and it became a main aim of the daily human use. Optical network is one of the best technologies to increase bandwidth over an existing fiber plant and provide high speed communication connections.

The FTTH access network is a point to multipoint fiber network that connects the users (e.g., promises, banks, schools, hospitals and business) which use passive optical splitter. This uses two pair optical fiber to serve multi-users [1]. FTTH optical access networks provide law attenuation (0.2 dB / Km) and high bandwidth (greater than 10 GHz /sec) for a single mode fiber [2]. The main aim of the FTTH is to enhance the quality of service of connection [3].

The FTTH is the last part of the fiber optical network which is composed of the Long haul network, the Metropolitan network, and the Access networks.

In this paper, we design and implement the FTTH access network for various communities such as premises, banks, schools, hospitals and business as a project in Minia city (a governorate lies 240 km to the south of Cairo, Egypt). In other words, we study the distribution and length of cables with the components of the FTTH network. The rest of the paper is arranged as follows: Section (2) introduces a background of the optical fiber networks communication. Section (3) gives a literature review. Section (4) design of the FTTH access network. Section (5) the results , discussion and comparison with previous work. And section (6) the conclusions and future work.

2. Background of Optical Fiber Network

2.1. Introduction

Optical network is a form of telecommunication systems that uses light as a transmission medium. An optical network consists of a transmitter which encodes an optical signal channel (through an optical fiber cable) which carries the signal to its destination and a receiver which reproduces the message from the received optical signal. Optical fibers are widely used in optical networks (instead of metal wires), which permits transmission over long distances, higher bandwidths (data rates) and less loss than other forms of communications.

2.2. Basics of Optical fiber

Nowadays, the main purpose of optical communication is to extend the capacity of the optical channels to fulfill the human needs of internet. We find several techniques to improve the communication channels such as:

1- Time Division Multiplexing (TDM).
2- Frequency Division Multiplexing (FDM).
3- Dense Wavelength Division Multiplexing (DWDM).

We can see the difference between TDM, FDM and WDM techniques in Figure (1).

2.2.1. Types of Optical Fiber Networks:

There are three types of fiber optical networks. These are the long – haul networks, the Metropolitan networks and the Access networks. The optical fiber networks are shown in Figure (2).

a) The long haul network is the core of networks. It is connected with a small group for very long distances and high bandwidth.

b) The metropolitan network is located between long - haul networks and access networks (Between different and long networks). The metropolitan dynamic networks may be needed to have bandwidths matching the long –haul transport networks. On the other side, the metropolitan networks are growing the address to match with the access technologies.

c) The access networks connect the customer by several ways to the metropolitan networks. There are many services of the access networks such as the DSL, IP services, cell phone and fiber channels (Optical channels or FTTx). Another view for the global network hierarchy is shown in Figure (3).

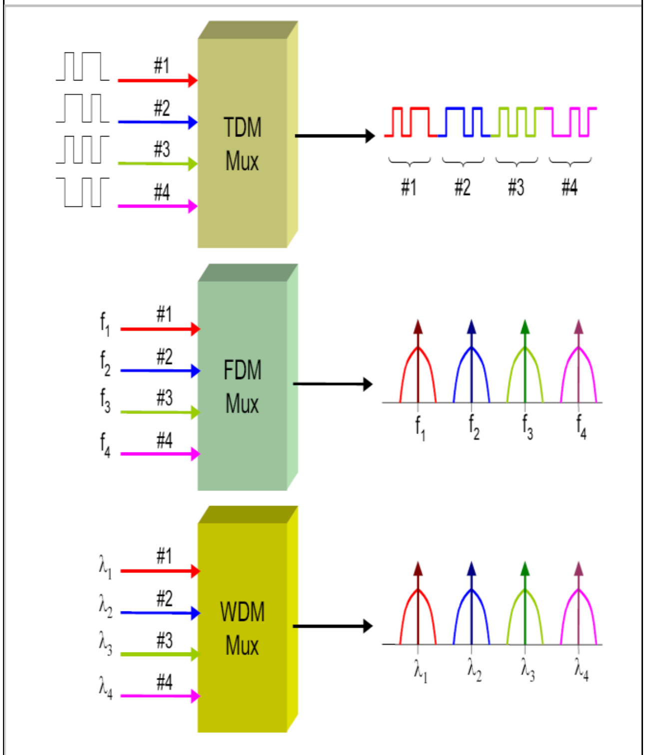

Figure (1): TDM, FDM and WDM Technologies

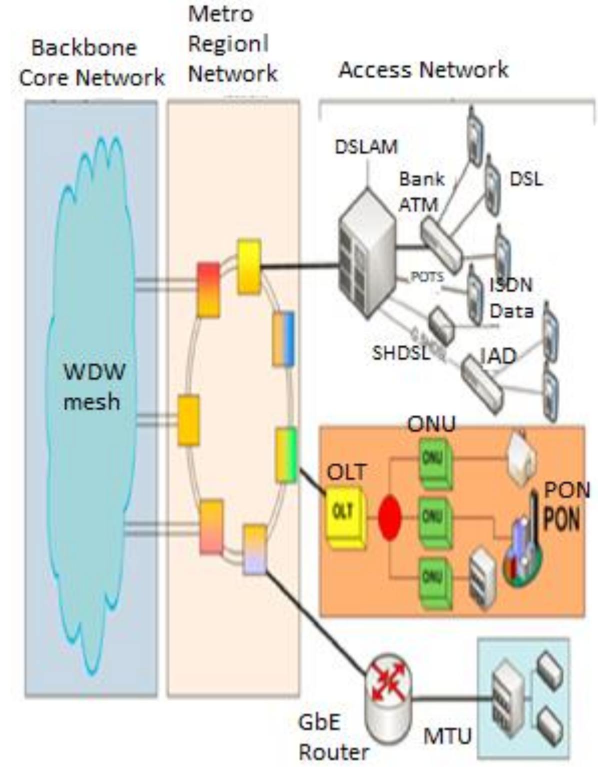

Figure (2): Types of optical fiber networks

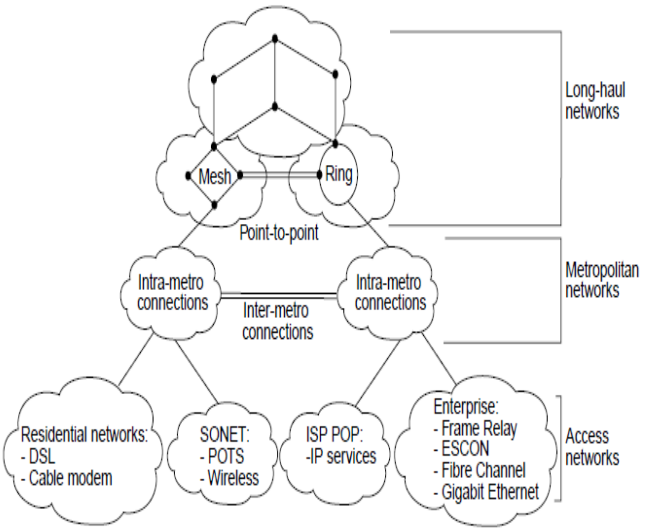

Figure (3): Global networks hierarchy

2.2.2. Active and Passive Optical Fiber Networks

The deployment of FTTH (Fiber-To-The-Home) access networks has come a long way before subscribers use optical fibers instead of copper lines [4]. There are two common systems available in FTTH networks. These are the PON (Passive Optical networks) and the AON (Active Optical networks).

a) PON – Passive Optical Networks

The Passive Optical Network (PON) is used as fiber and passive components, like optical splitter, rather than active components (Amplifiers, Repeater, Shaping, etc). PON can be called a point to multi – point (PMP) network see in Figure (4).

In passive optical systems, fibers, from the central office optical line terminal (LOT), are connected to optical network terminals (ONTs) or optical network units (ONUs) at customer premises and called PON system as shown in Figure (5). Between subscribers and the OLT, we can find an optical splitter which is also called PON splitter.

b) AON – Active Optical network.

AON arrangement is a Point-To-Point (PTP) structure as shown in Figure (6). In AON system, environmentally, electrical switching equipments are necessary such as routers or switch aggregators to manage signal distribution. See AON networks in Figure (7).

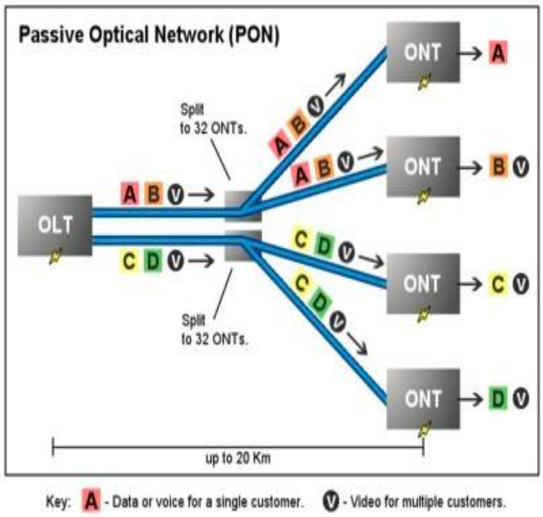

Figure (4): PON or point to multi – point (PMP) networks.

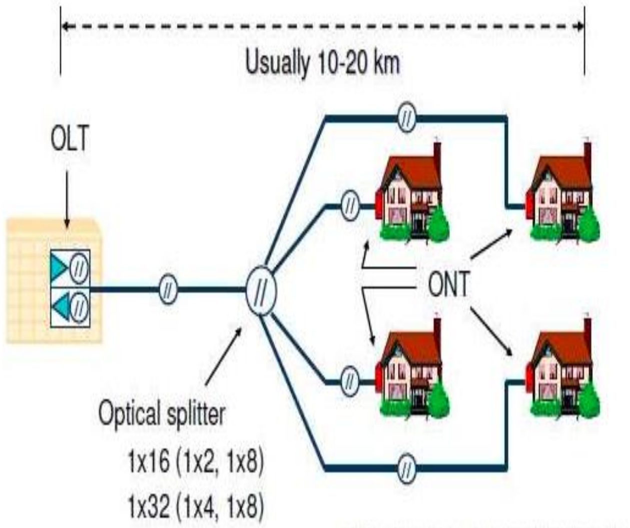

Figure (5): PON – Passive Optical Networks.

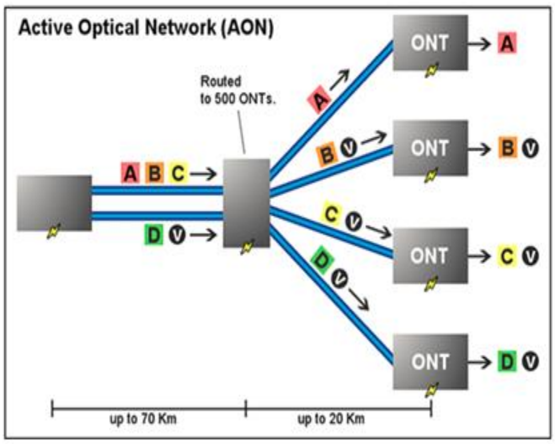

Figure (6) : AON or Point – To – Point networks

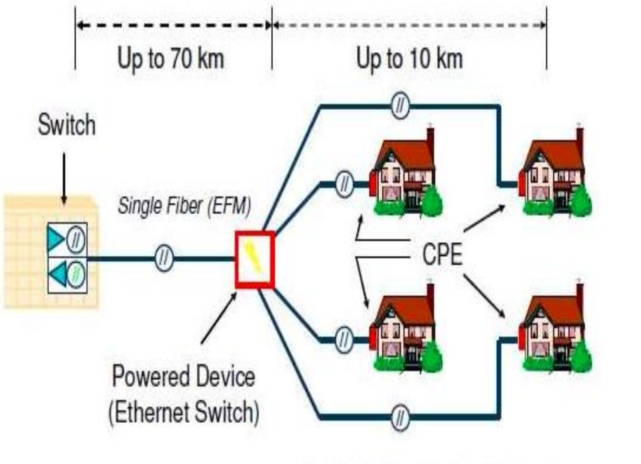

Figure (7): VON-Active Optical network

2.2.3. Differences between AON and PON

A) PON has less cost to install and operate. It has the same signal to all end users. The distance of installations is 20 Km and it is more reliable.

B) AON has more cost to install and use. It sends a unique signal to all end users. It can cover larger distances and it provides max speed regardless of user amounts.

2.3. Advantages and disadvantages of PON

2.3.1. Advantage of PON

a) Lower network operational costs
b) Elimination of Ethernet switches in the network
c) Elimination of recurring costs associated with a fabric of Ethernet switches in the network
d) Lower installation costs for a new or upgraded network (min 200 users)
e) Lower network energy costs
f) Less network infrastructure
g) Large bundles of copper cable are replaced with small single mode optical fiber cable
h) Increased distance between data center and desktop (>20 kilometers)
i) Network maintenance is easier and less expensive
j) Fiber is more secured than copper. It is harder to tap. There is no available sniffer port on a passive optical splitter. Data is encrypted between the OLT and the ONT.

2.3.2. Disadvantage of PON

a) The splitter has no intelligence and can’t be managed.
b) When the services accurse we can’t check for the problems.
c) If we needs to re-design the network or pull a new stand of fiber from the upstream splitter all downstream customer must come offline.
d) Every subscriber gets the same bandwidth.

2 .4. Generic operation of the PON

The basic components of FTTH access network are show in Figure (8).

2.4.1. OLT (Optical Line Terminal)

OLT is the main element of the network (Local exchange). It performs traffic scheduling, buffer control and bandwidth allocation. It uses a 48 VDC power supply. It uses at least 1 line card. One kind of OLT element (Alcatel Lucent 1662) is shown in Figure (9).

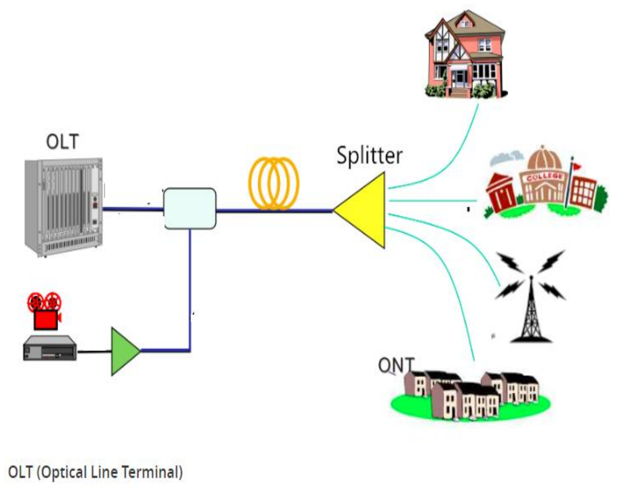

Figure (8): The basic components of FTTH access network.

Alcatel·Lucent

Fig(9) : OLT equipment (Alcatel – Lucent 1662)

2.4.2. ONT (Optical Network Terminal) [5]

This area is at customer's premises. ONT is the physical connection between the customer and OLT.

2.4.3. Optical splitter [6]

Optical splitter splits the power of the signal. Any fiber link enters the splitter is split into many out of fiber links. Thus, there are many levels of splitter. Optical splitter has a low loss, uniformity, minimal dimensions, supporting networks survivability and protection policy. Some kinds of optical splitter are shown in Figure (10).

Figure (10): Some kinds of optical splitter

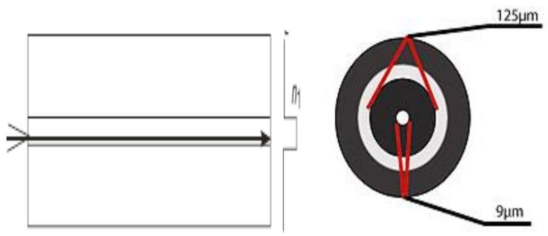

Figure (11): Single mode fiber

2.4.4. Classification and types of optical fiber

There are three main types of optical fiber

1) Single mode optical fiber.
2) Multimode optical fiber with stepped index.
3) Multimode optical fiber with graded index.

1) The first type (single mode)

a) It has a very thin core about (5-9) µm and relatively larger cladding.
b) It transmits one mode of light used wavelength 1310 or 1550 nm.
c) It has a high bandwidth (High transmission rate).
d) A high distance the signal is transmitted.
e) It eliminates any distortion.

We can see the single mode fiber as in figure (11).

2) The Second type (Multimode optical fiber with stepped index) [7][8]:

a) Larger diameter of core as 50µm
b) Used wavelength 850 to 1300nm.
c) Limited bandwidth
d) Transmission for short distance.

We can see multimode optical fiber with stepped index as in Figure (12).

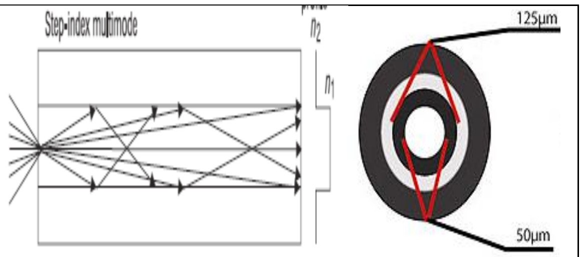

Figure (12): Step index multimode.

3) The third type (Multimode optical fiber with graded index):

There is a graded index multimode core diameter from 62.5/125µm. We can see the multimode optical fiber with graded index as shown in Figure (13).

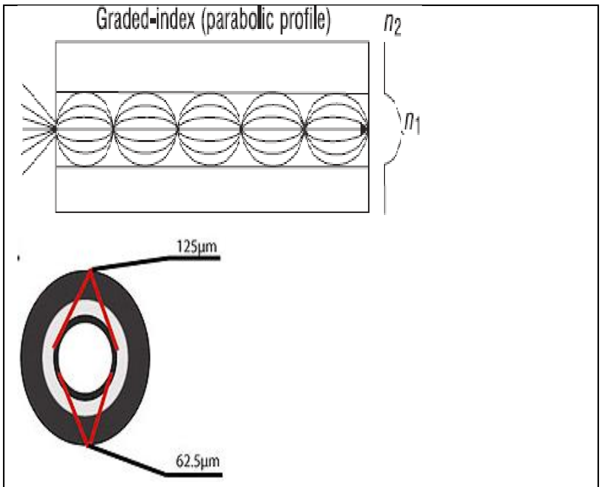

Figure (13): Graded index multimode

2.5. Optical fiber parameters

2.5.1. Attenuation

Two major mechanisms are responsible for the losses [9]:

A) Absorption.

Light is absorbed by the material. Also the glass, used for optical fibers, has an extremely low absorption coefficient. A little light is still lost to this effect. Figure (14) shows the absorption.

B) Scattering.

Light is deviated from its path and consequently lost. The most important factor is called Rayleigh scattering, which leads to power being back- scattered towards the transmitter. The effect is well known where it's responsible for giving us the blue sky by scattering sunlight. Figure (15) shows scattering effect of light.

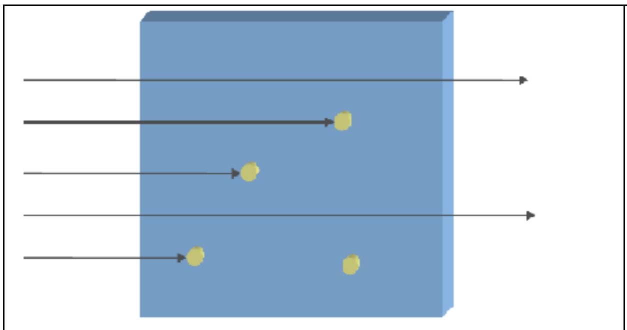

Figure (14): Light absorption.

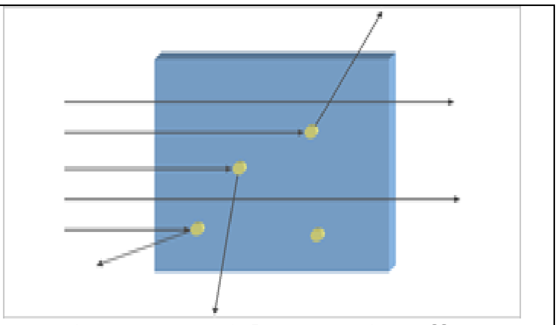

Figure (15): Light scattering effect.

2.5.2. Light dispersion

Light dispersion is based primarily on the fact that the refractive index of glass n (the optical "density") depends on the wavelength of light, which in turn causes these different wavelengths to travel at different speeds in the same medium (chromatic dispersion) [10].

In transmission technology, dispersion therefore is the tendency of optical pulses to spread as they travel through the optical fiber. As a consequence it becomes more difficult to distinguish if a received bit is '1' or '0'. This effect is called Inter-Symbol-Interference (ISI). The problem of dispersion becomes critical on long fibers carrying high bandwidth signals.

Total dispersion is measured in units of ps/nm and the dispersion coefficient of a fiber is in units of ps/nm-km, or pico-seconds per nanometer per km of fiber length. Mathematically speaking, the dispersion is the differential value of the Index of Refraction n with respect to the wavelength λ. Figure (16) shows the dispersion and speed of different wavelengths and the effects of chromatic dispersion

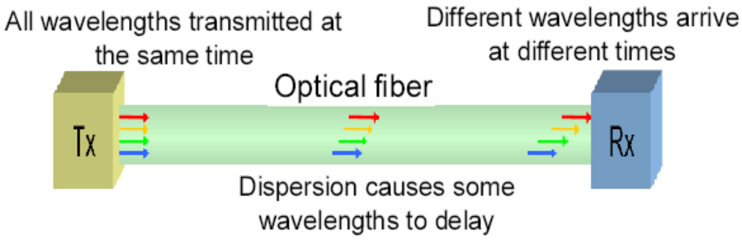

Figure (16): Dispersion and speed of different wavelengths and the effects of chromatic dispersion.

In fact, the phenomenon of "Dispersion" is composed of several types:

1) Mode Dispersion: Different modes in a multimode fiber have different paths and thus different travelling times (not relevant in single mode fibers).
2) Profile Dispersion: For graded index fibers impurities or imperfections in the grading profile cause additional dispersion.
3) Chromatic Dispersion: In the mono mode fiber the chromatic dispersion is the dominant factor. It is composed of:
   - Material Dispersion: This is a pure physical property and it describes the different speeds with different wavelengths in the used glass. It can be changed only very little by the doping of the fiber.
   - Waveguide Dispersion: This type of dispersion is highly dependent on the profile of the graded index. Thus, it is possible to influence the total dispersion of the fiber.

2.5.3. Polarization Mode Dispersion (PMD)

The base mode in mono mode fibers consists of two orthogonally polarized parts or polarization modes. Due to environmental conditions (stretching, bending, torsion, ...), the radial symmetry of the index profile is disturbed. Thus, the two parts have different speeds, leading to a temporal broadening of the pulse. The result of PMD is additional ISI.

Due to the coupling of these polarization modes, the total delay and pulse broadening are dependent only on the square root of the fiber length. The latter is a fiber property, which is of course depending on a lot of environmental conditions and it is usually specified as an average value by the producer. The contributing factors are:

a) Fiber core ellipticity.
b) Transverse stress.
c) Bending.
d) Twisting.
e) Isolators in Erbium Doped Fiber Amplifier (EDFAs).
f) Aging.

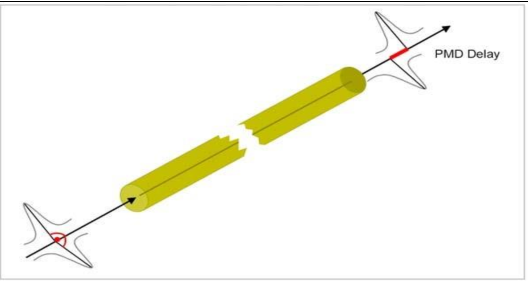

Figure (17): shows the polarization mode dispersion

In usual systems, the PMD is of no practical relevance. In DWDM systems, which are dispersion-managed and use extremely narrow bandwidths, the PMD becomes a very important factor limiting especially high-bitrate transmission.

One of the biggest problems of PMD is that it might be highly time dependent. This becomes clear, when we imagine e.g. a truck or a train passing by a fiber line, causing vibrations which in turn might cause fiber deformations. Figure (17) shows the polarization mode dispersion.

2.6. Advantages and disadvantages of optical fibers

Fiber optic communication system uses light pulses instead of electrical pulses to transmit information between two nodes [11]. The following advantages and disadvantages can be noticed about that system.

2.6.1. Advantages of optical fiber

a) The optical fibers carry greater information capacities than metallic conductors in either digital or analog form..
b) The optical fiber are lighter and smaller.
c) The optical fiber cables are cheaper to transport and easier to install than metal cables.
d) The optical fibers and fiber cables are very strong and flexible.
e) The optical fibers are so slender that they do not break when wrapped around curves of only a few centimeter radius.
f) Optical fiber is well protected from external interference such that radar and other signals cannot cause interference in the fiber.
g) It has greater bandwidth.
h) Resistances to high temperature.

2.6.2. Disadvantage of optical fiber

a) Its price and installation are more costly than other media.
b) The used transmitters and receivers equipment are more expansive.
c) It is more difficult and expensive to splice then wires.
d) It cannot carry electrical power to operate terminal devices.
e) At higher optical powers, fiber is more prone to fiber flux, so optical fiber may get damaged.

3. Literature Review

Boyer Heard [12] explained the main aim to provide highly scalable solution to service providers to make fiber reach the end user. An extensive research had been carried out to evaluate the downstream and upstream traffic. The system was analyzed on the basis of data rate, fiber length, number of users, wavelengths and the effects on BER as the key performance parameter. Optisystem simulation was developed between the data rate accommodated user. It had been revealed that, in downstream direction, doubling the number of users only requires switching to the lower data rate in order to maintain identical BER effects over the same fiber length.

Jani Saheb Shaik [13] and Frank Effenberger et at.[14] investigated optical networks with wavelength reuse for asymmetrical 2.5 G and symmetrical 10 G downstream and upstream data rate. The range of downstream extinction ratios for error-free upstream transmission at BER of 10-6 was extended from 3 to 4 dB.

Hiroyuki Yashima et.al.[15]simulated an optimized FTTH optical access network to provide the internet services for residential subscriber and described the requirements of equipment and optical fiber cable. To satisfy those requirements, they simulated an optimized architecture and described all functions of major elements. Finally they considered the main technical issues i.e., BER and Q factor to realize the FTTH access network and the future prospect for FTTH network. They would not need the outdoor cabinet site and no change of intermediate equipment would be required to upgrade future FTTH access networks. Maintenance would be easy because it requires maintenance only for the fiber systems.

M. A. Othman et. at [16] reported the broadband FTTH network evolution including high speed interfaces and services. The impact of FTTH network evolution on network architecture and transmission equipment localization on the optical access network was also mentioned and discussed to obtain an optimum network. Some technical challenges were discussed, namely concerning the optical extended budget, as well as the impact of access evolution on the FTTH network. They have described a possible evolution of the optical access networks using optical budget extension in order to optimize the number of optical central offices. The issues of central office location were presented in function of customer eligibility. Convergence of fiber technologies was also discussed, as possible topics of network development.

Ezeh & Diala [17] developed FTTH with high bandwidth and long-reach, offering triple play services (data, voice, and video). Advancement in the electronic equipment coupled with a fall in the price of fiber optic cables and equipment make FTTH deployment an affordable choice for the telecom operators that results in long term returns. Furthermore, the connection of homes and business to fiber optic networks facilitates enormous improvements in what broadband devices are capable of delivering. Current fiber optic technology can provide upload and download speeds of over a gigabit per second. Fiber networks are speedily being adopted by telecoms, because fiber can carry voice, data and video at higher speeds over a longer distance compared to copper.

Vincent Angilella, Matthieu Chardy and Walid Ben-Ameur [18] focus on the optical access network design problem in the context of FTTH where separation techniques such as splicing is considered and assuming the civil engineering structure like a tree. The passive optical splitter (also called “optical splitter” or “splitter”) is the key equipment of an optical network. This equipment is connected to one optical fiber on one side (upstream fiber), and to several fibers on the other side (downstream fibers). It splits the signal coming from the upstream fiber on downstream fibers, and groups the signals coming from the downstream fibers on the upstream fiber. So, optical splitter is necessary at every stage of a FTTH network. The authors mention that the main cost is the sum of the cost of cables, the cost of boxes and the cost of welds. Also, the cost includes manpower, optical passive splitter, optical fiber cables and material costs incurred by the network operator.

Franco Mazzenga, Romeo Giuliano and Francesco Vatalaro [19] analyze the improvement that can be achieved with low cost technical arrangement and devices into the present Fiber-To-The-Cabinet (FTTC) that is used to group the copper pairs shared among subscribers. With simple calculations to prove that the bit rate per user can be increased to achieve the present FTTH network standards. By acquired revenues, we can have a smooth transition to FTTH and furthermore, a fast additional bit rate enhancement. Gradual penetration of optical fiber into the access network through FTTH architecture has not progressed in several countries as could have been expected. Also, discussing the penalty has delayed this process e.g. high cost, weak demand and complex authorization procedures. Therefore, in several countries, full substitution of copper with fiber in the secondary part of the access network still can take many years if not decades. For example, based on data of the European Union, we can safely estimate that by 2025 the average FTTH coverage in Europe will only be about 50%, while in rural areas it drops to about 38%.

Domingues, M. F. et al. [20] presented the results of the FTTH infrastructure based on population and the cost is reduced under the heads of hospital and travel expenses. The time of reaching the patient for a health support staff at a remote location with accurate and proper diagnosis is the crying need for any large country. In the vast rural tract, it is necessary for the proper medical attention in time for the ailing patient as well as support for the health service infrastructure. By using FTTH, the tele-health practices may be enhanced with greater efficiency and that is at an affordable cost. Also, it can be possible to extend elementary healthcare to areas which are hard to reach, minimizing the need of travel and increasing the interaction between patient and minimal care provider. The fast data communication infrastructures work on training the remote healthcare workers and it has become possible to monitor the continuous preventive and community health initiatives on a daily basis by using FTTH infrastructure. The cost of sending health personnel in those areas has become minimized which in ripple affects the cost of maintenance of healthcare services in those areas. The different medical opinions are helpful in the faster recovery contexts and it also minimizes the chance of wrong diagnosis and good post recovery management which prevents the recurrence of diseases with use and procurement of proper medicine at proper time. This is also an important factor. All these options of healthcare can be best attended using FTTH framework.

Tatcha Sudtasan and Hitoshi Mitomo [21] explain the consumer choices among advanced Internet broadband technologies. The authors aim to illustrate the consumer decisions on choices of advanced Internet access which are influenced by the emergence of the Internet of Things (IoT) applications. The effects of IoT by consumer individual characteristics and their current use of networks on their decision pertain to the choice of advanced Internet access. The emergence of IoT applications accelerates the adoption of both advanced mobile broadband (5G) and advanced fixed broadband (FTTH). The presence of IoT enhances the consumer intention to use both advanced mobile broadband connection (5G) and advanced fixed broadband connection (FTTH).

4. Design of the FTTH Access Network

The FTTH network technology delivers data, including voice and video services, with high speed to the subscribers in home or

business by optical fiber cable. The FTTH architecture can accommodate a large number of subscribers. There is no standard FTTH access network model. It depends on the subscriber density and civil structures. In this section, we introduce the design aspects and algorithm of the FTTH network.

4.1. Parameters affecting in Performance

For the design purposes, we should study the following main parameters to measure the quality of communication signal:

1) The bit error rate (BER).
2) The Q factor.
3) The optical signal to noise ratio (OSNR).
4) The Crosstalk.

BER and Q-factor are famous parameters occurring in the optical FTTH network because of the effects of noise, interference, distortion, bit synchronization, attenuation; ….. , etc.[22]. Thus, we choose the BER, Q-factor, OSNR and crosstalk to evaluate the results of the design at the end points.

4.1.1 The bit error rate (BER)

The BER is defined as the average time of wrong bits contained in stream of bits to long averaging time. The main calculation is as follows:

$$\mathrm{BER} = \left[\frac{\text{bits in error}}{\text{total number of bit}}\right]_{\text{time average}} \qquad (1)$$

BER can also be considered as the probability of having a detection individual bit error.

Figure (18) shows the received signal by the decision circuit of the receiver with sampled clock recovery time t_D and current I. Current I_1 indicates that the received signal is bit one and I_0 indicates that the received signal is bit zero. The value I_D is the threshold current and the value I is the fluctuating current of the received signal. If $I < I_D$, then decision circuit decides that the bit is zero and if $I > I_D$, it decides that the bit is one. Because of the receiver noise, an error occurs in the dashed region when $I < I_D$ and then, the circuit decides a one bit and when $I > I_D$ it decides a zero bit [23]. Where BER can be calculated as follows:

$$BER=p(1).p(0|1) + p(0).p(1|0) \qquad (2)$$

where:

p(1), p(0) are the probabilities of receiving bits 1 and 0, respectively.
p(0|1) is the probability of deciding 0 when 1 is received.
p(1|0) is the probability of deciding 1 when 0 is received.
Since 1 and 0 bits are equally likely to occur then
p(1) = p(0) = ½ and the BER becomes:

$$BER=0.5[p(0|1) + p(1|0)] \qquad (3)$$

4.1.2 The Q – factor

This important parameter is widely used to evaluate the performance of communication systems. In equation (3), if a received signal is Gaussian, which has a mean value I and a variance σ^2, the bits 1 and 0 have mean values I_1 and I_0 and variance values σ_1^2 and σ_0^2 respectively. The optimum value of Q-factor can be calculated by [23, 24]:

$$Q = (I_1+I_0)/(\sigma_1+\sigma_0) \qquad (4)$$

where the relation between Q-factor and BER is:

$$BER=0.5\ \mathrm{erfc}(Q/\sqrt{2}) \qquad (5)$$

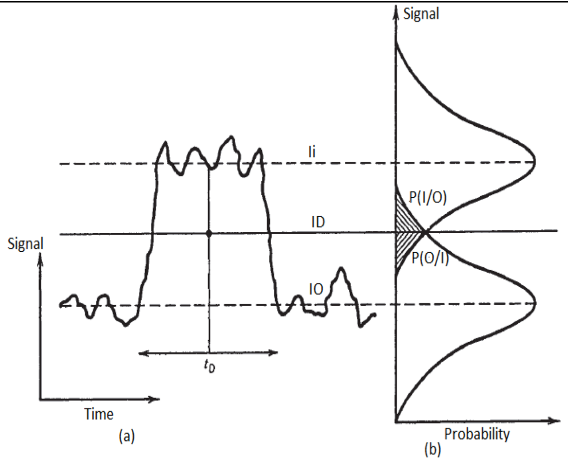

Fig (18): (a) Fluctuating signal generated at the receiver.
(b) Gaussian probability densities of 1 and 0 bits

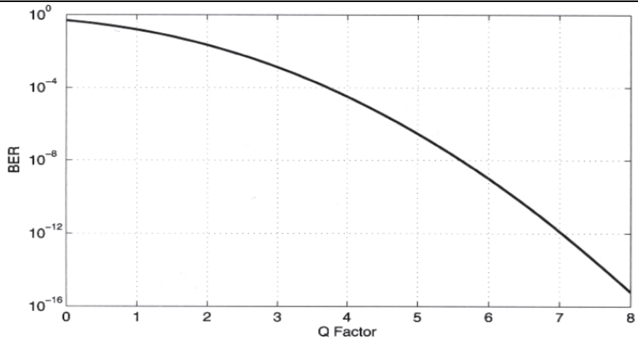

Figure (19): Relation between Q-factor and BER.

We can show that the relationship between the Q-factor and the BER is inversely as shown in Figure (19).

4.1.3 Optical signal to noise ratio (OSNR)

The OSNR is an important parameter for the design of optical fiber links. It introduces the relationship between optical signal and noise. The SNR, Q-factor and BER have great effects on the performance. The OSNR can be calculated by [25]:

$$OSNR = P_{in} - L - N_F - 10\log(N) - 10\log(h\nu\Delta\nu_0) \qquad (6)$$

where:

P_{in}: input power for each amplifier.
L: span loss between amplifier.
N_F: Amplifier noise figure.
N: Number of Amplifiers.
h: Blank constant.
ν: Light frequency.
$\Delta\nu_0$: Optical bandwidth.

There is a strong directly proportional relationship between the Q-factor and the OSNR [25, 26].This relationship is:

$$Q_{db} = 20\log\sqrt{OSNR}\sqrt{\frac{B_0}{B_c}} \qquad (7)$$

where:

B_0: is the optical bandwidth of the optical filter.
B_c : is the electrical bandwidth of the receiver filter.

4.1.4 The Crosstalk

Crosstalk is one of the major limitations for the optical add/ drop in all optical networks. Crosstalk occurs in devices that filter and separate wavelengths. A small proportion of the optical power in a particular channel (on a particular filter output) actually ends up in an adjacent (or another) channel. Crosstalk is critically important in WDM systems. When signals from one channel arrive at another channel, they become noisy in the other channel due to producing harmonics. This can cause serious effects on the signal-to-noise ratio and hence on the bit error rate of the system [27]. Crosstalk is usually quoted as the reason of the "worst case condition. This is where the signal in one channel is right at the edge of its allowed band. Crosstalk is known as the loss in dB between the input level of the signal and its (unwanted) signal strength in the adjacent channel(s). A figure of 30 dB is widely as an acceptable level for most systems. Figure (20) explains the meaning of the crosstalk and we can see that as an eye diagram in BER analyzer.

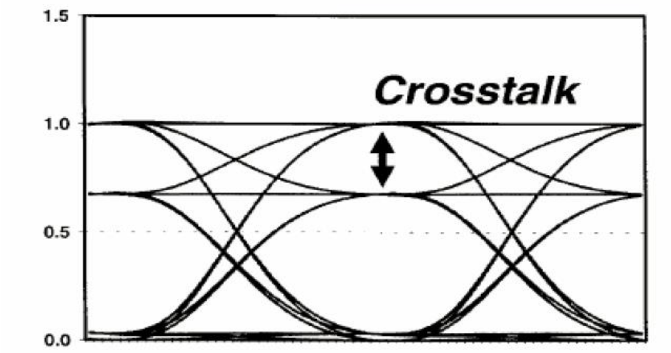

Figure (20): Explaining the crosstalk

4.2 FTTH Access Network Design Algorithm

The design process can go through the following steps:

1) Collecting the service providers' requests about their customers' demands (i.e., companies such as: Orange, Vodafone, Etisalat and Telecom Egypt). This is to determine the total required bandwidth for the next year based on their requirements.
2) The computed bandwidth (in step 1) is multiplied by a certain factor (k) (based on the plan of the Egypt Telecom and the increase of Internet service demands during the year, in our design: k=1.5) due to having new customers and/or increasing the internet speeds of some old customers.
3) The distances between the Central Optical Line Terminal (COLT) and the main sides in the compound areas (or mother villages) are determined. In our design, we take a sample of compound areas (i.e., Banks, Schools, Business companies, Hospitals and Residences).
4) The types of the required fiber optical cables are determined (e.g., the single mode type cable).
5) The required equipment are determined such as power splitters, power combiners, Muxs, DeMuxs, filters …… etc. .
6) A suitable software compiler is chosen (in the present work, we chose the OptiSystem 7) to obtain the Q-factors and BERs.
7) Five wavelengths are chosen for the download and five wavelengths are chosen for the upload between 1200 nm and 1600 nm. In this work, we chose the download wavelengths as: 1470 nm, 1490 nm,1510 nm, 1530 nm and 1550 nm respectively and upload wavelengths as: 1270 nm,1290 nm, 1310 nm, 1330 nm and 1350 nm respectively. The total bandwidth is 10 GB the free space between bands is 20 nm.
8) Results (Q-factor and BER) are obtained for the download of all active customers and upload in OLT for each stage.
9) For all stages BER should not be greater than 10^{-4} for a good design of the optical access network.

The pseudo code of this algorithm is given as in Figure (20) while Figure (21) shows the flowchart of the design process of the FTTH optical access network. This design process explains the steps of moving between the OLT and the customers.

```
1. Initialize total to zero
2. Initialize counter to zero
3. Declare bandwidth variable BW
4. set 0
5. set BW to BW*50/100
6. Declare distance D variable
7. if D is the required design distance
8. determine the distance D
9. else go to 5
10. determine the kind of optical fiber cable
11. choose the kind of equipment
12. choose the software compiler
13. choose the wavelength WL
14. design the optical access network
15. if BER < 10^4 then
16. design approved
17. else go to 11
18. end if
```

Figure (20): The pseudo code of the FTTH access network design algorithm

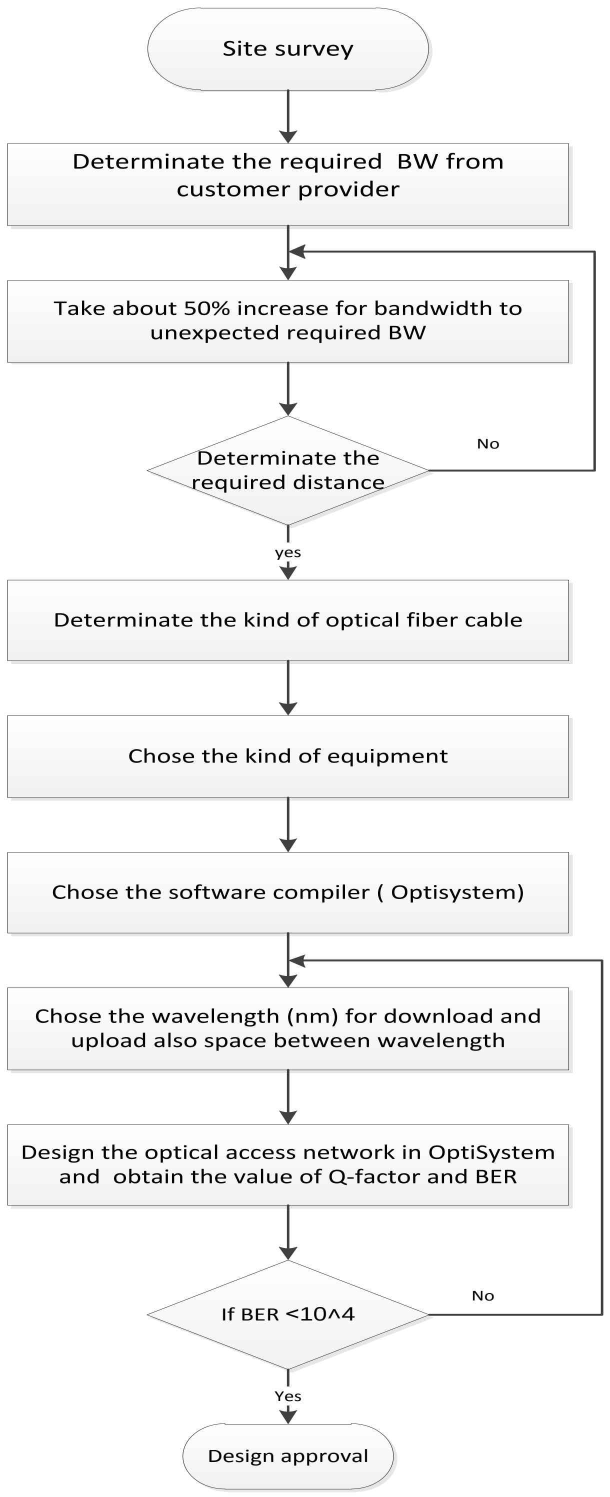

Figure (21): Flowchart of FTTH optical access design steps

4.3. Simulation of the FTTH access network

We need to design a simple access network. Thus, we consider the simple payload needed in any community such as in schools, hospitals, residency, banks and business. For that purpose, we use the OptiSystem 7.0 as an innovative optical communication simulation system to design and optimize the optical links and optical equipment's.

In the beginning, we chose five different wavelengths for download (downstream) ranging from 1450 nm to 1530 nm with a spacing 20 nm and the power 0 dBm. Also, we choose five different wavelengths for the upload (upstream) ranging from 1270 nm to 1350 nm with a spacing 20 nm. Thus, the available wavelengths range between 1200 nm and 1600 nm.

In figure (22), we can see an access network design that is composed of eight parts as follows:

1) The central (OLT) is one of the most important elements of the network, which is in charge of distributing the traffic to the clients. The first element located at the OLT is WDM transmitter. This laser part will broadcast the five different upload wavelengths from 1470 nm to 1550 nm with a spacing 20 nm. The next element is an optical multiplexer, which will multiplex these five wavelengths and transmit on a single fiber. Finally, the upload wavelength if the optical signal, from each user to the OLT, will take a different download wavelength from 1270 nm to 1350 nm with a spacing 20 nm. Note that the signal of the upload will pass through the same elements and therefore they have the same characteristics and parameters.
2) After 10 km, we find the splitter block (2), which contains a demultiplexer (DeMux) for the download traffic. The optical signal, coming from OLT, will be demultiplexed into 5 different optical branches, each of them with a different wavelength.
3) The hospital area: There is a huge hospital that covers a large sector of people and it has the latest technological advances. It takes a wavelength 1470 nm for the download and wavelength 1270 for the upload.
4) The business area: There are two buildings that give service to several companies. It takes a wavelength 1490 nm for the download and a wavelength 1290 for the upload.
5) The resident area: There are eight family homes that require a full service including (voice, video, HDTV, …., etc.). It takes a wavelength 1510 nm for the download and a wavelength 1310 for the upload.
6) The school area: It is next to the resident area. It includes an elementary school and a preparatory school. It is necessary to secure a broadband internet & an HDTV. It takes a wavelength 1530 nm for the download and a wavelength 1330 for the upload.
7) The bank area: It includes banks and sectors for financial transactions. It needs a fast internet to connect the banking software and the different banking machines. It takes a wavelength 1550 nm for the download and a wavelength 1350 for the upload.
8) The collector (Mux): All the upload signals, coming from different areas with their five wavelengths, are multiplexed using an optical multiplexer (1270 nm to 1350 nm with spacing 20 nm). The multiplexed signal is sent through the optical fiber 10 km to the OLT.

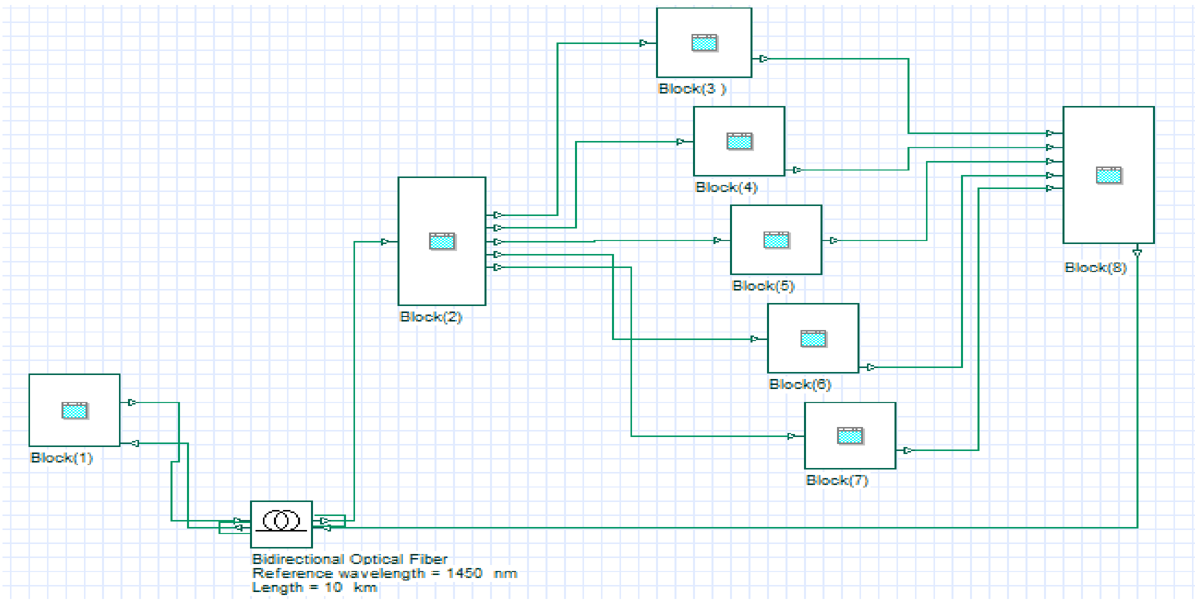

Figure (22): The main block diagram of access network: (1) the central area (OLT) , (2) Splitter (DeMux) , (3) Hospital area ,(4) Business area , (5) Resident area , (6) School area , (7) Bank area ,(8) Collector (Mux) from subscribers .

For illustration, we explain the hospital area (Block 3) in more details as in figure (23). It includes an optical fiber of 5 km length, the download equipment which is connected to an Optical Spectrum Analyzer_1 to declare and draw the spectrum for the download signal. Also, the WDM analyzer_1 is used to determinate the value of the OSNR .Finally, the BER analyzer is used to show the Q-Factor, BER and crosstalk (eye height) and draw the eye diagram.

For the upload path, the same elements are used and the same parameters are measured.

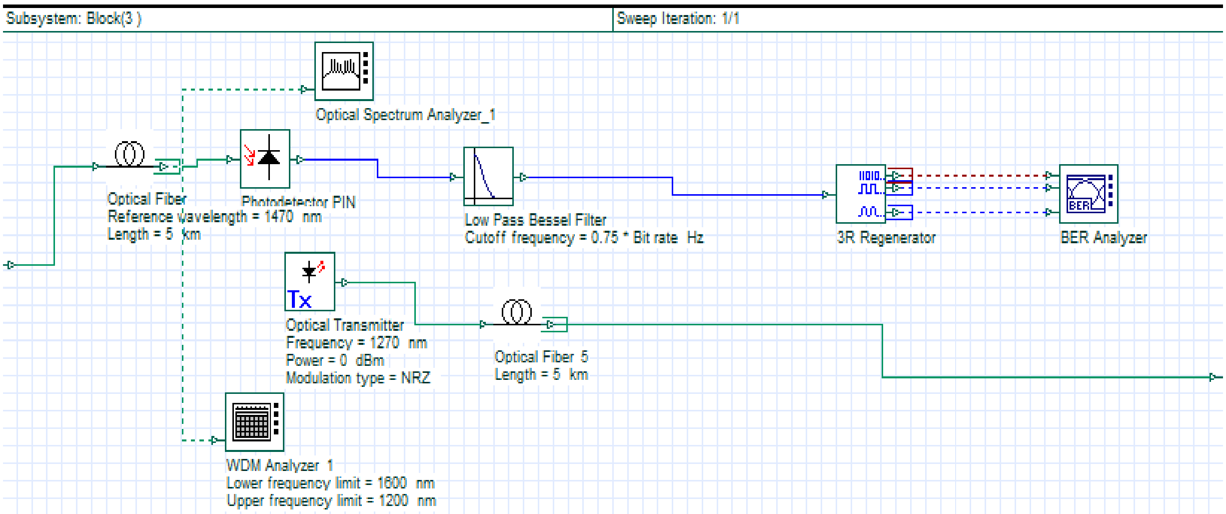

Figure (23): The main block diagram of hospital area.

We repeat the same steps of the hospital area for the other areas. Thus, the results of all areas of the FTTH network are shown and explained in the next section.

5. Results and Discussion

In this section, we obtain the values of the OSNR, BER, Q-Factor and Crosstalk (eye height) for all areas and then we determine the efficiency of FTTH optical network.

5.1 Results

Like we did in the previous section, we explain out results in details for the hospital area and then we gather all the results of the other areas. In the hospital area, the 5 km optical fiber carries information in both direction with a download wavelength 1470 nm and an upload wavelength 1270 nm. In Figure (24), the reading of the optical analyzer connected to the optical fiber is centered at 1470 nm as expected. Figure (25) shows the results of WDM Analyzer_1 to determene the OSNR for 1470 nm. We find that the OSNR value of 90.019784 is acceptable (Note that OSNR values should be greater than 40db to accept design of FTTH network). Figure (26) shows the Q-factors with the Eye-Diagram of the hospital area, and we can take the approximate vale of Q-factor form the peak curve as 27.8. Applying the analysis using eye diagram is a simple method and it helps to accurately assess the FTTH optical network. The measurement with the eye diagram is made in the time domain and it shows the distortion effect of the wave. Figure (27) shows the BER with the Eye-Diagram of the hospital area, and we can't take an exact or approximate value of BER form the curve (the scales is very small). Figure (28) shows the Q-factor and BER of the hospital area with the eye height (crosstalk) in count number with accurate values. Also, we can obtain the exact writen number for the needed parameters. We determine the Q-Factor value as 27.8931, the BER value as 1.5524 e-171 and the eye height (crosstalk) value as 0.000418106. These results are acceplable values to assure the correctness of the FTTH network design.

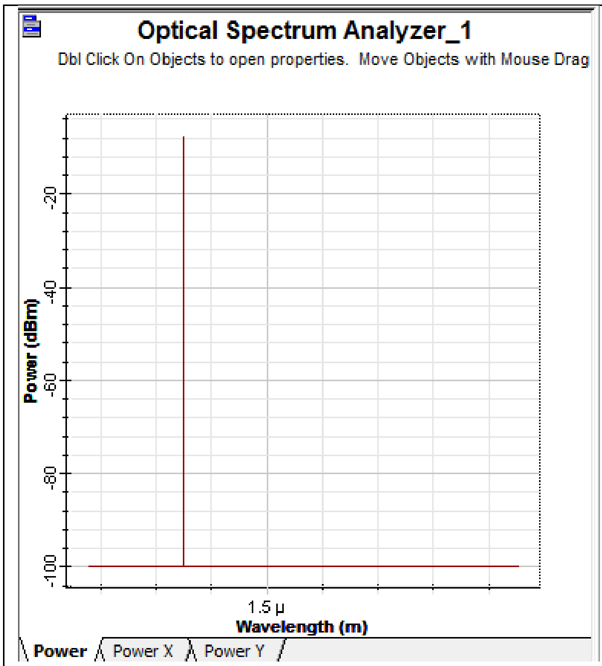

Figure (24): The hospital area download wavelength

WDM Analyzer

Wavelength (nm)	Signal Power (dBm)	Noise Power (dBm)	OSNR (dB)
1550	-100	-100	0
1530	-100	-100	0
1510	-100	-100	0
1490	-100	-100	0
1470	-5.9802156	-100	94.019784

Figure (25): The OSNR of the hospital area

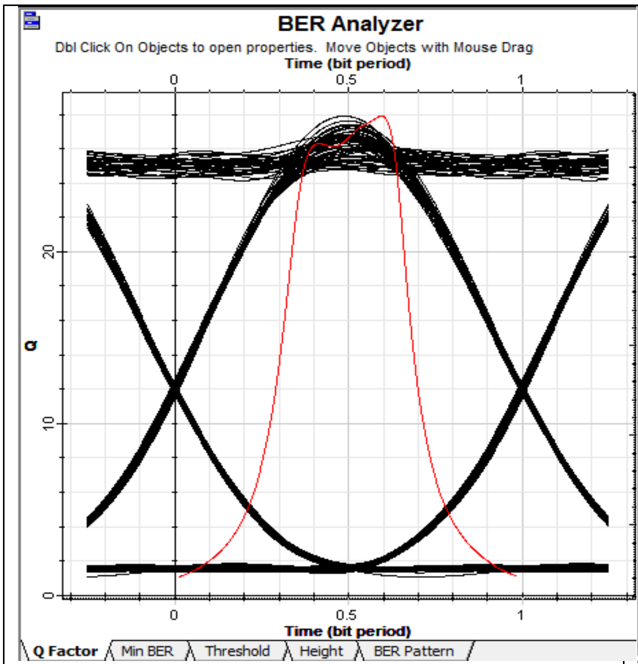

Fig (26): Q-factor for the hospital area

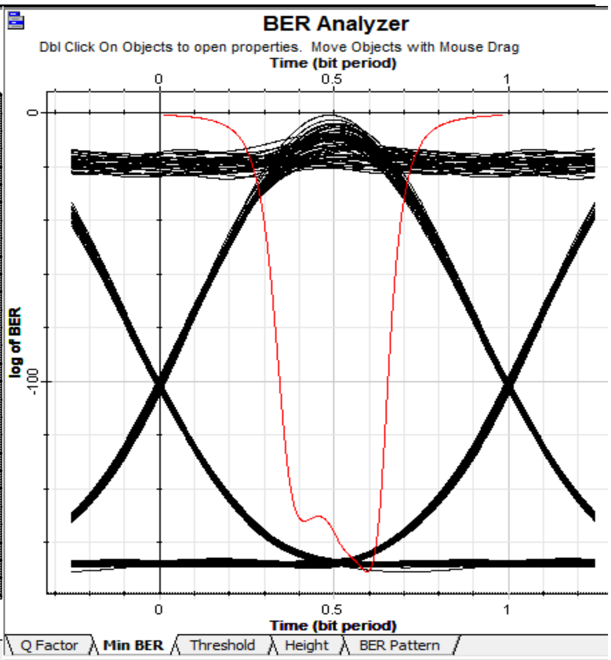

Figure (27): BER for the hospital area.

We repeat the same steps (of obataining the results of the hospital area) to obtain the results of BER, Q-factor, OSNR and cross talk for the other areas of the FTTH network design we discussed in section (4), including: the business area, the residency area, the school area, and the banking area. From these results, we can determine the quality of services of the FTTH network. Table (1) shows the result in the user terminals for all areas by WDM analyzer and BER analyzer including the count numbers for the OSNR, the Q-factor, the BER and the Eye height (Crosstalk).

Analysis

Max. Q Factor	27.8931
Min. BER	1.5524e-171
Eye Height	0.000418106
Threshold	0.000215836
Decision Inst.	0.595703

Figure (28): Q-factor and BER of the hospital area

Table (1): The main parameters of the FTTH network

No	Area name	Wavelength (nm)	OSNR	BER	Q-factors	Eye height
1	Hospital area (block 1)	1470	94.019784	1.931 e-171	27.885	0.000418
2	Business area (block 2)	1490	91.094739	1.047 e-239	33.040	0.000246
3	Resident area (block 3)	1510	85.888729	1.173 e-133	24.574	6.163 e-5
4	School area (block 4)	1530	91.834359	4.94 e-324	38.462	0.000261
5	Bank area (block 5)	1550	94.819729	0	39.714	0.000512

5.2 A Comparison with Previous Work

Boyer Heard [12] explains a method to provide highly modeling for users. We design the FTTH by using the Optisystem 7 to distribute the internet rates and speeds to the customers and determine the high quality of services with high values of Q-factor and BER less than 10^{-6}.

Jani Saheb Shaik [13] and Frank Effenberger et al [14] explain and determine the wavelengths of channels for the download and the upload. We choose the wavelengths in the range used for the access network (1200 nm to1600 nm with 20 nm spacing) while the upload range (1200 nm to 1400 nm with 20 nm spacing) and also the download rang (1400 nm to 1600 nm with 20nm spacing).

Hiroyuki Yashima et.al [15] proposed a high speed network for any bit rate with power control by declaring the BER and reached a high Q factor. In this paper, we discuss the main parameters (BER and Q factor) as design factors to control the performance of the transmission signal over the network on its arrival at the destination. Using these factors helps to obtain high quality services for all the required wavelengths (BER less than 10^{-6}).

M. A. Othman et. at [16] designed and analyzed an FTTH structure. In this paper, we chose the kinds of optical fiber with OLT and ONT for a simple community (School, Business, Hospital, Residency and Banking) we used optical fibers with lengths of 10 km and 5 km for a single mode fiber coble with optical splitter to fulfill the required bandwidth to the customers.

6. Conclusions and Future Work

6.1 Conclusion

In this paper, we presented a real community servicing FTTH optical access network. It provides services to users in schools, business, hospitals, residency, banks …… etc.). The design algorithm is explained and the Optisystem software is used for the simulation. The aim f the design is to determine the cable lengths and the required equipment (OLT, splitter, ONT, ……. etc.) and to can calculate the Q- factors and BER to obtain good quality services. Based on that, the main architecture of the distribution network is obtained to minimize the amount of optical cabling lengths and equipment needed for the distribution of services to the customers with low cost in the implementation of the FTTH optical access network. We also compared our work with the previous research works.

6.2 Future Work

Although extensive research has been studied in this thesis , a number of issues related to FTTH networks may still be worth investigating in the future. Next we using different simulation tools for the proposed FTTH architectures could help to estimate the performance for larger systems under different conditions and network parameters.

we hope to increases the number of users FTTH network.

we hope to generate a new technology to developing the optical access networks .

we hope to use different multiplexing techniques and compares between them.

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