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Design of Wireless Passive Optical Communication Network Based On Fusion of Fiber to the X Architecture

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Abstract: **- The steadfast increase in the demand for internet services had lead to the generation of stupendous traffic in the communication networks, which persuades the need for the implementation of the next generation networks with high data rate for reliable communication. Optical communication can be a solution to this problem which can provide communication with high bandwidth. The Wavelength Division Multiplexing in Passive Optical Network is preferred to be advantageous with low investment and maintenance cost. This work aims at identifying the best type of network by building a fictitious environment, analyzing the Fiber to the X architecture with respect to various performance measures such as Bit Error Rate(BER), Eye diagram to decide the most preferable and optimal network for that environment using simulation software. The simulation results with BER of less than 10-13 for the worst case and zero for the best case have been obtained. The eye diagram shows wider opening as the BER decreases. These results justify that the network is feasible and can be implemented in real cases.**

Key words: **Passive Optical Network, Fiber to the X, Wavelength Division Multiplexing, BER, Eye diagram.**

I. INTRODUCTION

The optical fiber communication plays a vital role in supporting the next generation services. It provides various advantages like long distance communication, higher bandwidth, increased resistance to electromagnetic interference, reduced signal degradation and increased security. The advancement in broadband applications such as high definition television (HDTV) broadcast, broadband Internet access, has created a growing interest among service providers to supply broadband services to residential and small business by improving networks [1]. To make this possible there must be a tradeoff between the total cost of infrastructure, services and quality of services that can be offered to end users. Nowadays, service providers invest a lot in their access networks to meet the stupendous demand for high-bandwidth broadband and also support many users [2]. Along with the technology and long reach, the service providers should also ensure the demands of the future consumers. As a result there is a steady increase in the development of Passive Optical Networks. PON is a telecommunication technology deploying a point-to-multipoint architecture, in which passive components such as fiber optic splitters are used to allow a single optical fiber to serve multiple end-points such as home, buildings, curb etc [3], without using individual fibers between the hub and customer. The Wavelength Division Multiplexing (WDM) is the technology that can provide the best solution to the tradeoff between the cost of components and the quality of services in PON, by considering the Coarse Wavelength Division Multiplexing (CWDM) for access networks and metropolitan areas and Dense Wavelength Division Multiplexing (DWDM) for long distance applications

II. RELATED WORKS

Earlier, the Digital Subscriber Lines (DSLs) were used that provides internet access by transmitting digital data over the wires of a local telephone network [4]. It allows simultaneous use of the telephone and broadband access on the same copper pair, with a maximum range of 10,000 feet only. The data rate of consumer DSL services ranges also from 256 kbps to 40 Mbps only in the direction to the customer. In CATV, the internet services are provided by using dedicated RF channel in coaxial cables for data transmission. They are not suitable for high load and bidirectional communication [5]. Then evolved the Passive Optical Networks that supports the triple play services in the broadband subscriber access network, which the technologies such as DSL and CATV cannot support due to the lack of bandwidth. The FTTX models bring the high capacity optical models closer to the homes, buildings and business areas [6]. PON eliminates the use of power supply, optical amplifiers and repeaters. Moreover, it reduces the number of required optical ports in the central office when compared to point-to-point solutions. A WDM-PON design is point-to-multipoint connection over the same physical infrastructure. It provides high capacity of optical fiber combined with low installation cost, maintenance cost of passive networks and offers lower latency than TDM-based approaches [7]. WDM-PON provides scalability as it can support multiple users by making use of multiple wavelengths over the same fiber [8]. It does not suffer power-splitting losses. Usual triple-play services are provided to normal subscribers. The main advantage of WDM-PON is that the OLT bandwidth is not shared thereby allowing every ONU to transmit at the peak speed. Hence, it is able to support higher data rate [9]. WDM technology in a Passive Optical Network provides reliable and efficient communication with an acceptable BER even for the worst case environment with losses, attenuation and presence of noise [10].

III. WDM-PON

WDM-PON (Wave Division Multiplexing Passive Optical Network) is a point-multipoint network that provides the dedicated bandwidth of a point-to-point network by sharing over a single fiber. It supports multiple users on a single optical fiber thereby proving scalability. 32 subscribers can be served by a single WDM-PON access fiber. It enables separate downstream wavelengths for each subscriber. This provides more bandwidth to each subscriber, more security, and better operational control since there is no interference in the downstream direction among the various wavelengths. The PON reduces the cost by replacing all the active components between the server and customer with optical passive components. Bidirectional communication is provided by using an upstream and downstream channel. Different wavelengths are assigned to both the channels in order to prevent interference since they co-exist in the same fiber. In downstream channel PON behaves like a point-to-multipoint network since the information is transmitted from the OLT to the ONT located at the end user premises. In upstream channel PON behaves like a point-to-point network since the information is transmitted from the ONT to the OLT.

A. Elements of PON

i. Optical Line Terminal

The Optical Line Terminal is located in the central office. It controls the bidirectional flow of information across the ODN (Optical Distribution Network). An OLT can support transmission distances up to 20km across the ODN. PON uses a wavelength of 1490 nm for combined voice and data transmissions and 1550 nm wavelength for video distribution in the downstream. Whereas, upstream voice and data traffic makes use of 1310 nm wavelength. Therefore interference is avoided between the two channels by superimposing two different wavelengths. Based on the distance at which the different ONTs are located, the OLT emits appropriate amount of light. So data will be transmitted at more power to the farthest ONT.

ii. Optical Network Terminal

The ONT also called as modem is located at the customer's premises. It interfaces the customer equipment and PON electrically. It can also aggregate, groom, and transport various types of information from the user and transmit it upstream over a single fiber to the OLT. The information associated with a particular user from the OLT is filtered and encapsulated. It is then sent towards the OLT header to route it to the appropriate network.

iii. Splitter

Splitters are passive optical components that are used as power dividers. It allows communication between the OLT and the various ONTs. Splitters can be used to multiplex or demultiplex signals and also to combine power. It consists of one input and multiple outputs to provide bidirectional optical distribution. Splitters are the main passive elements used in PON, which operates without external power, thereby lowering their cost of deployment, operation and maintenance. A splitter with two outputs is the worst case, it produces loss of 3 dB (half power).

B. FTTX Network

Fiber To The x comprises of the various optical fiber delivery topologies categorized according to where the fiber terminates. It includes fiber to the home (FTTH), fiber to the building (FTTB), fiber to the curb or cabinet (FTTC), etc. It can offer the highest speeds in Gbps since the remaining segments can use standard Ethernet or coaxial cable. It is capable of delivering triple play services directly to the customer premises from the central office [11].

IV. DESIGN OF WDM-PON

The WDM-PON design consists of deploying a Passive Optical Network in a fabricated environment with all the physical and structural elements required to design the network. This is followed by designing the active network or last mile using optical fiber. It also consists of the active elements that allow the data transfer from the central office to the homes, which enables to provide services to end users. The design consists of deploying a fabricated environment with different areas having various broadband requirements. The performance of data transmission in both upstream and downstream must be analysed to decide the preferable and optimal network in that environment by using simulation software. The fictitious environment consists of five different areas that require next generation networks to meet their broadband requirements. The five areas include School, Buildings,

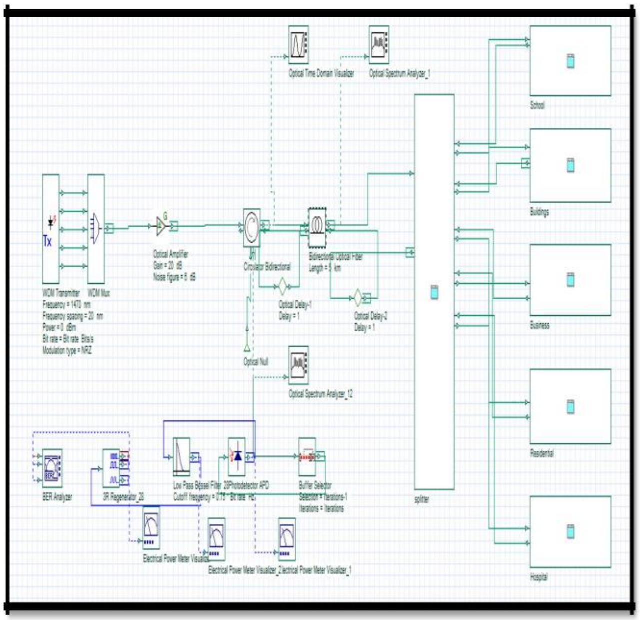

Fig.1. Design of WDM-PON

Business, Residential area and Hospital, each having different number of ONUs based on their requirements for broadband services. Two ONUs are used in School, Building, Business and Hospital blocks to provide advanced broadband services and HDTV over a huge region. Twenty ONUs are used in the residential area to provide triple play services.

A. WDM PON IN DOWNSTREAM

In downstream, the optical signal is transmitted from the OLT to the ONT's. The first element in the network is the optical transmitter located at the OLT. The WDM transmitter is used which broadcast's five different wavelengths from 1470 nm to 1550 nm with a frequency spacing of 20 nm. The transmission power is set to 0 dBm and NRZ modulation is used. The global bit rate of 2.5 Gbps is used. Then optical multiplexer is used to multiplexer these five wavelengths to transmit on a single fiber. This 1:5 multiplexer has an insertion loss of 3 dB. In order to prevent signal degradation an optical amplifier with 20dB gain is used to ensure good quality of signal in the case of major losses. An optical circulator with insertion losses of 3 dB and return losses of 65 dB is used to handle both the downstream and upstream traffic. The optical signal from the OLT is then transmitted through the optical fiber which reaches the multiplexer located at 100 km from the central office. The fiber dispersion value and dispersion slope value were set to 16.75 ps nm-1km-1 and 0.075 ps nm-2 km-1 respectively, and attenuation loss set to 0.2 dB/km. The data transmitted through the fiber then reaches the splitter which contains a multiplexer and demultiplexer. For downstream traffic, the signal from optical fiber is demultiplexed into 5 different branches with each of them carrying a different wavelength. This 1:5 splitter has a starting frequency of 1470 nm and a frequency spacing of 20 nm. The splitter with insertion losses of 3 dB is used in order to design the system that can produce an acceptable result even for the worst case. As the transmission wavelength increases the Quality factor increases and the BER decreases [12]. Based on the importance of good broadband services required in each of the area, the wavelength is assigned to the blocks. The first branch of the splitter is directed to the school area with 1470 nm wavelength, the second to the area with buildings with 1490nm wavelength. Third to the business block, with 1510nm, fourth to the residential area with 1530nm and fifth to the hospital block with 1550nm. The receiver consists of an APD with responsivity set to 10 A/W, gain set to 5 and dark current of 10nA. The signal is then filtered by a low pass Bessel filter with a cut-off frequency of 0.75xbitrate. The filtered signal is given to the 3R regenerator which has three output ports. The first output port is the bit sequence, the second one is a reference signal and the last one is the output signal. The three output signals are given to the BER Analyzer for performance analysis.

B. WDM PON IN UPSTREAM

In upstream direction, the optical signal travels from each of the ONTs to the OLT. The signal in upstream passes through the same elements as in downstream and therefore have the same characteristics. The ONU transmits at 1270 nm with frequency spacing of 20 nm, with a power of 20 dBm, NRZ modulation and 2.5 Gbps global bit rate. The first block receives data at 1270nm wavelength, second block at 1290 nm and so on upto the fifth block at 1350 nm. Therefore, TDMA is implemented in each of the five different areas for each user to transmit in a determined time instant. This avoids the collision among users when data is transmitted at the same time. It uses two cascaded Dynamic Select Y which allows the signal to be passed only at a determined time instant and the rest will be zero. For first Dynamic Select the switching time, Ts is given as,

$$Ts = \text{Timeslot} * (1/\text{Bit rate}) * \text{Sequence length} / N \qquad (1)$$

For the second Dynamic Y select, Ts is given as,

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Ts = Timeslot * (1/Bit rate) * Sequence length / N + Time window / N (2)

where N is the number of users. The receiver consists of a Buffer Selector, which is used to select only the latest iteration of the simulation, which produces the correct results. The signal is then passed through an Avalanche Photo detector which converts the incoming optical signal to electrical domain. The APD is set to responsivity of 10 A/W, gain set to 10 and dark current of 10nA [13]. The electrical signal is then filtered through a Low Pass Bessel Filter with a cutoff frequency of 0.75 x Bit Rate which is then regenerated by the 3R regenerator and analyzed using BER Analyzer.

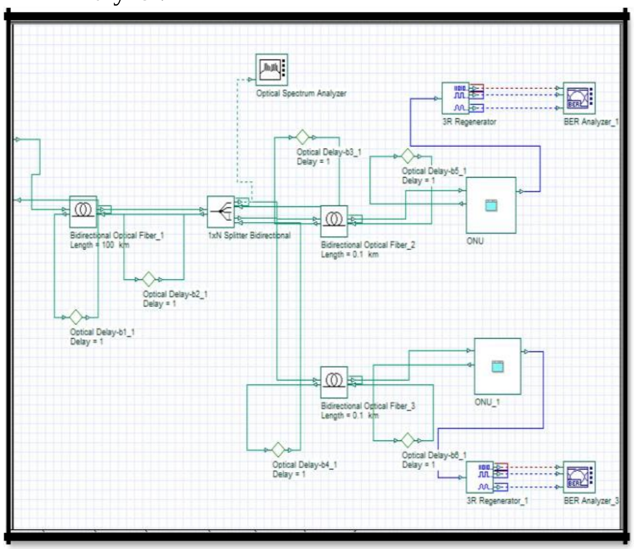

Fig.2. Schematic of the block in WDM-PON

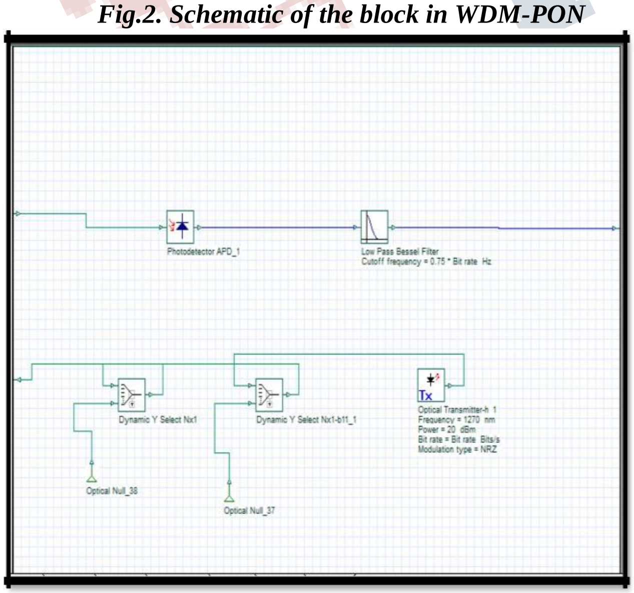

Fig.3. ONU in WDM-PON

V. RESULTS AND DISCUSSIONS

The simulation program Optisystem 7.0 is used for designing the WDM-PON network. The performance of the PON architecture in the upstream and downstream is evaluated using Bit Error Rate (BER) and Eye diagram.

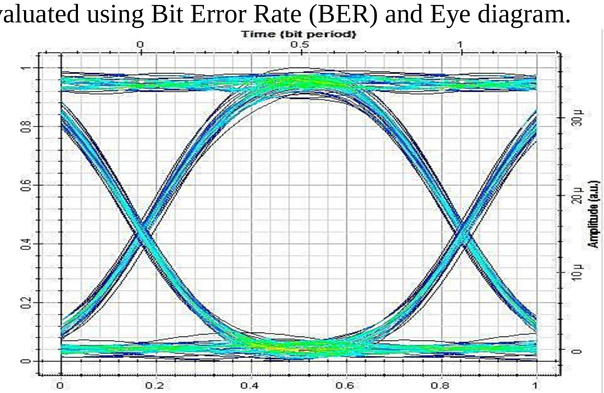

Fig.4. Eye diagram for School block

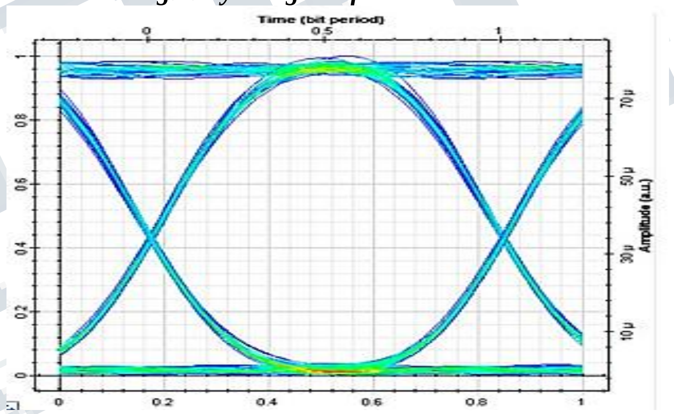

Fig.5. Eye diagram for Buildings block

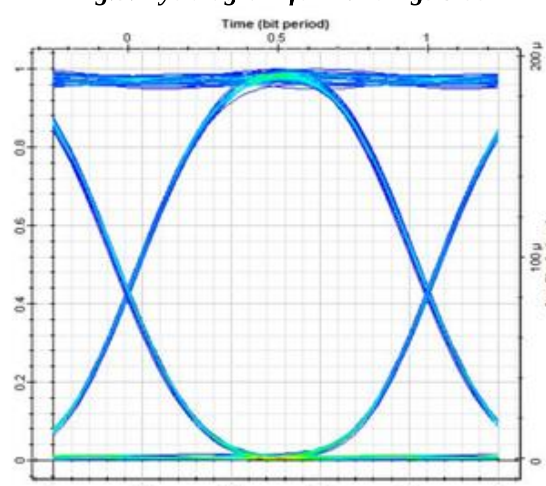

Fig.6. Eye diagram for Business block

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Any system with BER in the range of 10-9 to 10-12 and even less than that is acceptable, consistent and reliable. In eye diagram, the higher the vertical eye opening then greater is the immunity to noise. The eye diagram for the upstream transmission and various blocks in the downstream transmission are shown in Figure 4 - Figure 9.

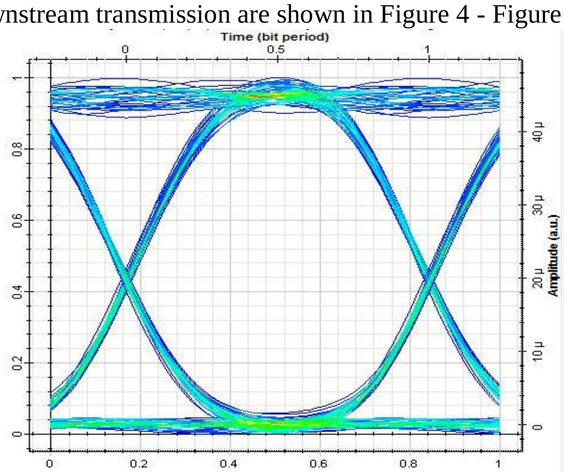

Fig.7. Eye diagram for Residential block

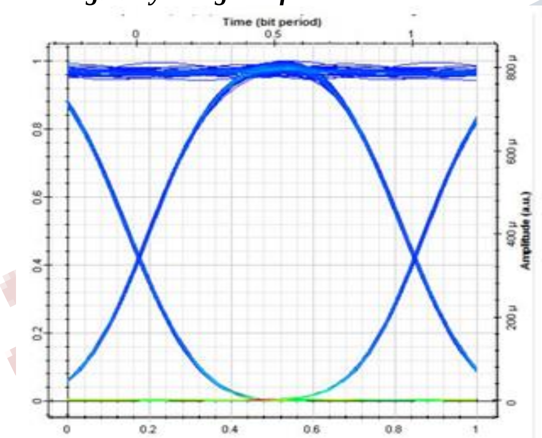

Fig.8. Eye diagram for Hospital block

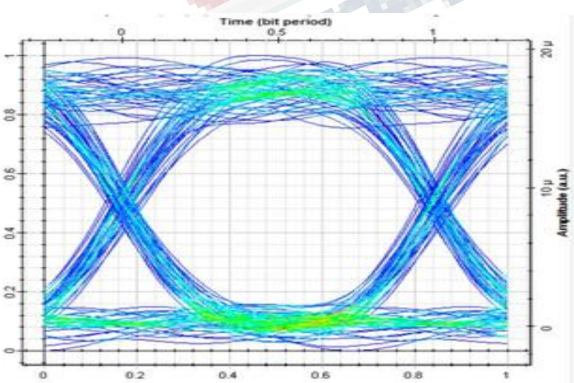

Fig.9. Eye diagram for upstream transmission

TABLE I: PERFORMANCE MEASURES FOR WDM-PON

CHANNEL		MAX Q-FACTOR	MIN BER
Down stream	School	23.47	4.42×10^{-122}
	Building	50.19	0
	Business	74.53	0
	Residential	31.06	4.59×10^{-212}
	Hospital	95.88	0
Upstream		11.25	9.5×10^{-29}

The Building, Business and Hospital blocks each containing 2 ONUs transmitting at 1490 nm, 1510 nm and 1550 nm respectively produce zero BER with good Q-factor, thereby making the transmission in downstream reliable and consistent by the fact that BER decreases as the wavelength increases. The School block consisting of 2 ONUs transmitting at 1470 nm produces BER in the range of 10-122 with good Q-factor. Even though the BER in this block is more than the BERs for other blocks, it is acceptable. As the number of ONUs increases, the BER increases and Q-factor decreases. So, the Residential block with 20 ONUs produces BER in the range of 10-212 which is acceptable. Also, as the relative distance of each ONU from the splitter increases, the BER also increases with decrease in Q-factor.

VI. CONCLUSION

A Passive Optical Network using WDM technology with FTTX was designed in a fabricated environment and its performance was analyzed. The performance measures such as BER and eye diagram were found for both upstream and downstream channels with different wavelength and different number of ONUs in the presence of attenuation and insertion loss, return loss for the optical network elements, noises like thermal noise, shot noise, etc. As the wavelength decreases, the number of ONUs decreases and fiber length increases, the BER increases thereby reducing the Quality factor. It is concluded that while designing an environment with WDM-PON with FTTX architecture, the important areas such as Hospitals which require low BER and high Q-factor value, areas with large number of ONUs such as residential and business centers, also the areas located at longer distances must be provided with larger wavelengths for data transmission. The simulation results with BER of less than 10-13 for the worst case and zero for the best case have been obtained. The eye diagram shows wider opening as the BER decreases. These results justify that the network is feasible and can be implemented in real cases.

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