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Bandwidth Enhancement, Bit Error Rate (BER) Improvement & Power Budget Evaluation for a Bidirectional CWDM-Passive Optical Networks

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Abstract

The novel approach was preferred by the Coarse Wavelength Division Multiplexing (CWDM) that has proven itself to improve the bandwidth of the optical networks and offers them rather quicker and easier installation. It also lowers the overall cost. The electrical power of the Passive CWDM does not require at all and are believed much consistent and robust to install in the extremely difficult atmosphere. It has been proven by various studies and experiments that the Passive Optical Networks (PON) shows a great impact while using CWDM technology to improve the data rate up to the much achievable limit. This present study demonstrates and studies that how the data rate and transmission be able to enhance by way of reducing the Bit Error Rate (BER), and properly calculating power optical budget. The system output results describe that its bandwidth enhanced carrying capacity reaches to 40 Gbps with maximum 46kms and minimum 3kms transmission distances. The simulations are designed in such a manner that it can hold a total of 128 customers with 64 uplink customers and 64 downlink customers with a minimum BER value and less Power Optical Budget.

Keywords: CWDM, PON, BER and Optical Budget.

Background

The communication of fiber optics uses light as carrier and transmits the useful information and quality data from one place to another. During the1970's, the cable media was much common than the media of optical fiber for it's much higher attenuation. The optical fiber attenuation was approximately decreased to 0.2dB/km by some scientists. A low transmission loss, resistance to electromagnetic interference and rather massive communication capacity are the three main advantages that can be accessible by fiber optics [1]. The service providers were connected to the access network, which we called the main office, and then to the consumers, such as populated homes. And a need for bandwidth has increased vigorously over the past few periods [1]. Substantial rises have been reported by market research in the number of users, from 35% to 40%, who are online after enhancing broadband connectivity [2]. Not only did the number of customers raise, but the number of voice service subscribers also rose from 8 percent to 9 percent each year, even though the voice-based service was used to be advertised only in limited amounts [2].

The broadband services carried with a gorgeous method developed by Passive Optical Networks (PON) to many subscribers over the last periods. The facilities originate from the Optical Line Terminal (OLT) only at the end side (head end) or main office (central office (CO)) and are supplied by an optical fiber feeder for approximately 10–15 kilometers. The optical power is divided beforehand into various output of distribution fibers by ways of an optical power splitter employed at the Distant Node (RN) in a typical PON [4]. Whereas all distribution fiber which is frequently less than 5 km in length, subsequently, facilities adjacent to the Optical Network Unit (ONU), in which an optical signal has already been installed, will be extended to all subscribers near to this OUN by additional broadcasting, such as copper wire, etc. [4]. The device price of PONs must hold it down just to make it commercially feasible and expensive with such high fiber dispersion in the entrance region. PON passive remote node systems that cover the cost of treatment of optical elements in outdoor fiber plants. The RN and the ONUs both must be kept in the compact amount and kept very simple [4]. The downstream services offered by a PON are, of course, video delivery services. The upstream channel is frequently given to forward the requirements of the subscribers back to the OLT. Normally, this upstream channel has a low data rate. Efforts have been made for the problem of long-term network maintenance due to the distributional nature of the traffic as well as the decreased amount of PON alarm. Conventional PONs is the transmission of two-way broadband linking data signals to the current wide use of the Internet and multimedia facilities it transmits [4]. The services offered to PONs are becoming ever more data-centric, with rising demand for bandwidth in both corporate and access network for broadband services of residential. PONs that uses the wavelength division multiplexing (WDM) approach have been developed as next generation optical access networks with the latest ease of low-cost optical component [4]. The bandwidth of the committee can be assessed by each individual OUN, based on which it can also be managed according to its own needs. The system and the network capability could be significantly improved with a predictable PON architecture. Fault management amongst the most well-known essential aspects of network management. Conventional methods of fault management depend on higher-level research, based on status reports obtained from multiple checkpoints on a functioning optical network. High-level fault analysis will perform severe above your head both in network signaling and in the network management system (NMS). There seems to be no assurance that higher layers can have physical layer recovery errors [4]. It is extremely anticipated to execute network long life methods in the optical layer to allow rapid network safety. It can be completed by a basic fiber link with a minor safety resource repetition [4]. It will take a long time to make some fiber cut repairs [4]. The long life of PON architectures is desired with security switching near some fiber cut. In this chapter, the long-life network design for PONs will be discussed in designing several concerns.

The “last-mile networks” term has been used for access networks as they contain the last part connection to the end subscriber’s side from central office in the past couple of years. They are called “first-mile networks” since they are the two-initial part of the broader network detected by subscribers of telecommunication services [3]. The examples of such access networks are the twisted copper pairs connecting to almost every residential home which is known as local loops. The national “coaxial cable” that falls from the community antenna TV-service suppliers. The use of radio waves by the division of access technique for the last-mile connection is called “Wi-Max”. Wide bandwidth and comparatively minor losses, optical fibers have typically been absorbed in the last few years. Optical fibers just have not been frequently used as the last mile connection, even though the fiber optics were publicized long time ago [4]. The telecommunication networks which were generated were technologically advanced for analog services over the years. The general bandwidth was 4KHz necessary for several years for voice examining to connect to the end subscribers. The telephone companies have organized a widespread twisted copper network in the advanced countries [5]. The transmission is not tough if such networks were upgraded for analog frequency. The Inductors in many old, twisted copper pair plants have been recognized to improve the voice frequencies band execution to achieve handsome economy. The high frequency signals were reduced by the loading coils farther than the voice frequency band and are troubling for broadband DSL services [6].

The access network can be used for the transmission of voice and multimedia services through copper, optical fibers cable media, wireless connections, or a combo of copper media and fiber medium. The local end that links the very last mile to feeder media can behaved as an active or passive in the allocation of data between users and the local exchange [6].

The existing network of wireless and wireline communication alternatives are usually arranged in point to multipoint network from topology perspective to provide broadband network connectivity. The WiMAX and Wi-Fi could provide a connectivity speed of 70 Mbit per second for distances of 5 kilometers and a connectivity speed of 50 Mbit/s up to 100 meters [6]. These technologies are not feasible to deliver high data rate internet and high-speed video applications. There have only been a few new products in place to incorporate WiMAX as the bandwidth that can be accessed is collective across hundreds of users. The Digital Subscriber Line (DSL) over the media of copper facilitate an additional point to point wireline connectivity technology alternative to provide up to 24 Mbit/s for, downstream subscriber [6]. The operative bandwidth for each subscriber at high frequencies due to simple noise restrictions is limited to the local loop length. The length of the local loop must be reduced to about 1000 meters to enable subscribers to access reasonable multimedia services at 30 megabits per second downstream of 1 megabit per second upstream capability. ITU-T G.993.2 is planned to standardize second generation network access with very high DSL2 and VDSL2 data rates. The replacement of the feeder portion of the network with optical fibers was accomplished by the creation of nearby fat-bandwidth pipelines for subscribers with hybrid fiber-copper access networks capable of delivering a data rate of more than 50 Mbit/s downstream [6]. The bit rate is attained maximum up to 100 meters. The greater distribution of the fiber to the subscriber is measured to meet the long-term growing bandwidth demand [6]. Fiber to the home (FTTH) designs have observed owing to overwhelming demand for broadband access networks.

There is overwhelming demand for huge broadband bandwidth to transmit high data at a faster speed with all this advancement in the field of communication systems. The high-speed networks for voice, data, or the video services by the need of the local users. This demand needs the networks at low cost with bigger volumes. The area of the communication method is transitioning from the copper wire used in the past to the fiber optic cable used today. The ability to transmit more data at higher speeds and over longer ranges improves growth. Higher bandwidth can be transmitted using a fiber optic cable. With the introduction of optical networks, an enormous transmitting capability can be reached over greater distances. Some considerations, such as fast and efficient wavelength transfer, de-multiplexing, multiplexing, optical separation of wavelengths and optical junction, need to be done to send higher data speeds [7].

The FTTH has been formed the novel technology to face these extreme rises. The PON execution is said to be the most applicable by using many applications of the fiber-to-the-home technology.

As can be observed from the name, Passive optical network (PON), depends majorly on passive components to the user's side from the main office. The Passive aspect means that this network does not require power to run. In PON, traffic carrying signals are assigned to users within a wider range of wavelengths. Return to the central office is also rendered using passive optical components [9]. This network has the following advantages [10].

1. PON, which being an optical connection, can transmit much more bandwidth in comparison to the traditional and conventional cables such as coaxial cable.
2. Since, the PON uses passive components, it needs low maintenance prices.
3. PON offers a large coverage area and provides high bandwidth as well.

- **Passive Optical Network Architecture**

If we talk about the structure, PON consists of some vital components such as the

1) (OLT) Optical line terminals
2) (RN) Remote node
3) (ONUs) Optical network units

The location of the OLT is in the main office, while the Remote Node has multiplex and DE multiplex couplers and splitters and downstream and upstream traffic, while the ON units are responsible for receiving downstream traffic from the Remote Node and providing upstream traffic [10].

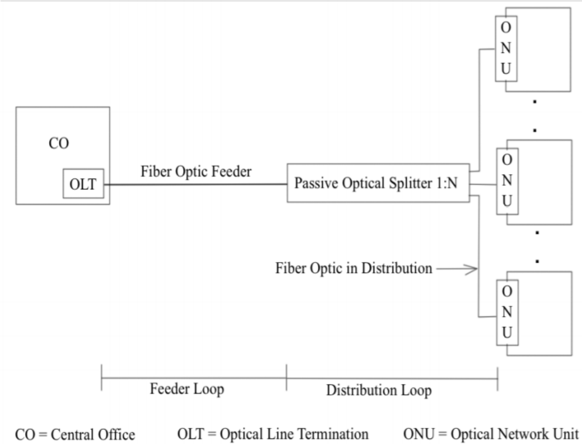
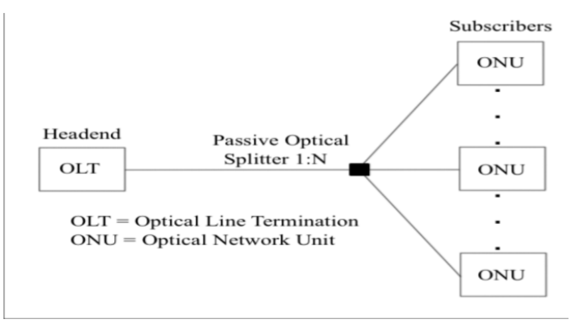


Figure 1.1: Standard PON Architecture Model [10]

- **Working of Passive Optical Networks**

PON is using a wavelength of 1490 nm. The digitized data, including 16 voices, was packed in the central office, and transmitted via the optical fiber in the downstream direction to the subscribers. The upstream direction runs between subscribers and the central office which utilizes 1310nm wavelength [11]. The wavelength of 1550 nm would be needed for video content to be transmitted. Whereas video facilities can only be delivered in the downstream direction. Figure 1.2 shows that all subscribers are using a wavelength of 1310 nm in the upstream direction. In addition, to set the interruption aside, perfect timing is necessary. The bi-directional PON phase begins at the central office as well as finishes at the central office since it has traffic downstream and upstream. One single optical fiber feeder transforms into a passive optical splitter. The basic aim of the passive optical splitter, as the name implies, is to divide the power into many paths, and that each path goes to its user [11].



Fundamental Bidirectional PON Principle Working [11]

The total amount of optical power that will be available to each subscriber is the total optical power that enters the optical splitter and is divide it by the number of subscribers in the scenario that the power of the optical splitter is similarly divided. Discussing the results, implementations and architecture of the device, the equal and unequal distribution of the optical power of the splitter can be chosen. The optical splitter is generally designed to transmit several paths to different users, ranging from two to sixty-four. The optical splitter can, however, deliver eight, sixteen or thirty-two paths in the PON model. As per ITU-T and IEEE, passive optical networks are networks which have an OLT with an active transmitter. In addition, an optical network device may either provide an active transmitter, or it may use the already received power to transmit the data again. Other than OLT and ONU modules, all other elements between the two must be passive such that they do not require any external power source [12].

- **Coarse Wavelength Division Multiplexing**

CWDM has successfully proven itself to be a trustworthy approach to increase the bandwidth of optical access networks and offer faster installation process with lowering the total cost in the past few years. The Passive CWDM are considered with zero electrical power. The Passive CWDM work in the most challenging environment. The network expansion was more flexibly installed and offers lowest budget.

The installation of Passive CWDM is easy because it can easily install into already existing “fiber splice cartridges” into street cabinets or any form of outside field plant. The following are the advantages of the Passive CWDM:

1. Low equipment and operational costs
2. Network upgradations would be reliable and cost-effective
3. The simplicity of specification and deployment is guaranteed
4. The expansion is facilitated by the elastic solution
5. Nothing exclusive and has open standards

All capacity is not needed for PON networks at a single optical node which would be in the ring or in point-to-point forms. The data transported from the fiber over specific channels may be increased or decreased when it is needed. The CWDM node can be applied at any location in the field. The figure given below explains how to achieve this improvement capacity. The method is cost-effective and simple to operate. A "passive CWDM improvement" removes the constraint for distribution of further network equipment.

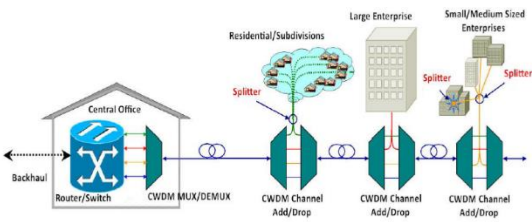


Figure 1.3: Efficient working of a passive CWDM optical network [13]

The advantages of the above shown passive CWDM PON architecture are as follows:

1) low down CAPEX
2) low down OPEX
3) zero electrical power needed
4) It can be rapidly raised when further bandwidth demand rises.

The Passive CWDM ensures much better fiber operation capacity which encourages considerably bigger data traffic, since the demand of bandwidth after the ONT's increases. It allows network operators to apply many optical nodes over several locations by minimizing annual investment and almost zero operation cost.

- **Overview of Bit Error Rate**

The bits in error with number of total bits in known Telecommunication transmissions. For example, a transmission which implies that if transmitted bits were 1,000,000 bits with a BER of 10-6, the error recorded was one bit. It also helps in indicating of how often data must be re-transmitted because of any error reported [13].

BER improvement depends by choosing a strong signal strength, based on modulation technique like line coding or low and powerful, and the use of channel coding schemes along with forward error code consolidation [14]. BER transmission is the number of observed bits which are wrong until the error correction is calculated by dividing the number of transmitted bits that comprises the redundant error codes. The BER is lower than the transmission BER. The information BER while is affected by the power of the forward error correction code.

We are struck by high-level networking systems such as tablets, smartphones and their applications that demand more bandwidth such as Internet of Things (IoT), remote health facilities, mobile networking, sharing of files, digital cloud storage, multimedia and web conferencing, wireless video & audio distribution of today's world [29]. The exponential rise in demand for bandwidth for commercial applications increases this need increased data speeds at the end of the customer. Higher bandwidth subscribers are provided with higher transmission of data rates, reduced crashes, busy signals, improved device efficiency, more immediate users, better data transfer capacity, etc. next generation based passive optical networks 2 technology is more than the demand of the end consumer. Flexible services close the user are given by next generation based passive optical networks-2 [29]. Low potential and quality of service (QoS) will be assured to next generation based passive optical networks-2 clients. Efficiency to reach huge data rates for end consumers is through the implementation of the NG-PON2 network. The network such as TWDM-PON is the main primary strategy for next generation based passive optical networks-2. It offers data rate 40 giga bits per second of 40 Kilometers from the first point to multipoint wavelength access stripped of the amplifier, that is a cost-efficient solution and has a much higher capacity. Service providers need next generation based passive optical networks-2 systems to access higher power, greater bandwidth, and more consumers for longer reach. The definition conceptualizes TWDM based passive optic network for uplink using burst mode, and downlink using continuously mode for 50 GB/s transmission with scheme of non-return-to-zero modulation schemes, and optical network amplifiers [29]. The use of NRZ modulation technique with a high speed of 80 Gbps for 50 Km is designed by a bi-directional TWDM-

PON with the lowest BER using a 5 to 10 dBm power optimization process [29]. The study describes the efficiency of TWDM based passive optic network for different range and wavelength variations in the ONU by using NRZ and coding scheme of Pulse-amplitude modulation (PAM4) for direct detection and intensity modulation [29]. Manchester, Differential Phase Shift Keying (DPSK) and Differential Quadrature Phase Shift Keying (DQPSK) studies about various distances and different data rates. Description of the Bit Error Rate (BER) as well as the Q factor for optical systems [29]. NRZ Feeding Forward Equalization (FFE) and Decision Feedback Equalizer (DFE) and Duo-binary have developed adaptive equalization techniques for the construction of the 25 Gigabit-Ethernet Passive Optical Network (G-EPON) via a pre-requisite critical analysis [29]. A description of the different number of tap modulation techniques, where duo binary performance is better as compared to NRZ [29]. NG-PON2 built on Nyquist NRZ transmission technique based on Direct Modulated Laser (DML) and APD. Power displays -28.4 dBm in receiver sensitivity for the TWDM-PON network [29]. Comparative study of advanced modulation schemes such as NRZ, RZ, Duo binary and PAM-4 for 8 channels WDM-PON for various data rates without dispersion compensation and amplifiers [29]. The BER including error factor presented by the below figure 1.4 BER vs. Q-factor by knowing the value of Q factor [30].

$$BER = \frac{1}{2} \operatorname{erfc}(Q/\sqrt{2})$$

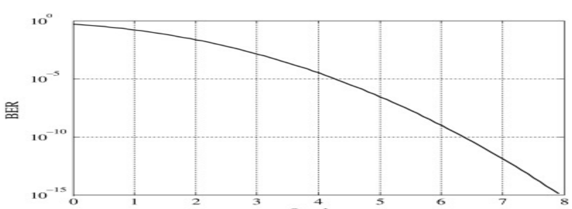


Figure 1.4: BER vs. Q-factor (30).

Whenever the height of the eye opening is as large as conceivable in the eye diagram, the time for sampling the received waveform is the greatest. Due to the height, the amplitude distortion in the signal is reduced. The vertical distance between the highest signal level and the top of the eye opening is the degree of alteration. It is also motivating to differentiate between 1's and 0's in the signal when the eye ends further. The height of the eye is as follows [30].

$$Eh = (m1 - 3\sigma 1) - (m0 - 3\sigma 0)$$

Literature Review

- **Standard GPON Details**

The communication distance of the standard GPON is stretched over 100 kilometers of joint access or metro link sections, the new two-state MAC bandwidth of assignment protocol is described as a versatile and highly effective network for bandwidth allocation on long-range passive optical networks of gigabit [6]. This protocol allows the fiber optic terminal to cross useless timeslots from every cycle of packet transmission with a computer-produced cycle of polling to maximize the bandwidth of transmission media. Our new technique is not in accordance with the advanced algorithm, network design has shown substantial enhancement in channel performance, mean packet delivery delay and packet drop in existence of service class and service level variance [6].

Existing broadband enabled network systems are linked, such as DSL and Wi-Fi, and GPONs able to deliver much higher bandwidth implementations with a longer connection distance of up to 60 kms [6]. To further increase the connection distance and minimize the number of main offices, it has been there increasing interest in advancement of the larger split, longer-range passive optic network and cut the price of high bandwidth connections over 100 kilometers of combined access or metro sections [6]. CAPEX and OPEX are lowered by decreasing the amount of COs. In the calculation, the quality of service for many multimedia technology-based services, like HDTV and VOD, can be enhanced directly from the user sites to the edge switch in the long-haul network, while the service provider and the ISPs may correctly apply the combined management of OUN requirements [6]. The simple long-range scheme, which uses the TDM Bandwidth Allocation System was limited to designs that can be used to about sixteen to thirty-two users. In addition to distribute the count of users, there is a tendency for hybrid (mixed) WDM and TDM to enhance the bandwidth and cuts the cost [6]. Hybrid (mixed) architectures are designed by addition of a wavelength router to the optical passive splitters and operating several TDM based passive optic networks virtually. In the design, each virtual TDM based passive optic networks has one or two distinct wavelengths for both downlink and uplink transmissions that are identical to the standard TDM based passive optic networks topology. The downlink signals for many passive optical networks are modulated with various wavelengths of light sources and then linked together until they are sent out. Modulation of downlink signals by different wavelengths of light sources can be transferred through an optical fiber that is single and after that routed to every dedicated splitter for each virtual TDM based passive optic networks. Each single of the downlink signals is then divided into N number of copies for N number of ONUs. The inverted route for uplink transmissions will be strengthened. In hybrid (mixed) techniques, design is extended to several virtual TDM based PONs, hence the number of consumers is significantly raised. The long-range PON network is designed by several virtual TDM based PONs, and each one works on its own, as a product, also every virtual TDM based passive optic networks can be assessed by an autonomous TDM-DBA algorithm [6]. Direct execution of TDM-DBA access protocols would result in a utilization of low channel rate and a high packet latency due to long in propagation. The aim of the work offered is to implement a new DBA protocol for long-range GPON designs based on the goal of applying every idle timeslot to increase the usable transmission of bandwidth mostly in existence of COS as well as service level distinction [6]. Internet service providers can simply add/off various classes of multiple services with acceptable QoS and can create network reliability based on the level of customer service [6].

- **GPON Standard Accomplishments**

As per GPON standard to achieve services level integration, the OLT recognized the ONUs bandwidth supplies before communicating the uplink bandwidth maps to inform the ONUs about their assigned windows [6]. The uplink channel of network will stay idle between the two polling periods. In the light of the 100 kilometers long-range representative PON [6], the direct execution of the DMB or other DBA protocols is required to demonstrate restricted bandwidth of service while additional timeframes remain idle throughout each polling period as opposed to the regular GPONs [6]. It is an improvement of up to five hundred microseconds in packet time from 125 microseconds (μs) in 25 kilometers-passive optical networks. A total of 1000 microseconds will remain useless in each period due to the contact of bandwidth and uplink bandwidth maps between OLT and ONUs [6]. To get substantial channel output and packet delay efficiency, a new two-state DMB (TSD) protocol is built to remove idle timelines [6]. The idle timeslots can set up virtual polling cycles where the ONUs can transmit data using a measurement method to assess their bandwidth needs [6]. In the TDM-MAC protocol, because the ONUs can only transmit its data to the allocated timeslots, the TSD protocol allows the OLT to set up standard uplink bandwidth roadmaps for the ONUs to address their registered messages, and to set up virtual uplink bandwidth maps according to the ONU's requirements for bandwidth assessment [6]. Related to the ADMB protocol, the first stage in calculating ONU bandwidth needs is to contend for their uplink buffer data arrival rate, it is mostly possible to accurately represent differences in ONU bandwidth and to remain constant for two consecutive cycles, to accurately reflect differences in ONU bandwidth [6]. The significant data rate can be achieved by dividing the assigned bandwidth need with the previously OLT processing interval period. The OLT will calculate the estimated bandwidth demand for each ONU by the data arrival time with a reasonable time frame, and then the OLT can allocate and send funding messages before the start of each virtual cycle [6]. The study of the most important TDM-DBA protocols expected to date, an original algorithm is defined to overcome present restrictions and improved network performance [6]. The newly developed GPON simulation platform is employed which is known as the "Dynamic Minimum Bandwidth" scheme planned to launch various service level repairing for ONUs by means of definite bandwidth and buffering line up position [6].

Present TDM-MAC protocols may be private as static or can be statistical, consistent with fixed or dynamic allocated bandwidth sharing protocols [6]. The former always assign a constant timeline for transmission to each ONU without considering into account criteria for bandwidth, service-related agreements and QoS. In consequence, on wider scale they rejected for use in Next Generation Passive Optical Networks standards due to their inadequate bandwidth operating rates [6]. In general, the latter employ more strong features to support increased bandwidth usage, delivering realistic QoS except for individual services [6]. To increase QoS, multiple accumulated data rates must be maintained through new generation protocols (6) allowing service providers to assign multiple service levels to customers based on the supply of customers [6].

In this direction, an advanced DBA protocol has been designed to define three different kind of service levels. Supported at each ONU service level, the supporting algorithm will, in the first place, assign a reasonable "guaranteed minimum bandwidth" to satisfy their specific service condition based on the total capability of the network [6]. Afterwards, the OLT will allocate any "unused bandwidth" from the initial distribution phase to the ONUs on demand based on the status of their buffer lineup [6]. Succeeding changes in network capability, the OLT will be able to accommodate the ONU's "secure" and "empty" bandwidths to comply with subscriber agreements [6].

The observed network performance is expected in view of the planned protocol, the algorithm built to define the OLT modeling approach in OPNET beside the algorithms of the published protocols [6], which is possible because the GPON simulation model has been set up to produce the same efficiency as the literature. Simulation estimates have been calculated in the context of stable network traffic patterns in terms of packet latency and channel performance [6]. In some TDM-DBA algorithms, local traffic is reserved to high, medium, and low priority for time-sensitive network access. When the OLT collects bandwidth status updates from the ONU, it first assigns uplink bandwidth to meet high priority traffic, and then moves the available bandwidth to medium and low priority. This priority function is useful in FTTB or FTTC frameworks where multi-level clients share the resources of a single ONU [6] and each report message includes only a summary of the ONU subscriber bandwidth requirements. The OLT needs to search a single ONU fairly, showing the same quality of service. After all, to provide triple-play services on a full-service access network, the SLA must be calculated in the planning of the bandwidth [6]. In accordance with this justification, the SLA is taken into consideration in the specified DMB protocol based on the FTTH framework, with the intention of providing more bandwidth for higher service level subscribers than for their lower equivalents to determine network integrity and QoS consulting for optimum network capacity for buffer line up and service level subscribers [6]. The number of ONUs operating in the network at a given time varies on a regular basis and the amount of bandwidth allocated to operating ONUs should be increased to fully exploit the extra capacity [6]. The potential to repeatedly change the defined minimum bandwidth for each polling cycle is one of the key features of the DMB algorithm [6].

Realistic networks generate an increasing imbalance in the usage of the network, forcing ISPs to include a variety of service packages to meet the client 's desires [6]. A monthly rental for high-level service customers should be built over their lower equivalents, giving them high priority at the same time in the recovery of the network The development of the DMB should combine multiple service level delivery with varying importance in the retrieval of the network to comply with this feature [6]. This was done by adding a parameter expressed as 'weight' in the proposed algorithm [6]. To change the sure minimum bandwidth in conjunction with the weight parameter, the total network bandwidth is allocated to quite a few small segments, and a subset of these segments can then be allocated to individual active ONUs according to their weight. With the goal of simulating realistic network conditions, weight values are set to comply with the NTT VDSL service plan equivalent to 50, 70 and 100 Mbit/s for service levels of 2, 3 and 4 respectively [6].

- **Future of Optical Networks**

Takahashi et al. proposed, projected, and established a novel procedure to overwhelm the problem of data loss from the fibers to be able to display the specific loss spreading of Passive Optical Networks [16]. The mounted accommodations configure subdivisions from the central office without any change. They named this method “end reproduction sponsored Brillouin time domain analysis”.

Colin Yao reported a main profit of all optical networks and stated that when the data increases there will not be any need to replace the electronics, as entirely this signal processing and directing happens in the optical domain [17].

Fischer et al. introduced polymer fiber optics which offers a lot of advantages when equated to the additional data communication solutions for example fiber glass, the wireless communication systems, and copper cables [18]. In contrast to glass fiber optics, polymer optical fibers are reported to provide a reliable and smaller amount of exclusive optical signal managing and are seen to be more elastic for plug-in linkages.

Hapcos et al. did research where they explored optical communications from high-altitude systems [19]. High-level systems are aircraft that are located even above the clouds at an altitude of almost 16 to 25 kilometers. The disapproving special effect on the laser beam is less clear than straight over the ground.

Rastislav et al. performed an analysis of negative impact of the optical communication network on the optical fiber signal transmitted in the atmosphere [20]. Th analysis focused on the effect of Four Wave Mixing (FWM) is especially studied. The optical transmission's media having a strongest impact on transmitted signal whose effect is Non-Linear which is known as Four Wave Mixing phenomena. They apply multiplexing to the division of wavelength. As a result, a simulation model has been defined for the suitable CWDM optical transmission path with somewhat brief descriptions of the key elements used in this specific circumstance.

Basak et al. had used wider channel spacing for the CWDM system, which makes it possible to use simpler and therefore cheaper control modules, such as non-cooled lasers with a wider wavelength of acceptance and optical filters with a wider passband [21]. They reported that CWDM system utilizes two and three windows of optical transmission. They also pointed out that CWDM technology is more likely to be used for short to medium distance related network applications.

The transmitter is a source of light, the output of which acts as a carrier wave in the optical network. Frequency Division Multiplexing (FDM) methodologies are used in broadcast systems, with most optical communication links using Time Division Multiple Access (TDMA) methodologies. The processes used to receive and transmit an optical signal are semiconductor devices [21]. Most common light source used in the transmissions is laser diode (LD) and light emitting diode (LED) in which the power spectral density and manufacturing criteria have changed. At the receiving end of the optical carrier, the PIN photodiode or Avalanche photodiode (APD) operates as a photodetector and switches back the modulated light back to the electrical signal [21]. Optical power is directly proportional to the current of the photodiode.

S. Alam et al. recommended a signal part handling approach and ODTR data signals were transmitted through single made transmissions communication system [22]. The authors planned methods for assessing real average signal loss in optical communications. The single-ended aspect had many compensations, such as consistency of result, time returns and effort handling. The Bit error rate was efficient by using the RZ signal function generator with the electro-absorption modulation method.

G. Chaudhary et al. planned two different algorithms SGMOS and SGRS in the research paper [23]. The authors primarily defined the issue of survivable multicast traffic grooming for WDM bi-directed ring networks. In the study, the authors supposed the signal link failure model. The authors offered SGMOS and SGRS algorithms to prepare multicast meetings with the aim to professionally handle obtainable bandwidth, condense network resources and protect multicast conferences from the single link failures. It was spotted in the simulations that the projected algorithms consume much less resources like backup links, wavelength, and ports.

- **DWDM Network Data Transmission System**

A. Alosio et al. had significance in the underwater telescope. DWDM network establish fibers, an optical amplifier, and passive optical fibers [24]. The novelists restrained presentation of DWDM optical network using the system of measurement of BER and OSNR.

Dense wavelength division multiplexing (DWDM) refers primarily to multiplexed optical signals within the 1550 nm band to influence the cost of erbium doped fiber amplifiers (EDFAs), which are influential between 1525 to 1565 nm (C band) or 1570 to 1610 nm (L band) (21) for wavelengths. In the first place, EDFAs were recognized for additional SONET/SDH optical-electrical optical (OEO) regenerators, which were essentially out-of-date. EDFAs can magnify any optical signal within their operating range, albeit at a modulated bit rate [21].

New modulation techniques are crucial for the allocation of a massive quantities of data based on which current techniques cannot be supported. These techniques should be smart to offer high data rates, acceptable Bit Error Rate (BER) and maximum delay [25]. Orthogonal Frequency Division Multiplexing (OFDM) is being used for Digital Audio Broadcasting (DAB) as well as Digital Video Broadcasting (DVB) in Europe and for Asymmetric Digital Subscriber Line (ADSL) high-speed wired data connections. OFDM also is congruent as the physical layer for the HIPERLAN2 wireless networking standard in Europe and then as the IEEE 802.11a, g standard in the US, encouraging unprocessed data rates between 6 and 54Mbps. Orthogonal Frequency Division Multiplexing (OFDM) is a digital data transmission technique identified to meet the needs for higher bandwidth in communications that could be used in both wired and wireless networks [25].

Orthogonal Frequency Division Multiplexing (OFDM) is a widely used modulation and multiplexing future technology that has become the baseline of many telecommunications standards, including wireless local area networks (LANs), digital terrestrial television (DTT) as well as digital broadcast radio in several parts of the globe [25]. In the ancient and modern, the OFDM is described in the literature as Multi-carrier, Multi-tone, and Fourier Transform. The OFDM perception is based on the smattering of data to be interrelated over several carriers, each of which is modulated at a low rate. Carriers are made orthogonal to one another by taking the frequency spacing among them adequately [25]. A multi-carrier system, such as FDM (Frequency Division Multiplexing), splits the total bandwidth available in the spectral range into sub-bands for multiple carriers to integrate in parallel.

- **Review of CDMA, CWDM and DWDM Systems**

Bhardwaj et al. carried out a review study and stated that scientists had asked for six ways of spreading the user capacity of CDMA systems, both by optimizing over the years, i.e., maximum probability (ML), identification, interference cancelation (IC) techniques, or even other strategies, like the re-correcting receiver [25]. CDMA is simultaneous to the last instance where people who speak the same language can recognize each other, and not others. A shared code is given to each community of participants in the CDMA radio. There are many codes in the same channel, but still only users connected to the code can connects.

Optical communication networks the Dense Wavelength Division Multiplexing (DWDM) utilizes channels of 100 wavelengths, allowing higher speed, higher capacity based optical communications networks for the Internet enabled world. DWDM systems are comparatively spacious and cost wise optimistic for long-distance communication. Medium to short-haul platforms are very cost-sensitive, even though traffic in network is moderately high as in metropolitan areas [21]. The time to start is by using the Coarse Wavelength Division Multiplexing (CWDM) system in these systems to reduce costs intensely with reasonable bandwidth potential. In contrast, the reliability required for DWDM bases passive modules such as MUX/DEMUX and add/drop subsystems used in DWDM systems also requires very narrow filtering or wavelength segregating features that remain stable over a significant temperature range [21].

Silica optical fibers have produced several applications in power supply, optical communication, sensing and non-linear optics [22]. The fiber optic waveguide comprises of two parts, perhaps even a central dielectric index with a refractive index n1 and a dielectric index with a typically lower refractive index n2 (n1 > n2). In the geometric calculation for index guide fibers, the light is directed whenever the total internal refection is due to Snell's law.

Monette et al. extended the limited bandwidth of white phosphorescent LEDs to a multi-input single-output (MISO) visible light communication (VLC) system [26]. An anticipated LED preparation model is provided, consequential to improved results as correlated with those previously mentioned in the literature. The impact of the angle of the receiver field of view (FOV), the angle of transmission of the LED, and the number of LED arrays used for the transmission are deemed at varying speeds. System performance is restricted by the signal-to - noise ratio (SNR) and the constant bit error rate (BER) at separate data rates.

Radio frequency (RF) constraint spectrum can be overcome by optical wireless communication (OWC). OWC offers broad uninhibited bandwidths which allow wireless home networking systems to unload their data traffic as a replacement for preoccupied RF systems [26]. OWC is protected against interference from electromagnetic sources and is designed to be secure, as light could not enter walls. The availability of highlight emitting diodes (LEDs) tends to result in low-cost and so well-organized illumination devices [26]. These devices will shortly replace traditional fluorescent lamps and light bulbs, paving the way for a new system known as Light Fidelity (Li-Fi) that appears to be utilizing visible light contact (VLC). In VLC, LEDs have a double function both for illumination and transmission of data by modulating the light intensity at a rate which cannot be identified by human eyes [26]. VLC is evaluated securely, power-efficiently, and does not boost health concerns, making it an excellent efficient high-speed communication technology. The commercially available LEDs have a constrained modulation capability as well as the transmission bandwidth of the VLC systems used is limited [26].

In home and office settings, typical indoor light fixtures must offer an illumination level of approximately 200–1000 lux, embraced by the tasks required. White colored LEDs will be more needed for global illumination unlike single-colored LEDs (i.e., red, green, yellow, blue, etc.). White light has either been satisfied by combining red, green, and blue colored LEDs (i.e., RGB white LEDs) or by connecting phosphor to a blue LED (i.e., phosphor white LEDs) [26]. Phosphor white LEDs would be more widely used because they are much simpler to use at a lower price. Phosphorus coating reduces its speed performance to just a few MHz's. The phosphor-based LED typically consists of a blue LED chip covered by a yellow phosphor sheet [26]. Whenever this phosphor-based LED is being used for VLC, the modulation bandwidth is restricted by the lengthy lessening time of the phosphor, which constrains the transfer speed of the VLC. White LEDs are frequently blue InGan LEDs with such an appropriate material coating. Cerium (III)-doped YAG (YAG: Ce3 +, or Y3Al5O12: Ce3 +) is sometimes used with a continual decomposition of tens of nanoseconds. Processes such as blue filtering and some pre-equalization and post-equalization are different procedures stipulated in the literature for the expansion of both bandwidths and data rates [26]. In the case of blue-filtering, a significant enhancement in the bit-error-rate (BER) was achieved, the communication path was controlled to only 30 cm. post-equalization practices are achieved at the end of the receiver, resulting in noise resolution and communication distance constraints within the centimeter range [26]. The most current bandwidth addendum by pre-equalization and post-equalization circuits had been clarified by Huang et al., but the bandwidth was only extended to 304 MHz’s with various modulation initiatives such as orthogonal frequency division multiplexing (OFDM) are applied by other researchers. But composite modulation methods raise the difficulty of the system 's architecture [26].

Initially, a new series of LED arrays is designed and introduced in an indoor VLC solution to ensure more uniform light (i.e., illumination) distribution. The encouragement of either the receiver and the transmitter dimensions on the transmission performance of the written program is analyzed and the output is correlated with many other predictable patterns of distribution in the literature with same number of LEDs used [26]. The SNR and BER performance of the pre - planned systems are evaluated to describe the efficiency of the model for all LED distribution patterns studied. The impact of expanding the number of arrays on the inspection of factors that influence system performance [26]. Due to limitations of the bandwidth of the blue phosphorus white LED used. This is suggested by a modern pre-equalization circuit intended to address those drawbacks. The proposed analog pre-emphasis circuit is needed to further extend the LED bandwidth with the aid of a blue filter to 416 MHz, which is the largest bandwidth in the research to the best of authors' understanding [26]. The simulated MISO VLC system model using MATLAB is first available and the results of the analyzed parameters of the various distribution patterns on system output are associated [26].

In their research, Amman et al. proposed a novel "microstrip antenna" for increased and widespread bandwidth [27]. Several considerations, including physical structure, performance, impedance bandwidth, radiation quality, and radiation pattern, should be retained when choosing an antenna topology for ultra-wideband (UWB) architecture. The key problem in the configuration of the UWB antenna is to achieve very wide bandwidth with good radiation efficiency [27]. Several approaches to increase the impedance bandwidth of small antennas and boost the characteristics of broadband antennas are being thoroughly studied. Examples of methods used to increase the impedance bandwidth of the planar monopoly antenna include the use of the beveling process [27].

The bandwidth of the resonant antenna is not quite large, since it has only one resonance. However, if two or even more resonant resources are available with each working at its own resonance, the combination of these several resonances may result in multiband or broadband output [27]. Ultra-wide bandwidth could be reached if there are sufficiently resonant sections, and their resonances can converge well. Impedance balancing over the whole frequency spectrum is more difficult to achieve as there are more resonant sections (27). That would make the construction of the antenna more difficult and costlier to produce. Continuous radiation properties are more difficult to achieve as there are more altered radiating elements [27].

Jiao et al. revealed a Bandwidth Optimization strategy using Cutting Notches and Slots Truncation [28]. The antenna geometry is configured by the "rectangular monopoly norm" and is known by the inclusion of a T-slot for both the patch and the feed line. The T-slot cutting of the patch and feed strip concerned the current path, thereby providing a broad and improved bandwidth.

Demonstration of residual dispersion, spectral efficiency, and dispersion resistance for resemblance coding with RZ and NRZ for powerful modulation using a 40 Gbps direct detection coherent receiver of 30 kms of standard single mode fiber (SMF) and used SMF and Dispersion Correction Fiber (DCF) prior, post and symmetric fiber structure architectures, they accomplished a high data rate and long range over advanced fiber optic networks [29]. The 100G-PON system based on NRZ transmission using Germanium and Silicon Avalanche Photo Detector (APD) has demonstrated a sufficient power budget for high transmitting data [29]. They modelled the asymmetrical Next Generation Passive Optical Network (XG-PON) for downstream and upstream transmission by CSRZ and RZ. Such modulation systems have been tested with different fiber lengths. Output is compounded by Polarization Mode Dispersion (PMD) and CSRZ is more effective when it comes to RZ format [29]. The new NG-PON2 is planned for 2048 consumers using a 100 km long TWDM-PON architecture with optical amplifiers. The noise emission and distortion of the optical amplifier and the degradation of the splitter are measured and determined. The specification is tested for the parameter QoS [29]. Brief description of different modulation coding techniques such as NRZ, RZ, CSRZ-DPSK, RZ-DPSK, NRZ-DPSK, and DB in the WDM-PON data transmission system [29]. The researcher examined the downstream DPSK signal at the expected WDM-PON with RSOA at ONU for 25 kms. Demodulated noise is simplified using the Orthogonal Frequency Division Multiplexing (OFDM) signal. The results showed a higher BER of 10-10 [29]. The thesis research investigates widely used modulation formats such as CSRZ, NRZ, RZ and DB in view of BER, Q factor, optical range, and duration, evaluated for polarization effects, spectral efficiency, and dispersion. [29].

The numerous forms of modern modulation formats assisted the proposed architectures required to hold a maximum bandwidth of 400 Gigabits Ethernet connections. Their optical power expenditure, digital complexity and power dissipation are connected through simulations. The problems of the physical layer implementation are addressed [29]. New modulation technology and low-power detection devices and integrated optical modulators are used in this system to reduce costs and resources. Experiments also addressed the losses caused by all kinds of defects and the restriction of the bandwidth of opto-electronic components and the related corrective methods based on DSP algorithms [29]. Architecture of Downlink/Uplink unicast 8 channels of 2.5 Gb/s and one broadcast channel of 10 Gb/s using the cyclic properties of arrayed wave guide grating with reflective Bragg fiber grating that produces colorless operation in TWDM-PON. The appropriate cumulative budget loss of power for the network is approximately 36.5 dB with a receiver sensitivity of 29.83 dBm [29]. RSOA can be used to build TWDM-PON with forwarding and DML for upstream transmission using filtering to evaluate the power budget for different modulation methods [29]. WDM–OFDM–RoF system is based on a single-sided optical coupler (O-TSSB) transmitter. The function of harmonic distortion and intermodulation distortion in this process is technically inspected and built to effectively reduce nonlinear distortion by using the 0.6 (O-TSSB) modulation index transmitter at 50 km distance with a BER of 10−3 [29]. The author suggests a functional study of the performance of the receiver in different SMF modulation techniques. Four modulation processes have been used, namely Duo binary (DB), 'Return to Zero' (RZ), 'Non-Return to Zero' (NRZ) and Differential Quadrature Phase [29]. Four techniques for the application of TDHMF Tx are proposed. BER minimization allows PM-QPSK/PM-16QAM output like PM-8QAM output. In TDHMF, non-linear propagation, interleaving polarization and predistortion allow the maximum range predicted by the GN model [29], 40 Gbps are PON using different modulation types including RZ-OOK, NRZ-OOK, RZ-DQPSK and RZ-DPSK for 20 kms distance leveraging TDMA and OCDMA at zero dispersion at BER less than 10-3 [29]. The paper addresses the WDM-PON for long-term and short-term uses. The loss budget was determined based on various modulation [29]. The paper studies the output of the WDM-PON proposal employing improved modulation formats that include amplitude modulation and phase modulation for power, noise, crosstalk, dispersion, and polarization [29]. Shift Keying's (DQPSK). The outcome stated that DQPSK was the smartest of all led by DB. In general, NZR has shown fair results. RZ has shown the lowest results in the WDM system [29].

The simulation model for the study of different WDM-PON network designs is built within the programming context of the MATLAB (Matrix Laboratory) as well as its further components are designed to optimize optical power budget resources and transmission media of passive optical networks [31]. This system uses sophisticated wavelength distribution algorithms close to WDM-PON network designs [31]. In the simulation model, network designs are generated and subsequently verified for availability of use based on specified optical fiber parameters and essential passive optical elements [31]. The second input stage, attenuation values for symmetric power splitters and OADM elements are given. Mostly on basis of these input parameter settings, various options for connecting access networks with a distinct number of ONT terminals to the ODN metropolitan portion are created [31]. Subsequently, each feasibility for network communication is demonstrated and its usability for the configuration of the network with symmetric power splitters and OADM elements is calculated. For example, considerations for WDM-PON network designs based on the given input parameters are proposed [31].

The goal of the network architecture is to achieve a position where the other access network with a specified required amount of ONT terminals cannot be connected to the ODN access network as per established standard input parameters [31]. This means that ODN access networks could have different numbers of ONT terminals based on overall attenuation. Network designs comprising symmetrical power splitters and OADM components are not suitable choices since they exploit the capacity and efficiency of optical communication networks arising from a lesser amount of ONT terminals connecting to network designs contained asymmetrical power splitters [31]. Based on the results of the change in defined input data to achieve a better set of connected ONT terminals, the architecture of a network composed of symmetrical power splitters is more appropriate in the case of a limited number of access networks with larger splitting ratios and a network made up of OADM elements, a higher proportion of access networks with lower splitting ratios in particular access networks are a better option [31].

Based on an overview of the possibilities for the WDM-PON network architecture, the most appropriate solution is a network configuration composed of asymmetric power splitters. It can be used as a WDM-PON network architecture where DWA algorithms are sufficient [31]. After choosing the WDM-PON network architecture, the simulation programmed specifies the necessary splitting ratios of asymmetric splitters for both operational and shielding optical fibers for each access network [31]. Dividing ratios for asymmetric power splitters relevant to the architecture of the chosen network. Although the method of development of optical power splitters is not ideal and the loss of power due to substrate absorption is known at about the same time, all values of the user splitting ratios only for different access networks are rounded up to integral number above if the necessary optical power budget is met with a possible backup to increase the efficiency of signal transmission and optical signal alert at ONT terminals [31]. For the WDM-PON network architecture, the optical power level figures for each ODN connection component can be measured on a distance-dependent basis for both operating and shielding optical fibers [31].

The optical power link budget of each access network is a linear decrease due to the attenuation of the optical fiber and a broad leap in the kilometer calculated. This leap is compounded by the location of the optical power splitters and by the determination of the minimum power for the usability of the network [31]. The remaining portion of the optical power is passed to successive access networks through the ODN metropolitan portion. At the same time, the attenuation generated by the symmetric power splitter used by the ONT terminal connected towards this access network is complicated [31]. From the point of view of successive access networks, a slight decrease in the power level is occurring at a level which is characterized by exchanging the established optical capacity in the formerly placed access network [31].

Methodology

- Research Based Methodology

It is very important to understand the methods on which our research is based while reaching our targeted results. The methodology involves the simulation of Algorithm in OptiSystem 7.0 and MATLAB software. Figure 3.1 below is the Basic Design of PON Architecture. The Optical Line Terminal (OLT) relates to CWDM Multiplexers and CWDM DE multiplexers. It is then connected with Downlink and Uplink bidirectional optical fiber which is then connected with the Power Splitter. The Power Splitter leads to Optical Network Units (ONUs) and finally reached the common subscriber through Optical Distribution Network (ODN).

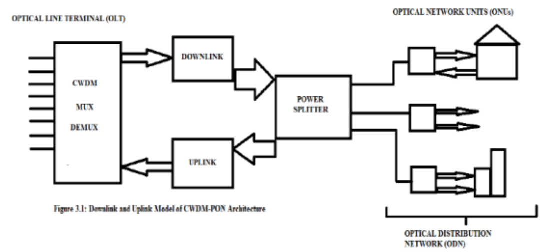


Figure 3.1: Downlink and Uplink Model of CWDM-PON Architecture

- Description of Project Simulation

The CWDM-PON bidirectional optical fiber has been designed in OptiSystem 7.0 having fiber attenuation is taken to be 0.2 dB/km for the downlink and uplink direction. Fiber Dispersion was taken to be 30 ps/nm-km. The optical line coding technique used for data transmission is Return to Zero (RZ)-Pulse Code Modulation (PCM) for the Downlink and Uplink direction. The following parameters of data was inserted in the designed simulation in OptiSystem 7.0 for the Downlink and Uplink direction.

- Description of Downlink Direction

In Downlink Direction, CWDM Mux 4×1 of single wavelength to be 5 Gbps data rate having 4 wavelengths of single 20 Gbps for whole optical carrier connected with the components of Optical Fiber CWDM Multiplexer. It is then connected with CWDM Optical Fiber and CWDM DE-Mux 1×4 which is further connected with the components of Optical Fiber Demultiplexer. Similarly, procedure repeats for CWDM Mux 4×1 and CWDM De Mux 1×4 again.

- Description of Uplink Direction

In Uplink Direction, CWDM Mux 4×1 of single wavelength to be 5 Gbps data rate having 4 wavelengths of single 20 Gbps for whole optical carrier connected with the components of Optical Fiber CWDM Multiplexer. It is then connected with CWDM Optical Fiber and CWDM De Mux 1×4 which is further connected with the components of Optical Fiber CWDM Demultiplexer. Similarly, procedure repeats for CWDM Mux 4×1 and CWDM DE-Mux 1×4 again.

- Procedure of Benchmark Results

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The bandwidth 10 GHz is inserted in the CWDM Multiplexer and Demultiplexer. The mathematical calculation is as follows:

10 GHz = 10 G × 1 Hz Whereas 1 Hz = 2bps
10 GHz = 10 G × 2bps = 20 Gbps

Single 20 Gbps each having 5 Gbps for each wavelength so for downlink and uplink direction 20 Gbps is specified.

Total Bandwidth = 20 Gbps Downlink + 20 Gbps Uplink

Total Bandwidth = 40 Gbps Downlink and Uplink Direction

- **Basic Methodology of Results**

In the below Figure 3.4 CWDM-PON Numerical Model, we have used CWDM MUX and CWDM DEMUX having 20 Gbps data rate for whole optical carrier. The 4 Optical Transceivers are connected with CWDM MUX and CWDM DEMUX with single wavelength of 5 Gbps data rate. Our data rate increased to 40 Gbps.

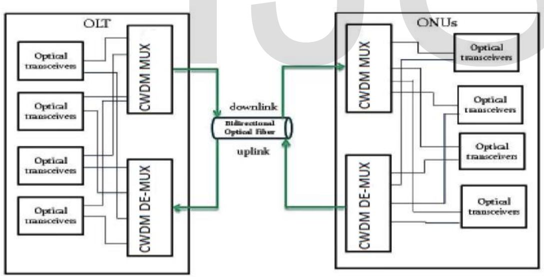

Figure 3.2: Numerical Model of a CWDM-PON

We have calculated optical power penalties through empirical justifications of results in the OptiSystem 7.0 for the Downlink and Uplink direction in the Linear Region with different No. of Splits/ No. of Customers at different transmission distances having Max. Q Factor and Mini. BER displayed in the Eye Diagram Analyzer and Power Received, Transmit Power and Power Losses are displayed in the Optical Power Meter.

Finally, we have plotted four graphs of No. of Customers (ONUs) vs. Transmission Distance, No. of Customers (ONUs) vs. Q factor, No. of Customers (ONUs) vs. Power Received and No. of Customers (ONUs) vs. Bit Error Rate in the Downlink and Uplink direction. We have found maximum No. of Customers (ONUs) with best quality services at subscriber end by producing minimum Q factor, Power Received and Bit Error Rate in the Downlink and Uplink direction.

Discussion

- **Penalties of Optical Power for the Downlink Direction in Linear Region**

The below Table 4.1 shows the optical power budget in linear region for downlink direction. We have taken the No. of Splits/No. of Customers (ONUs) at 2, 4, 8, 16, 32, and 64. The minimum practical value of Loss Power and Power Received is recorded to be -9.339 dBm at Transmission Distance of 3 KMs having maximum of 64 No. of Customers (ONUs) achieved. However, the table also describes the other practical values of Loss Power and Received Power in dBm at different Transmission Distances in KMs. The below Table 4.2 shows the minimum Q factor of 3.49 dB and Bit Error Rate of 1.9 × E-4 is recorded with Transmission Distance of 3 KMs at 64 ONUs.

Number of Customers in Splits (ONUs)	Distance of Transmission in Kilometers	Losses in dBm	Transmit Power in dBm	Received Power in dBm
2	46km	-17.934	-2.430	-17.934
4	35km	-15.735	-2.430	-15.735
8	22km	-13.137	-2.430	-13.137
16	9km	-10.538	-2.430	-10.538
32	5km	-9.737	-2.430	-9.737
64	3km	-9.339	-2.430	-9.339

Table 4.1: Linear Region Power Values for Downlink Direction

No. of Customers in Splits (ONUs)	Transmission Distance	Q factor	Power transmitted	Power Received	BER (Bit Error Rate)
2	46km	6.29	-2.430	-17.934	1.55 × E-10
4	35km	7.20	-2.430	-15.735	2.70 × E-13
8	22km	8.03	-2.430	-13.137	4.30 × E-16
16	9km	9.14	-2.430	-10.538	2.76 × E-20
32	5km	6.14	-2.430	-9.737	3.33 × E-10
64	3km	3.49	-2.430	-9.339	0.00019

Table 4.2: Downlink Direction of Bit Error Rate & Quality Factor in Linear Region

- **Empirical Justification of Results for Downlink Direction in Linear Region**

The above Table 4.1 and Table 4.2 shows the Empirical Justifications of results below for Downlink Direction in Linear Region through

OptiSystem Software. The No. of splits 2, 4, 8, 16, 32 and 64 are inserted into Power Splitter. The transmission distances 46kms, 35kms, 22kms, 9kms, 5kms and 3kms are inserted into Optical Fiber CWDM Length. The Max. Q Factor and Mini. BER are taken from Eye Diagram Analyzer at different transmission distances and No of Splits in the tables. The values of Losses in dBm, Power Transmit in dBm and Received Power in dBm at above No. of Splits and Transmission Distances are taken from Optical Power Meters. The Max. Q Factor of 9.14 dB and 3.49 dB are recorded at 9kms and 3kms. The Mini. BER of 0.00019 is recorded at 3kms for 64 No. of Customers. The below results are empirically justified in OptiSystem 7.0 software and hence proved for Downlink Direction in Linear Region.

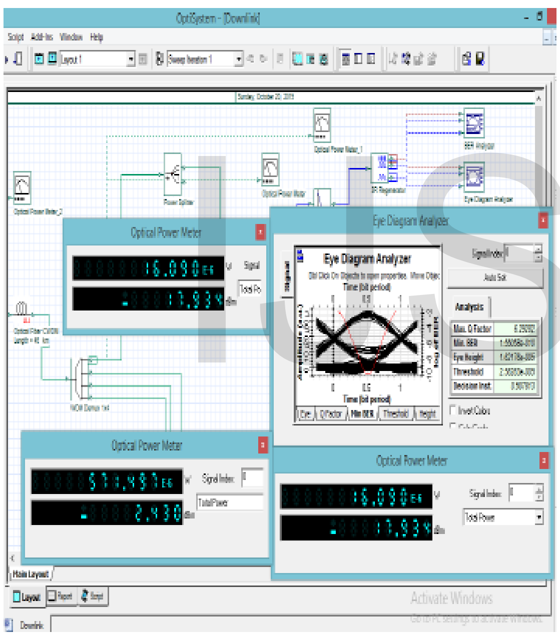

Figure 4.1: Downlink Power Splitter for 2 ONUs [34]

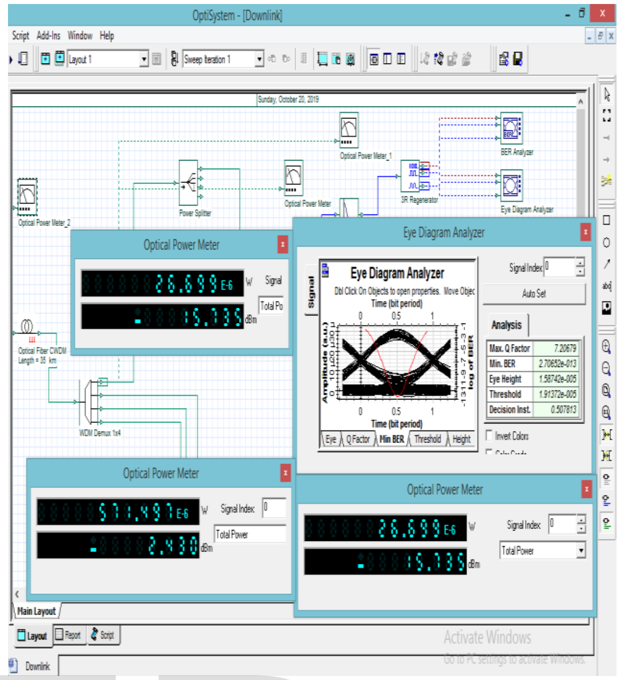

Figure 4.2: Downlink Power Splitter for 4 ONUs [34]

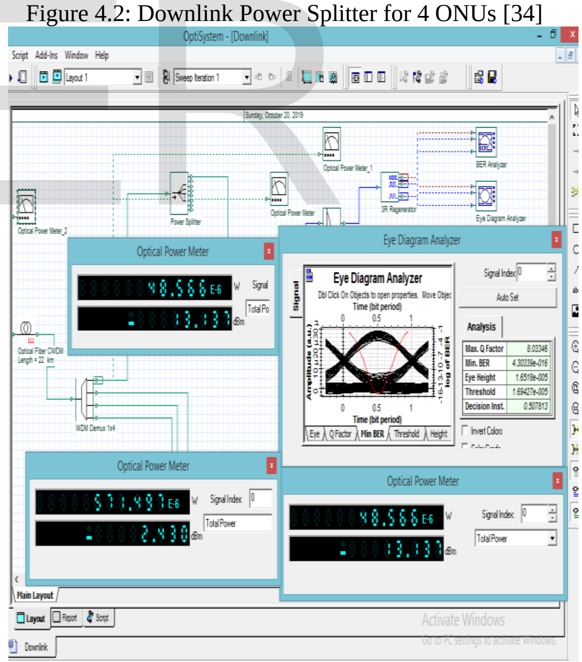

Figure 4.3: Downlink Power Splitter for 8 ONUs [34]

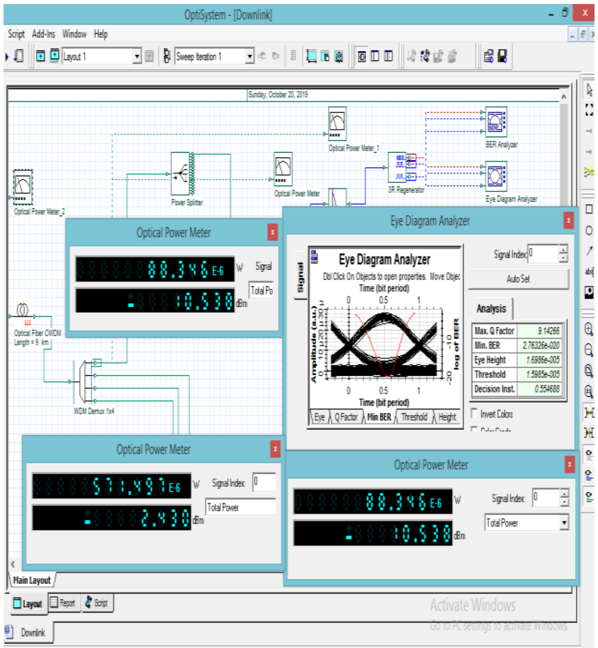

Figure 4.4: Downlink Power Splitter for 16 ONUs [34]

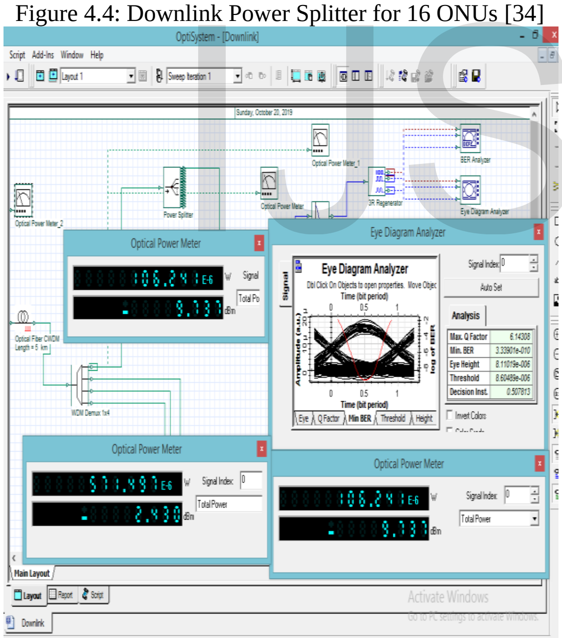

Figure 4.5: Downlink Power Splitter for 32 ONUs [34]

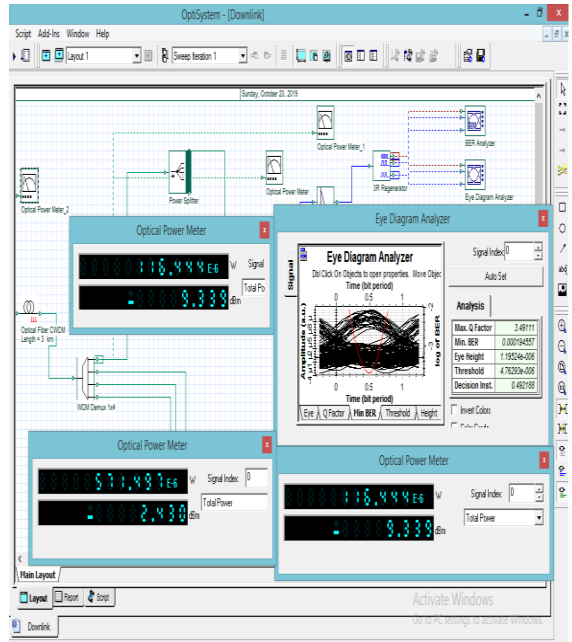

Figure 4.6: Downlink Power Splitter for 64 ONUs [34]

- **No. Of Customers (ONUs) in the Uplink & Downlink Direction**

Now we have plot two figures having four graphs each in the MATLAB software with the help of MATLAB coding techniques. The below two figures including four graphs each in the downlink and uplink direction are discussed one by one having ONUs (No. of Customers) along x-axis and Transmission Distance (KMs), Q factor, Power Received and Bit Error Rate is along y-axis.

- **No. Of Customers (ONUs) in Downlink Direction**

MATLAB Code

%Downlink

```
dONUs= [2 4 8 16 32 64];
dTrnsdist= [46 35 22 9 5 3];
dqf=[6.29 7.20 8.03 9.14 6.14 3.49];
dpr= [-17.9 -15.7 -13.1 -10.5 -9.7 -9.3];
dber=[1.55*exp(-10)  2.70*exp(-13)  4.30*exp(-16) 2.76*exp(-20) 3.33*exp(-10) 1.9*exp(-4)];

figure(1);
subplot (2,2,1);
plot (dONUs,dTrnsdist);
xlabel('ONUs');
```

```
ylabel('Distance (KMs)');
grid on;
title({'Downlink';, 'ONUs vs Transmission Distance (KMs)'});

%figure(2);
subplot (2,2,2);
plot (dONUs,dqf);
xlabel('ONUs');
ylabel('Q-Factor');
grid on;
title({'Downlink';, 'ONUs vs Q-Factor'});

%figure(3);
subplot (2,2,3);
plot (dONUs,dpr);
xlabel('ONUs');
ylabel('Power Received dBm');
grid on;
title({'Downlink';, 'ONUs vs Power Received dBm'});

%figure(4);
subplot (2,2,4);
plot (dONUs,dber);
%ylim([1.3*exp(-5) 9.5*exp(-24)])
xlabel('ONUs');
ylabel('Bit Error Rate');
grid on;
title({'Downlink';, 'ONUs vs Bit Error Rate'});
```

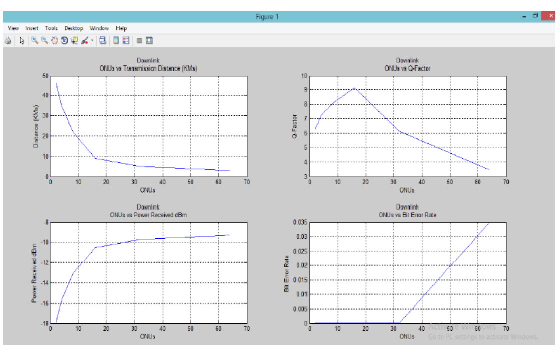

Figure 4.7: Direction of Downlink Model [35]

The above 1st graph of Figure 4.1 having ONUs (No. of Customers) along x-axis and Transmission Distance (KMs) is along y-axis in the downlink direction. The graph shows that 2 ONUs at Transmission Distance of 46 KMs, 4 ONUs at 35 KMs, 8 ONUs at 22 KMs, 16 ONUs at 9 KMs, 32 ONUs at 5 KM and 64 ONUs at 3 Kilometer. This proves that the total number of customers (ONUs) increases with decrease in Transmission Distance (KMs).

The 2nd graph of above Figure 01 having ONUs (No. of Customers) along x-axis and Quality factor (dB) is along y-axis in downlink direction. The graph shows that 2 ONUs at Q factor of 6.29 dB, 4 ONUs at 7.20 dB, 8 ONUs at 8.03 dB, 16 ONUs at 9.14 dB, 32 ONUs at 6.14 dB and 64 ONUs at 3.49 dB This proves that the Number of Customers (ONUs) increases with the decrease in Q factor dB. In the 3rd graph of above Figure 01 having ONUs (No. of Customers) along x-axis and Power Received (dBm) along y-axis in the downlink direction. The graph shows that 2 ONUs at Power Received of -17.9 dBm, 4 ONUs at -15.7 dBm, 8 ONUs at -13.1 dBm, 16 ONUs at -10.5 dBm, 32 ONUs at -9.7 dBm and 64 ONUs at -9.3 dBm. This proves that the Number of Customers (ONUs) increases with the decrease in Power Received (dBm).

In the 4th graph of above Figure 01 having ONUs (No. of Customers) along x-axis and Bit Error Rate along y-axis in downlink direction. The graph shows that 2 ONUs at BER of 1.55 × E-10, 4 ONUs at 2.70 × E-13, 8 ONUs at 4.30 × E-16, 16 ONUs at 2.76 × E-20, 32 ONUs at 3.33 × E-10 and 64 ONUs at 1.9 × E-4. This proves that the total number of customers (ONUs) increases as the Bit Error Rate also increases.

- **Penalties of Optical Power for the Uplink Direction in Linear Region**

The below table 4.3 shows the optical power budget in linear region for Uplink direction. We have taken the No. of Splits/No. of Customers (ONUs) at 2, 4, 8, 16, 32, and 64. The minimum practical value of Loss Power and Power Received is recorded to be -27.799 dBm and -9.737 dBm at Transmission Distance of 5 KMs with maximum total of 64 No. of Customers (ONUs) achieved. However, the table also describes the other practical values of Loss Power and Received Power in dBm at different Transmission Distances in KMs. The below Table 4.4 shows the minimum Q factor of 3.32 dB and Bit Error Rate of 3.6 × E-4 is recorded with Transmission Distance of 5 KMs at 64 ONUs.

No of Customers in Splits	Distance of Transmission in Kilometers	Losses in dBm	Power Transmit in dBm	Received Power in dBm
2	35km	-18.745	-2.430	-15.735
4	32km	-21.156	-2.430	-15.135
8	30km	-23.767	-2.430	-14.736
16	25km	-25.777	-2.430	-13.736
32	10km	-25.700	-2.430	-10.738
64	5km	-27.799	-2.430	-9.737

Table 4.3: Linear Region Power Values for Uplink Direction

No. of Customers in Splits (ONUs)	Distance of Transmission	Q factor	Power transmitted TX	Power Received RX	BER (Bit Error Rate)
2	35km	9.17	-2.43	-15.735	2.20 × E-20
4	32km	8.78	-2.43	-15.135	7.37 × E-19
8	30km	6.05	-2.43	-14.736	6.45 × E-10
16	25km	4.93	-2.43	-13.736	3.45 × E-7
32	10km	4.83	-2.43	-10.738	5.27 × E-7
64	5km	3.32	-2.43	-9.737	0.00036

Table 4.4: BER & Q factor for Uplink Direction in Linear Region

- **Empirical Justifications of Results for Uplink Direction in Linear Region**

The above Table 4.3 and Table 4.4 shows the Empirical Justifications of results below for Uplink Direction in Linear Region through OptiSystem Software. The No. of splits 2, 4, 8, 16, 32 and 64 are inserted into Power Splitter. The transmission distances 35kms, 32kms, 30kms, 25kms, 10kms and 5kms are inserted into Optical Fiber CWDM Length. The Max. Q Factor and Mini. BER are taken from Eye Diagram Analyzer at different transmission distances and No of Splits in the tables. The values of Losses in dBm, Power Transmit in dBm and Received Power in dBm at above No. of Splits and Transmission Distances are taken from Optical Power Meters. The Max. Q Factor of 9.17 dB and 3.32 dB are recorded at 35kms and 5kms. The Mini. BER of 0.00036 is recorded at 5kms for 64 No. of Customers. The below results are empirically justified OptiSystem 7.0 software and hence proved for Uplink Direction in Linear Region.

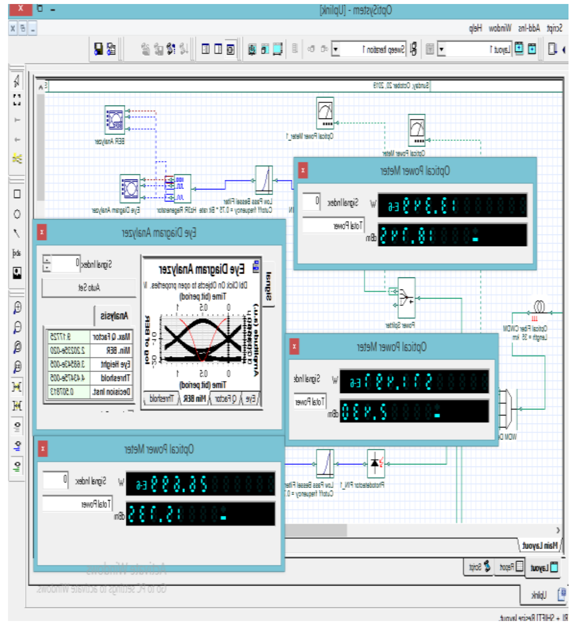

Figure 4.8: Uplink Power Splitter for 2 ONUs [34]

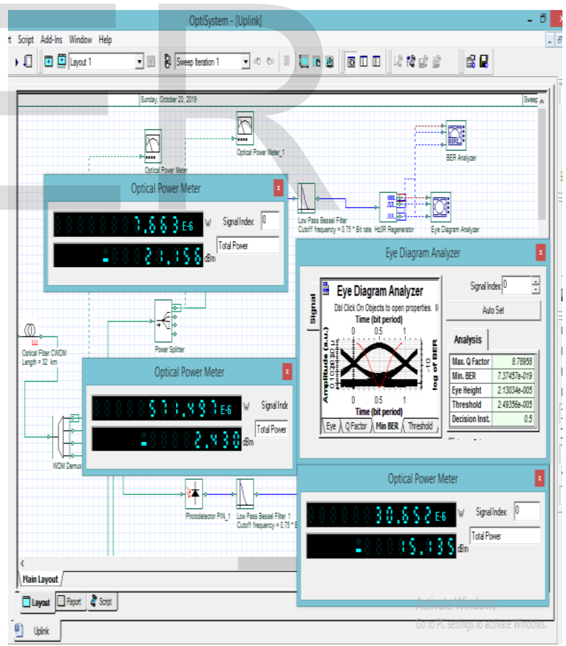

Figure 4.9: Uplink Power Splitter for 4 ONUs [34]

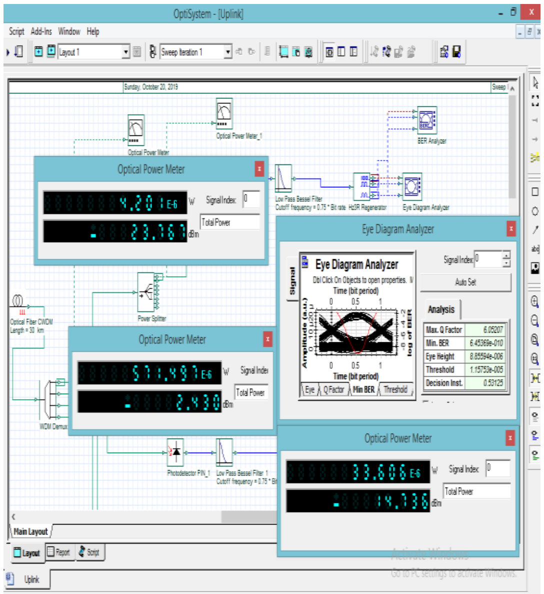

Figure 4.10: Uplink Power Splitter for 8 ONUs [34]

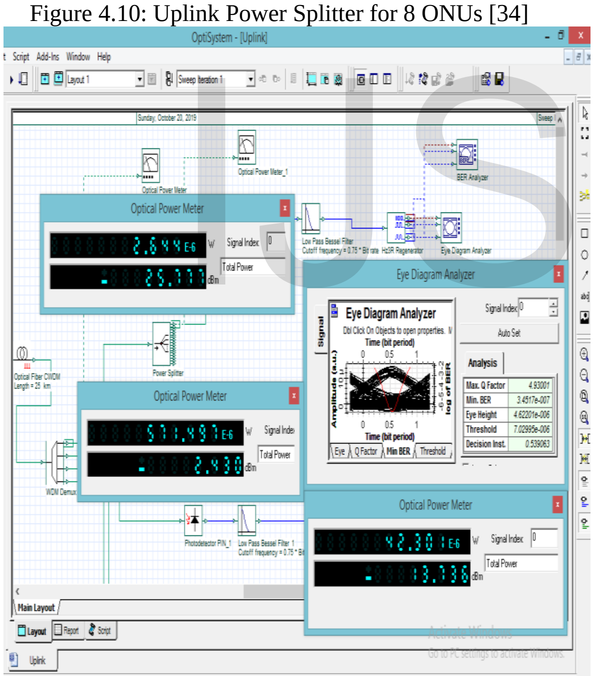

Figure 4.11: Uplink Power Splitter for 16 ONUs [34]

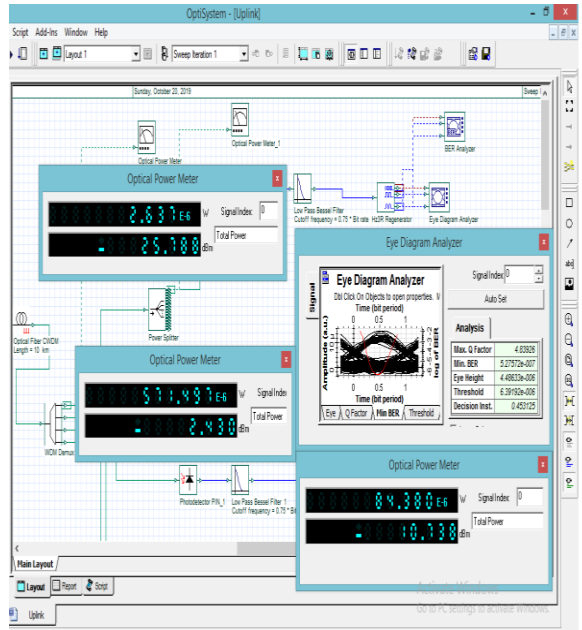

Figure 4.12: Uplink Power Splitter for 32 ONUs [34]

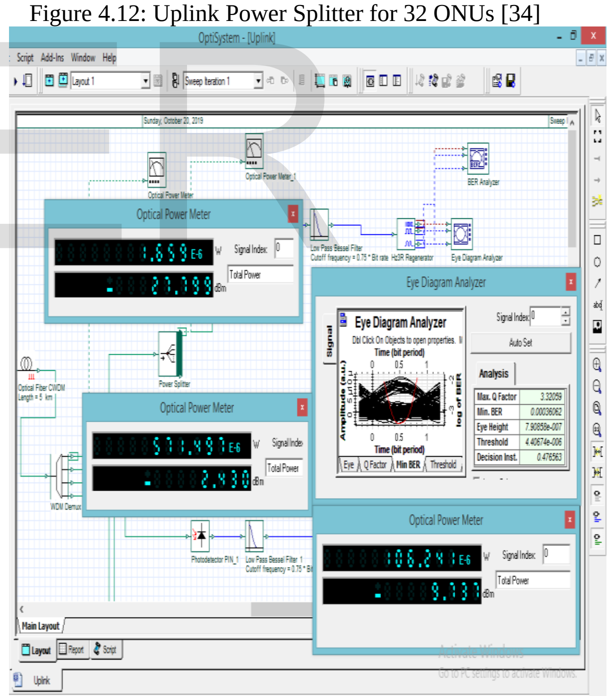

Figure 4.13: Uplink Power Splitter for 64 ONUs [34]

- **No. Of Customers (ONUs) in the Uplink Direction**

MATLAB Code

```
%Uplink
uONUs= [2 4 8 16 32 64];
```

```
uTrnsdist= [35 32 30 25 10 5];
uqf=[9.17 8.78 6.05 4.93 4.83 3.32];
upr= [-15.7 -15.1 -14.7 -13.7 -10.7 -9.7];
uber=[2.20*exp(-20) 7.37*exp(-19) 6.45*exp(-10)
3.45*exp(-7) 5.27*exp(-7) 3.6*exp(-4)];

figure(2);
subplot (2,2,1);
plot (uONUs,uTrnsdist);
xlabel('ONUs');
ylabel('Distance (KMs)');
grid on;
title({'Uplink';, 'ONUs vs Transmission Distance
(KMs)'});

%figure(2);
subplot (2,2,2);
plot (uONUs,uqf);
xlabel('ONUs');
ylabel('Q-Factor');
grid on;
title({'Uplink';, 'ONUs vs Q-Factor'});

%figure(3);
subplot (2,2,3);
plot (uONUs,upr);
xlabel('ONUs');
ylabel('Power Received dBm');
grid on;
title({'Uplink';, 'ONUs vs Power Received dBm'});

%figure(4);
subplot (2,2,4);
plot (uONUs,uber);
%ylim([1.3*exp(-5) 9.5*exp(-24)])
xlabel('ONUs');
ylabel('Bit Error Rate');
grid on;
title({'Uplink';, 'ONUs vs Bit Error Rate'});
```

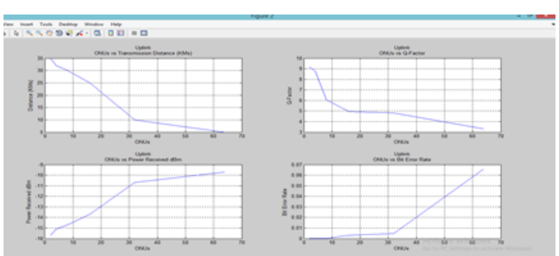

Figure 4.14: Direction of Uplink Model [35]

In the 1st graph of above Figure 4.2 having ONUs (No. of Customers) along x-axis and Transmission Distance (KMs) is along y-axis in the uplink direction. The graph shows that 2 ONUs at Transmission Distance of 35 KMs, 4 ONUs at 32 KMs, 8 ONUs at 30 KMs, 16 ONUs at 25 KMs, 32 ONUs at 10 KMs, and 64 ONUs at 5 KMs. This proves that the Number of Customers (ONUs) increases with the decrease in Transmission Distance (KMs).

In the 2nd graph of above Figure 02 having ONUs (No. of Customers) along x-axis and Quality factor (dB) along y-axis in uplink direction. The graph shows that 2 ONUs at Q factor of 9.17 dB, 4 ONUs at 8.78 dB, 8 ONUs at 6.05 dB, 16 ONUs at 4.93 dB, 32 ONUs at 4.83 dB and 64 ONUs at 3.32 dB. This proves that the Number of Customers (ONUs) increases with the slight increase in Q factor at 16 ONUs and 32 ONUs and finally decreases the Q factor (dB) at 64 ONUs.
In the 3rd graph of above Figure 03 having ONUs (No. of Customers) along x-axis and Power Received (dBm) along y-axis in the uplink direction. The graph shows that 2 ONUs at Power Received of -15.7 dBm, 4 ONUs at -15.1 dBm, 8 ONUs at -14.7 dBm, 16 ONUs at -13.7 dBm, 32 ONUs at -10.7 dBm, and 64 ONUs at -9.7 dBm. This proves that the Number of Customers (ONUs) increases with the decrease in Power Received (dBm).

In the 4th graph of above Figure 02 having ONUs (No. of Customers) along x-axis and Bit Error Rate along y-axis in uplink direction. The graph shows that 2 ONUs at BER of 2.20E-20, 4 ONUs at 7.37E-19, 8 ONUs at 6.45E-10, 16 ONUs at 3.45 × E-7, 32 ONUs at 5.27 × E-7 and 64 ONUs at 3.6 × E-4. This proves that the number of customers (ONUs) increases as the Bit Error Rate also increases.

- **Comparative Analysis with the Benchmark Results**

The research paper published in IEEE 2017 International Conference on Communication, Computing and Digital Systems (C-Code) has a lot of vulnerabilities. The optical line coding technique used for data transmission was Dual Polarized Quadrature Phase Shift Keying (DP-QPSK), while we have used Return to Zero-Pulse Code Modulation (RZ-PCM) technique for data transmission which seems to be more effective for data transmission in terms of achieving quality benchmark results. Similarly, fiber attenuation was taken to be 0.2 dB/km for the downlink and 0.5 dB/km for the uplink direction having fiber dispersion was taken to be 16 ps/nm-km, while we have used 0.2 dB/km as fiber attenuation and 30 ps/nm-km fiber dispersion for both the downlink and uplink direction as a contribution for achieving the benchmark results. The Ideal Multiplexers and Ideal Demultiplexers changed to CWDM Multiplexers and Demultiplexers. The single wavelength which carries 2.5 Gbps and single 10 Gbps optical carrier produces less data rate due to 5 GHz bandwidth was inserted in the Ideal Multiplexers and Ideal Demultiplexers. We have changed single wavelength to be 5 Gbps and single 20 Gbps for whole optical carrier which produces more data rate due to 10 GHz bandwidth is inserted in the CWDM Multiplexers and CWDM Demultiplexers. The mathematical computation of comparative analysis with the benchmark results are as follows:

The bandwidth 5 GHz was inserted in the Ideal Multiplexer and Ideal Demultiplexer. The mathematical calculation is as follows:
5 GHz = 5 G × 1 Hz   Whereas 1 Hz = 2bps
5 GHz = 5 G × 2bps = 10 Gbps

Single 10 Gbps for whole optical carrier each having 2.5 Gbps for each wavelength so for downlink and uplink direction 10 Gbps is specified.

Total Bandwidth = 10 Gbps Downlink + 10 Gbps Uplink

Total Bandwidth = 20 Gbps Downlink and Uplink Direction

Now for the benchmark results, we have changed the bandwidth to be 10 GHz which is inserted in the CWDM Multiplexers and CWDM Demultiplexers.

The mathematical calculation is as follows:

10 GHz = 10 G × 1 Hz   Whereas 1 Hz = 2bps
10 GHz = 10 G × 2bps = 20 Gbps

Hence proved, single 20 Gbps for whole optical carrier each having 5 Gbps for each wavelength so for downlink and uplink direction 20 Gbps is specified as contribution.

Total Bandwidth = 20 Gbps Downlink + 20 Gbps Uplink

Total Bandwidth = 40 Gbps Downlink and Uplink Direction

The previous research results of optical power penalties for the downlink and uplink in the linear region having No. of Splits/Customers and transmission distances for the downlink and uplink was 2 at 30 km, 4 at 29.5 km, 8 at 28km, 16 at 21 km, 32 at 5 km, 64 at 1.5 km. The power receive Rx (dBm) for the downlink was -12.00, -17.86, -23.42, -21.03, -22.69, -23.50 while for uplink was -19.789, -25.470, -30.490, -31.881, -21.661, -21.031. Similarly, the power transmit Tx (dBm) for the downlink and uplink in the linear region was 0, 0, 0, 0, 6, 10. The Q-factor (dB) for the downlink and uplink in the linear region was 9.76, 9.83, 9.87, 9.75, 9.58 and 9.25. The Bit Error Rate (BER) was not calculated but calculated and improved in the benchmark results as a contribution.
While comparing the above results with the benchmark results are as follows:

The optical power penalties for the downlink in the linear region having No. of Splits/Customers and transmission distances are 2 at 46 km, 4 at 35 km, 8 at 22 km, 16 at 9 km, 32 at 5 km, 64 at 3 km. The power receive Rx in dBm are -17.934, -15.735, -13.137, -10.538, -9.737, -9.339. The power transmit Tx in dBm is -2.430. The Q-factor (dB) recorded are 6.29, 7.20, 8.03, 9.14, 6.14 and 3.49. The improved Bit Error Rate (BER) are 1.55 × E-10, 2.70 × E-13, 4.30 × E-16, 2.76 × E-20, 3.33 × E-10 and 1.9 × E-4.

Similarly, the optical power penalties for the uplink in the linear region having No. of Splits/Customers and transmission distances are 2 at 35 km, 4 at 32 km, 8 at 30 km, 16 at 25 km, 32 at 10 km, 64 at 5 km. The power receive Rx in dBm are -15.735, -15.135, -14.736, -13.736, -10.738, -9.737. The power transmit Tx in dBm is -2.430. The Q-factor (dB) recorded are 9.17, 8.78, 6.05, 4.93, 4.83 and 3.32. The improved Bit Error Rate (BER) are 2.20 × E-20, 7.37 × E-19, 6.45 × E-10, 3.45 × E-7, 5.27 × E-7 and 3.6 × E-4.

Hence proved with the above comparative analysis with the benchmark results are improved as a contribution.

Conclusions

- **Conclusion of No. of Customers in the Downlink and Uplink Direction**

In the downlink direction of Figure 01, the maximum 64 ONUs (No. of Customers) achieved at Transmission Distance of 3 KM, Q-factor of 3.49 dB, Power Received of -9.339 dBm and BER of 0.00019. In the uplink direction of Figure 02, the maximum 64 ONUs (No. of Customers) achieved at Transmission Distance of 5 KMs and Power Received of -9.737 dBm. Q-factor of 3.32 dB and Bit Error Rate of 0.00036 is achieved at maximum of 64 ONUs (No. of Customers). The results prove that maximum No. of Customers (ONUs) are accommodated with minimum Transmission Distance, Q factor, Power Received and Bit Error Rate (BER) which clearly shows that at customer end the Quality of Service (QOS) is better than before. The maximum subscribers receive best services which results in the lowest call drop issues and clear voice services.

- **Conclusion of Optical Power Budget in Linear Region**

The Power Budget of Optical Fiber is evaluated in different No. of Splits/Customers for uplink and downlink direction in Linear Region. The tables prove following above results taken for downlink direction in Linear Region to be 64 ONUs at 3 KM Transmission Distance with -9.339 dBm Power Received and 64 ONUs at 5 KMs Transmission Distance with -9.737 dBm Power Received for uplink direction in Linear Region. Above results obtained clearly proves that the maximum No. of Customers accommodated with maximum Transmission Distance and minimum Power Loss and Received Power. The subscribers receive the quality services with the following results obtained.

Future Works Recommendations

We can improve the system further by changing the multiplexers like Analog Switches and Multiplexers. It will make the system reliable with the increase of signal capability. The use of Optical Time Division Multiplexers further improves the data rate at the transmitter and receiver. The system can be boosted by using the Configurable Optical Add-Drop Multiplexer with the help of which the signal sources would be easily identified at the transmitter and receiver.

By reducing the distance with the suggested Multiplexers and Demultiplexers the Bit Error Rate would be decreased which would result in the reduced signal losses and noise. The accommodation of number of customers at the subscriber's end would be increased up to maximum. The power budget would be decreased because of less signal losses and noise factor reduction.

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