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DESIGN AND IMPLEMENTATION OF WDM-PON BASED FTTH SYSTEM USING MATLAB

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Master's Thesis

Supervisor
Asst. Prof. Dr. Mesut CEVIK

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Hayder Ahmed Shakir AL-SADOON

Signature

DEDICATION

I dedicate and promise this research project to my supervisor, who is significant for guiding me during the entire research project, as well as to my family, who has always supported me during difficult times.

PREFACE

First and foremost, I would like to express my gratitude to my dissertation supervisor, Asst. Prof. Dr. Mesut CEVIK, for his guidance and assistance. I got a lot better at grasping the reasoning behind the study by talking about my progress, issues, and suggestions with my advisor, Asst. Prof. Dr. Mesut CEVIK, a few times each week. The technical need of this study activity became more clear to me as a result.

ABSTRACT

DESIGN AND IMPLEMENTATION OF WDM-PON BASED FTTH SYSTEM USING MATLAB

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Fiber optics, based on the transmission of data through light signals in thin strands of glass or plastic fibers, offer immense advantages over traditional copper-based systems. They provide virtually unlimited bandwidth, low latency, immunity to electromagnetic interference, and the ability to transmit signals over long distances without significant loss. Passive Optical Networks (PONs) are a cost-effective solution for implementing FTTH networks, where a single optical fiber can serve multiple end-users by employing passive components such as splitters. This thesis makes significant contributions to the field of WDM-PON based FTTH systems using MATLAB. The research focuses on the design and implementation of a WDM-PON architecture and addresses various challenges associated with system performance, resource allocation, crosstalk, noise, scalability, and cost-effectiveness

Keywords: FTTH, WDM, PON, MZM, DML.

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ABBREVIATIONS

EPON	:	Ethernet Passive Optical Network
GPON	:	Gigabit Passive Optical Network
OLT	:	Optical Line Terminal
CO	:	Central Office
FTTH	:	Fiber to the Home
WDM	:	Wavelength Division Multiplexing
PONs	:	Passive Optical Networks
IoT	:	Internet of Things
EVM	:	Expected Value Method
MZM	:	Mach-Zehnder Modulator
DMLs	:	Direct Modulated Lasers
FDM	:	Frequency Division Multiplexing
Gbps	:	Gigabits Per Second
RN	:	Remote Node
ACS	:	Access Control System
ODN	:	Optical Distribution Network
MTBF	:	Mean Time Between Failure
ONT	:	Optical Network Terminal
AON	:	Active Optical Network
TDMA	:	Time-Division Multiple Access
APON	:	ATM Passive Optical Network
BPON	:	Broadband Passive Optical Network
DBA	:	Active Optical Network
TDMA	:	Dynamic Bandwidth Allocation
HPAs	:	High Power Amplifiers
ONU	:	Otical Network Unit

1. INTRODUCTION

1.1 INTRODUCTION

Fiber to the Home (FTTH) is a promising technology that provides high-speed broadband connections directly to residential and business users. It offers a significant improvement in data rates, capacity, and quality of service compared to traditional copper-based networks. FTTH networks employ various optical communication technologies to deliver high-bandwidth services, and one such technology is the Wavelength Division Multiplexing Passive Optical Network (WDM-PON). This background section provides an extensive overview of the context and motivation behind the design and implementation of a WDM-PON based FTTH system using MATLAB.

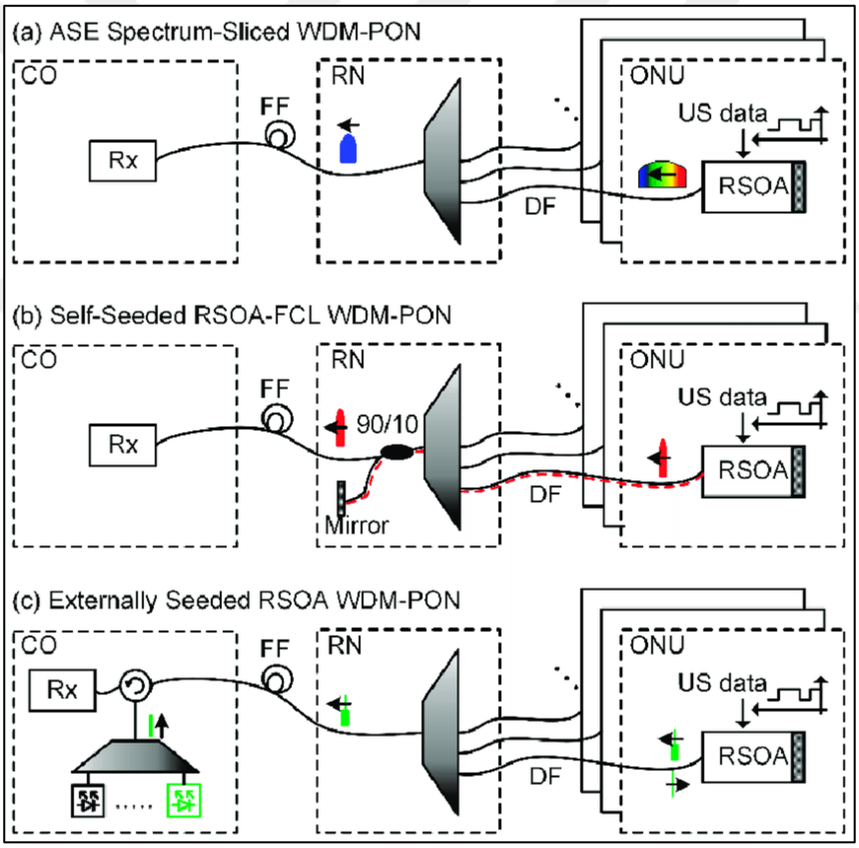

Figure 1.1: Multiplexing Passive Optical Network (WDM-PON).

The exponential growth of data traffic due to the proliferation of internet-enabled devices, streaming services, cloud computing, and emerging technologies such as virtual reality and the Internet of Things (IoT) has put immense pressure on existing telecommunication networks. Copper-based networks, with their limited bandwidth and susceptibility to electromagnetic interference, are struggling to meet the ever-increasing demand for high-speed data transmission. This has led to a pressing need for the deployment of fiber optic networks like FTTH.

1.1.1 Fiber Optics and Pons

Fiber optics, based on the transmission of data through light signals in thin strands of glass or plastic fibers, offer immense advantages over traditional copper-based systems. They provide virtually unlimited bandwidth, low latency, immunity to electromagnetic interference, and the ability to transmit signals over long distances without significant loss. Passive Optical Networks (PONs) are a cost-effective solution for implementing FTTH networks, where a single optical fiber can serve multiple end-users by employing passive components such as splitters.

1.1.2 Wdm-pon: Enabling Higher Bandwidth

Wavelength Division Multiplexing (WDM) is a technology that allows multiple optical signals with different wavelengths to be transmitted simultaneously over a single fiber. By leveraging WDM in a PON architecture, it is possible to provide dedicated wavelengths to each user, thereby enabling higher bandwidth and ensuring individual user isolation. WDM-PONs have gained significant attention due to their ability to support multiple wavelengths and accommodate a large number of subscribers.

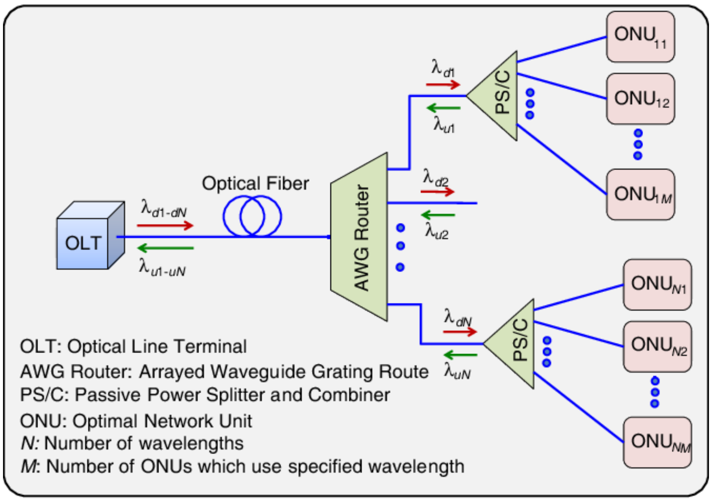

Figure 1.2: Enabling Higher Bandwidth with WDM-PON.

1.1.3 Matlab a Powerful Simulation Tool

MATLAB, a widely used programming environment and simulation tool, offers numerous capabilities for modeling, simulating, and analyzing complex systems. It provides a convenient platform to design, implement, and evaluate the performance of communication systems, including optical networks. MATLAB's extensive toolbox and built-in functions make it a suitable choice for developing and validating algorithms, protocols, and architectures for WDM-PON based FTTH systems.

1.2 RESEARCH OBJECTIVES

The design and implementation of a WDM-PON based FTTH system using MATLAB aims to address the need for high-speed broadband access in a cost-effective manner. This research project intends to explore various aspects of WDM-PON technology, including system design, signal modulation, optical components, power budget analysis, network performance evaluation, and resource optimization. By utilizing MATLAB, the study seeks to develop a comprehensive simulation model that accurately represents the behavior of the proposed system and facilitates performance analysis under different operating conditions. The successful design and implementation of a WDM-PON based FTTH system using MATLAB can bring significant benefits to the telecommunications industry, service providers, and end-users alike. These benefits include ultra-fast internet access, improved network reliability, enhanced quality of service, increased scalability, and the potential for future-proofing networks. The research findings can aid in optimizing network deployment strategies, resource allocation, and network management techniques, ultimately leading to the widespread adoption of FTTH technology. The rapid growth in data demand and the limitations of traditional copper-based networks necessitate the development of advanced technologies such as WDM-PONs for FTTH deployment. MATLAB serves as a powerful simulation tool for designing and implementing such systems, enabling researchers to explore and analyze various parameters and optimize network performance. This background section has provided a comprehensive overview of the motivations, objectives, and potential benefits associated with the design and implementation of a WDM-PON based FTTH system using MATLAB.

1.3 PROBLEM STATEMENT

Despite the significant advantages of Fiber to the Home (FTTH) networks and the potential of Wavelength Division Multiplexing Passive Optical Networks (WDM-PONs) in delivering high-speed broadband access, there are still several challenges that need to be addressed. This section presents the problem statement, highlighting the key issues and gaps that exist in the design and implementation of a WDM-PON based FTTH system using MATLAB.

1.3.1 Limited Availability of Real-World Testbeds

One of the major challenges in designing and implementing a WDM-PON based FTTH system is the limited availability of real-world testbeds. Building physical test networks for extensive experimentation is expensive, time-consuming, and may not accurately represent the complexities of large-scale deployment scenarios. Therefore, there is a need to develop robust simulation models and tools that can accurately mimic real-world conditions to evaluate system performance.

1.3.2 Complexity in Wdm-Pon System Design

Designing a WDM-PON based FTTH system involves various complex tasks, such as selecting appropriate optical components, determining optimal power budgets, implementing signal modulation techniques, and evaluating system performance under different scenarios. The integration of these components and protocols in a coherent and efficient manner poses a significant challenge. There is a need to develop comprehensive design methodologies and algorithms that can assist in the efficient deployment and optimization of WDM-PON systems.

1.3.3 Performance Optimization and Resource Allocation

Efficient resource allocation and performance optimization are critical for ensuring reliable and high-quality service in WDM-PON based FTTH networks. Effective allocation of wavelengths, bandwidth, and power to individual users is essential to maximize network capacity and provide fair access to all subscribers. However, finding optimal resource allocation strategies that balance the competing demands of different users while considering network constraints is a complex optimization problem. Developing efficient algorithms and protocols for resource allocation and performance optimization is essential for the successful implementation of WDM-PON based FTTH systems.

1.3.4 Impact of Channel Crosstalk and Noise

In WDM-PON systems, the presence of channel crosstalk and noise can significantly degrade system performance. Crosstalk occurs when signals from different wavelengths interfere with each other, leading to signal degradation and reduced throughput. Additionally, various sources of noise, such as optical amplifiers and environmental factors, can introduce additional impairments. Addressing the impact of crosstalk and noise and developing mitigation techniques to improve system performance is crucial for achieving reliable and high-speed data transmission in WDM-PON based FTTH systems.

1.3.5 Scalability and Cost-Effectiveness

Scalability and cost-effectiveness are key considerations for the widespread deployment of FTTH networks. As the number of subscribers increases, the network should be able to accommodate the growing demand without compromising performance or significantly increasing costs. Optimizing network scalability, managing the cost of optical components, and developing cost-effective deployment strategies are important challenges that need to be addressed in the design and implementation of WDM-PON based FTTH systems. The design and implementation of a WDM-PON based FTTH system using MATLAB face several challenges, including the limited availability of real-world testbeds, the complexity in system design, the need for resource optimization, the impact of crosstalk and noise, and the requirements for scalability and cost-effectiveness. Addressing these challenges will contribute to the development of efficient and reliable FTTH networks that can meet the increasing demand for high-speed broadband access.

1.4 THESIS CONTRIBUTIONS

This thesis makes significant contributions to the field of WDM-PON based FTTH systems using MATLAB. The research focuses on the design and implementation of a WDM-PON architecture and addresses various challenges associated with system performance, resource allocation, crosstalk, noise, scalability, and cost-effectiveness. The following are the key contributions of this thesis:

1.4.1 Comparison of Mzm Estimates Using the Expected Value Method (EVM)

The thesis presents a detailed comparison of Mach-Zehnder Modulator (MZM) estimates using the Expected Value Method (EVM). By employing MATLAB simulation, the study evaluates the performance of different MZM estimation techniques, considering factors such as signal quality, modulation efficiency, and cost-effectiveness. This analysis provides valuable insights into the selection and optimization of MZMs for WDM-PON based FTTH systems.

1.4.2 Estimation of the Dml Using the Expected Value Method (EVM)

In addition to MZM estimation, the thesis extends its focus to the estimation of Direct Modulated Lasers (DMLs) using the Expected Value Method (EVM). MATLAB simulations are used to evaluate the performance of DMLs in terms of signal quality, bit error rate, and system cost. The findings contribute to the understanding of DML characteristics and their suitability for WDM-PON deployments.

1.4.3 Analysis of Fdm Subcarrier Spacing

The thesis conducts a comprehensive analysis of Frequency Division Multiplexing (FDM) subcarrier spacing in WDM-PON systems. By employing MATLAB simulations, the study investigates the impact of different subcarrier spacing configurations on system performance, including data rate, spectral efficiency, and crosstalk. The analysis provides valuable insights into the optimal subcarrier spacing for achieving high throughput and minimizing interference in WDM-PON based FTTH systems.

1.4.4 Simulation of High Power Amplifiers

The thesis includes the simulation of High Power Amplifiers (HPAs) used in WDM-PON systems. MATLAB is employed to model the behavior of HPAs and analyze their impact on system performance, including power budget, signal quality, and noise. The simulation results contribute to the understanding of HPA characteristics and their optimization in WDM-PON based FTTH deployments.

1.4.5 Overall System Performance Evaluation

This thesis conducts a comprehensive evaluation of the overall system performance of the WDM-PON based FTTH architecture. MATLAB simulations are employed to assess key performance metrics such as signal-to-noise ratio, bit error rate, and spectral efficiency under various operating conditions. The findings provide valuable insights into system optimization, resource allocation strategies, and network management techniques to enhance the performance and quality of service in WDM-PON based FTTH systems. This thesis contributes to the advancement of WDM-PON based FTTH systems using MATLAB through a range of analyses and simulations. The comparison of MZM and DML estimates using the Expected Value Method, the analysis of FDM subcarrier spacing, the simulation of high power amplifiers, and the overall system performance evaluation provide valuable insights and recommendations for designing and optimizing WDM-PON based FTTH systems, enabling efficient and reliable high-speed broadband access for end-users.

2. LITERATURE REVIEW

2.1 INTRODUCTION

The Internet's capacity to serve as a communications network on a worldwide scale has considerably expanded over the course of the past few decades, and its use is now virtually ubiquitous. The Internet, in both its wired and wireless incarnations, has fundamentally changed the way in which people communicate with one another by making it possible to make connections quickly at any given time. This has resulted in a dramatic increase in the volume of online conversation. The Internet of Things (IoT) [1,2] is giving rise to a new paradigm in which "anything" may be accessed and/or controlled remotely in order to better coordinate the real world with machine-based systems. This new paradigm allows "anything" to be accessed and/or controlled remotely. This new paradigm makes it possible to control "anything" from a remote location. The term "Internet of Things" (IoT) refers to a global network that consists of billions of Internet-enabled physical items that are able to collect and share data with one another. There will be a large growth in the number of distinct Internet of Things hardware alternatives as a result of the widespread application of sensors and actuators in a variety of industries, such as cyber security, automation, metering, healthcare, utility businesses, and consumer electronics. Gartner [3] predicts that by the year 2022, the average home would most likely have more than 500 intelligent gadgets. Over the course of time, the discipline of communications continues to develop and advance. These technologies find applications in a wide range of domains, including personal use, corporate use, military use, government use, and entertainment use [4]. They utilized copper networks in the past, which only provided a speech service; however, they have since converted to utilizing technologies that mix numerous services into a single medium. Previously, they only supplied a speech service. One of the most promising access technologies that is currently being built out to give incredibly fast internet service is the fiber-to-the-home network, which is abbreviated as FTTH for short. Because it makes use of the technology of passive optical networks, it is capable of being built at greater distances than the typical copper network and can carry more data at once [5].

2.2 RELATED WORKS

The Ethernet passive optical network (EPON) stands out as a mechanism for the delivery of services that is both flexible and adaptive [6]. This type of network is based on PON, which is a type of passive optical network. The increased bandwidth made available by PON makes it possible to circumvent issues with access networks that are brought on by bottlenecks in the last mile [7]. Both IEEE 802.3ah (1G-EPON) and IEEE 802.3v (10GEPON) are the two standards that have been used to standardize EPON [8]. The Ethernet passive optical network (EPON) and the gigabit passive optical network (GPON), respectively, are defined by both the IEEE 802.3ah standard and the ITU-T G.984 standard. The optical line terminal (OLT) in the central office (CO), the optical network (fiber optic cable and optical power splitter), and the ONU (optical network unit) at the customer's location are the essential elements that are shared by both technologies [9]. You can refer to these elements by any name you like. Users within the coverage area can be offered triple-play services, which consist of internet, voice, and video, if this technology is put to use. These services comprise internet, voice, and video. In a manner analogous to this, the maximum bandwidth of the system has the potential to range anywhere from 1 to 2.5 Gbps, depending on the configuration that the service providers decide to use. In recent years, there has also been the emergence of a trend toward a transmission bit rate of 10 gigabits per second (Gbps), which is denoted by the abbreviation Gbps. For instance, in a 10 G network, the downstream and upstream transmission bit rates can be set to the same value (referred to as symmetrical mode) or different values (referred to as asymmetrical mode), respectively. On the other hand, in the majority of circumstances, the upstream transmission bit rate is set to 1 Gbps, while the downstream transmission bit rate is set to the 10 G transmission bit rate [10]. The fiber-to-the-home (FTTH) commercial infrastructure that is currently in use in Malaysia is able to provide asymmetrical transmission bit rates of up to 2.5 Gbps in the downstream direction and 1.25 Gbps in the upstream direction. The process of defining new standards has begun, and numerous research institutions have already recorded transmission bit rates of up to 40 Gbps. However, both the IEEE 802.3av and the ITU-T G.987 specifications need a transmission bit rate of 10 Gbps GEPON for the development of consumer networks in the last mile. Exciting new technologies like the 10 Gigabit Passive Optical Network (XG-PON), for instance, have the potential to be implemented in the first mile access network. However, due to the fact that this design incorporates a propagation delay of 0.3 milliseconds between the ONU and the OLT, the waiting periods for bandwidth grants from the ONUs would necessarily be significantly increased. According to the assertions made in [11–13], a number of different tactics have been put into practice in order to cut down on lag time as much as possible and make the most of the bandwidth that is now available. An enhancement of the level of service is being provided concurrently with the growth of the available capacity. It would appear that FTTH is able to offer its customers what is known as "triple-play" as a service option. The supply of data, audio, and video services to clients from the same application is referred to as "triple play," and this is because they must be supplied to consumers over a single channel in order to be considered "triple play." At the moment, subscribers have the option of selecting the transmission bit rate that best suits their needs from a range of alternatives that are now accessible for these services. A data service requires ranging from a few kilo bytes per second to less than 5 Mbps, depending on the application [14,15]. A voice communication channel requires 64 kbps, a video phone will require roughly 1–2 Mbps, and a video phone will require approximately 64 kbps. HDTV requires a connection speed of between 8 and 15 Mbps, while standard definition television just requires a connection speed of 4 Mbps. The technologies and cable installation that are connected with passive optical networking serve as a foundation for the PON. As a direct result of this, both the alternatives for deployment and the costs of doing so will become more attractive. The feeder and the distribution are the two separate sorts of network segments that a PON would typically have. These two types of network segments are referred to respectively as the feeder and the distribution. A passive optical splitter is located at the remote node (RN), which can be reached by following the feeder segment all the way from the central office (CO) to its terminus at the remote node. The RN is the beginning point of the distribution segment, which continues all the way to the location of the subscriber. Figure 1 is a visual illustration of the concept that FTTH has developed. The implementation of FTTH on a more extensive scale brings with it the responsibility of ensuring the dependability and resilience of the system once it is operational. It is likely that the service provider will be able to more easily meet the SLA that has been created with the assistance of this. There is a correlation between issues with fiber optic cables and more than a third of the service interruptions that are reported to the FCC. This is the case because fiber optic cables are used to transmit data over long distances. When compared to mechanical failures in transmission equipment, issues of this sort typically call for a longer period of time to be resolved. Private optical networks, commonly known as PONs, need to be concerned about fault tolerance because this is a direct consequence of the problem. In an EPON system, network failures can be broken down into two distinct kinds, each of which is distinct from the other. In the first instance, this condition is referred to as a dead node, while in the second occurrence, it is referred to as a broken connection. When there is a break in the fiber connection that is running between the optical line terminal (OLT) and the splitter, a link failure will occur. The portion of fiber that runs from the splitter all the way to the optical network unit (ONU) is known as a branch. Failure at a single node in a FTTH network, such as an OLT, splitter, or ONU, will result in a disruption throughout the entirety of the network. In the event that one of the PON network's links breaks, the entire system will be rendered unworkable as a result of the failure of the feeder fiber. In the event that one of our branches experiences an outage, there will be only one ONU that is impacted. In the case that one of the PON's nodes experiences failure, the network as a whole will experience an outage. This includes circumstances in which an OLT or splitter fails to function properly. It has been discovered that the three components of the PON system that have the largest degree of relevance are the OLT, the feeder fiber, and the splitter. In order to solve this problem, the feeder and trunk components of the FTTH network each come equipped with their very own distinctive group of protection and restoration procedures. If there is an issue with the link, one solution is to have the ONU talk directly to the switching mechanism of the OLT. This is one way that can be taken. Because of this strategy, in order for each ONU in the distribution segment to serve as a component of the protective link that connects all of the ONUs, it needs to be equipped with two optical interfaces [20]. Another method you may implement to reduce the likelihood of a link failure affecting either an OLT or an ONU is to make use of dual OLT links and interfaces [21]. As a result of the additional redundancy that is introduced at the OLT end, this method will also make it possible for OLT cards to malfunction. In addition, the article [22] suggests a protection and restoration system that is based on the downstream test signal. This signal is used to determine whether or not the system is functioning properly. The access control system (ACS), which is a module that is built into the final stage of the optical splitter, will allow the system to continue operating normally in the event that the distribution component of the system encounters a failure. This will allow the system to continue to fulfill its intended purpose. In addition, a study and review project on the rollout of FTTH in Japan has been finished, and a system for securing PON networks that is both efficient and cost-effective has been developed. Protection switches and controllers are deployed at both the OLT and ONU ends of the system that provides protection in order to give the necessary level of security. The method for detecting uses a message that has already been predefined, in accordance with the requirements laid out by the OAM standard [23]. Alternately, an OTDR has been proposed as a possible instrument that may be utilized in the monitoring and assessing the performance of detection link faults [24,25], and this idea has been studied. In addition, as is stated in [26-29], a number of efforts are being undertaken in WDM-PON systems to assure the dependability of future optical access networks. These efforts are being made to ensure that future optical access networks will be able to handle traffic.

2.3 CONCLUSIONS FROM RELATED WORKS

The WDM-PON system, which requires a more intricate scheme, can be more challenging to put into operation than the existing TDM-PON system, which is known as E/GPON. This is because the WDM-PON system requires a more complicated scheme. This is because the PON and its components were designed to function at a wide variety of wavelengths and are able to accept them. The reason for this is that the PON was developed. As a result, a link and equipment redundancy scheme, a detection mechanism, and a controller design to oversee the activities will be necessary for the protection and restoration technique for either the FTTH network or the PON. Additionally, there will be a need for a redundancy plan for the links themselves. This is due to the fact that a method for detection will be necessary to be implemented.

3. OPTICAL NETWORKS

3.1 OPTICAL ACCESS NETWORK

3.1.1 Architecture of PON Networks

Passive optical networks are composed of optical fibers and various optical devices and systems. In short, a PON network consists of an OLT (Optical Line Terminal), an ODN (Optical Distribution Network) containing optical splitters (splitters) and several ONUs (Optical Network Units). As we can see in Figure 3.1.

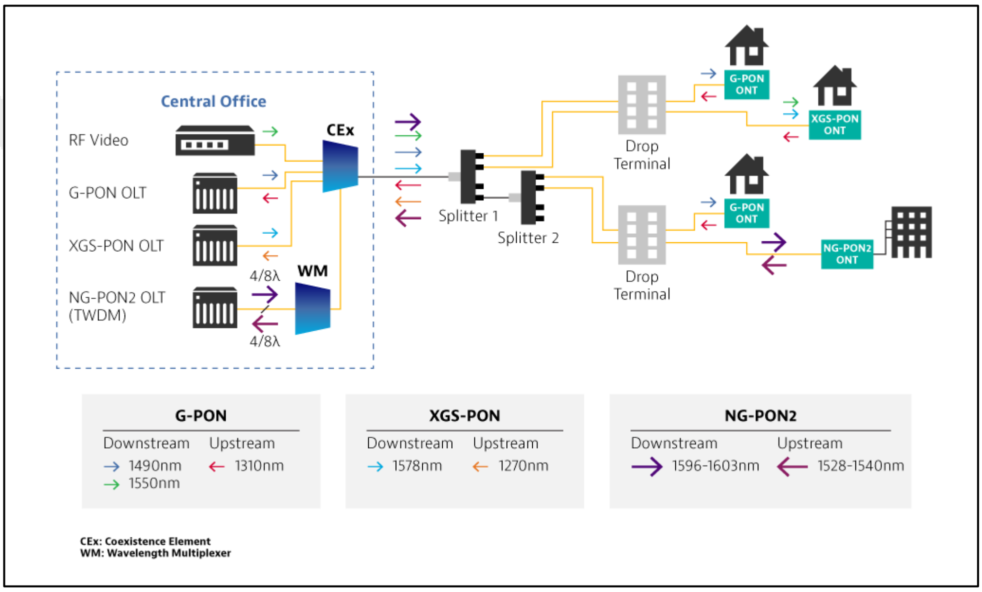

Figure 3.1: Components of a PON Network.

3.1.1.1 OLT (optical line terminal)

The OLT (Figure 3.2) is active equipment that is located on the telecommunications operator's premises, located at the CO (Central Office). The OLT controls and manages the transmission of ONUs, requiring a receiver that operates in burst mode (sporadic volumes of traffic). The bursts are several bits coming from a given ONU. Therefore, it is necessary to control the different signal amplitude levels, since the ONUs are located at different distances from the OLT.

Several aspects must be considered by the engineer responsible for the network design, such as:

a. Power: It must be sufficient to allow good signal reception at the destination. The larger the network, the greater the power required as the distances will be greater;

b. Wavelength: Chromatic dispersion is the differentiated behavior of light when it propagates inside this material. The chromatic dispersion effect is smaller for shorter wavelengths since the index of refraction generally decreases with wavelength.
c. Noise: Must not suffer random noise amplitude fluctuations (related to equipment cost and manufacturer);
d. Insensitivity to the environment: It must have greater resistance to possible climate changes that could compromise its functioning;
e. Cost: The cost/benefit should be the best possible;
f. Reliability: Must be rated with a high MTBF (Mean Time Between Failure). MTBF numbers represent a statistical approximation of how long a set of devices should last before they fail.

There are two types of optical emitters in an OLT. LEDs and laser diodes. LED emitters are simpler, cheaper and more reliable, however, they have a wider spectrum of light derived from an incoherent emission, they have worse efficiency in the coupling of light in the fiber and limitations in the speed of modulation. They are therefore used in systems with lower transmission capacity. Semiconductor laser-type emitters are more expensive and more sensitive to temperature variations, generating more coherent radiation, with a narrower spectrum and a more directive beam with higher powers. They are mostly used in high transmission rate optical systems and/or long distance transmissions.

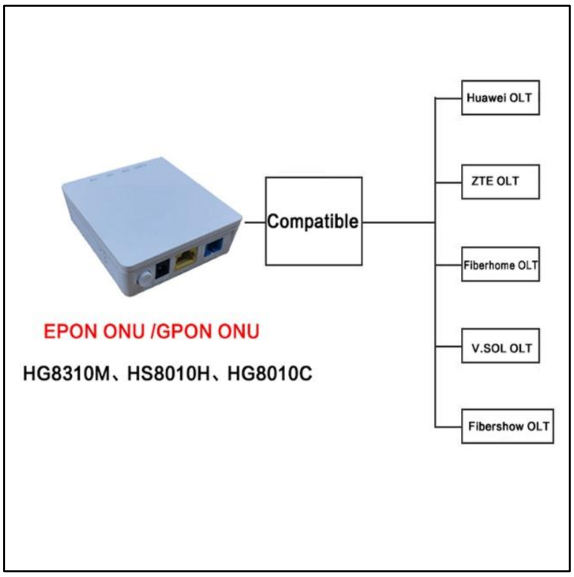

Figure 3.2: FiberHome OLT PON

3.1.1.2. ONx (UN/ONT)

The function of the photodetectors inside an ONU is to absorb the light transmitted by the fiber and convert it into electrical current for processing by the receiver. Ideally, the photodetectors should have the greatest range possible, operating at the lowest possible levels of optical power, and performing the conversion with a minimum of errors and noise, but each manufacturer has a maximum and minimum power value supported. A ONU is a device that depending on its location can be called either an ONU (Optical Network Unit) or an ONT (Optical Network Terminal), this location is also called the degrees of penetration of the optical fiber. to-the-Cabinet) and FTTC (Fiber-to-the-Curb) it is called ONU and when it is in FTTH (Fiber-to-the-home) and FTTB (Fiber-to-the-Building) configuration it is named of ONT. Furthermore, when the OLT sends broadcast messages, the ONUs/ONTs recognize only messages destined for it and ignore the others. This happens because a single fiber has its power divided into a certain fraction, which is necessary for the ONU/ONT to be able to recognize which data is destined for it, the data can be transported according to the technology operating in the network Obs:

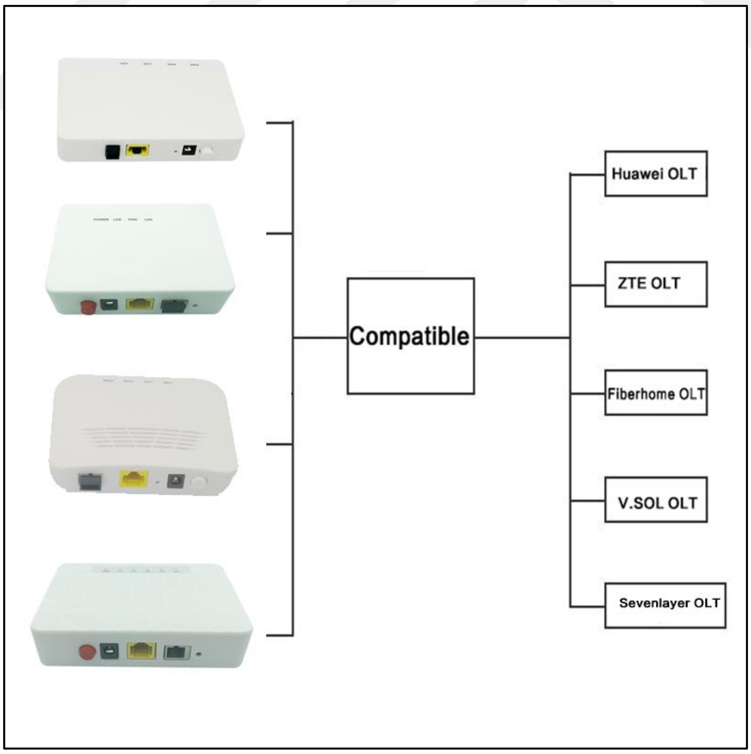

Figure 3.3: Manufactured by FiberHome.

3.1.1.2. Power divider (splitter)

The passive splitter, better known as optical splitter is a passive device capable of combining and dividing the optical signal in the following direction:

a. Downlink: In this sense, this device will divide the input signal and direct it to all the output ports that are connected to the ONUs, as shown in Figure 3.4

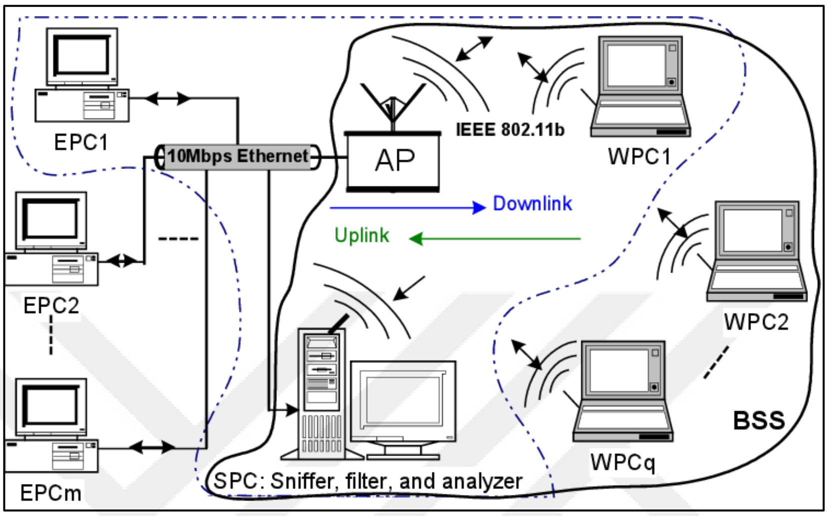

Figure 3.4: Traffic in the Downlink Direction.

b. Uplink: In this sense, this device combines all the signals sent from the ONUs towards the OLT. Each ONU establishes direct communication with the OLT, but not with the other ONUs as illustrated in Figure 3.5

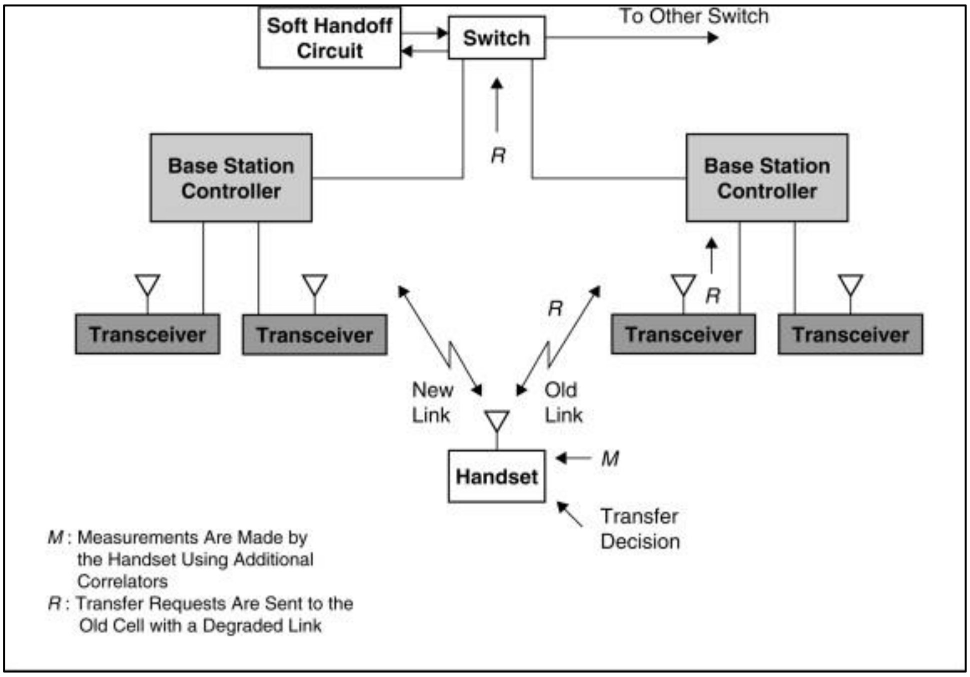

Figure 3.5: Traffic in the Uplink Direction.

3.1.2 Active Optical Network (AON)

Active optical networks or AON networks (Active Optical Network) present a big difference in relation to PON solutions: they need active equipment (switches, routers or multiplexers) in their ODN, that is, they require electrical power to distribute the optical signal. The topologies adopted by these access networks can be point-to-point topologies (Figure 3.6), a fiber dedicated to an end user, or point-to-multipoint topologies (Figure 3.6), which require active equipment implemented in the access network. transport. As the equipment is active, the cost of implementation and maintenance are much higher compared to PON networks.

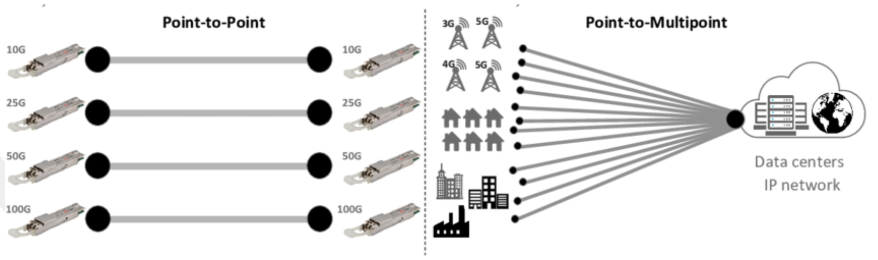

Figure 3.6: P2P (point-to-point) and P2MP (point-to-multipoint) networks.

3.1.3 Passive Optical Network (PON)

The passive optical networks or PON networks (Passive Optical Network) in the access network were designed based on a point-multipoint network topology, where the medium is common to multiple users who share the same bandwidth. These networks are then called passive networks because, with the exception of terminal equipment (OLT and ONU), there is no need to use electricity in the transmission network. In this way, as there is no active equipment in the ODN, network planning is simplified and operation and maintenance costs are reduced.

3.1.4 Fiber Optic Penetration Degrees (FTTx)

Depending on the fiber optic termination point, FTTx architectures have different designations, the most common are: FTTN (Fiber-To-The-Node), FTTCab (Fiber-To-The-Cabinet), FTTC (Fiber-To-The-Curb), FTTB (Fiber-To-The-Building) and FTTH (Fiber-To-The-Home).

3.1.4.1 FTTN/FTTCab

This architecture consists of optical cables from the central to the distribution cabinet serving relatively small areas, with a radius of around 1500 m. The connection of the terminals (ONU) to the cabinet will be supported by coaxial cable or the traditional copper twisted pair. They are intended for distribution to a population density of a few hundred users.

3.1.4.2 FTTC

This architecture describes the implementation of optical fiber from the CO to a cabinet that adds a small area of about 300 m in radius, associated with a small population density, which are interconnected to this cabinet through coaxial cable or copper twisted pair, in the same way as FTTN/FTTCab. This architecture differs from that designated by FTTCab mainly in the fiber range factor, as it allows a maximum range of 300 meters while the FTTCab has a greater range, between 300 to 1500 meters

3.1.4.3 FTTB

This architecture concerns the implementation of optical fiber from the OC to the entrance of buildings whether they are residential or business, not reaching the client's apartment. The connection between the cabinet located at the entrance to the building and the user's equipment is ensured by means of copper twisted pair cables, coaxial cable

3.1.4.4 FTTH

This scenario contemplates the implementation of optical fiber throughout the access network, that is, from the distribution center to the final equipment, placed in the customer's residence. The types of FTTH networks are able to obtain a higher data transmission rate because only optical fiber is used for communication, no coaxial cable or copper twisted pair is used .As previously discussed in section 2.1.1 (Need for high-speed internet), the FTTH network type is the one that best represents the future, as with the increase in bandwidth the least possible loss of signal/data will be required.

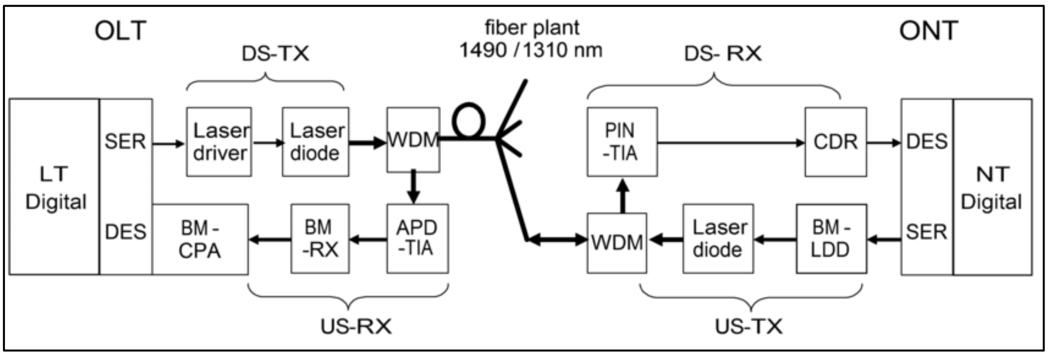

Figure 3.7: Degrees of Penetration of an optical network (FTTx).

3.1.5 Topology of PON Networks

Passive optical networks can be implemented using three physical topologies: ring, bus or tree. Each topology has different characteristics, being implemented according to the needs of the project. However, another topology can be applied, in the form of a star

3.1.5.1 Ring topology

In the ring topology, two ONUs are connected to an OLT creating two transmission segments. The other ONUs are connected serially, forming an optical bus, as illustrated in Figure 3.18. The main advantage is protection, because just like in electrical power systems, if a fiber break occurs, network traffic flows in the other direction, also known as network redundancy. However, it has the same disadvantage as the bus topology, since the optical signal is attenuated whenever it passes through a splitter.

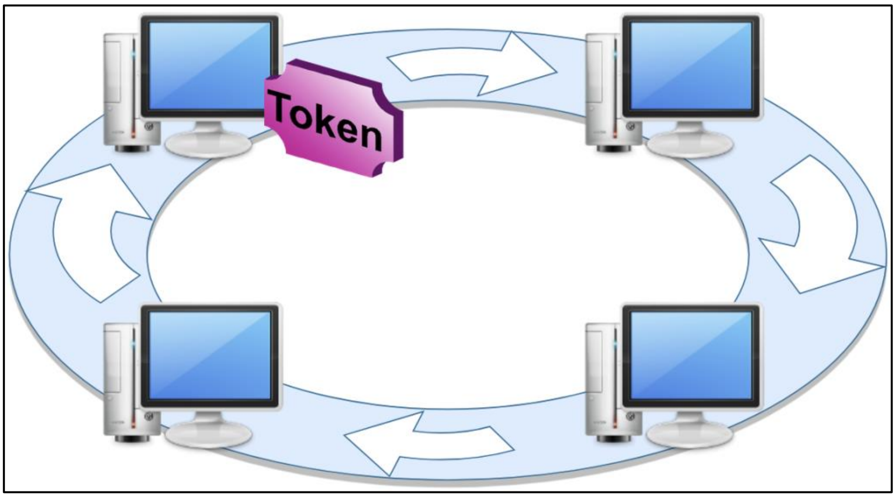

Figure 3.8: Ring Network Topology.

3.1.5.2 Bus Topology

In a bus topology, the ONUs are interconnected to the OLT according to the scheme in Figure 3.9. As you can see, there is a fiber cable connected to the OLT and subsequently each ONU receives a fiber from a splitter with a derivation factor of 1:2. For each splitter introduced into the network, there is a loss of optical signal power. For this reason, ONUs further away from the OLT receive a weaker optical signal.

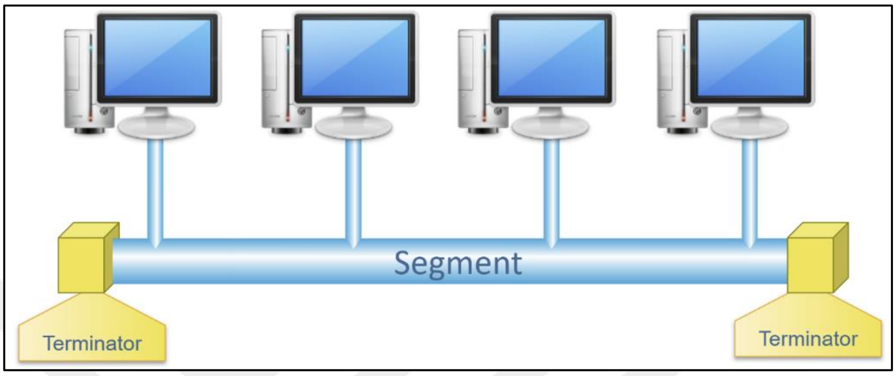

Figure 3.9: Bus Network Topology.

3.1.5.3 Tree topology

In the tree topology, an OLT is connected to a passive optical splitter through a fiber. From this splitter, the ONUs are interconnected to the OLT, as illustrated in Figure 3.10. This topology in the downlink sense it is point-to-multipoint, in the uplink sense it is point-to-point. This topology is the most used in PON networks, due to its simplicity and low cost of implementation and maintenance. However, it has a disadvantage, as the entire network depends on a single fiber (between the OLT and the first splitter), which, in the event of a failure/rupture, leaves the entire downlink optical network without internet.

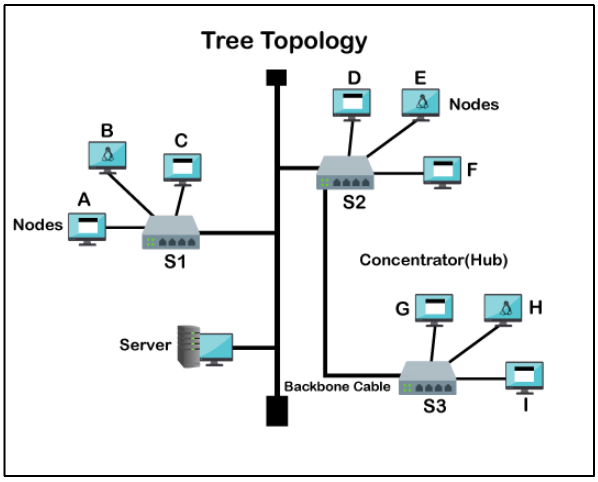

Figure 3.10: Tree Network Topology.

3.1.5.3 Star topology

This topology provides point-to-point connectivity between OLT and ONT/ONU. (Figure 3.11). This topology allows the delivery of dedicated bandwidth at high rates to end users and has a low cost of operation, administration and maintenance.

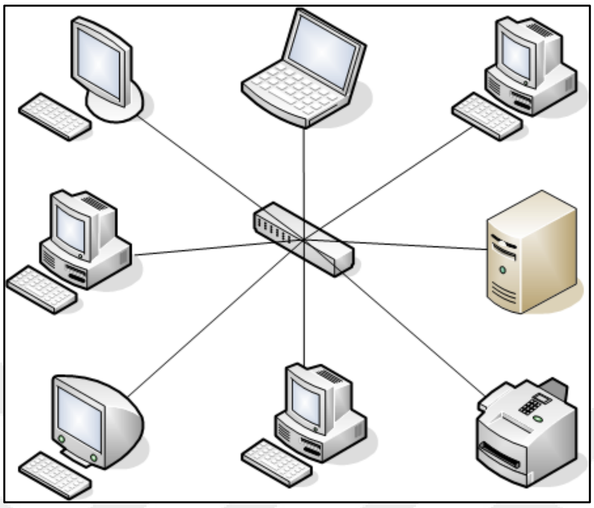

Figure 3.11: Star Network Topology.

3.2 Multiple Access Techniques

In PON networks, it is necessary to control multiple access to the channel in the uplink transmission, because all ONUs share the same fiber (normally 1:64). The most used techniques for multiple access are the following: TDMA, WDMA, OCDMA, SCMA

3.2.1 TDMA (TDM-PON)

TDMA (Time-Division Multiple Access) is a technique of multiple access by time division, dividing the total bandwidth of the link into several channels. This bandwidth distribution for these channels is done by assigning a time interval, called time slot. Thus, the TDMA technique allows each ONU to use a timeslot, which can be fixed or variable, exploiting the entire bandwidth of the channel. This scheme uses the same wavelength for transmission, only one type of transceiver is needed for all ONUs, facilitating the operation and maintenance of the system. Consequently, costs are lower than other techniques (WDMA, OCDMA, SCMA). The uplink communication frames from different ONUs are transmitted in such a way that they reach the OLT in a sequential way, which requires a synchronization of the transmissions, considering the entire period that it takes the propagation of the signal from each ONU to the OLT, to avoid collision of the signs. Transmission control is normally carried out at the center by the OLT, indicating the instant at which the ONU must send its data. The TDMA technique in PON networks is called TDM-PON. The TDM-PON technologies most in use today are:

a. Broadband-PON (BPON) (ITU G.983 Recommendations);
b. ethernet-PON (EPON) (IEEE Standard 802.3ah);
c. gigabit-PON (GPON) (ITU G.984 Recommendations).

3.2.1.1 APON

APON (ATM Passive Optical Network) was the first passive optical technology to emerge defined by the ITU-T according to the G.983.1 standard. APON is based on the ATM (Asynchronous transfer mode) protocol, and allows data transfer of 622 Mbps downlink and 155 Mbps uplink. The maximum connection distance is 20 km (total attenuation between 10 and 30 dB) and it supports splitters with a split factor up to 1:64. As an example, APON operating at 622 Mbps with a 1:32 splitter can provide speeds of around 20 Mbps to each customer. If the splitter is 1:64, APON can enter a speed of about 10 Mbps, in the downlink direction. Despite being a protocol based on the TDM-PON technique, two wavelengths can be used over the same optical fiber, using a wavelength of 1550 nm for downlink traffic and 1310 nm for uplink traffic

3.2.1.2 BPON

BPON (Broadband Passive Optical Network) is an evolution of APON technology, allowing the implementation of WDM and dynamic bandwidth allocation for uplink (DBA – Dynamic Bandwidth Allocation). This technology has the ability to provide different priorities in assigning bandwidth to its users, depending on the desired and supported services/applications, since it implements DBA

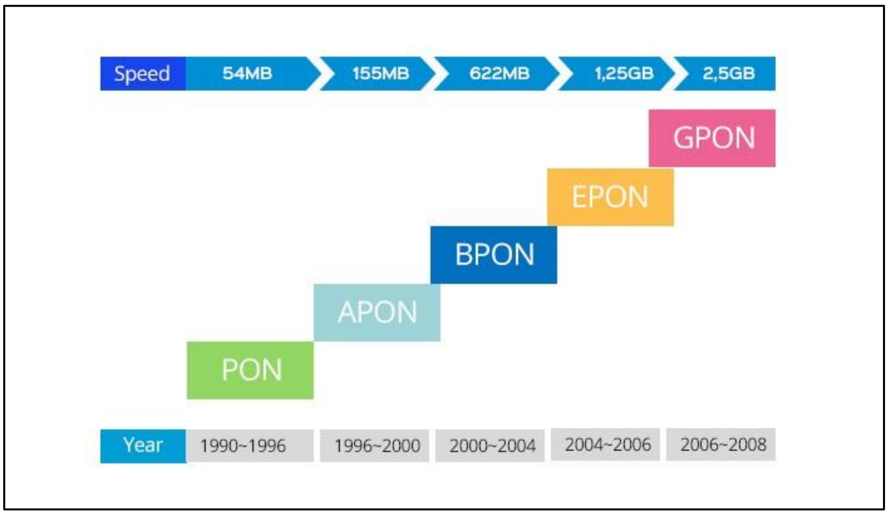

Figure 3.12: APON/BPON Operating Ranges.

Figure 3.9 illustrates the differences that exist regarding the operating wavelength range of APON and BPON. While APON has a bandwidth of 100 nm in each direction, BPON has its downlink bandwidth reduced to 20 nm and reserves a 10 nm bandwidth at 1550 nm for video transmission. This architecture offers ATM-based services, video distribution, leased lines and Ethernet access. It provides a bandwidth of about 155 Mbps uplink and 622 Mbps downlink. However, despite the improvements over APON, they have a high implementation cost, as well as several technical limitations. Thus, it has been moving slowly to solve the problems posed by this technology, which today allows asymmetric speeds of up to 1.2 Gbps as follows

3.2.1.3 EPON

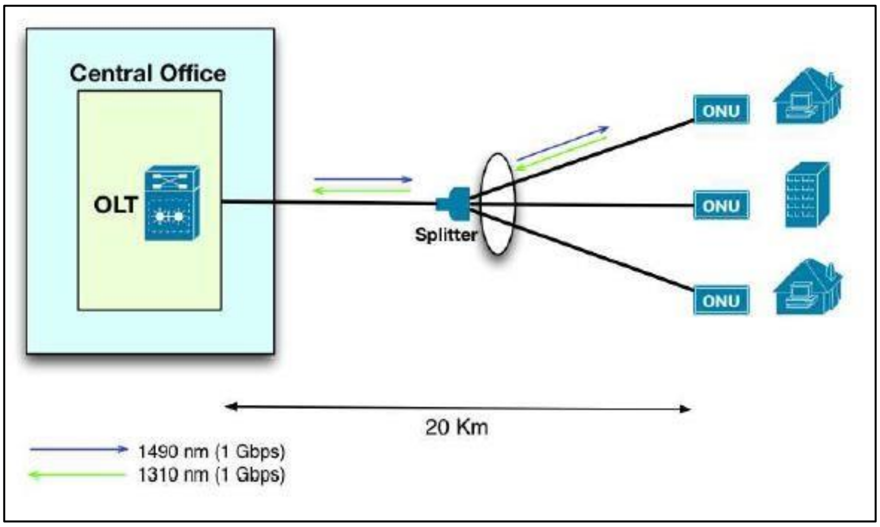

Figure 3.13: EPON Network

Alongside the ITU developments, the IEEE also standardized a passive network technology. Then comes the EPON (Ethernet Passive Optical Network) also called GEPON (Gigabit Ethernet Passive Optical Network) with the IEEE 802.3ah standard, the EPON (Figure 3.13) provides rates of 1 Gbit/s in both directions using the wavelength 1490 -1500 nm for downlink and 1260-1360 nm for uplink and maximum distance of 20 Km. Wavelengths 1550-1560 nm are reserved for additional services such as analog video broadcast. Despite the similarities with GPON, EPON also has some differences. It uses an 8b/10b line encoding. This means that a 10-bit signal is encoded for each group of 8 bits, ensuring easier clock extraction. With this type of coding, it implies a 20% increase in overhead, which means that despite supporting a line transmission rate of 1.25 Gbps, its maximum capacity will be 1 Gbps, both uplink and downlink

3.2.1.4 GPON

GPON technology is an evolution of BPON and is defined according to the ITU-T G.984 standard. There are a series of G.984.n recommendations (n = 1,2,3,4,5,6) (Table 6) that define the general characteristics of GPON, namely the physical layer, the transmission convergence layer and the interface of control and management. It allows higher transmission rates compared to the previous technology (BPON), supporting 2.5 Gbps downlink and 1.25 or 2.5 Gbps uplink.

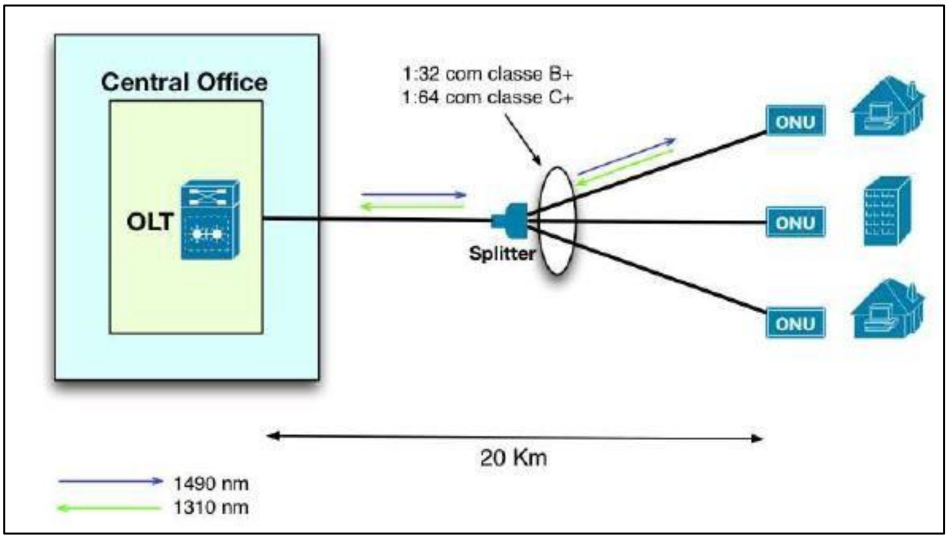

Figure 3.14: GPON Network.

In GPON systems there are different flows of information and each one corresponds to a different wavelength. The operating wavelengths for the downlink communication channel

are 1480-1500 nm and 1260-1360 nm for the uplink communication channel. An additional wavelength, situated at 1550-1560 nm can be used, in the downlink direction, for RF video distribution. The division of the splitters can vary from 8 to 128 (although the maximum to be implemented in practice is 64) and the maximum range is 20 km. As for the optical distribution network classes that define the total attenuation, just as BPON supports classes A, B and C in addition, the classes are also specified
B+ (total attenuation between 13 to 28 dB) and C+ (total attenuation between 17 to 32 dB) in the G.984.2 specification

3.2.1.5 10G-EPON

The evolution of EPON is 10G-EPON (10 Gigabit - Ethernet PON), IEEE released P802.3av to provide 10 Gbit/s downlink, and between 1 and 10 Gbit/s uplink. Figure 3.15 illustrates the operating wavelength ranges of 10G-EPON. So that the migration from EPON to 10G-EPON technology is not so costly for the internet provider, it is necessary that the two technologies can coexist in the same ODN. For this to happen, 10G-EPON must use a different wavelength in the downlink transmission, in the range of 1575-1580 nm. In uplink transmission, however, the wavelengths conflict, requiring the use of the TDMA multiple access technique. Despite this, the bandwidth is lower compared to EPON, between 1260-1280 nm

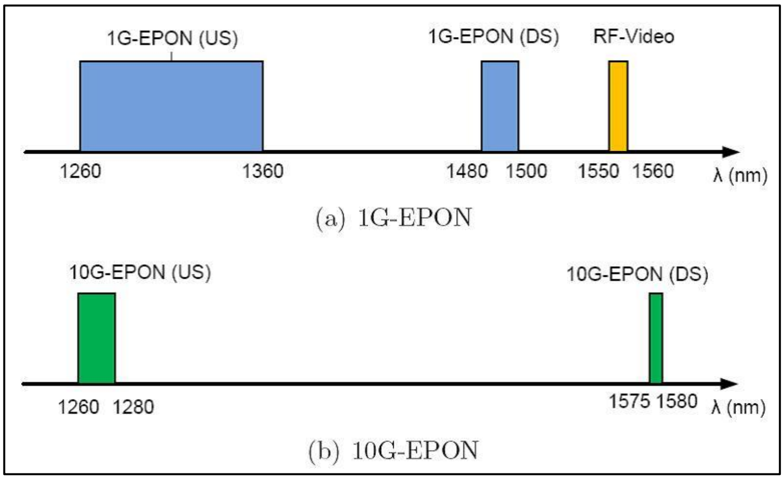

Figure 3.15: EPON/10G-EPON Wavelength Ranges.

Like EPON, 10G-EPON allows distances of 20 km and a split ratio of 1:32. In systems that, at a rate of 10 Gbps, all channels are required to have recourse to FEC (Forward Error Correction), which allows, through changes in the digital signal that is being transmitted, improvements in systemic performance. This technology uses 64b/66b coding, which means that a 66-bit signal is encoded for each group of 64 bits, with a loss of 2 bits.

3.2.1.6 10G-PON

The evolution of GPON technology is 10G-PON (10 Gigabit – PON) and is defined by the ITU-T G.987 standard. As can be seen in Figure 3.16, the downlink transmission occurs in the 1575-1580 nm band with a data transfer rate of 10 Gbps. In the uplink sense, it operates at 1260-1280 nm supporting a data transfer rate of 2.5 Gbps. However, this technology also supports symmetric rates, i.e. 10 Gbps up and down, and in this case it will be necessary to use more expensive transmitters in the ONUs 10G-PON technology is capable of supporting high-definition video (HDTV) or even 4K-resolution video distribution services, while supporting the range of services already supported by its predecessor GPON

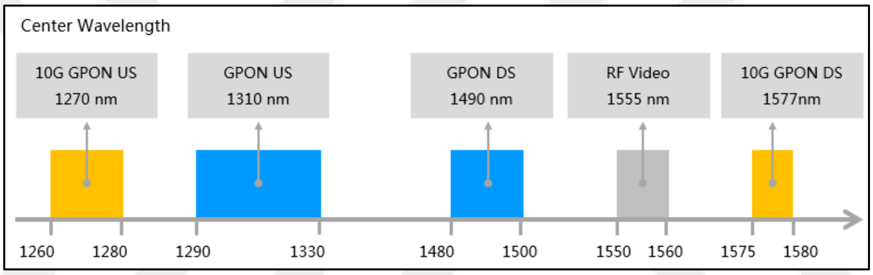

Figure 3.16: GPON/10G-PON Wavelength Ranges.

For 10G-PON technology to coexist with GPON technology, their wavelengths must be taken into account. In the case of GPON technology, the 2.5 Gbit/s downlink transmission is limited to the 1480-1500 nm band and the uplink transmission is limited to the 1260-1360 nm band. In the case of 10G-PON technology, 10Gbit/s downlink transmission is limited to the 1575-1580 nm band and uplink transmission is limited to the 1260-1280 nm band. In uplink transmission, the bands that delimit the respective transmissions conflict as well as in 10G-EPON, allowing the sharing of this region of the spectrum characterized by low chromatic dispersion. This sharing requires time-domain separation for the two channels, using the TDMA multi-access technique. As with 10GE-PON,

3.2.2 Hybrid Schemes

It is also possible to implement hybrid PON solutions (Hybrid-PON) WDM (Wavelength-division multiplexing) and TDM (Time-division multiplexing) techniques can be combined when a subset of ONUSs share a common wavelength. This architecture maintains scalability because new users can be added to each group (WDM or TDM) without having to add new hardware to the OLT. Figure 3.17 illustrates an example of a hybrid network that, in addition to using WDM and TWM techniques, uses ring and tree network topologies.

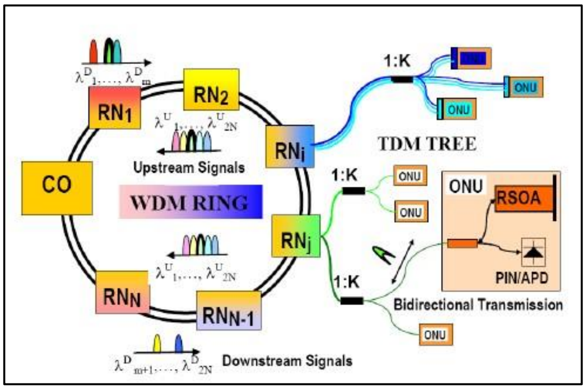

Figure 3.17: Example of a WDM/TDM Hybrid Optical Network.

3.3 ELEMENTS OF A PON OPTICAL NETWORK

3.3.1 Active Elements

The active elements of a PON network are the OLT and the ONU described in section 3.1.1.

3.3.2 Passive Elements

3.3.2.1 Amendments

According to Fiberwan, splices serve to unite two fibers and are essentially of 3 types:

a. Mechanical splice: This process consists of aligning two fibers through the use of a small piece made for this purpose (Figure 3.18), which keeps these fibers positioned face to face, without actually having a definitive union. The investment cost of this method is relatively low, but it is not advisable in systems that require high reliability;

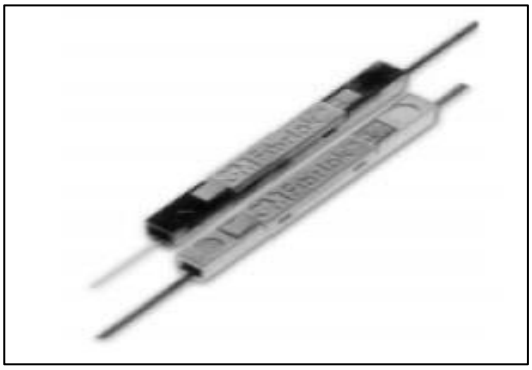

Figure 3.18: Mechanical Splice.

b. Splicing by coupling connectors: This process is very similar to the mechanical splicing process, where two fibers must be aligned. In this case, an optical connector is placed on each fiber and these two connectors are fitted into an optical coupler in order to make alignment between the fibers possible, without actually having a definitive union. This is the process with the lowest recommendation of the 3 types, since despite the lower cost it is the one that takes the most time to carry out.

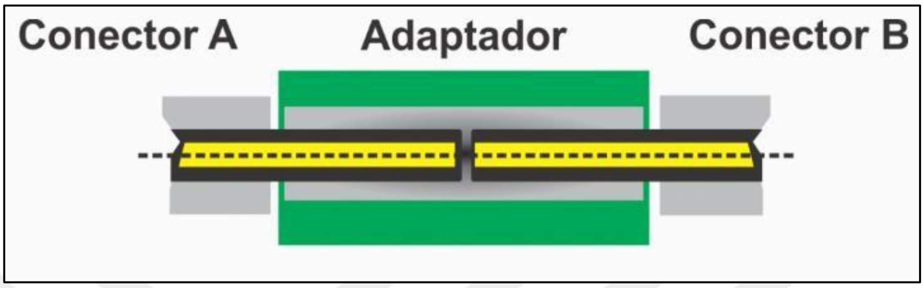

Figure 3.19: Splicing by Coupling Connectors.

c. Fusion: To fuse two fibers into one, a fusion machine is required, which is very expensive. According to Nunes (2016), if the fusion is well performed, it usually has an attenuation of less than 0.05 dB. Figure 3.20 shows the fusion of two fibers.

Figure 3.20: Fusion Machine.

3.3.2.2 Adapters, connectors, pigtails

Adapters allow you to join two fiber optic cables terminated in connectors. There are several types of adapters which allow the joining of different types of connectors. Figure 3.21 shows some sets of adapters.

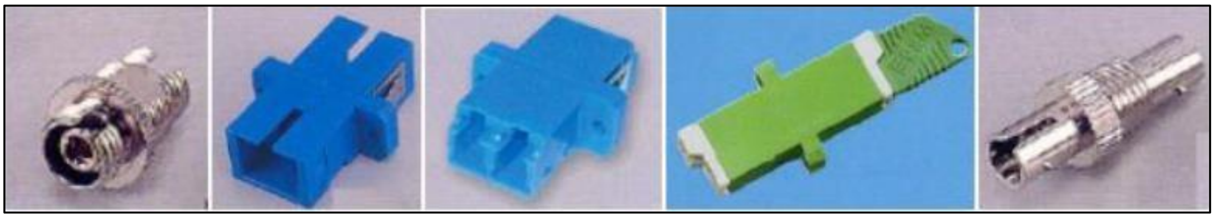

Figure 3.21: Some Types of Adapters.

Connectors are tools that have the function of connecting the optical fiber to some appliances or other devices. There are several families of connectors that have attenuations ranging from 0.1 to 1 dB (Figure 3.22).

	Pre-polished	Adhesive	Mechanical
Enterprise (indoors)	✓	✓	✓
Outside Plant	X	✓	X
Harsh Environments (Industrial)	X	✓	X
Patch Cords	X	✓	X
Fast Installation	Best	Slow	Medium
Craft Sensitiveness	Lowest	Medium/High	Highest
Connector Types	SC, ST	SC, ST, LC, FC	SC, ST, FC
Fiber Types	MM and SM	MM and SM	MM and SM
Reusable	Limited (only once)	No	Virtually unlimited

Figure 3.22: Six types of Fiber Optic Connectors, Characteristics and Applications.

The patch cord (pigtail) is a designation for the optical cables used between active equipment and optical distributors. They can have different connectors at the ends, as shown in Figure 3.23. Usually the yellow colored cables are single-mode optical fibers, while the orange ones are multimode.

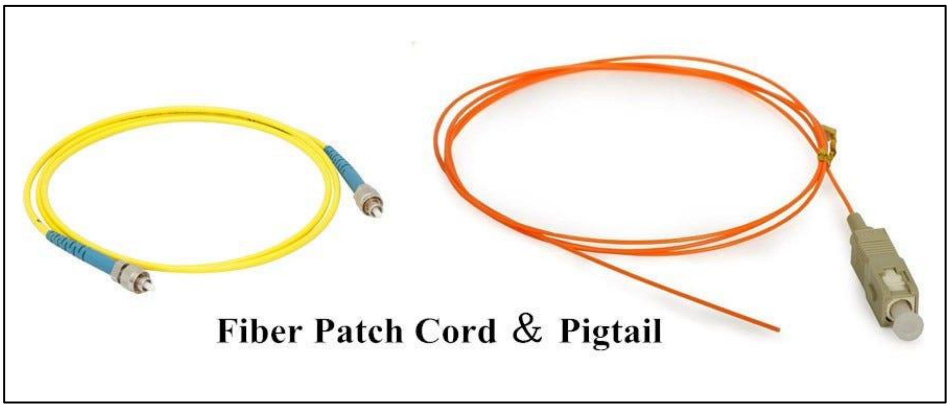

Figure 3.23: Patch Cord / Pigtails.

3.3.2.3 Optical attenuators

Optical attenuators allow you to change the signal intensity to avoid saturation in the receivers, they are normally used to reduce the power at the input of an ONU or ONT as these devices have a range of power to work with. The attenuation value can be from 1 dB to 20 dB in 1dB steps, they can be fixed or variable.

Picturization	Connector Type	Coupling Type	Fiber Type	Polish	No. of Fibers	Typical Applications	Comment
	ST	Twist on	Single mode /Multimode	PC, UPC	1	LANs	Keyed
	FC	Screw on	Single mode /Multimode	PC, UPC, APC	1	Datacom, Telecommuni-cations	Keyed
	SC	Snap on	Single mode /Multimode	PC, UPC, APC	1	CATV, Test Equipment	Keyed
	LC	Snap on RJ45 style	Single mode /Multimode	PC, UPC, APC	1	Gigabit Ethernet, Video Multimedia	Small Form Factor (SFF)
	MU	Push/Pull	Single mode /Multimode	PC, UPC, APC	1	Medical, Military	Small Form Factor (SFF)
	MT-RJ	Snap on RJ45 style	Single mode /Multimode	N/A	2	Gigabit Ethernet, Asynchronous Transmission Mode (ATM)	One of Mating Connectors must have Alignment Pins
	MPO (MTP)	Push/Pull	Single mode /Multimode	N/A	4, 8, 12, 16, 24	Active Device Transceiver, Interconnec-tions for O/E Modules	One of Mating Connectors must have Alignment Pins

Figure 3.24: Some Types of Attenuators.

3.3.2.4 Optical filters

These filters have the function of multiplexing a fiber into several wavelengths, creating several channels. Each channel allows the transmission of a different signal.

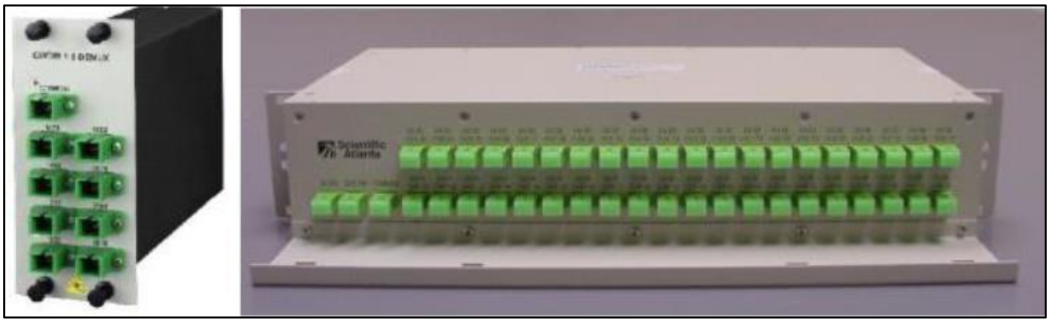

Figure 3.25: Optical Filter.

3.3.2.5 Power dividers (splitters)

Splitters are passive equipment that allow you to divide the power of the optical signal to several ONTs/UNUs. On the market, there are splitters from 1:2, 1:8, 1:16, 1:32 and 1:64 (in/out). However, it is worth noting that the higher the splitter split ratio, the more attenuation will be introduced to the transmitted signal.

You can check the inside of one of these devices in Figure 3.26.

Figure 3.26: Optical Splitter 1/64.

3.3.2.6 WDM coupler

The WDM coupler has the function of multiplexing wavelengths in the same optical fiber. It works similarly to splitters, with the difference being mentioned above. An example of this type of equipment is represented in Figure 3.27.

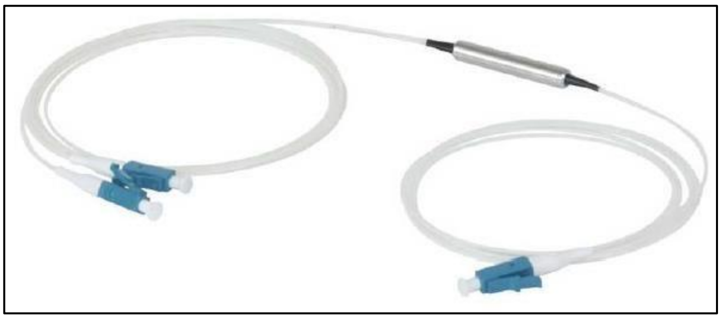

Figure 3.27: WDM Coupler.

3.3.2.7 Termination box or optical distributor (DIO)

Optical distributors are used to terminate or interconnect fiber optic cables (the fibers coming from the backbone are spliced into pigtails and these are housed inside the DIO housing). Explaining it another way, a DIO serves to accommodate, organize and protect the mergers made between optical cables and optical extensions. There are models for installation in racks or for installation on the wall. Figure 3.28 presents an optical distributor for installation in racks and an optical distributor for installation on walls.

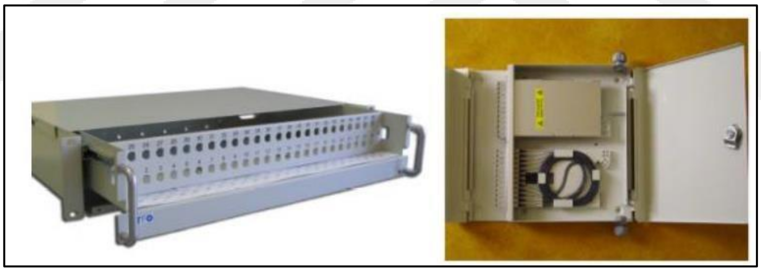

Figure 3.28: Optical Distributor In Rack Format (on The Left) and Optical Distributor Installed on The Wall (on the Right).

3.3.2.8 Optical distribution box (ODC)

The distribution boxes are responsible for housing and distributing the optical fibers of a network. They receive the fibers coming from the OLT and distribute them to the optical termination boxes (CTO). An example of a CDO box is shown in Figure 3.29.

3.3.2.9 Optical termination box (CTO)

Optical termination boxes (or service boxes) have a similar function to optical distribution boxes. The CTO boxes serve as an interface between the CDO boxes and the customer's home where the ONU/ONT is located. An example of a CTO box is shown in Figure 3.30.

Figure 3.29: Optical Distribution Box (ODC).

Figure 3.30: Optical Termination Box (OCT).

3.3.2.10 Fiber optic cables

Figure 3.31 illustrates the basic elements that make up a fiber optic cable.

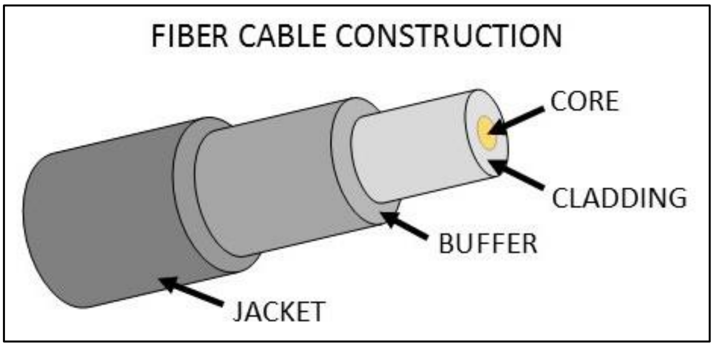

Figure 3.31: Structure of a Generic Fiber Optic Cable.

These elements are described

i. Nucleus (or core): The nucleus is where the transmission of light pulses actually occurs;

ii. Shell (or refraction layer): It is responsible for covering the core and the propagation of all light beams, preventing losses along the paths;
iii. Internal coating (Coating): It has the function of primary protection, isolating external impacts and preventing natural light (external) from reaching the internal glass fibers, which could result in interference in the transmitted signal;
iv. Strengthening fiber: They have the function of protecting the fiber from breaks that can occur in situations of twisting the cable, impacts during transport, in addition to allowing the cable to be pulled during the installation process;
v. Plastic protection (or protective cover): This protective layer is made up of a plastic layer and is responsible for external protection, preventing natural wear and tear due to exposure to the environment.

3.3.2.11 Types of fiber optic cables

The internal composition of the Optical fibers cables can be:

a. loose tube buffer: Optical fibers are found in plastic tubes with an inner diameter considerably larger than the outer diameter of the fibers. The inside of this tube is, as you can see in Figure 3.32, generally filled with a gel, isolating the fiber from external mechanical forces applied to the cable.

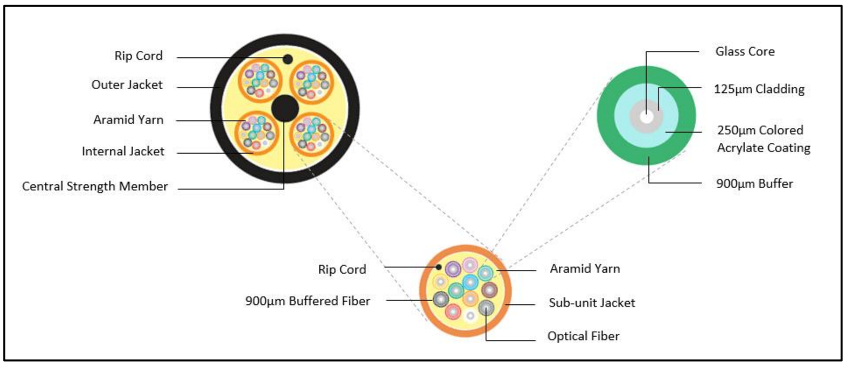

Figure 3.32: Loose Tube Buffer Cable.

b. Tight buffer: In this type of structure, the fibers receive a secondary coating of nylon or polyester. The fibers, after receiving this coating, are grouped together with a traction element that will give it mechanical strength, on this set an external coating is applied that will protect the cable against physical damage. In addition, it facilitates repair by fusion when there is fiber breakage, as they all break in the same place. However, these cables have less insulation against temperature variations and less tolerance to mechanical stress. Figure 3.33 illustrates such a cable.

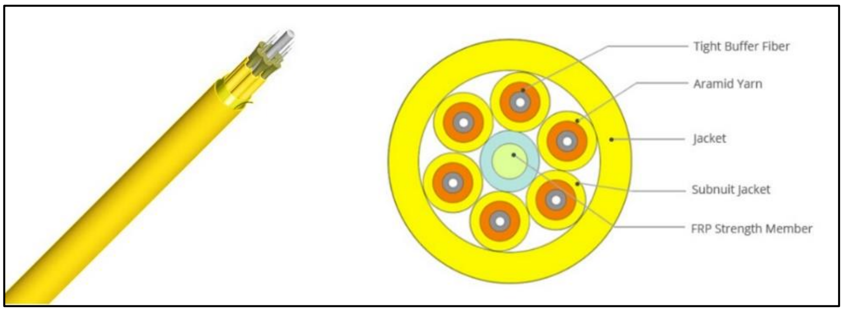

Figure 3.33: Tight Buffer Cable.

c. groove: In a groove type structure, the optical fibers are accommodated loosely in an internal structure of the STAR type. This structure also has a traction element or tensioning element incorporated in its interior, the basic function of this element is to provide mechanical resistance to the set. A structure of this type allows for a much larger number of fibers per cable. Figure 3.34 illustrates such a cable.

d. Ribbon: This type of structure derives from the groove type, in these cables the fibers are grouped horizontally and surrounded by a layer of plastic, becoming a compact set. These assemblies are housed in the grooves of the groove-type cable stellar structures. This configuration is used in applications where a very large number of optical fibers are needed (for example, 4000 fibers). Figure 3.35 illustrates such a cable.

e. Armed: They are used in ducts or in places affected by rodents. They typically have a corrugated metal strip between two layers of thermoplastic material, as shown in Figure 3.36, which prevents rodents from penetrating.

Figure 3.34: Groove Cable.

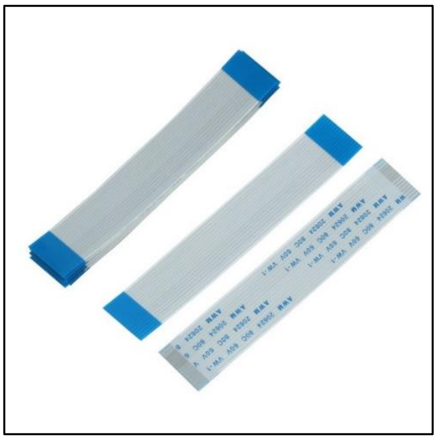

Figure 3.35: Ribbon Cable.

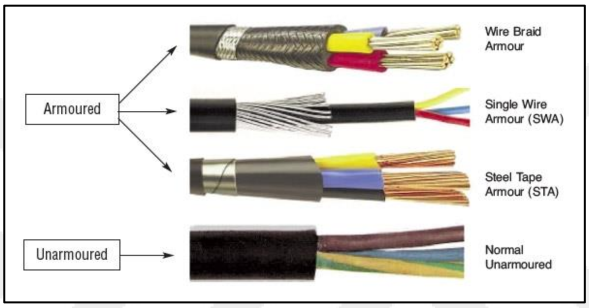

Figure 3.36: Armored Type Cable.

f. Self-supported or “in 8”: These are cables for outdoor installation on poles, being self-supported by a steel wire combined with the optical cable, forming the number 8 when seen from the front. Figure 3.37 illustrates such a cable.

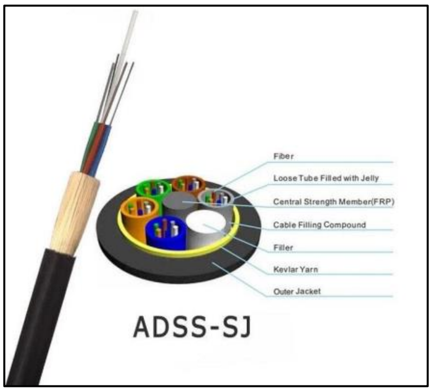

Figure 3.37: Self-Supported Cable.

3.4 POWER BUDGET

The calculation of the power budget consists of determining the maximum distance that the optical fiber can be distributed in the network without the need to place repeaters or signal amplifiers, that is, it has the objective of guaranteeing that there is a sufficient light signal. in the optical receiver (ONU) to cover the losses in the distribution of the optical fiber. The power budget is calculated in decibels (dB). There are two important concepts related to power budget: Link Power Budget and Link Loss Budget. The first is the difference between the power introduced into the fiber and the sensitivity of the receiver connected to the fiber optic cable. The Link Loss Budget is the total loss value of any link component in the optical network. In all cases, the Link Loss Budget must always be lower than the Link Power Budget¸ otherwise the link will be compromised as the receiver will not receive the required signal. As can be seen in Figure 3.38, the total Link Power Budget is the sum of the Link Loss Budget and the safety margin for futures According to the ITU-T recommendation G.957 specifies a margin between 3 to 4.8 dB to take into account the degradation of equipment and possible repairs

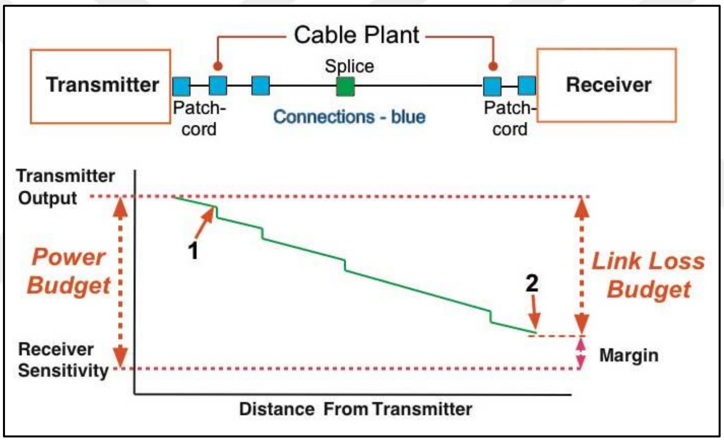

Figure 3.38: Link Power Budget (on the Left) vs Link Loss Budget (on the Right).

3.4.1 Loss of Passive Components

Throughout the optical network there are several passive components that, when inserted into the network, produce a small attenuation, these components are described in section 3.3.2. In a splitter, the input optical power is divided by the various output paths that the component has. Thus, the more output paths the splitter has, the greater the power division (N) and therefore greater attenuation will be introduced. Ideally, the attenuation of an optical splitter is calculated according to equation 3.1

$$Splitter\ Loss\ =\ 10\ \times\ log(N) \tag{3.1}$$

3.4.2 Sizing a PON Network

The first step in sizing a PON network is to decide which wavelength the network will transmit and then select the network components to operate in that region. In FTTx networks there are 3 wavelengths: 1310, 1490 and 1550 nm. The calculation of the power budget will have to be carried out for the three wavelengths, since the fiber attenuation varies with the same. To calculate the power budget, it is important to initially know the characteristics of the chosen optical components that will be found at each end of the optical fiber (OLT and ONU). The amount of light available in the system is calculated using equation 3.2. The variable PT represents the transmitted power of the signal that is emitted in the fiber and PR is the received power (receiver sensitivity).

$$Link\ Power\ Budget\ =\ PT\ -\ PR \qquad (3.2)$$

As previously explained, through the power budget it is known what is the maximum attenuation that can exist in the optical distribution network, between the transmitter and the receiver. There are several classes that characterize the maximum attenuation allowed in an optical distribution network, which both the OLT and the ONU describe in their manuals. Figure 3.39 illustrates an example of sizing the power budget of a PON network. The calculation of the total attenuation introduced is performed using equation 3.3

$$\text{Link Loss Budget (dB)}\ =\ (\propto \lambda \times\ \text{L})\ +\ (\text{n}\ \times\ \text{C})\ +\ (\text{S})\ +\ (\text{n}\ \times\ \text{J})\ +\ (\text{W}) \qquad (3.3)$$

Where:

i. $\propto\lambda$= Fiber attenuation that depends on its wavelength (dB/km);

ii. L= Optical fiber length (km);

iii. n= multiplicative factor;

iv. C= Losses by connectors;

v. S= Loss by splitters;

vi. J= Losses due to fiber melting;

vii. W= Losses per WDM coupler.

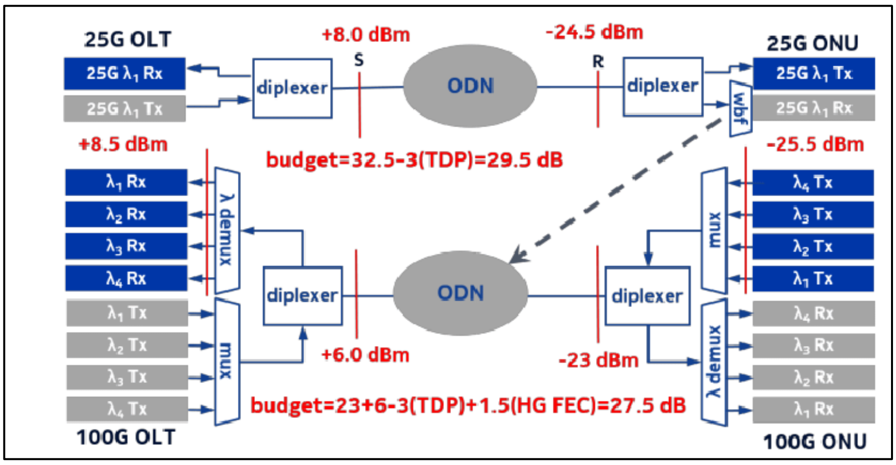

Figure 3.39: Dimensioning of the Power Budget of A PON.

EPON and GPON technologies have very similar network sizing and power budget calculation, as they have almost identical infrastructure.

4. PROPOSED METHOD

Researchers have discovered that it is possible to develop a convergent passive optical network architecture that makes use of common WiMAX OFDM transceivers for transmission to and from faraway ONU/BSs. The modeling was done with VPI and MATLAB, and it was shown that this was doable. This is supported by the available evidence. Importantly, we determine the maximum number of subcarriers that can be handled in an FDM window by carrying out transparent communication on five WiMAX FDM subcarriers while comparing external to direct modulation assessment metrics. This helps us determine the maximum number of subcarriers that can be handled in an FDM window. Because of this, we are able to establish the maximum number of subcarriers that can be managed within an FDM window.

4.1 THE INTEGRATED ARCHITECTURE'S FOUNDATIONAL ROF PRINCIPLE

There is a possibility that the performance of TDM-PON networks as well as broadband wireless networks could be improved using RoF techniques [2, 3]. This is due to the fact that they make it possible to converge fixed and mobile networks using FDM at a cheap cost and with high scalability [1, which is one of the reasons why they are so beneficial]. In the prior chapters, we have investigated a variety of possible recommendations for hybrid optical/wireless architectures and provided greater detail regarding these recommendations. However, there has not been a thorough examination into the use of WiMAX over legacy PONs in order to improve their operating features in terms of aggregate capacity, reach, and the number of users that can be supported. This would allow for an increase in the number of users that could be supported. The example of a layout that demonstrates how all of these considerations were incorporated into the overall design may be seen in Figure 4-1. This graphic is meant to illustrate the process that was followed in order to produce the overall design. It is vital to keep in mind that the visual is simply illustrating a high-level summary of the architecture when taking into consideration the ideas that have been discussed in this chapter. This is something that must be kept in mind at all times. Additional aid can be provided by scalability and dynamicity. Nevertheless, the modifications and associated modes of operation completely incorporate all of the aspects that have been discussed up to this point in the discussion.

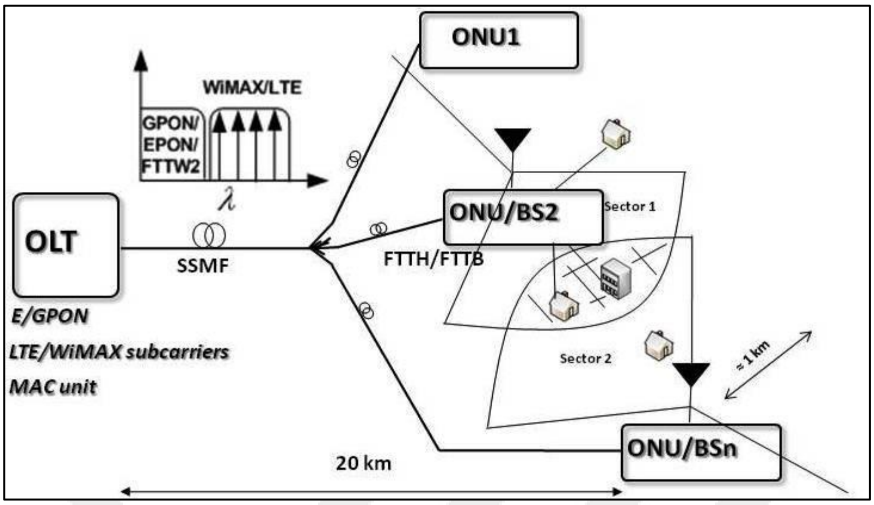

Figure 4.1: The proposed Optical/Wireless Integration Uses Frequency Division Multiplexing.

One OLT is deployed in the central office (CO), while additional ONU/BSs are dispersed over the network in various locations to act as access points for mobile devices. The OLT is located in the CO. The operational logistics terminal (OLT) can be found in the central office (CO). Within the confines of the central office (CO) lies the operational logistics terminal, also known as OLT. After all of the upstream and downstream data have been transferred from an OLT through a single feeder optical fiber, the signals are passively divided using an optical splitter and distributed to a large number of network segments. This process occurs after all of the data have been transmitted from an OLT. Within the OLT, frequency multiplexing is carried out in order to prevent interference between legacy PONs located further downstream and RF broadband wireless channels located further upstream. Both of these types of PONs are located farther downstream than the OLT. These two places are situated further away from the OLT than the first. After initially being modulated onto an optical carrier and then traveling through the system, the combined spectrum is subsequently sent to each out-of-band unit in the system (ONU/ BS). This occurs after the combined spectrum has been transmitted. It is possible to transfer any kind of wireless signal format across the optical fiber while using this technology, and it is not dependent on the capabilities of the xPON in any way. Because the OLT is in charge of all wireless processing and subcarrier distribution, the implementation of solutions for remote base stations is significantly facilitated by the fact that it is a lot less complicated. As a result of this, broad deployment of base stations would make it possible to reuse frequencies more effectively and achieve higher levels of spectral efficiency. This would be made possible by the increased availability of base stations. This would be a result of the deployment of additional base stations, which would lead to the situation. In order for the OLT to accomplish this goal, the traffic will be multiplexed across a remarkably large number of different sub-carriers. After then, these sub-carriers are going to be broadcast throughout the ODN, and once they reach the user's end, they are going to be demultiplexed, and vice versa. As a consequence of this, the customer premise equipment (CO) can be conceived of as a PON OLT that doubles as a wireless base transceiver station (BTS). In addition, the modernized architecture demonstrates that upstream transmission can be based on a TDMA technique, which is typical of ordinary xPONs. This is one of the advantages of the modernized architecture. This is something that could not have been done with the architecture that was in place before. Alternately, dedicated wavelengths could be supplied to each ONU and BS in order to guard against interference brought on by optical beats, reduce the cost of deployment by doing away with the requirement for subcarrier multiplexing, and boost the overall performance of the network. In conclusion, but this is by no means the least important point, in order to evaluate the usefulness of the network in terms of signal routing, additional research is required because RoF may impose a variety of impairments on the common wireless signal formats. However, this is not the case with the least important point. Before determining the effectiveness of the network, this step needs to be completed.

4.2 WIMAX SPECIFICATIONS AND REQUIREMENTS

When a user is moving around, the air interface management needs to be able to swiftly respond to changing signal strengths and swap a connection between base stations in order to facilitate simpler mobility. This is necessary in order to make mobility easier. This is essential in order to further the cause of mobility. During times of inactivity, the air interface required improvements to make it more efficient in terms of the amount of power that it consumed. This was especially important for devices that were powered by batteries. Enhancements to the WiMAX air interface that boosted data transmission speeds were implemented so that this objective could be achieved. The utilization of OFDM technology for the purpose of signal transmission is directly responsible for the network's resistance to high delay spreads on the wireless channel. This resistance was achieved through the use of OFDM technology. In the chapter that came before this one, this topic was discussed in depth. The implementation of WiMAX technology can take either a stationary or mobile form, depending on the circumstances. Although the mobile WiMAX standard allows for both the FDM and TDM multiplexing schemes, only the TDM multiplexing scheme will be used in the initial deployments of mobile WiMAX [6]. This decision was made despite the fact that the mobile WiMAX standard permits both of these multiplexing techniques. The many different kinds of physical characteristics that mobile WiMAX possesses are outlined in the table that can be found below. We are able to accommodate a wide variety of channel bandwidths, and the particular channel bandwidth that is used is dictated by the regulatory limitations that are present in any given deployment situation. We are able to accommodate a wide variety of channel bandwidths.

Table 4.1: Specifications for Mobile WiMAX.

Parameter	Value
Chanel Bandwidth	1.35 MHz, 3.5 MHz, 6 MHz, 16 MHz, 25 MHz.
FFT size	Typical: 1034
Number of Antennas	Tx: 1, 4, 6 Rx: 1, 6, 6
Multiple Access Technology	DL: OFDMA UL: OFDMA
Modulation Schemes	QPSK, 16QAM, 64QAM

A comprehensive explanation of the construction of a WiMAX frame utilizing the TDM protocol is presented in Figure 4-2. Under the majority of conditions, a WiMAX TDM frame will function for a period of time equal to 5 milliseconds. The beginning of the sub-frame is signaled to begin with the beginning of the transmission of the downlink preamble. Mobile users have an easier time detecting the cell and synchronizing themselves with the frame time [6]. The next step is to position the various frame control elements, such as the FCH, DL MAP, and UL MAP. This operation comes after the previous step. The FCH data will need to be decoded, which will first be handled by a mobile device. That location stores information pertaining to the length of the MAPs as well as the encoding technique that was applied to them. Included are, among other things, various features of user data injection, a variety of schemes for modulation and coding, zone shifts, and more. Learning to read FCH and MAPs is a skill that is required of virtually everyone who uses the system. When it comes to the first transmission zone for downlink sub-frames, the employment of PUSC mode is an absolute requirement at all times [6]. The information that was gleaned from the customer will be sent for the remainder of the time slice that is still open for use.

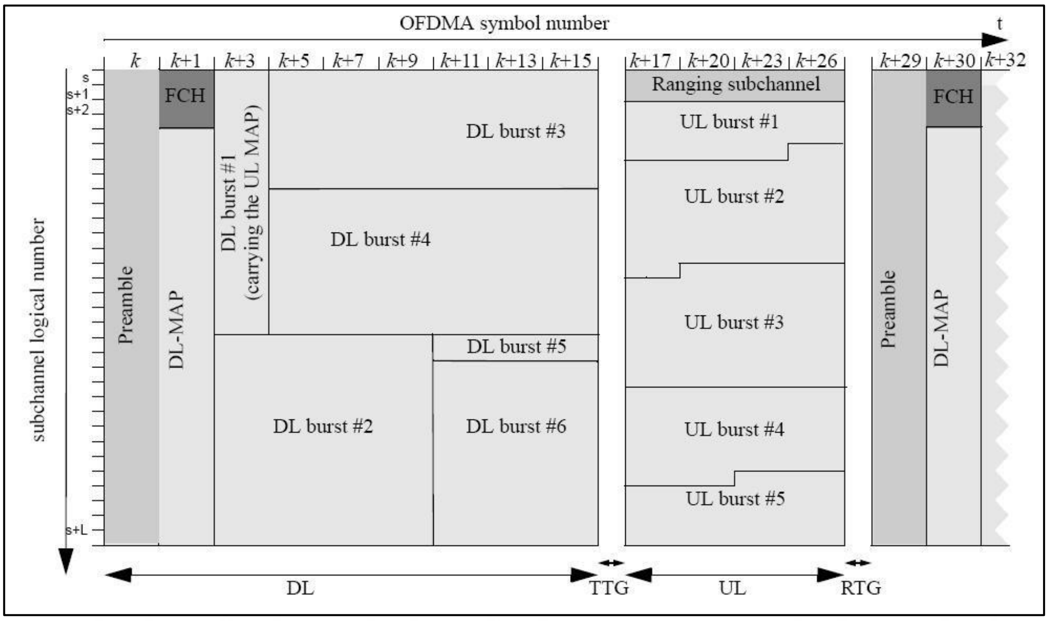

Figure 4. 2 Frame Format Used in Mobile WiMAX OFDMA [6].

It is possible to modulate the subcarriers in the downlink using QPSK, 16QAM, or 64 QAM (as shown in Table 4-1); however, only QPSK and 16QAM are available for modulation in the uplink. Pilots are normally positioned within the sub-frames for the sake of channel estimates and synchronization (the specific placements of these pilots are defined by the allocation mechanism that is being employed [6]); however, there are certain exceptions to this general rule. The presence of a CP in each OFDM symbol confers on them the ability to withstand interference from many paths. The primary distinction between mobile and fixed WiMAX standards in regard to the PHY is that fixed WiMAX normally makes use of a subcarrier spacing of 256, whilst mobile WiMAX makes use of a variable subcarrier spacing. This is due to the fact that mobile WiMAX employs a variable subcarrier spacing. This is one of the most important distinctions. Because there is a vastly larger number of possible sub-channels, mobile WiMAX data transfers to individual users can be multiplexed in time in addition to frequency. This is made feasible by the increased number of sub-channels. As a result of this, we refer to it as orthogonal frequency division multiple access, which is abbreviated as OFDMA for short. In light of the information presented above, as well as the fact that the modulation techniques utilized by IEEE802.16d [4] and IEEE802.16e [6] are so comparable to one another, the forthcoming feasibility studies will be based on fixed WiMAX. This should be sufficient to demonstrate that wireless signals can readily transit via an optical network, even when they are being relayed to distant base station antennas and users. In other words, this should prove that optical networks are compatible with wireless communications.

4.3 WIMAX TRANSCEIVER COMPONENTS FOR VPI/MATLAB

The OFDM transmitter and receiver need to be constructed in VPI in co-simulation with MATLAB utilizing the functional blocks described in the chapter before this one in order to achieve exact WiMAX signal routing via the xPON. Only then can exact WiMAX signal routing be achieved. As can be seen in Figure 4-3, the pseudorandom binary sequence, which is also known as PRBS, is transferred from the VPI in the OFDM transmitter to the input MATLAB interface, which acts as the OFDM coding block. This is done in order to ensure that the data being communicated is secure.

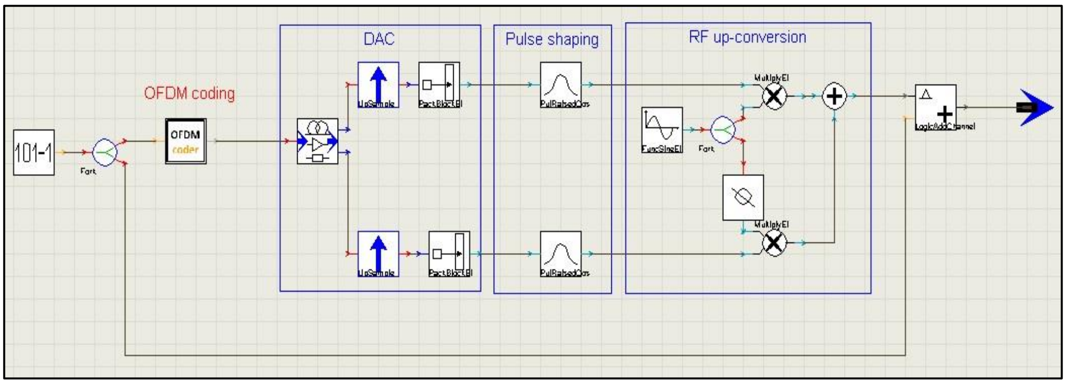

Figure 4.3: The OFDM Transmitter Consists of VPI/MATLAB Components.

The OFDM coder utilizes MATLAB for symbol mapping, IFFT, and cyclic prefix, with the output then being sent to VPI for post-processing (namely, SER and EVM estimates). Figure 4-4 depicts the MATLAB interface settings.

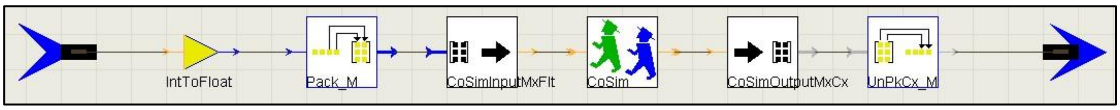

Figure 4.4: OFDM Transmitter With A MATLAB Interface.

The PRBS sequence that is produced by VPI is initially compressed into a matrix form, with Nbits set to be equal to BitRate multiplied by the number of samples produced by TimeWindow [9]. The TimeWindow parameter provides information about how long the simulation will last. Therefore, the control of the number of symbols that are used in the simulation rests with this parameter (i.e. Nsymbols=N/BitsPerSymbol). After that, the bit stream is sent to MATLAB, and the cod function, is called upon in order to carry out the symbol mapping. we will find information that can be used to learn about the functions and simulation coding that are associated with the OFDM transmitter and receiver. To finish the translation of the symbols from the frequency domain into the time domain, first an IFFT with 256 points is applied to the symbols in the frequency domain, and then the translated symbols are used. This process is repeated until the symbols have been successfully translated. The procedure of include the 1/4 cyclic prefix in the matrix is accomplished through the application of a technique known as the concatenation of matrices. After the symbol set has been finished, it is delivered to the VPI so that it can undergo analog-to-digital conversion and signal shaping with the help of the output matrix variable. This occurs after the symbol set has been finished. This happens once the symbol set has been completed in its entirety. The process of transforming digital signals to analog signals continues with the next step, which is called quantization. After the amplitudes of the symbols have been brought to a consistent level in the phase before this one, this step then takes place. Figure 4-5 shows the stages that need to be completed for this treatment to be successful [9. As was said earlier in the phrase, the simulations can only reach a maximum of 14 quantization levels. This limitation places a limit on the amount of information that can be simulated [4].

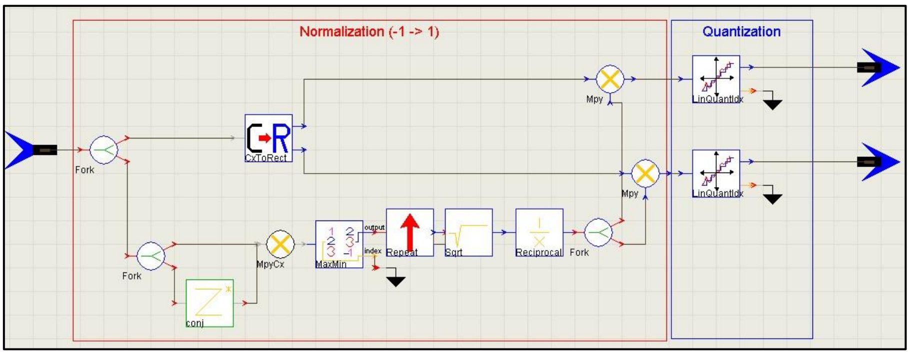

Figure 4.5: The Method of Quantization.

[4, as was previously detailed in Figure 4-3] The signals for the I and Q channels were shaped by applying square root-raised-cosine filters with a roll of factor of 0.25. Before the RF upconversion, this step was carried out. The amount of time that is necessary to send one OFDM symbol is identical to the amount of time that is necessary to transmit one bit; hence, the bandwidth of these filters is equal to the amount of time that is necessary to transmit one OFDM symbol. In order to accomplish OFDM reception, the signal that is being received is first downconverted, and then the signal that has been downconverted is applied to an ISI shaping filter that possesses the same characteristics as the filter that was used at the transmitter. Figures 4–6 provide an illustration of the configuration of the receiver.

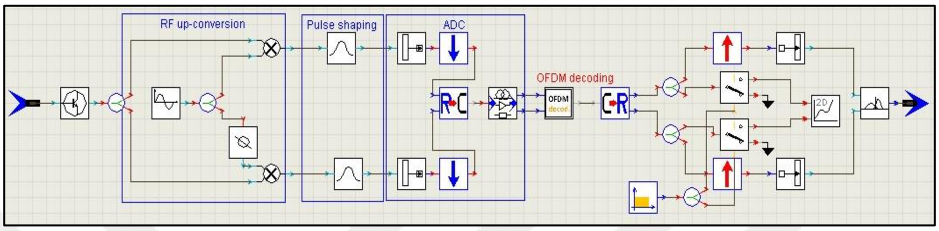

Figure 4.6: VPI/MATLAB Receptacle for OFDM Signal Reception.

The consequent I and Q streams are Quantized and Sent to a MATLAB Simulator via the CoSim Interface Shown in Figure 4-7 for Further Processing.

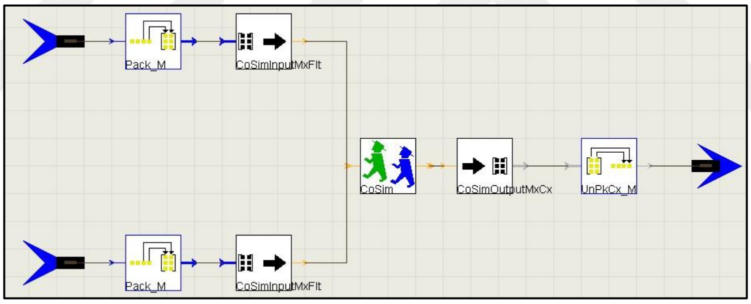

Figure 4.7: OFDM Receiver MATLAB Interface.

4.3.1 High Power Amplifier (HPA)

It was also required to accurately replicate, using VPI, the additional distortion that was produced to the WiMAX signals while they were being broadcast as a result of the high power amplifier (HPA). This was essential because the high power amplifier (HPA) was responsible for the additional distortion. This insured that there would be no fluctuations in the network's performance. Figure 4-8 illustrates this point. The nonlinear components of the transfer function, such as amplitude clipping and the related distortion of the transmitted signal-to-noise ratio, can be imitated with the help of a limiter block. This block can also be used to simulate other types of distortion. The transfer function also contains a number of other nonlinear characteristics. This is filtered so that unwanted components do not infiltrate into nearby channels and cause difficulties. This is done so that they cannot cause problems. By altering the limiter block's maximum and lowest amplitudes, it is possible to make changes to the required sent EVM in order to bring it into compliance with standard [4].

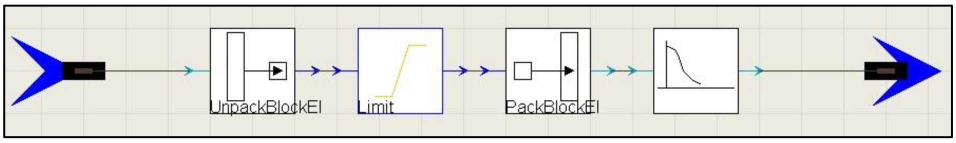

Figure 4.8: Simulation of High Power Amplifiers.

To that extent, limiter amplitudes of 0.68V and -0.68V were required to achieve -31dB EVM figures, the maximum allowed for 64-QAM modulation in WiMAX [4]. This estimation is performed based on back-to-back transmission of the OFDM signal in the absence of the wireless channel. The obtained spectrum at the output of the amplifier is shown in Figure 4-9 clearly demonstrating the HPA signal distortion corresponding to a maximum achievable SNR of 31 dB [2].

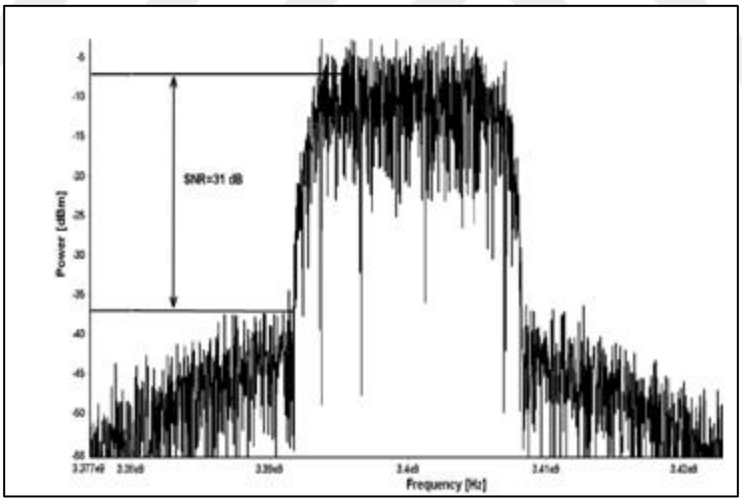

Figure 4.9: HPA Spectral Output.

4.4 SIMULATION OF WIRELESS CHANNELS

In order for the evaluation of the wireless signal's capacity to propagate to be successful, it is essential that the wireless channel be implemented in the suitable manner. Path loss and multipath delay spread are the two features that have the most common and widespread influence on the transmission of wireless signals. In order for the model to be able to accurately replicate probable network scenarios, it will need to be methodically developed to ensure that it takes into consideration each of these characteristics. There are a variety of well-established models that can be used to evaluate the performance of wireless channels for a stationary application. Each of these models was developed for a unique combination of conditions and frequency ranges. Because of this, it is possible to conduct an accurate evaluation of the performance of wireless channels for fixed applications. The Hata-Okumura model [10] is the suburban model that is used most commonly for the goal of predicting and modeling signal levels in macrocellular environments. This is because the Hata-Okumura model is considered to be the most accurate. This gizmo can only function at frequencies between 500 and 1500 MHz, with the ability to increase it to a maximum of 2 GHz [10]. It is anticipated that wireless networks of the fourth generation, referred to as 4G, would make use of frequencies that are higher than 2 GHz. Cost 231 Another option for use over metropolitan areas is the Walfish-Ikegami (W-I) model [11, 12]. However, just like the earlier model, it has a frequency cap that is no higher than 1.9 GHz at most. In order to properly achieve the baud requirements of the intended specification channels, an experimentally based route loss model was used [13]. This model took relevant frequency correction factors into consideration. The model parameters that can be found in Appendix B have been utilized to a significant degree in order to determine the proper wireless channel route losses for the simulation models that are specifically specified in chapter 6. As a result of the scattering of the sent signal, wireless channels may exhibit multipath delay and fading patterns in addition to path loss. This is because of the propagation of the signal. As a direct consequence of this, the creation of an additional model was necessary. In the following part of this article, we are going to talk about how this may be used to imitate the wireless channel for fixed radio protocols such as IEEE802.16d.

4.4.1 Matlab Modelling

Using a delay spread SUI-4 model that has a reasonable level of delay is one way to complete the task of establishing precise signal routing to and from an end user through hybrid optical and wireless channel links. This can be done both to and from the end user. In spite of the fact that wider delay spread channels like SUI-6 might be investigated in order to simulate the worst-case scenario, the absence of any wireless channel coding would result in an increased number of mistakes being forecasted, which would consequently limit the ability to make an accurate prediction of the system's performance. Up to three of the possible pathways must each have a value of K that is equal to zero in order to demonstrate wireless communication between the transmitter and the receiver that is independent of a line of sight. A value of 0 for the Tap 1 parameter implies that no extra penalties are applied to the initial propagation delay and attenuation of this technique. In conclusion, the channel causes the received signal to incur a maximum delay of four seconds and an attenuation of twenty decibels.

Table 4.2: Multipath Channel Parameters for IEEE802.16d Based on the SUI-4 Standard.

SUI-4 Channel Model			
	Tap 1	**Tap 2**	**Tap 3**
Delay (μs)	1	2.5	20
Power (dB) for 30º ant.	1	-20	-25
K factor for 30º ant.	1	1	1

To begin, we make use of the formula that is presented in [4] in order to compute the duration of an OFDM symbol. This formula can be found here. The CIRpowers function incorporates symbol time into its computations in order to provide more accurate results. Using this function, the variance of each channel path may be determined. After the path variances have been calculated, the genh function is used in order to generate the Rayleigh channel coefficients that are appropriate for the specified SUI. This comes after the computation of the path variances. In order to accomplish this, we incorporate sinusoids into the Jakes Model [15], which enables us to generate fading coefficients. This is necessary in order to achieve our goal.

4.5 ANALYSIS OF FDM SUBCARRIER SPACING

Using the produced models, the initial focus of transmission measurements was on the downstream direction in order to establish the network's viability and to develop the FDM architecture as a feasible alternative for the transparent transmission of WiMAX across

PONs. This was done in order to establish the network's viability and to construct the FDM architecture. This was done in order to determine whether or not the network was viable, as well as to determine whether or not the network was a viable option for the transmission of WiMAX across PONs. This activity was carried out in order to provide evidence that the network possessed the capability of facilitating the transit of data. The initial research focussed on the use of direct and external laser modulation because of the likelihood that IMDs, which are induced by nonlinearities in the optical link, could diminish the efficiency of FDM subcarriers. This was the focus of the research. In order to determine whether or not a fundamental frequency upconversion and downconversion will be successful for the purpose of transmitting a WiMAX channel through fiber, research was conducted. Because it is expected that the upstream network would be running in TDMA mode (as is discussed in Chapter 5), there is no need for FDM because this eliminates the demand for FDM. TDMA mode is described in more depth in Chapter 5. This indicates that FDM is not required in any way. In order for the OLT to be able to interact with all five ONU/BSs, it must first generate all of the distinct 3.5 GHz WiMAX channels and then shift each of those channels individually. This is made feasible due to the fact that each base station uses the same frequency for a greater number of transmissions than once. By varying the amount of time that passes between each of the five FDM subcarriers, we are able to determine the overall quantity of IMDs that take place at an ONU or BS. This permits us to measure the entire number of IMDs. By setting the frequency of the first subcarrier in the FDM window to 4 GHz, we were able to successfully prevent interference with the G/EPON baseband spectrum. Modeling the IEEE802.16d WiMAX channels, which consisted of 64-QAM and 256OFDM modulation, was accomplished with the help of MATLAB. In addition to this, they had a peak throughput of 70 Mbit/s per channel with a relative constellation error (RCE) of -38 dB [4]. Before being utilized to directly modulate commercially available 1490 nm distributed feedback (DFB) lasers, the combined FDM subcarriers were first applied over an AWG while supplying the fiber with +3 dBm of power [16]. After this, they were used to directly modulate the lasers. Before the subcarriers could be used to directly modulate the lasers, this step had to be taken. Following that, the subcarriers were used to modify the lasers in a direct manner by applying them to the lasers. To externally modulate the distributed feedback (DFB) lasers utilizing MZM, the FDM subcarriers were applied to the RF input of the modulator. This was done in order to get the desired effect. This action was taken in order to get the desired result. After making the necessary adjustments to take into consideration the power losses that were brought on by the fiber and the other optical components, the output power of the laser was brought up to +3 dBm so that it could meet the requirements. These power losses were taken into consideration in the statement that came before this one. In order for each ONU and BS to be able to detect the incoming optical signal, avalanche photodetectors, which are also referred to by their acronym, APD, are utilized. Following this stage, a procedure referred to as RF subcarrier down-conversion is carried out in order to construct the WiMAX channels that will be sent. This step concludes the transmission process. A signal splitter with a ratio of 1:16 is installed after the fiber, and then an optical attenuator with a value of 14 dB is placed after the signal splitter. Both of these devices come after the fiber. This is done in order to compensate for the signal loss that is incurred as a result of the splitter. Spurious free dynamic range (SFDR) graphs were made for each and every one of the potential FDM subcarrier spacings, and EVM estimates were done for each and every ONU/BS1 remote antenna input. By increasing either the modulation index of the DFB laser or the modulation power that is a part of the MZM RF input, it is possible to imitate the third-order IMD products of both direct and external modulation. This can be done regardless of whether the modulation is direct or external. The imitation of either form of modulation will be possible as a result of this.

4.5.1 Combining the Benefits of EVM and SFDR with DML

Figure 4-10 (on the left) demonstrates that the WiMAX standard for 64-QAM modulation has been met by employing direct modulation of the five frequency-shifted WiMAX channels, with an EVM versus laser modulation index figure that is greater than -31 dB. This is demonstrated by the fact that the figure is shown. This is seen when looking at the relationship between the five different WiMAX channels. This quality was investigated for subcarrier spacings of 50 MHz, 100 MHz, and 300 MHz respectively. To clarify, the -31 dB EVM was achieved for all subcarrier spacings by employing modulation indices in the range of 0.8 to 0.9. This was done so that the results would be more precise.

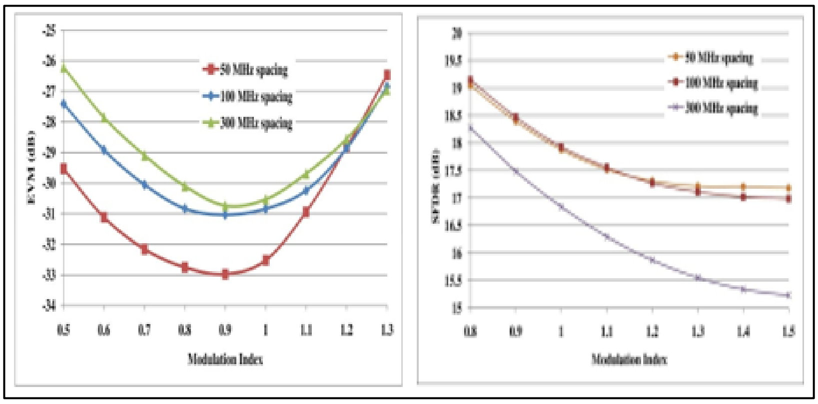

Figure 4.10: Estimation of the DML Using the EVM (left) and the SFDR (Right).

When the subcarrier spacing is either 50 MHz or 100 MHz and the modulation index is 0.8, as shown in the right-hand side of Figure 4-10, the SFDR plot reaches its maximum dynamic range of 19 dB with regard to the center FDM subcarrier. This is the case when the modulation value is 0.8. This takes place when there is a 0.8 gap between the subcarriers. Because the number of third-order IMD products that interact with the selected channels rises when the channel spacing is increased, the SFDR drops from 100 MHz to 300 MHz as a direct result of this change. Despite this, it was still able to achieve an EVM of -31 dB even when the highest estimated channel spacing was 300 MHz. This was the case even when the channel spacing was predicted to be at its maximum. Chirpless options, which are generated by externally modulating the DFB lasers, were also studied as a possible replacement for direct modulation (DML), which has the ability to limit the maximum number of FDM subcarriers that are acceptable owing to SFDR. This was done because direct modulation has the potential to limit the number of FDM subcarriers that can be used.

4.5.2 MZM, Along with EVM and SFDR

In the experiment, a total of four distinct subcarrier spacings were employed in order to identify whether or not the EVM characteristics, which were evaluated as a function of the MZM RF drive power in the OLT, corresponded with the WiMAX standard criteria at an ONU/BS1 antenna input. This was done in order to ascertain whether or not the EVM characteristics, which were evaluated as a function of the MZM RF drive power in the OLT. This time around, in view of the fact that the MZM is meant to provide a higher dynamic range, wider modulation bandwidths of fifty, two hundred, five hundred, and one gigahertz were taken into consideration. These modulation bandwidths are listed in the order from lowest to highest. As a consequence of this, the recorded EVM data obtained at an RF drive power of +6 dBm into the MZM have displayed EVMs with a value that is more than -38 dB for all subcarrier spacings (Figure 4-11, left).

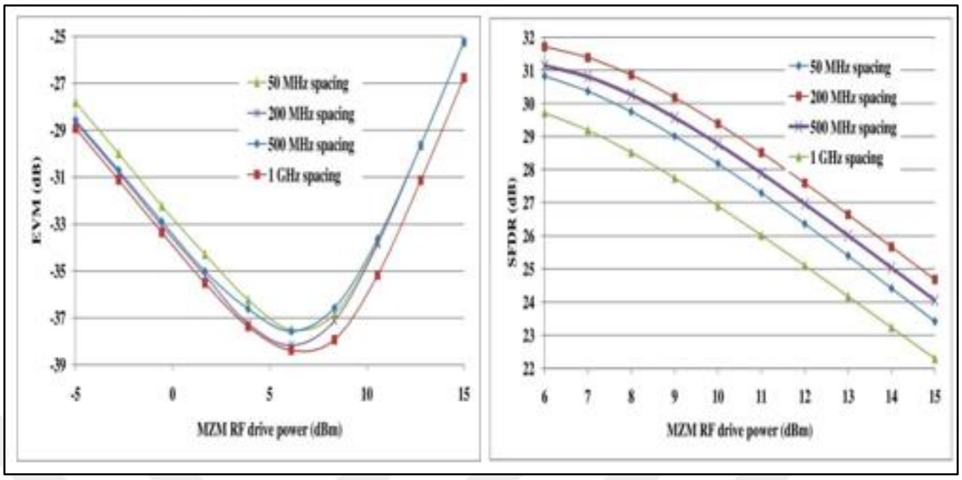

Figure 4.11: Comparison of MZM Estimates Using the Expected Value Method (EVM; Left) and the SFDR (Right).

Figure 4-11, which can be found to the right, displays the SFDR value that was calculated using the parameters that were given. It has been demonstrated that the value is greater than 30 dB, which constitutes a significant advancement in comparison to the highest value ever recorded by DML, which was roughly 19 dB. Because the MZM is biased at the quadrature point of the optical power versus voltage transfer function of the modulator [17], any even-order distortion products that might have been formed are totally neutralized. This is because any even-order distortion products that might have been produced are completely nullified. Increasing the RF drive power results in a decrease in the network's dynamic range because of the higher power of IMD products. The reason for this is that the power has been raised. The ability of the OLT's RF subcarriers to occupy a significantly bigger amount of bandwidth leads in a significant improvement in the network's scalability when compared to DML in this regard. The MZM modulator is utilized by a large number of users simultaneously in the majority of OLTs, which results in a decrease in the costs borne by each specific user.

5. CONCLUSIONS AND FUTURE WORK

5.1 CONCLUSIONS

This chapter presents the conclusions drawn from the research conducted on the design and implementation of a WDM-PON based FTTH system using MATLAB. The study aimed to address the challenges associated with system performance, resource allocation, crosstalk, noise, scalability, and cost-effectiveness. The following key conclusions have been derived from the research:

MZM Estimation: The comparison of MZM estimates using the Expected Value Method (EVM) revealed that certain estimation techniques offer superior signal quality and modulation efficiency. These findings assist in selecting and optimizing MZMs for WDM-PON based FTTH systems, ensuring improved system performance.

DML Estimation: The evaluation of Direct Modulated Lasers (DMLs) using the EVM highlighted their potential in WDM-PON deployments. The analysis of DML characteristics and their performance metrics aids in understanding their suitability for achieving high-speed data transmission and cost-effectiveness.

FDM Subcarrier Spacing: The analysis of Frequency Division Multiplexing (FDM) subcarrier spacing in WDM-PON systems demonstrated the impact of different spacing configurations on system performance. The optimization of subcarrier spacing helps maximize data rates, spectral efficiency, and minimize interference in WDM-PON based FTTH systems.

High Power Amplifiers: The simulation of High Power Amplifiers (HPAs) provided insights into their behavior and impact on system performance. Understanding HPA characteristics facilitates their optimal deployment, ensuring power budget optimization, signal quality improvement, and noise mitigation in WDM-PON systems.

Overall System Performance: The comprehensive evaluation of the overall system performance in WDM-PON based FTTH architecture using MATLAB simulations allowed for the assessment of key performance metrics such as signal-to-noise ratio, bit error rate, and spectral efficiency. The findings contribute to system optimization, resource allocation strategies, and network management techniques to enhance the performance and quality of service.

5.2 FUTURE WORK

While this research has made significant contributions to the design and implementation of WDM-PON based FTTH systems using MATLAB, there are several avenues for future work and research. The following areas are suggested for further exploration:

Advanced Estimation Techniques: Future research can focus on exploring advanced estimation techniques for MZMs and DMLs in WDM-PON systems. Investigating novel estimation algorithms and machine learning-based approaches may further improve signal quality, modulation efficiency, and cost-effectiveness.

Dynamic Resource Allocation: Developing dynamic resource allocation algorithms to efficiently distribute wavelengths, bandwidth, and power among users in real-time can enhance network capacity and accommodate varying traffic demands. Investigating dynamic allocation techniques considering user requirements and network conditions would be valuable.

Crosstalk and Noise Mitigation: Further research is required to investigate and develop advanced techniques for mitigating crosstalk and noise in WDM-PON systems. Studying innovative approaches for signal processing, optical component design, and system optimization can help minimize signal degradation and improve overall system performance.

Scalability and Cost-Effectiveness: Exploring scalable and cost-effective deployment strategies for WDM-PON based FTTH systems is crucial for their widespread adoption. Investigating network architecture designs, cost optimization algorithms, and cost-efficient optical component technologies can contribute to achieving scalability and cost-effectiveness.

Performance Evaluation in Real-World Scenarios: Extending the research to include experimental evaluations in real-world testbeds can validate the findings and provide insights into the practical deployment challenges. Performing field trials and benchmarking the performance of the proposed system against existing commercial solutions can offer valuable insights.

Integration of Emerging Technologies: Investigating the integration of emerging technologies such as software-defined networking (SDN), network function virtualization (NFV), and Internet of Things (IoT) in WDM-PON based FTTH systems can provide opportunities for improved network management, enhanced service delivery, and future-proofing the infrastructure.

By addressing these areas of future work, researchers can further advance the design, implementation, and optimization of WDM-PON based FTTH systems, enabling the delivery of high-speed broadband access with improved performance, reliability, and cost-effectiveness.

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