



Research Article

ANALYSIS AND APPLICATIONS OF THE HYBRID WDM/TDM PASSIVE OPTICAL NETWORKS

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ABSTRACT

Time Division Multiplexing (TDM) and Wavelength Division Multiplexing (WDM) are the most popular multiplexing methods. Each of these multiplexing methods has its own pros and cons. In this study, structures and types of passive optical networks are investigated, and the most commonly used multiple access methods in passive optical networks such as TDMA, Time Division Multiple Access, and WDMA, Wavelength Division Multiple Access, methods are explained. Performance of hybrid wavelength division multiplexing/time division multiplexing passive optical network (WDM/TDM PON) system is analyzed. Models of TDM PON and Hybrid WDM/TDM PON optical communication systems are compared at a frequency of 193.1 THz on Opti-System 16.0 simulation software. Gain performances of the multiplexing methods for different distances at 10 Gbps are determined by simulations.

Keywords: Communication technologies, optical communications, passive optical network, optical fiber, multiplexing.

1. INTRODUCTION

Since the discovery of transmission of information in the form of light in the 1880s, fiber optic communication technology has gained a significant place among today's communication technologies. Availability of silicon, the raw material of optical fiber, in abundance in nature and low cost of optical fiber mass production, as well as high data transmission speed at high bandwidth with low transmission losses make this technology state of the art in modern communication [1, 2].

As a result of the introduction of new services, such as three-dimensional high-definition television, cloud computing and more and more internet-based applications, the required bandwidth for the end user has been ever increasing, approximately 50% a year. Due to increased demand for more bandwidth, optical network bandwidth services have been growing rapidly, and there have been great efforts to develop more economical and reliable subscriber networks based on optical technology.

Prospects from future telecommunication technologies are increasing day by day due to the

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public appeal of reliable data transmission at higher data rates and speeds. Optical networks play a vital role in meeting these demands. Therefore, passive optical networks need to fulfill reliable, high data rate transmission at high bandwidth and long reach capability requirements [3].

2. OPTICAL NETWORKS

Today, optical networks can be classified as:

2.1. Point to Point Optical Networks (PPON):

This type of network is based on forming a separate optical line from the provider's central office to each customer. There is no active electronics in the distribution network. The initial investment of such a system design is rather high, but it provides highest capacity. Furthermore, a PPON guarantees reliability in service and maximum flexibility for future expansion projects of the system.

2.2. Active Optical Networks (AON):

In this network type, a single feeder fiber carries entire optical network signals from a core switch located at central office to an electrically powered active equipment, called an aggregation switch, such as an Ethernet switch, router or multiplexer, thereafter independent distribution fiber lines are connected to a number of premises gateways, namely optical network terminals near the end user, such as a cabinet, apartment or office. An electronically active element enables AONs to transmit data between the users and the central unit after decomposition. Data transmission is secured by means of a dedicated fiber between central office and each customer's premise, allowing uninterrupted data exchange between the end points of each fiber only. Comparing to the first model, accessing the end user is cheaper, since shorter lengths of individual fibers are laid. However, the active element causes extra power consumption and maintenance costs [4].

2.3. Passive Optical Networks (PON):

This type of network is constructed by the replacing the electronically active element of an AON with a passive optical equipment, such as an optical splitter, or arrayed waveguide grating. By means of this equipment, data are decomposed and then transmitted to the receiving site. Advantages of a PON are savings in system implementation because it allows sharing of each fiber by many users, as well as elimination of power consumption and maintenance costs of the intermediate active element. Privacy is ensured by time shifting and personal encryption of each subscriber traffic. Passive optical systems have become very popular in optical fiber access networks due to their reduced initial investment as well as operation and maintenance costs. They are often called Passive Optical Networks (PON) [4].

As shown in Figure 1, a Passive Optical Network, PON, consists of an Optical Line Terminal, OLT, at central office and a number of Optical Network Units, ONU, near the end users, an optical bracket that divides and combines information flow between OLT and ONU's, and fiber cables connecting these devices.

OLT is a unit located at the central office providing bi-directional data transmission through the optical distribution network. OLT distributes audio, data and video traffic from the local network to all downstream ONU devices. In the upstream direction, in contrast to the downstream transmission, it is responsible for importing various kinds of content and data from the end users. The ONU unit is placed directly in the user's home or workplace. The ONU device provides the necessary electrical-optical transformations to form the connection point in the optical network. ONU can provide different communication services based on the service provided [6, 7].

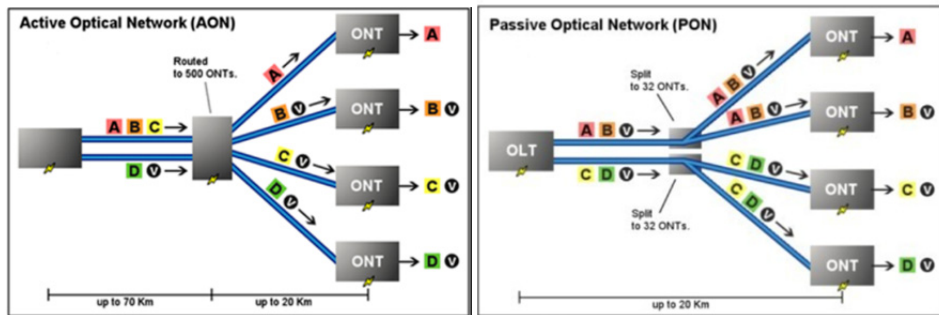


Figure 1. Active Optical Network (AON) and Passive Optical Network (PON) [5]

3. SYSTEM ARCHITECTURE

Multiplexing techniques allow the same transmission band be used by multiple users without interference, thus reducing operation cost. Data from multiple sources can be transmitted effectively to multiple users by multiplexing techniques. The most commonly used multiplexing methods in optical access networks are:

- TDMA (Time Division Multiple Access),
- FDMA (Frequency Division Multiple Access),
- CDMA (Code Division Multiple Access),
- WDMA (Wavelength Division Multiple Access),
- OCDMA (Optical Code Division Multiple Access System).

Today, standardized PON architectures use the TDMA multiplexing method.

3.1. TDM PON Architecture

Figure 2 shows the physical tree topology of TDM PON. At the Central Office, CO, the Optical Line Terminal, OLT, transmits the data to the downstream traffic. The signal from OLT is transmitted to an optical combiner/splitter, which is a passive component for bringing together and dividing the signals between the OLT and ONUs, by means of a feeder optical fiber, then split signals are distributed among the ONUs, which are optoelectronic components located near the user ends. Backward traffic from the ONUs to the OLT takes place through the same combiner/splitter element functioning as a combiner [8].

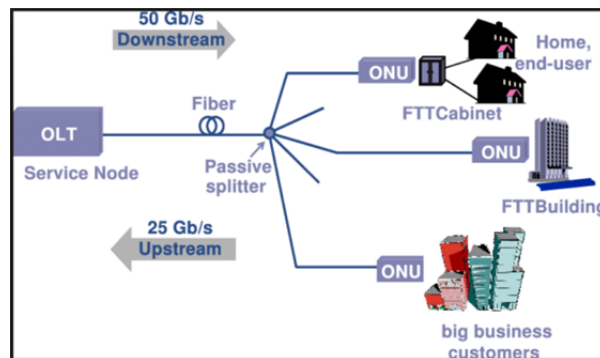


Figure 2. TDM PON architecture

3.2. Hybrid WDM/TDM PON

While the time division multiplexing can serve a small number of participants at reasonable rates, with low prices, wavelength division multiplexing can serve a high number of participants, but the price is much higher. Existing passive optical networks (GPON, EPON, new generation NG-PON, etc.) are based on low flexibility, low bandwidth time division multiplexing architecture. WDM components are relatively costly, limiting the widespread use of WDM-PON (Shown in Figure 3). As shown in the Figure 4, a new network called hybrid WDM/TDM-PON is introduced to eliminate the disadvantages of both TDM-PON and WDM-PON. It combines the advantages of WDM and TDM technologies. Hence, the existing TDM-PON is upgraded to future WDM-PON.

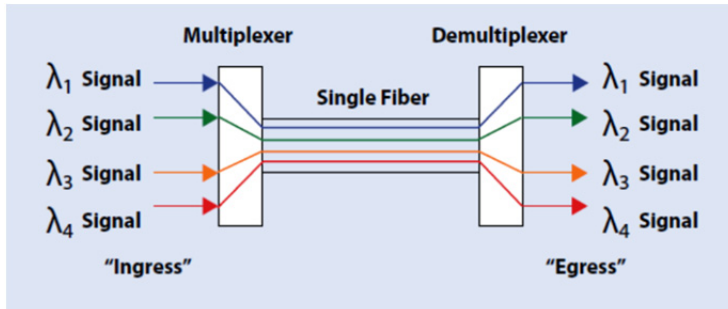


Figure 3. WDM system [6]

In this study, performance of a hybrid WDM/TDM PON architecture is analyzed and compared with that of TDM-PON architecture. Hybrid WDM/TDM has higher scalability and is therefore flexible. The hybrid WDM/TDM PON architecture provides access to both higher bandwidths and more distant areas, i.e. it has a longer reach than TDM-PON.

The hybrid WDM/TDM passive optical network architecture enables flexible allocation of the bandwidth resources depending on the traffic requirements. This architecture not only employs similar components in each optical network unit but also allows all ONUs to share all wavelength resources.

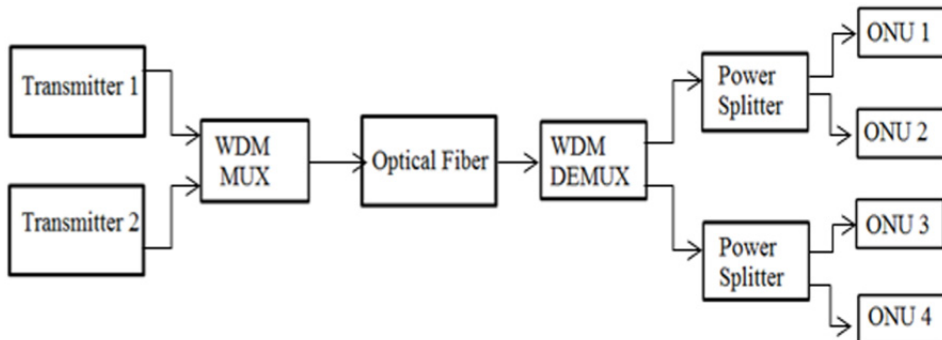


Figure 4. Hybrid WDM/TDM PON architecture [9]

4. PERFORMANCE EVALUATION

The performances of the reference and the proposed systems are evaluated by testing them in the OptiSystem 16.0 simulation tool of Opti-Wave Corporation. For instance, TDM PON reference system architecture and various measuring instruments are shown schematically in Figure 5. To compare performances of the networks, BER indicators at different fiber lengths are calculated. The simulated PON network supports two users, with the objective of determining the Q-factor and min BER achievable at different fiber lengths. For the reference system architecture, continuous wave (CW) laser input having power level of 10 dBm is fed to a transmitter, output of which is launched through the optical fiber. The 1:2 power splitters are used to feed the signals to two individual channels. To visualize optical spectrum, waveforms, eye diagrams, etc., various measuring instruments such as optical spectrum analyzer, optical power meter, BER analyzer and eye diagram analyzer are used. The BER, Q-factor and eye height are the most commonly used performance parameters [10].

1) Q-Factor

The Q-factor is a parameter to measure the signal quality which is necessary for determining the bit error rate, BER. Usually, the Q-factor is used as a figure of merit. The Q-factor is defined as

$$Q = \frac{m1-m0}{\sigma1+\sigma0} \tag{1}$$

where, m1 and m0 are the average values of the received signals at sampling instants, and $\sigma1$ and $\sigma0$ are the standard deviations, when a logical 1 or 0 is transmitted, both respectively [5].

2) Bit Error Rate, BER

The Bit Error Rate, BER, is defined as the percentage of bits which are in error, with respect to the total number of bits received during a transmission. It is usually expressed as a negative power of ten. The BER is an indicator of how often a packet or other data unit has to be retransmitted because of an error. Knowing the Q-factor, the BER can be calculated by

$$BER = \frac{1}{2} \operatorname{erfc} \left(\frac{Q}{\sqrt{2}} \right) \tag{2}$$

3) Eye Height

Best time for sampling of the received waveform is considered to be the instant for which height of eye opening is the largest. Eye opening height decreases as the amplitude distortion of the signal increases. The degree of distortion is defined by the vertical distance between the top of the eye opening and the maximum signal level. It is more difficult to distinguish between ones and zeros in the signal when the eye closes more. The eye height is given by [9]

$$EH = (m1 - 3\sigma1) - (m0 + 3\sigma0) \tag{3}$$

In this study, 10 km, 30 km and 50 km fiber lengths are considered for the reference TDM PON system. Simulated input signal's optical spectrum is given in Figure 6. Optical spectrums of the output signal are given in Figure 7 for receiver side fiber lengths of 10 km, 30 km and 50 km, respectively.

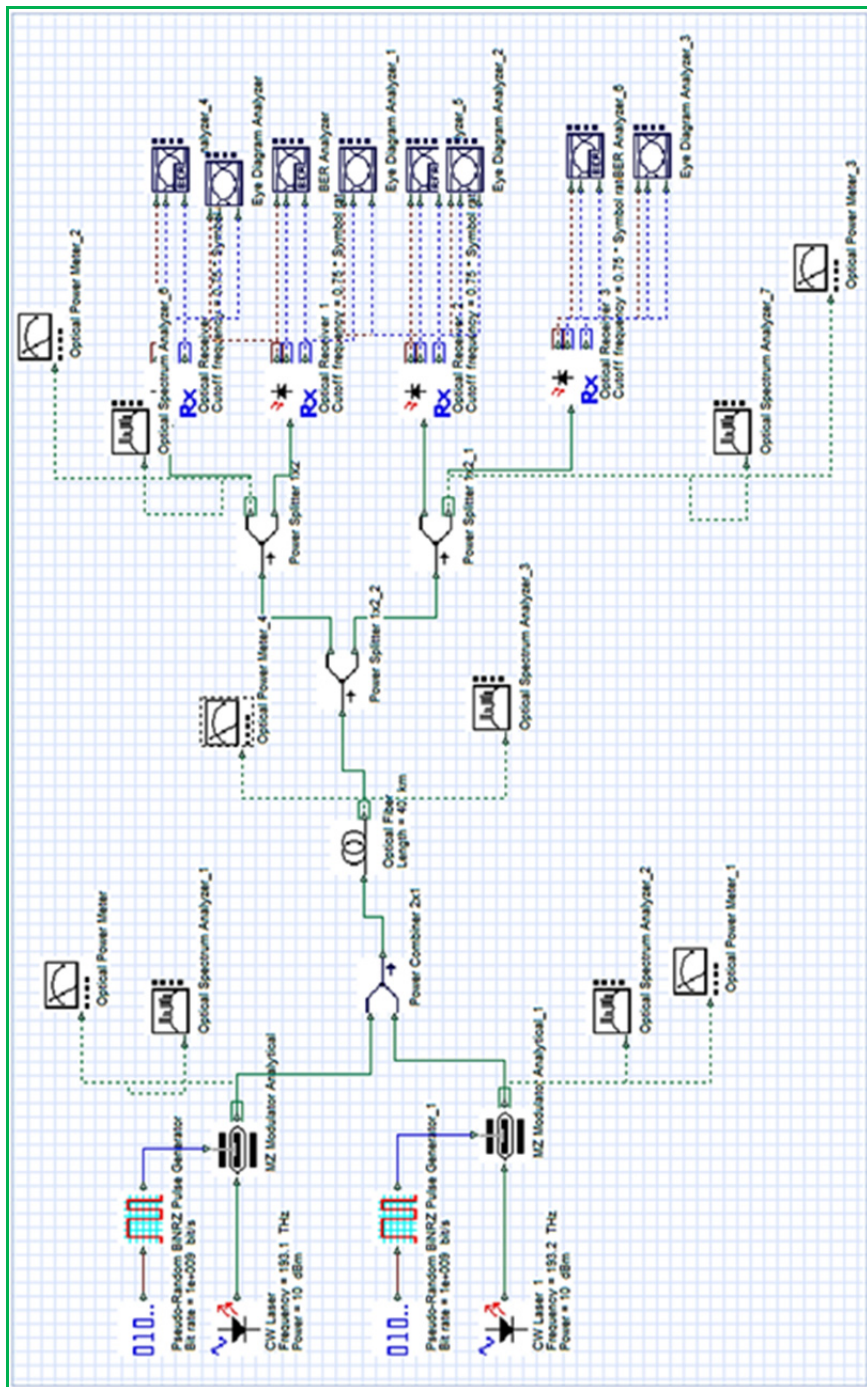


Figure 5. TDM PON reference system [10]

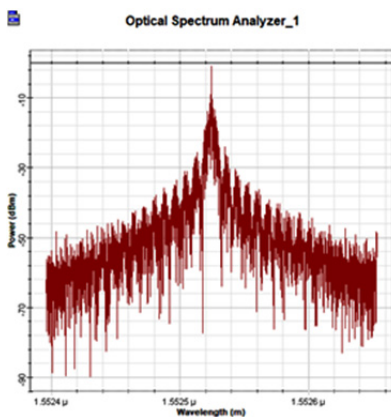
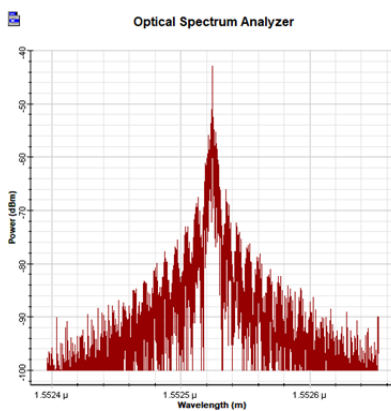
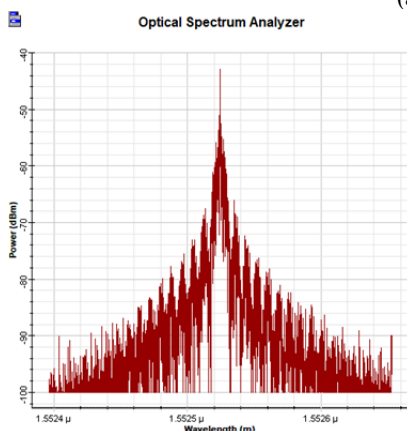


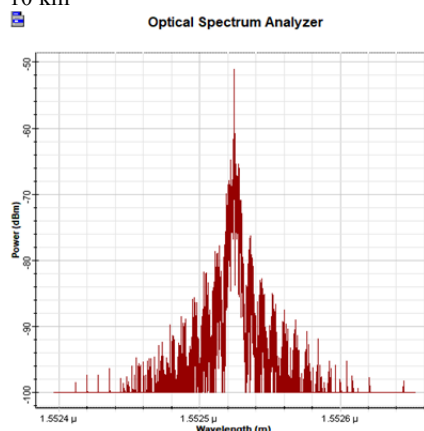
Figure 6. Optical spectrum of input signal



(a) 10 km



(b) 30 km



(c) 50 km

Figure 7. Optical spectrum of the output signal for 10 km, 30 km and 50 km receiver side fiber lengths for the reference TDM PON system

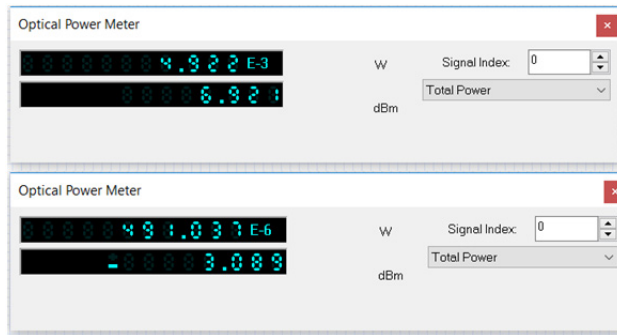


Figure 8. Optical powers of input and output signals measured in Watts and dBm for a fiber length of 10 km, for the reference TDM PON system

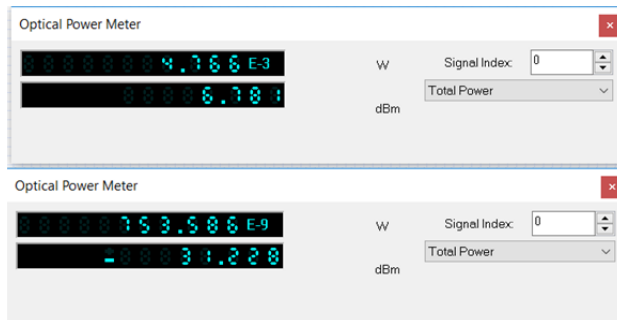
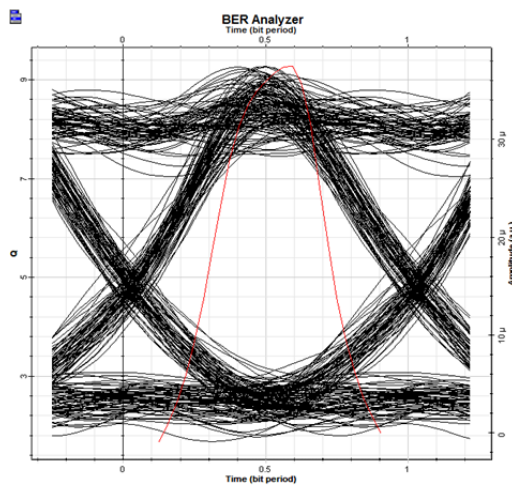
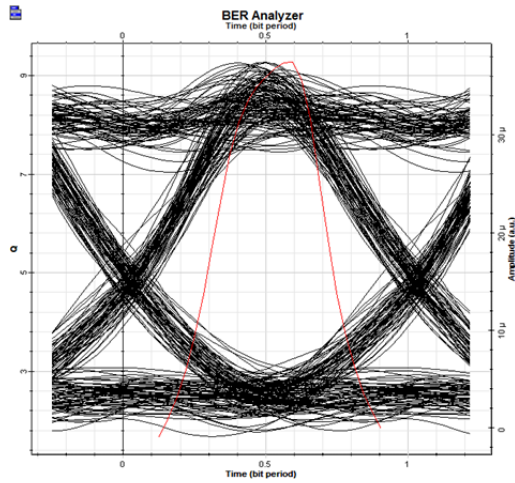


Figure 9. Optical powers of input and output signals measured in Watts and dBm for a fiber length of 50 km, for the reference TDM PON system

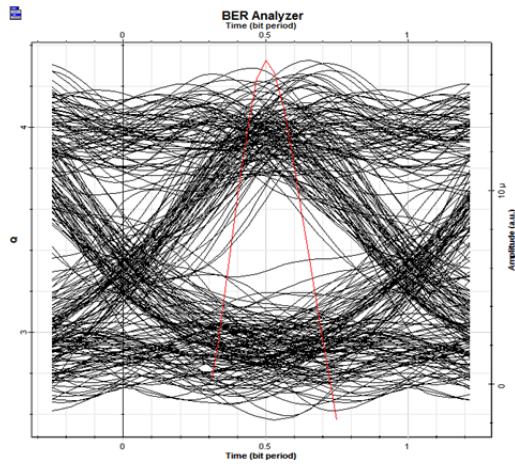
Optical powers of the input and output signals for a fiber length of 10 km and 50 km are shown in Figures 8 and 9, respectively.



(a) 10 km



(b) 30 km



(c) 50 km

Figure 10. Eye diagram of TDM PON system at the same data rate for 10 km, 30 km and 50 km distance between the central office and the customer

Table 1. Comparison of performance parameters of TDM PON for various fiber lengths

	10 km	30 km	50 km
Max. Q-Factor	413.208	54.22	24.2
Min BER	0	0	0.008
Eye Height	0.00098	3.67e-005	4,00E-04
Threshold	5.97e-005	1.34e-005	7.13e-007

The performance criteria of the TDM PON System are shown in Table 1 with maximum Q-factor, minimum BER value and eye height. As shown in the table, the transmission performance of a 50 km long fiber line has been considerably reduced.

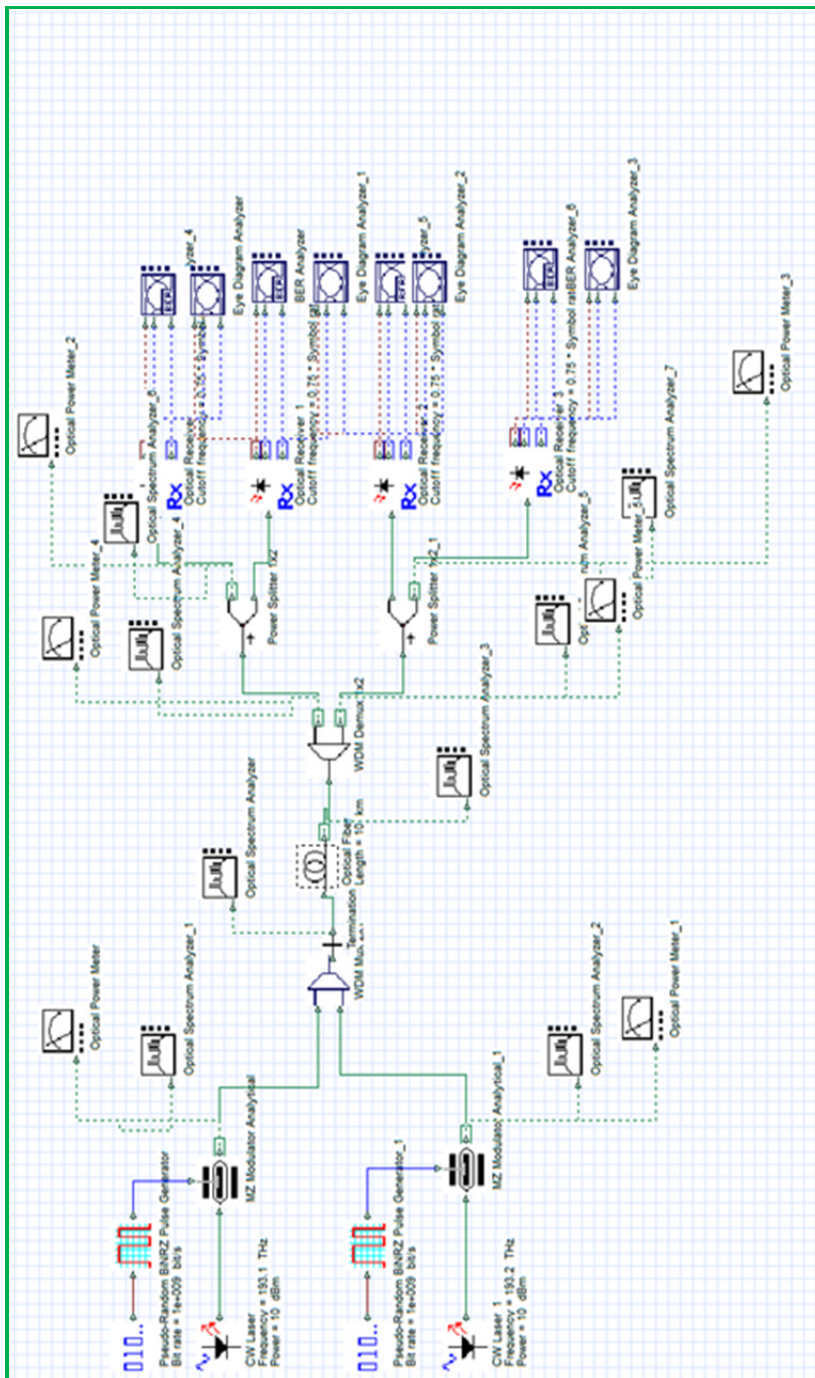


Figure 11. Hybrid WDM/TDM PON system [10]

Then, the proposed hybrid WDM/TDM PON system shown in Figure 11 is analyzed by OptiSystem software. In this architecture, two signals are transmitted with different wavelengths. Continuous wave (CW) laser beams each having a power level of 10 dBm are fed to two transmitters, outputs of which are modulated by Mach-Zehnder modulators using a pseudo random bit sequence with NRZ format. Two signals are then combined by WDM multiplexer and launched through the optical fiber. The signal is then demultiplexed by WDM demultiplexer. Finally, the 1:2 power splitters are used to feed the signals to two individual channels. Fibers having various lengths, 10 km, 50 km and 70 km, are applied to the hybrid WDM/TDM PON system. Optical spectrums of input and WDM multiplexer signals are shown in Figure 12.

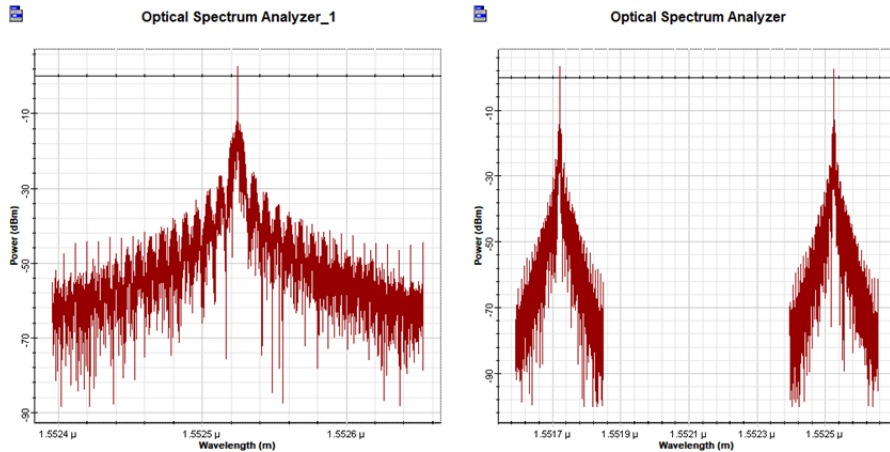


Figure 12. Optical spectrums of input signal and WDM multiplexer signal

Optical spectrum of the signal at the receiver side of the hybrid WDM/TDM PON is given in Figure 13.

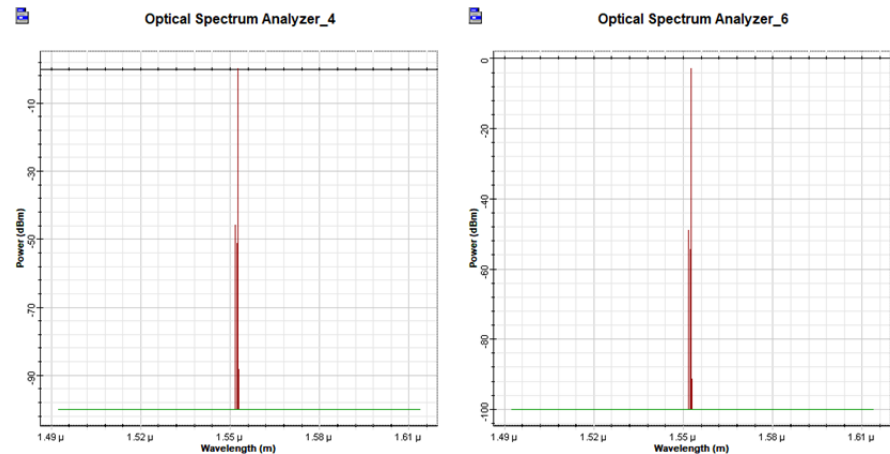


Figure 13. Optical spectrums of the signals at the exit of WDM demux, at the receiver side of the hybrid WDM/TDM PON

Optical powers of input and output signals measured in Watts and dBm for fiber lengths of 10 km, 50 km and 70 km are given in Figures 14, 15 and 16, respectively, for the hybrid WDM/TDM PON system.



Figure 14. Optical powers of input and output signals measured in Watts and dBm for a fiber length of 10 km, for the hybrid WDM/TDM PON system

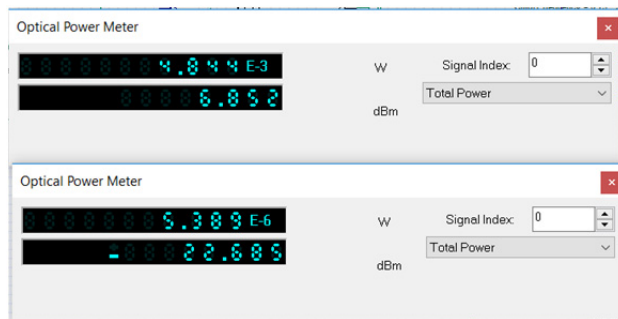


Figure 15. Optical powers of input and output signals measured in Watts and dBm for a fiber length of 50 km, for the hybrid WDM/TDM PON system

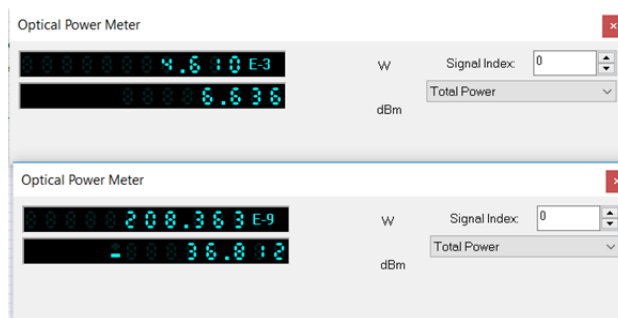
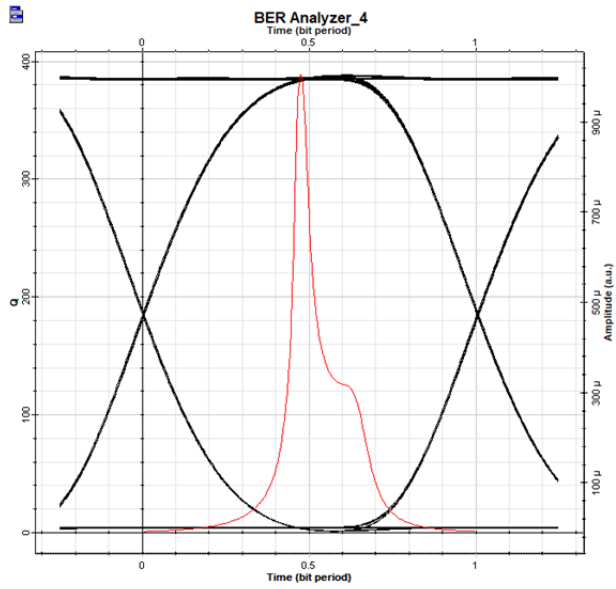
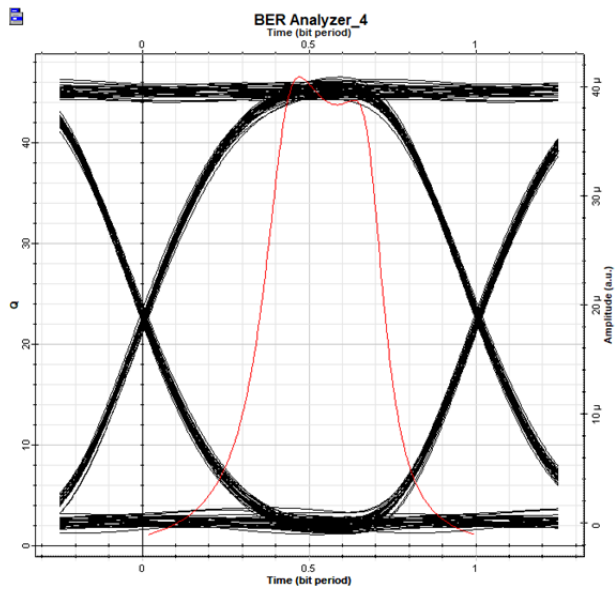


Figure 16. Optical powers of input and output signals measured in Watts and dBm for a fiber length of 70 km, for the hybrid WDM/TDM PON system

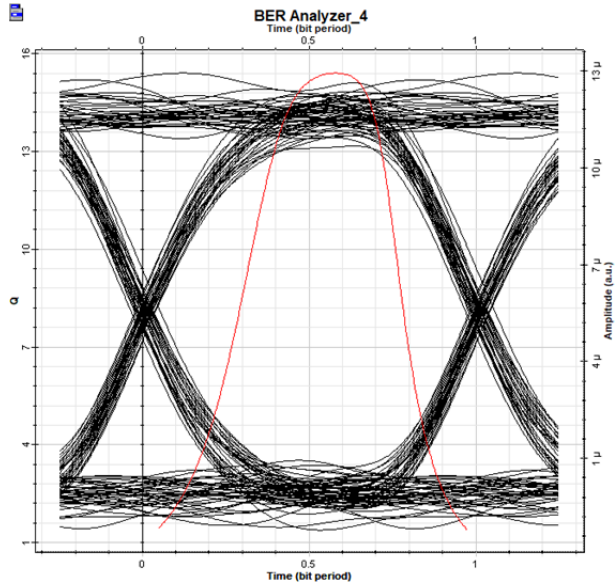
Eye diagrams of the hybrid WDM/TDM PON system at the same data rate are given in Figure 17 for (a) 10 km, (b) 30 km, and (c) 50 km distance between the central office and the customer.



(a) 10 km



(b) 30 km



(c) 50 km

Figure 17. Eye diagrams of hybrid WDM/TDM PON system at the same data rate for (a) 10 km, (b) 30 km, and (c) 50km distance between the central office and the customer

Table 2. Comparison of performance parameters of hybrid WDM/TDM PON for various fiber lengths

Distance	10 km	30 km	50 km
Max. Q-Factor	450.78	72,3345	45.48
Min BER	0	0	1.44e-053
Eye Height	0.007	3.73e-005	9.27e-006
Threshold	0.00068	1.58e-005	4,48E-06

The performance criteria of the hybrid WDM/TDM PON system are shown in Table 2 with maximum Q factor, minimum BER value and eye height. As shown in the table, the transmission performance of a 50 km long fiber line has been considerably reduced. When Table 2 and Table 1 are examined, it is seen that the transmission performance of hybrid WDM / TDM PON system with 50 km fiber line length is better [10].

5. CONCLUSIONS

A reference TDM PON and a hybrid WDM/TDM PON, which is proposed in this study, are analyzed by OptiSystem 16.0 simulation tool of Opti-Wave Corporation and their various performance parameters are compared. In hybrid PON, WDM and TDM techniques are combined in the optical fiber path to optimize the bandwidth. Transmission of the data with different wavelengths through the same fiber is possible. Optical spectrums and optical powers of signals at various locations are compared. Min BER, max Q-factor and eye diagrams for both systems operating with various fiber lengths are compared. It is observed that, for two transmitters at OLT, and for the same data rate, when the distance between the central office and customer is

increased, then the quality factor and eye height decrease while BER increases. The simulation results confirm that performance of the proposed hybrid WDM/TDM PON is superior to those of the current TDM PON networks. For this reasons, the hybrid WDM / TDM PON offers higher access and higher broadband for the next generation of optical networks.

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