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Design and Performance Evaluation of Hybrid WDM/TDM Passive Optical Networks Using Star Topology

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ABSTRACT

In this paper, we have analyzed the performance of the hybrid wavelength division multiplexing/time division multiplexing passive optical network (WDM/TDM PON) system using the star topology architecture. We are comparing the proposed hybrid passive optical network for the different data rates and distance by simultaneously varying the number of transmitters at OLT.

Keywords: *EPON, hybrid PON, WDM/TDM PON, OLT,ONU, power splitter, power combiner, data rate, bit error rate, eye height, quality factor*

INTRODUCTION

The Ethernet passive optical networks (EPON) are considered as the best solutions for the delivery of broadband integrated services with low cost ethernet equipment as well as low fiber infrastructure. The EPONs are the point to multipoint access networks which have no active elements between the source and destination. These PON consists of one optical line terminal (OLT) connected to many optical networks units (ONUs). The optical line terminal is located in the central office and the ONUs are located at the user's location in large numbers to some distance away from OLT. It basically consists of two channels, one for the downstream traffic and another for the upstream traffic.

In the downstream, the traffic is being transmitted from the OLT through one fiber which are then received selectively by each ONU. In the upstream, the traffic is being transmitted from ONUs to the OLT i.e. multiple ONUs share a same transmission channel for the transmission of data to OLT.

The EPONs can support only up to 32 ONUs efficiently at a maximum distance of 20 km from OLT and up to 64 ONUs at maximum distance of 10 km from OLT, beyond which its performance degrades [1]. Since the number of subscribers are increasing day by day there is need to deploy more ONUs. Therefore, it has become necessary to upgrade the existing EPON architecture.

In the present paper, we have investigated the performance of the hybrid passive optical networks. The rest of the paper is organized as follows: section II presents the introduction to hybrid passive optical networks. In section III, we present the simulation setup for hybrid passive optical networks and section IV presents the analysis and comparison result of the proposed architecture. Finally, section V contains the conclusion of the paper.

Hybrid Passive Optical Networks

The passive optical networks were actually considered as the ultimate solution in the FTTH (Fiber-to-the-Home) market. The Time-division multiplexing passive optical network (TDM-PON) such as ethernet PON (EPON) and Gigabit PON (GPON) are the promising technologies for optical access network. The WDM-PON supports many subscribers than TDM-PON and also offers great security by use of different wavelength channels. So, it is regarded as the next generation choice of FTTH.

But WDM components are relatively costly due to which it limits the widespread use of WDM-PON. Therefore, 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 technology. Hence, the existing TDM-PON is upgraded to future WDM-PON.

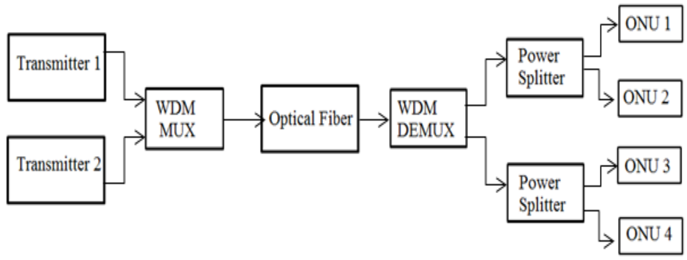

Fig 1 Block Diagram for Hybrid WDM/TDM PON

The hybrid WDM/TDM passive optical network architecture provides flexible allocation of the bandwidth resources depending on the traffic requirements. This architecture not only employs the similar components in each optical network unit but it allows all ONUs to share all wavelength resources. The main aim behind the hybrid WDM/TDM PON is:

(i) smooth migration from the current PON (TDM) to future PON by incorporation of WDM technology and

(ii) supporting large number of ONUs

The block diagram of simulation setup for hybrid WDM/TDM passive optical network is shown in Fig 1. Figure shows the downstream setup. In the proposed system, central office is equipped with the optical line terminal devices and an ONU device is being installed at the user end. In Fig 1, the OLT consists of two transmitters which are multiplexed and sent over optical fiber. Then using demultiplexer and power splitter signal is sent to four subscribers at ONU.

A. *Wavelength Division Multiplexing-PON*

The main approach to build a WDM-PON is to employ a separate wavelength from the OLT to each ONU. It creates a point-to-point link between central office and each ONU. In this, different sets of wavelengths may be used to support different independent PON sub networks, all operating over same fiber infrastructure.

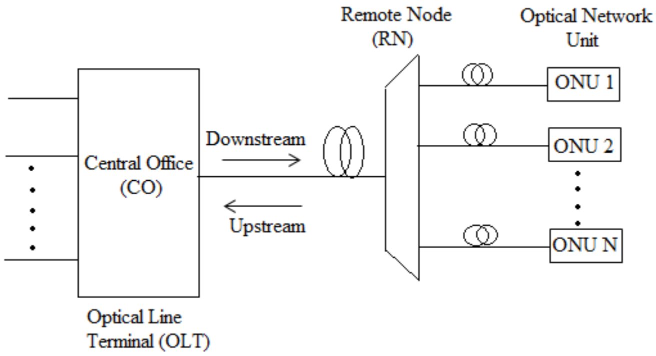

Fig. 2 WDM-PON architecture

In the downstream direction of the WDM-PON as shown in Fig. 2 the wavelength channels are routed from the OLT to the ONUs through a multiplexer and fiber. Then a demultiplexer is used at remote node (RN) to send signal to different ONUs. The requirement of WDM-PON is that it should be scalable in bandwidth as well as in number of users. The challenges that it faces is the costly components and temperature control.

B. *Time Division Multiplexing-PON*

In TDM-PON, as shown in Fig 3, the central office (CO) assigns time slots to multiple ONUs. Each ONU can use the full bandwidth over the optical link in its assigned time slot duration. To connect the multiple ONUs, a passive optical power splitter is used at remote node. It couples 1/N of the total power from each ONU user into optical fiber for transmitting back from ONU to OLT at the central office.

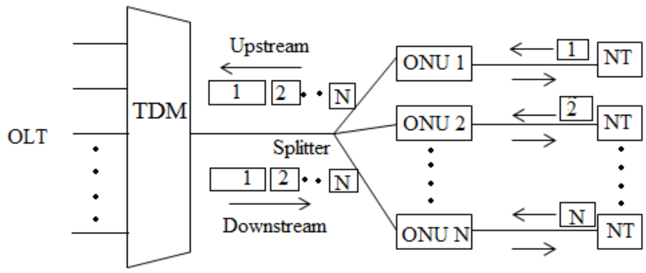

Fig. 3 TDM-PON architecture

SIMULATION SETUP

Our simulation is performed and analyzed using OptiSystem software. Fig 4. shows the general simulation in optisystem software for two transmitters at the OLT with data rate of 10 to power 9 and distance of 50 km. In this proposed architecture, the two signals are transmitted with different wavelengths as 193.1 THz and 193.2 THz. Each transmitter section consists of continuous wave (CW) laser input having power level of 0 dBm. The output of which is modulated by mach-zehnder modulator using a pseudo random bit sequence with NRZ format. The NRZ format is used here so as it is the most suitable data format for data transmission [2]. Then the two signals are then combined using WDM multiplexer and launched through the optical fiber having a length of 50 km. The signal is then again demultiplexed using WDM demux. The 1:2 power splitters are used to feed the signals to two individual channels. All of these output signals of power splitters reach to the users at the receiving end. A PIN photo detector is used to analyse the results.

To visualize optical spectrum, waveforms, eye diagrams etc. various measuring instruments like optical spectrum analyzer, optical power meter, BER analyzer and eye diagram analyzer have been used. Various eye diagrams are taken at different data rates. The Q-factor, BER values and eye height are calculated to verify the results.

Our basic study here is done for three cases. Case (A) is when the distance is varied; the Q-factor, BER values and eye height are calculated. In case (B), the data rate is varied and the parameters are compared. In case (C), the number of transmitters are increased at the OLT and parameters are compared.

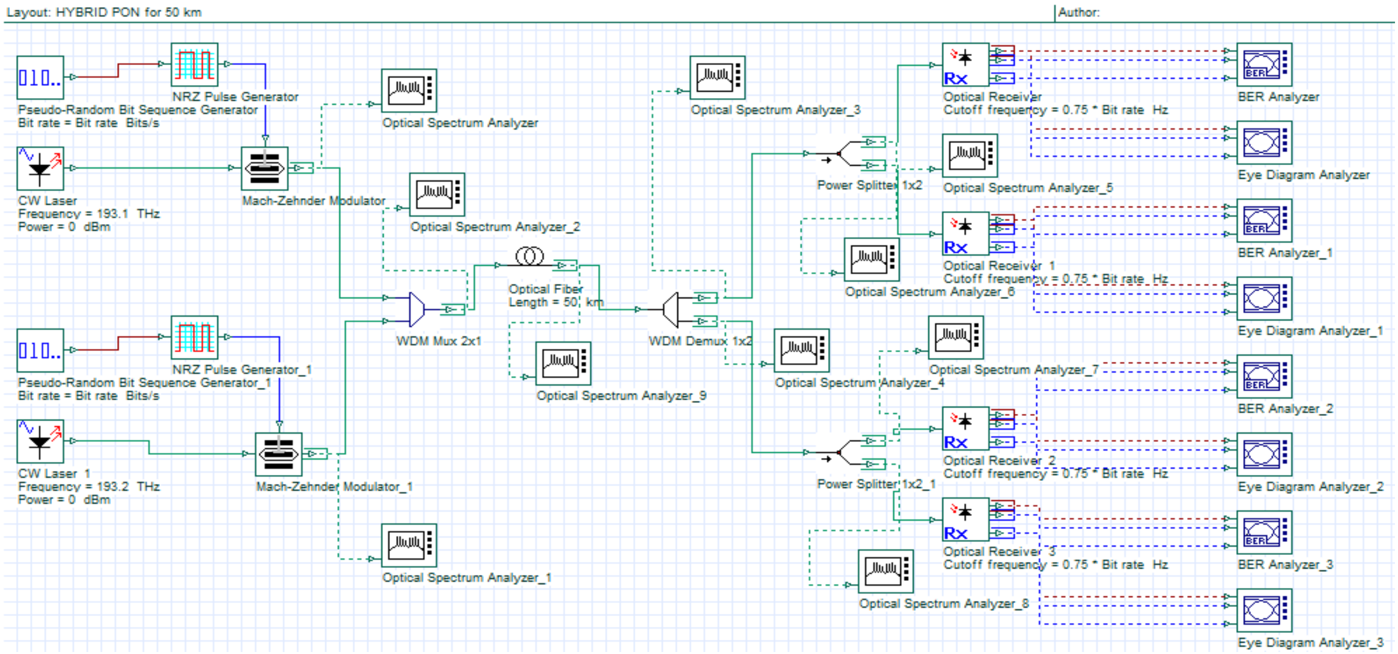

Fig. 4 Simulation Setup for Hybrid WDM/TDM PON Architecture for 50 km Fiber Length in OptiSystem Software

The BER, Q factor and eye height are the most commonly used performance parameters.

(1) Q-Factor

The Q-factor is defined as the parameter to measure the signal quality for determining the BER. Usually as a figure of merit we use Q-factor. The Q-factor is defined as-

$$Q = \frac{m_1 - m_0}{\sigma_1 + \sigma_0}$$

where m_1, m_0 are the average value of received signal at sampling instants when a logical 1 or 0 is transmitted and σ_1, σ_0 are the standard deviations respectively.

(2) Bit Error Rate

The Bit error rate is defined as the percentage of bits that consists errors with respect to the total number of bits received during a transmission. It is usually expressed as ten to a negative power. The BER is an indication 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 estimated by-

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

(3) Eye Height

When the height of eye opening is largest then it is considered as the best time for sampling of received waveform. Due to amplitude distortion in the signal the height gets reduced. 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 1's and 0's in the signal when the eye closes more. The eye height is given by

$$E_H = (m_1 - 3\sigma_1) - (m_0 + 3\sigma_0)$$

Result And Analysis

The performance of hybrid PON is done using optisystem software. The results obtained from analysis for the three cases has been described below:

A. Distance is varied

Fig. 5(a)-5(d) shows the eye diagrams of hybrid passive optical network systems using NRZ modulation format at 50, 65, 70 and 75 km distance respectively. The red line in figure shows curve for quality factor.

It is observable from the figures that when the distance is increased for same data rate 10^9 and for two transmitters at OLT, then the quality factor and eye height decreases and BER is increasing. We observe from the graph that the eye height is decreasing with the increase in the distance. Due to this, the receiver is unable to detect the bit correctly whether it is logical 1 or logical 0. The different values measured are shown in Table I.

Table I

Comparison of parameters for different distance for two transmitters

DISTANCE(Km)	Q	BER	EYE HEIGHT
50	59.79	0	4.7561 e-005
65	33.29	2.10366 e-005	2.2687 e-005
70	25.01	1.95366 e-005	1.7446 e-005
75	18.61	1.12771 e-005	1.3217 e-005

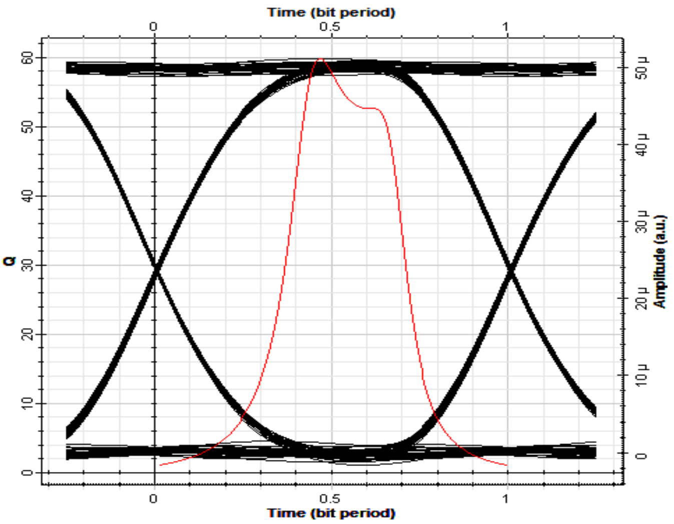

Fig. 5(a) Eye Diagram of hybrid PON system at 50 km for two transmitters

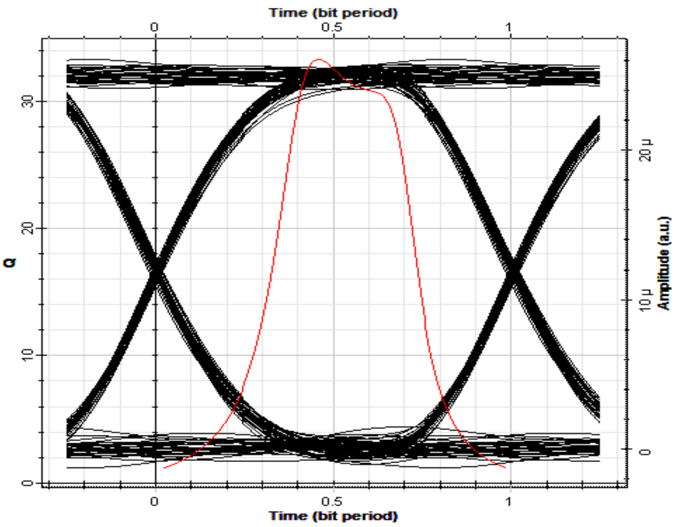

Fig. 5(b) Eye Diagram of hybrid PON system at 65 km for two transmitters

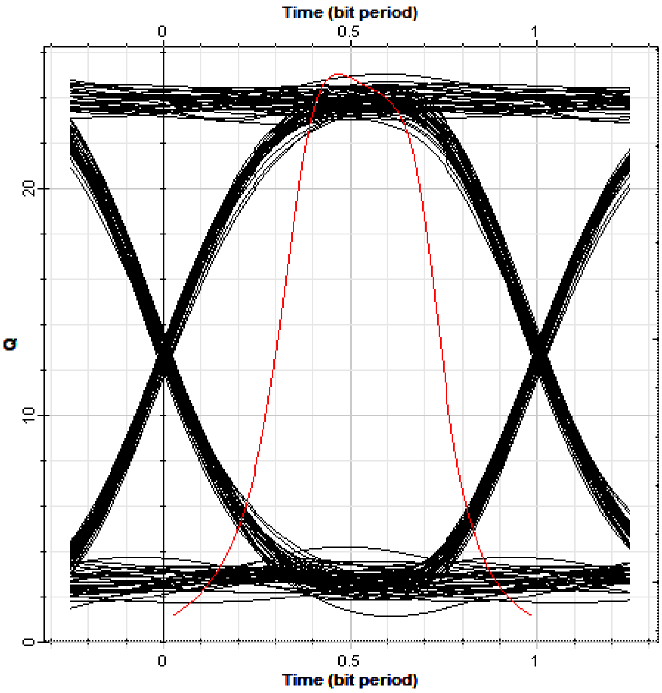

Fig. 5(c) Eye Diagram of hybrid PON system at 70 km for two transmitters

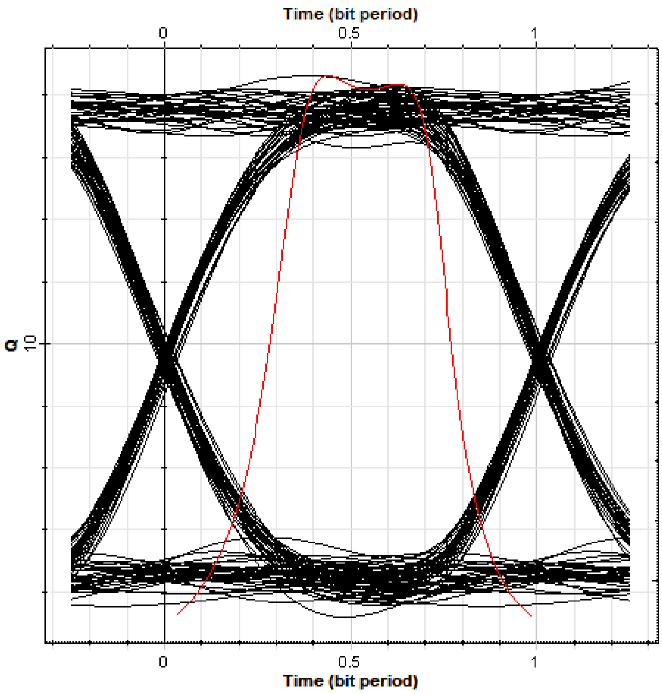

Fig. 5(d) Eye Diagram of hybrid PON system at 75 km for two transmitters

B. *Data rate is varied*

Fig. 6(a)-6(c) shows the eye diagrams of hybrid passive optical network system using NRZ modulation format at different data rate 10^8, 10^9 and 10^{10} respectively for the same distance 50 km.

It can be seen from the diagram that when data rate is increased, the eye height and quality factor decreases and BER increases as shown in Table II. From graphs also, we observe that the eye height and quality factor is decreasing with the increase in the data rate. Due to this, the receiver is unable to detect the bit correctly whether it is logical 1 or logical 0.

The red line in figure shows curve for quality factor.

Table II

Comparison of parameters for different data rate for two transmitters

DATA RATE	Q	BER	EYE HEIGHT
10^8	239.03	0	4.9267 e-005
10^9	59.79	0	4.7561 e-005
10^{10}	3.695	9.39922e-005	7.0447 e-006

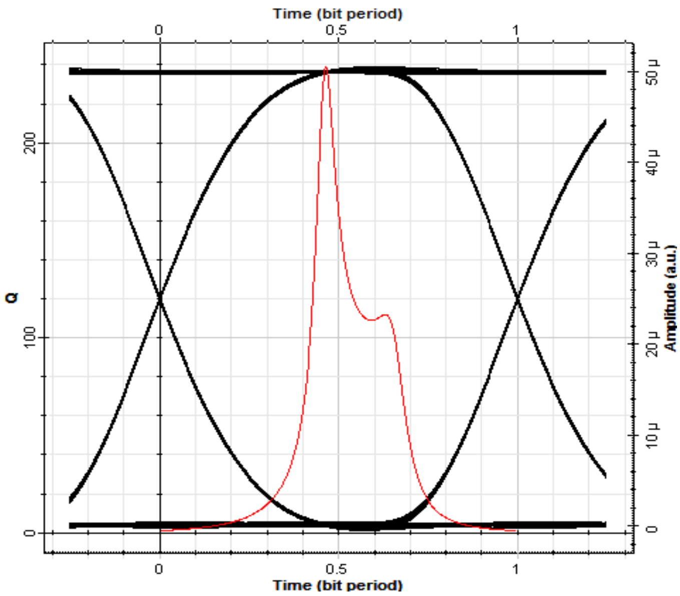

Fig. 6(a) Eye Diagram of hybrid PON system at data rate 10^8 for two transmitters

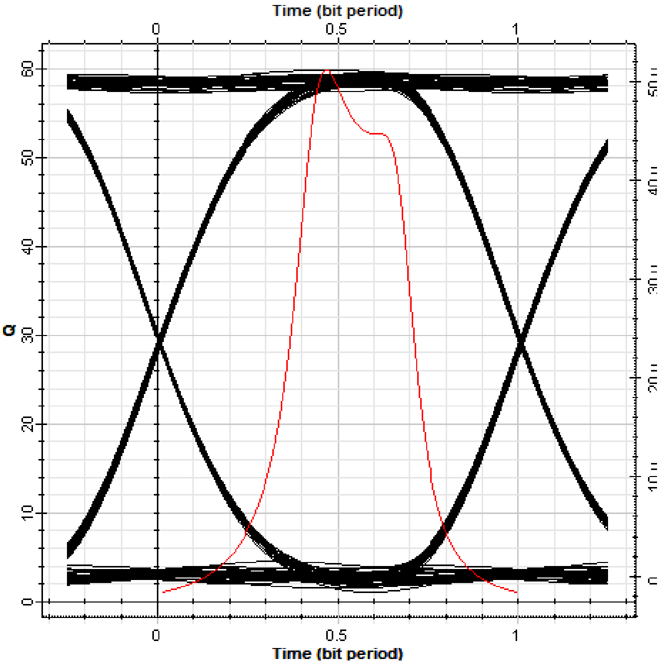

Fig. 6(b) Eye Diagram of hybrid PON system at data rate 10^9 for two transmitters

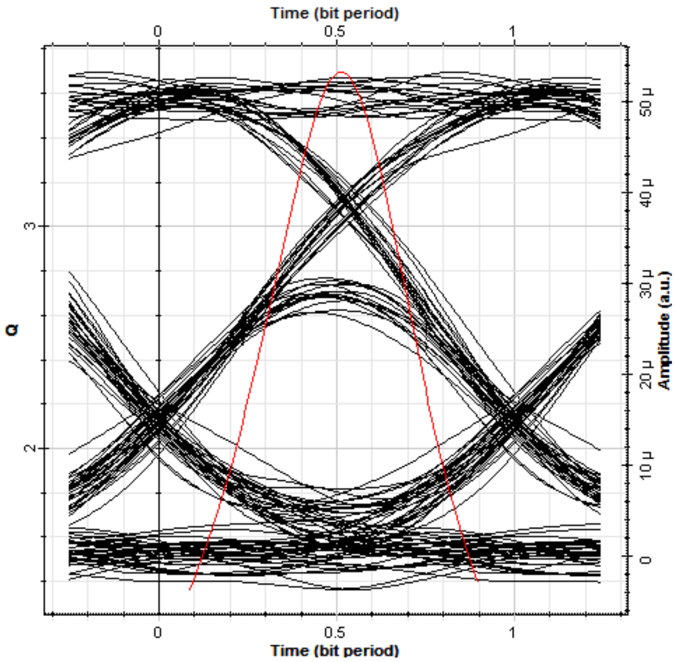

Fig. 6(c) Eye Diagram of hybrid PON system at data rate 10^{10} for two transmitters

C. Number of transmitters are increased

Fig. 7(a)-7(b) shows the eye diagrams of hybrid passive optical network system using NRZ modulation format when three transmitters are used at different data rate 10^9 and 10^{10} respectively for the same distance 50 km. It can be seen from the diagram that when data rate is increased, quality factor and eye height decreases and BER increases as shown in Table III.

If we compare for two transmitters and three transmitters at the same data rate 10^9, we observe that the quality factor increases from 59.79 to 71.21 as shown in table II and table III.

The red line in figure shows curve for quality factor.

Table III

Comparison of parameters for different data rate for three transmitters

DATA RATE	Q	BER	EYE HEIGHT
10^9	71.21	0	4.7891e-005
10^{10}	3.693	9.48052e-005	7.0221e-006

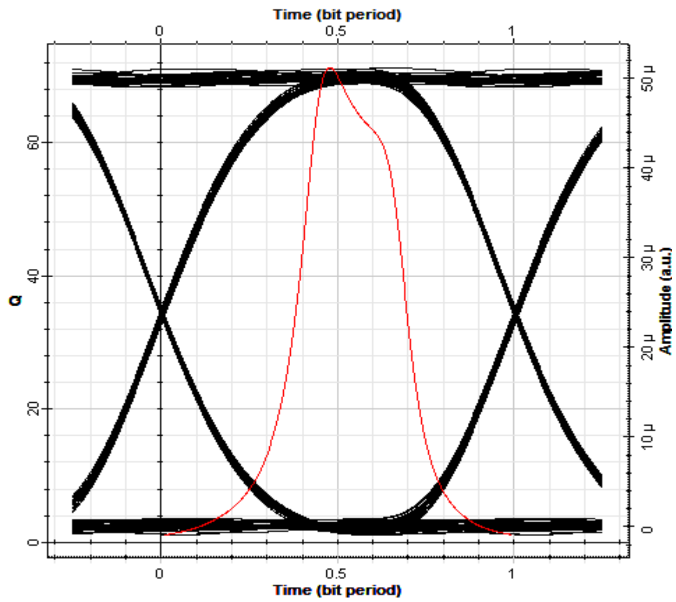

Fig. 7(a) Eye Diagram of hybrid PON system at data rate 10^9 for three transmitters

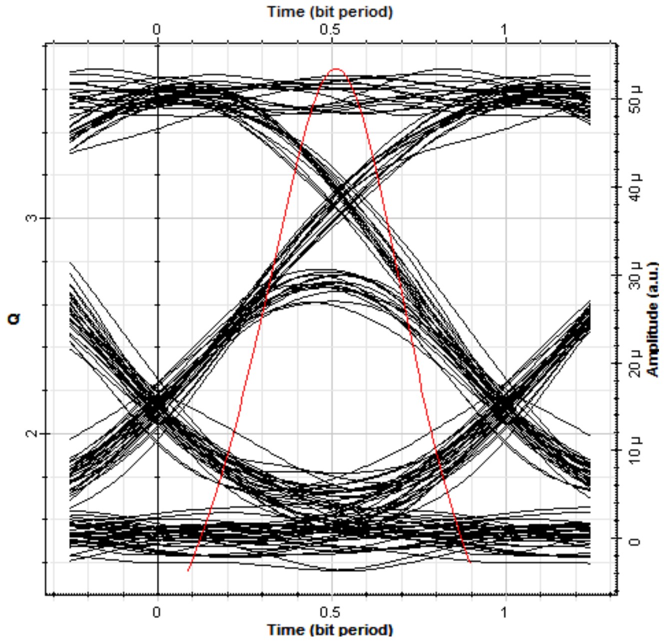

Fig. 7(b) Eye Diagram of hybrid PON system at data rate 10^{10} for three transmitters

CONCLUSIONS

In this paper, hybrid PON networks are investigated. In hybrid PON, the combination of WDM and TDM techniques has been applied in the path of optical fiber so as to optimize the bandwidth in hybrid PON. The user can transmit the data of different wavelengths through the same fiber. We have analyzed the performance of hybrid WDM/TDM passive optical network using star topology in optisystem software and compared the various parameters. It has been observed that BER increases with the increase in data rate and distance and the quality factor and eye height decreases.

There is much more scope for the further work so as to increase the number of users, achieve longer distances and simultaneously improving the performance of the network.

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