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Design & Analysis of Noise-Resilient Mix Data Rate Passive Optical Network Supporting Simultaneous Transmission of Both NGPON Standards

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Abstract

In this paper, we have designed and investigated high data rate supported Wavelength Division Multiplexing Passive Optical Network (WDM-PON) architecture having 16 channels. In this proposed technique, Differential Quadrature Phase Shift Keying (DQPSK) modulated signal having 40 and 10 Gbps in downstream and Inverse Return-to-zero (IRZ) modulated upstream is used with 20, 10 and 2.5 Gbps data rate. Transmission performance of proposed system has been compared on the basis of Bit error rate (BER) analysis at 10 Km fiber length in both directions. Simulation results validate that proposed technique can simultaneously support high data rates for both next generation passive optical networks (NGPON) standards with good receiver sensitivity and noise-resilient transmission of all 16 high capacity WDM channels.

***Keywords**: Next Generation-Passive Optical Network (NGPON), Differential Quadrature Phase Shift Keying (DQPSK), Inverse Return-to-Zero (IRZ) and Bit error rate (BER)*

1. Introduction

Recent industrial analysis forecasted that telecom operators have to deploy high data rate supported networks to tackle with drastic increase in bandwidth demands for upcoming broadband applications and profitability in business [1]. In this scenario technological roadmap is proposed by Full Service Access network (FSAN) which indicates the trends of high data rate supporting techniques in next generation passive optical networks NG-PON [2]. Due to low cost point-to-multi point design with high data rate, high quality and modern services supporting features, passive optical network (PON) is become most promising candidate in next generation access networks. Till now, several standards of PON have been introduced by ITU-T and IEEE such as ATM-PON (APON), Broadband-PON (BPON), Gigabit-PON (GPON), Extended GPON (XGPON), and Next Generation-PON 1(NG-PON 1) and the recent Next Generation-PON 2 (NG-PON 2) have been introduced [3-5]. Initially, FSAN launched APON and BPON during 2000 to 2002 and ITU-T standardized under the recommendations G.983.x and deployed till 2007. Then GPON was introduced and termed as a next generation access network and standardized under the ITU-T recommendation of G.984.x during 2001 to 2004 and remain deployed till 2012. Meanwhile, 10G-GPON (XGPON) have been standardized during 2007 to 2011 under the ITU-T recommendations of G.987.x and is being deployed

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from 2012 to 2015. Then FSAN and ITU-T started working up-gradation of XGPON to more improved PON and thus NGPONs have been emerged having Asymmetric 10Gbps downstream and 2.5 Gbps upstream transmission, it was just enhancement of TDMPON from existing GPON. But evaluation of NGPON-2 is much improved technology in PON, it upgraded not only from 10 Gbps to 40 Gbps but also shifting TDM to WDM multiplexing for future bandwidth demands [3]. Now the comparative analysis of various PON standards and their parameters is shown in Table 1 [4], whereas Figure 1 elucidates that every next standard of PON focusing towards improvement of data rates.

Table 1. Comparative Analysis of Various PON Standards

PON Standard	Recommended By	Downstream Data (Max)	Upstream Data (Max)	Number of Users	Bandwidth Per user
APON	ITU-T G.983.1	155Mbps	155Mbps	16-32	10-20Mbps
BPON	IEEE G.983.x	622Mbps	155Mbps	16-32	20-30Mbps
EPON	ITU-T 802.3ah	1.25Gbps	1.25Gbps	16-32	40-80Mbps
GPON	ITU-T G.984.x	2.5Gbps	1.5Gbps	32-64	100Mbps
XGPON	ITU-T G.987.x	10 Gbps	10 Gbps	64	100Mbps
10GE-PON	IEEE 802.3av	10 Gbps	10 Gbps	64	100Mbps
NGPON-1	FSAN	10 Gbps	2.5 Gbps	64	100Mbps
NGPON-2	FSAN	10 / 40 Gbps	10 Gbps	64	100Mbps

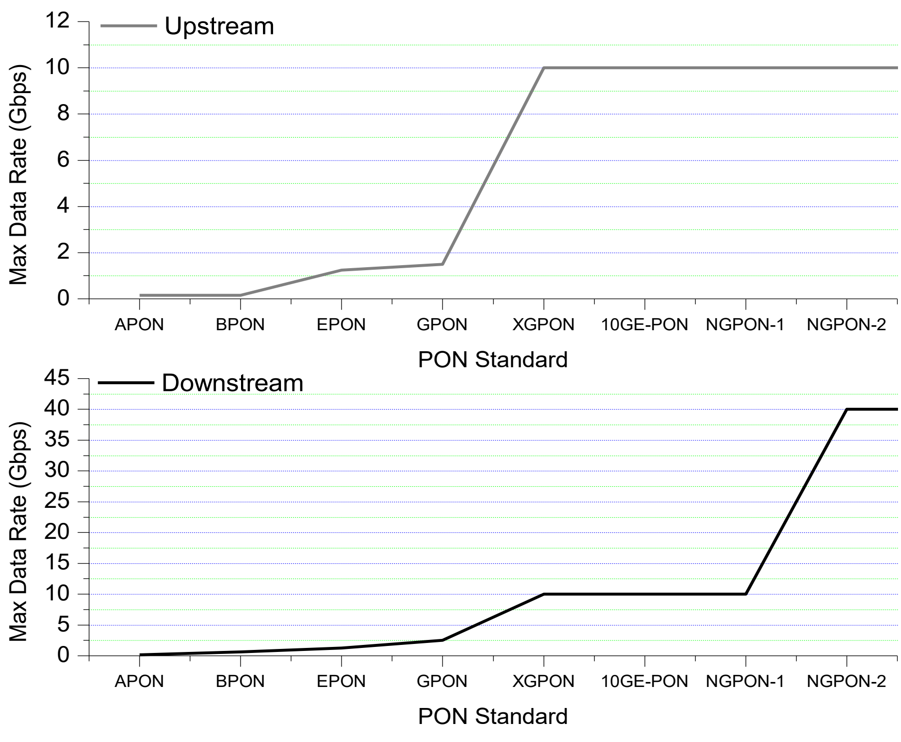

Figure 1. Maximum Data Rate in Upstream and Downstream of Different PON standards

To achieve high data rate transmission, several advanced modulation formats have been proposed such as DQPSK with IRZ [6], RZ-DQPSK with On-Off keying (OOK) [7], Carrier suppressed RZ CSRZ-QDPSK [8], RZ-DQPSK with dispersion compensated fiber (DCF) [9], three different Differential Phase Shift Keying (DPSK) techniques and the WDM PON with semiconductor optical amplifier (SOA)[11]. But these techniques are either low data rate supported or single standard transmission based i.e. single data rate transmission furthermore only single or few WDM channels with various limitations decrease their effectiveness. However, few other techniques have been introduced for integrated standards such as coexistence of XGPON and NG-PON in [12, 13] but they support up to 10Gbps only. Hence, these techniques are not suitable for future challenges.

In the centralized Laser source PON, Laser is deployed in Transmitter at Optical line terminal (OLT) for downstream signal and when this signal is received at Optical Network Unit (ONU) at receiver, it is reused as a carrier for upstream data transmission and modulated by electrical data stream of customer side, this is termed as "Remodulation". Since ONU is not dependent on any specific wavelength, it is known as "Colorless ONU" which is very useful for maintenance and inventory management in PON [14-16]. Dispersion affects the performance of optical fiber. Due to these affects different types of dispersion compensators are used to enhance the performance of optical fiber. Fiber Bragg Grating (FBG) is usually used for dispersion compensation because of its low insertion loss and cost [17-19]. DQPSK is very popular for high data rate and multi-level transmission. Since it transmits 2 bits/symbol so as compared to DPSK it has half spectral occupancy but twice transmission capacity at the same symbol rate. It also has much better receiver sensitivity than intensity modulated techniques. DQPSK can also perform much better against polarization mode dispersion (PMD) and nonlinear effects because of its constant envelope [20]. IRZ is an especial case of intensity modulation technique in which optical power is available in each bit period at both the mark levels and the space levels of signal. It has double optical bandwidth as compared to NRZ. Here, it is used at ONU and the phase re-modulation is stored in the constant and high power part of the waveform, due to this IRZ modulated upstream can also work at higher extinction ratio (ER) and much better receiver sensitivity than NRZ [20].

In this paper, we have proposed and investigated mix and high data rates based 16 Channels WDM-PON which can simultaneously support both NG-PON standards. We employ DQPSK modulated downstream with 40 and 10 Gbps data rate and IRZ based upstream having 20, 10 and 2.5 Gbps data rates. FBG is used to overcome transmission impairment effects with 10 Km fiber span in both directions. Simulative investigations of results show that simultaneous transmission of both NG-PON 1 (10 Gbps downstream and 2.5 Gbps in upstream) and NG-PON 2 (40 Gbps downstream and 20 or 10 Gbps in upstream) can be achieved successfully with good receiver sensitivity in both directions. Hence proposed noise-resilient transmission PON can simultaneously support both standards on NGPON.

2. Working Principle & Simulation Setup

The proposed architecture of mix and high data rate supported NG-PON simulative design is shown in Figure 2, in which 16 High capacity WDM channels from 193.1 THz to 194.6THz are used having 0 dBm (1 mW) launched power in each. In downstream transmission at OLT, these channels are modulated with mix data rate of 40 and 10Gbps DQPSK format, on the other hand for upstream transmission at ONU, IRZ modulated channels with 20, 10 and 2.5 Gbps data rates are used and fiber span is set for 10Km with following parameters settings as shown in Table 2.

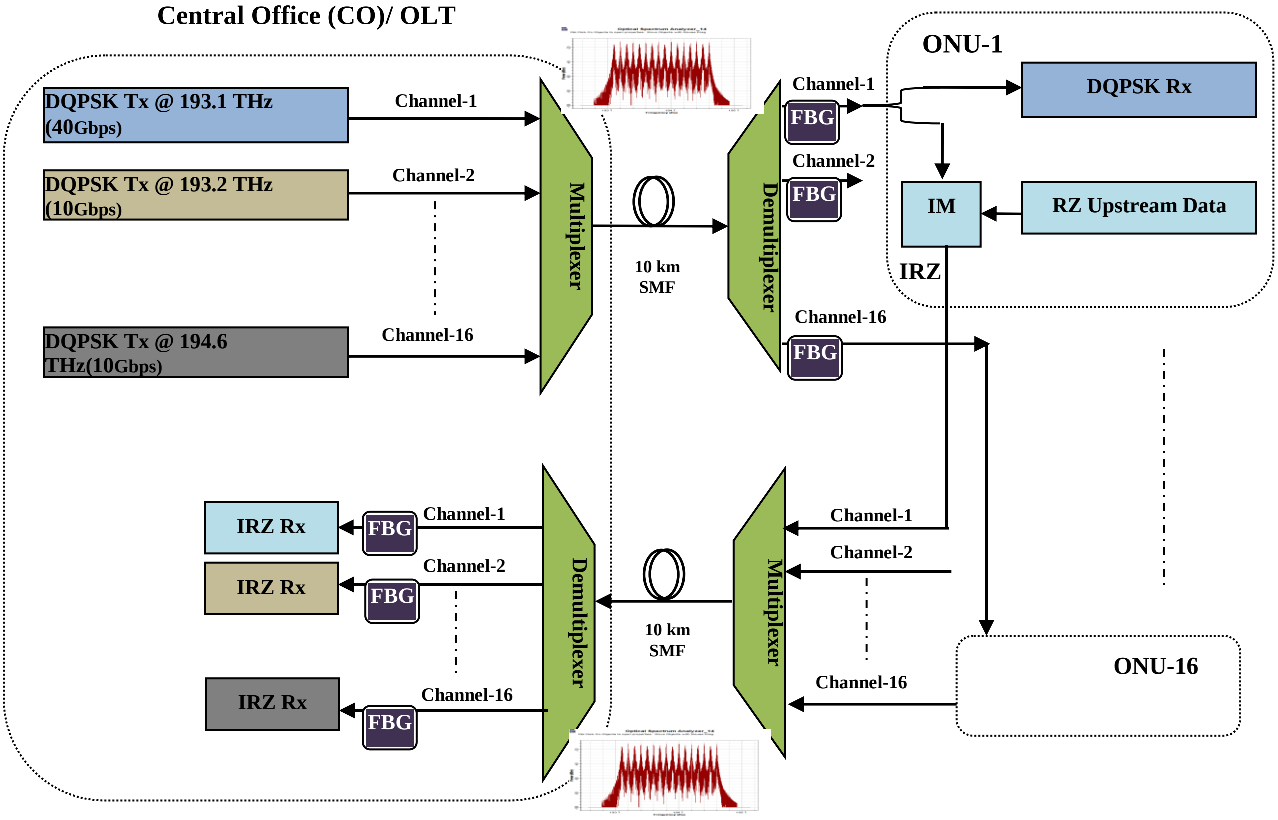

Figure 2. Working Principle and Architecture of Proposed NG-PON with FBG

Table 2. Parameters of Proposed Simulation Setup

Parameters	Data
Laser Launched Power	0dBm (1mW)
Data Rate of 16 DQPSK Downstream Channels	Channels 1,3,5,7,9,11, 13 and 15 at 40 Gbps Channels 2,4,6,8,10,12, 14 and16 at 10 Gbps
Data Rate of 16 IRZ Upstream Channels	Channels 1,5,9 and13at 20 Gbps Channels 3,7, 11 and 15 at 10 Gbps Channels 2,4,6,8,10,12, 14,16 at 2.5 Gbps
Channels Frequencies	From 193.1THz to 194.6 THz
Dispersion parameter	16.75 ps/nm/km
Non Linear index-coefficient	2.6×10^{-20}
Slop of Dispersion	0.075 ps/nm^2/km
Effective Core Area	80 um^2
Fiber Attenuation	0.2 dB/km

All related details such as launched power, data rate, and frequency and spacing of each channel and specifications of single mode fiber (SMF) is mentioned in the Table-2.

DQPSK modulated signal is generated through pre-coded data and two Mach Zehnder modulators (MZM) and IRZ signal is produced from single MZM of combined clocked signal and NRZ data. As shown in Figure 2 that WDM multiplexer and de-multiplexer are employed for channels multiplexing and de-multiplexing.

To overcome transmission impairments and fiber nonlinearity effects Fiber Bragg Grating (FBG) is placed before receiver in both directions. At ONU, power splitter separates downstream in two parts one for DQPSK receiver and other as a carrier for upstream in intensity modulator (IM). Moreover, to retrieve DQPSK signal we used Mech-Zehnder Delay interferometer (MZDI) and balanced detector and simple photo detector as an IRZ receiver. This setup is employed at receiver in twice, first one is for In-phase (I) and second one is for Quadrature-phase(Q) of DQPSK signal. Then received electrical bit stream are analyzed via Bit-error-rate analyzer to ensure successful transmission of data. Snapshot of simulation set up in Optisys software of proposed design of 16 channels PON is shown in Figure 3

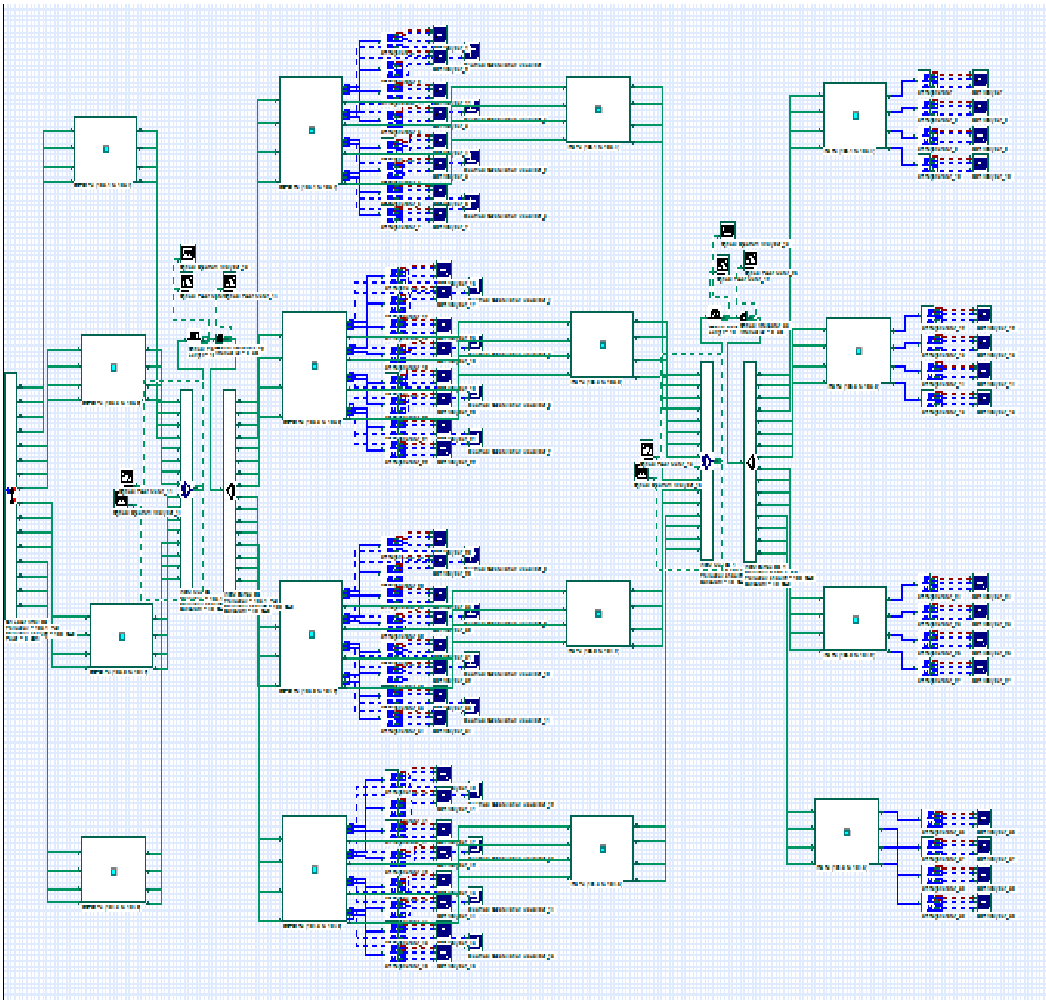

Figure 3. Snapshot of Proposed Mix data rate 16 Channels PON simulation Set up in Optisys Software

3. Results Discussion

It can be observed from spectrum analyzer diagrams over the fibers in proposed architecture in Figure 2 and the snapshot of simulation setup in Figure 3 that 16 channels have been employed in both directions. Since, mix data rate channels are used so we randomly analyzed four different channels *i.e.*, 1, 6, 11 and 16 in both downstream as well as upstream.

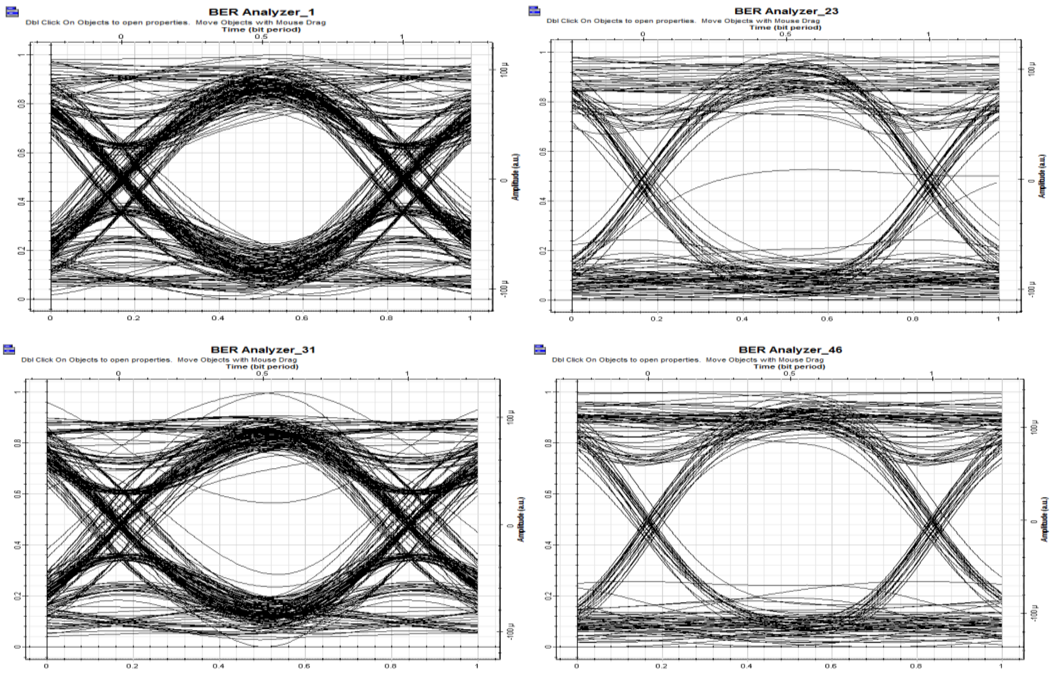

Figure 4. Eye Diagram for DQPSK Channels 1 & 6 on Top (from left to right) 11& 16 Bottom (from left to right) in Proposed Downstream WDM-PON

In Figure 4 eye diagrams of selected DQPSK modulated downstream channels are shown at different data rates for 10 Km fiber span, it can be seen that eyes diagrams are wide and open, which indicates that channels are good for transmission. Results in Table.3 ensure the feasibility of proposed design but slight variations in results can be observed due to different data rate and position in the frequency spectrum. Therefore, channel-1 and channel-16 have better BER value because they have to face interference from one side only as first and last channels. Similarly channel-16 is better because low data rate as compared to channel-1.

Table 3. Analysis of Selected DQPSK Downstream Channels

Selected DQPSK Channel #	Data rate downstream	Eye Height @ 10 Km	BER @ 10 Km
Channel-1 (193.1 THz)	40 Gbps	1.10×10^{-4}	8.06×10^{-18}
Channel-6 (193.6 THz)	10 Gbps	1.15×10^{-4}	1.29×10^{-16}
Channel-11 (194.1 THz)	40 Gbps	1.03×10^{-4}	1.16×10^{-15}
Channel-16 (193.6 THz)	10 Gbps	1.52×10^{-4}	3.91×10^{-21}

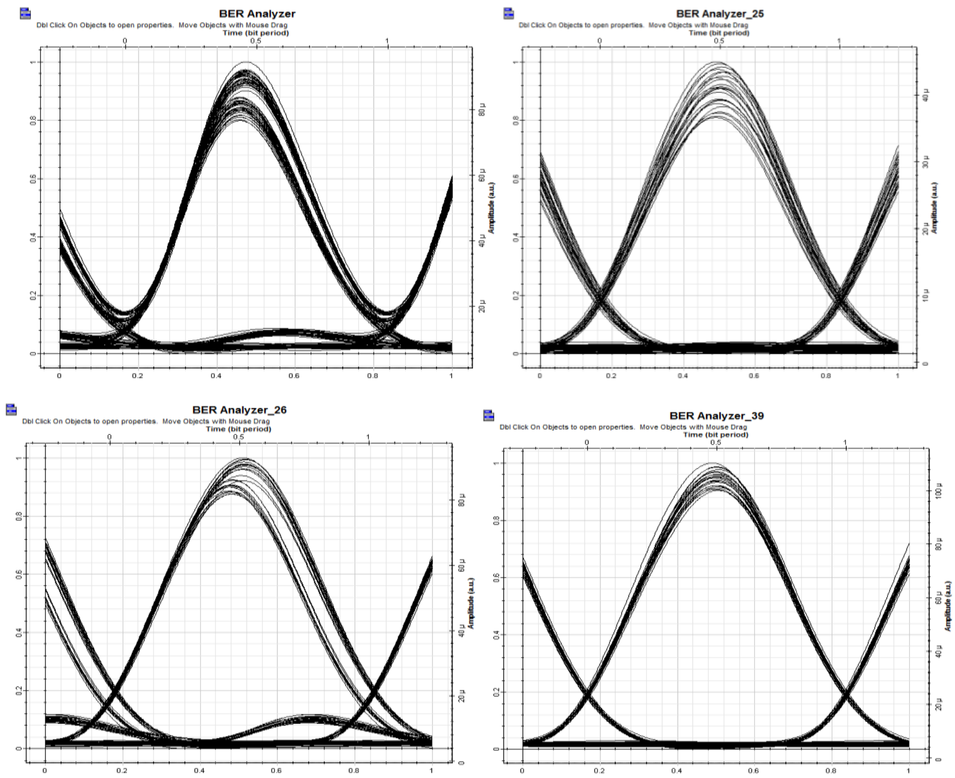

Figure 5. Eye Diagram for IRZ Channels 1 & 6 on Top (from left to right) 11& 16 bottom (from left to right) in Proposed Upstream WDM-PON

Similarly, eye diagrams of selected IRZ channels are shown in Figure 5, the wide and clear eye opening reflects error free transmission in upstream at different data rates channels. Feasibility of proposed design can be verified from the results in Table.4. Again, variations in result are due to different data rate and position of the channel in the frequency spectrum.

Table 4. Analysis of Selected IRZ Upstream Channels

Selected IRZ Channel#	Data rate in upstream	Eye Height @ 10 Km	BER @ 10 Km
Channel-1 (193.1 THz)	20 Gbps	5.78×10^{-5}	1.47×10^{-81}
Channel-6 (193.6 THz)	2.5 Gbps	1.08×10^{-4}	1.12×10^{-157}
Channel-11 (194.1 THz)	10 Gbps	6.99×10^{-5}	1.92×10^{-88}
Channel-16 (193.6 THz)	2.5 Gbps	8.98×10^{-5}	3.12×10^{-215}

We have further investigated the selected channels for received (Rx) power versus BER analysis in both downstream and upstream as shown in Figure 6 and Figure 7 respectively. It csan be noticed that Channel 1 and Channel 11 has higher BER values at certain received power as compared to channels 6 and 16 due to the high data rate are more effected by transmission impairment during the transmission at same fiber span. Even though receiver sensitivity of selected channels at standard bit error rate (1×10^{-9}) is in the range of -30 dBm to -44 dBm, which is acceptable values for such a high and mix data rates transmission of 16 channels simultaneously.

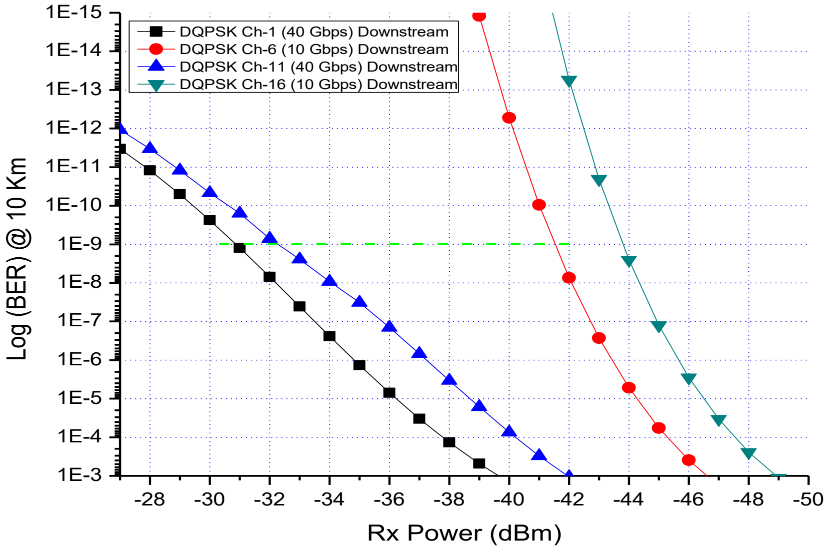

Figure 6. Rx Power Vs BER Analysis of DQPSK channels 1, 6, 11 and 16 in Downstream

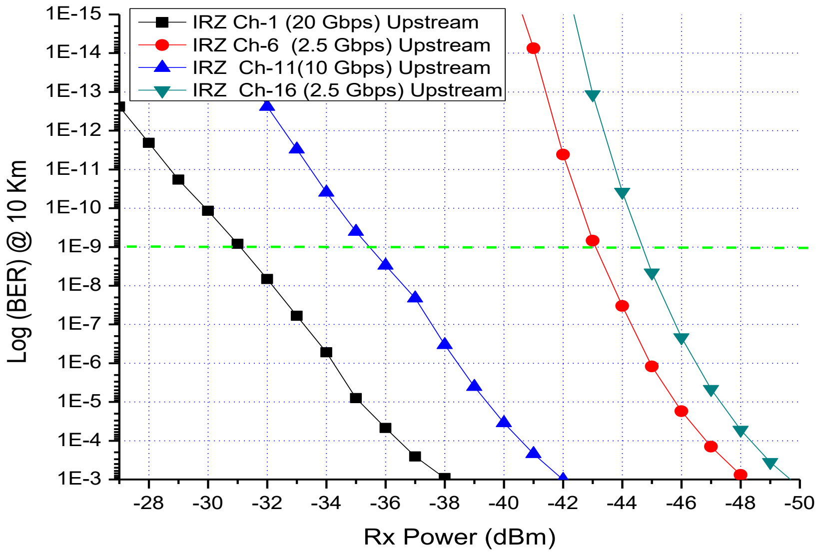

Figure 7. Rx Power Vs BER Analysis of IRZ Channels 1, 6, 11 and 16 in Downstream

4. Conclusion

We proposed a mix and high data rates based 16 Channels WDM-PON which can simultaneously support both NG-PON standards. Channels number 1, 6, 11 and 16 have been investigated for BER values at different received power in DQPSK based downstream and IRZ upstream at 10 km fiber span. Analysis of proposed design validates technique that simultaneous high capacity transmission of 8 channels aggregated 80 Gbps of NG-PON 1 and 8 channels aggregated 320 Gbps of NG-PON 2 in downstream are supported with lower receiver sensitivity and with acceptable range of bit errors. Hence, this technique is a feasible solution for future high data rate, high capacity, noise-resilient and simultaneous transmission of both NGPON standards.

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