Performance Analysis of 2.5Gb/s Bidirectional WDM/TDM-PON with Narrowband AWG for Varying Extinction Ratio using ANFIS

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Abstract: *In the present work, we investigate the impact of extinction ratio* **(ζ)** *of Mach-Zehnder (MZ) amplitude modulator on the performance of 2.5Gb/s Wavelength Division Multiplexed Passive Optical Networks (WDM-PONs) for optical fiber length varying upto 60km. The system performance has been analyzed by varying the value of ζ from 2 to 22dB. It is found that the system gives optimum performance at extinction ratio value 20dB beyond which it saturates. Further, the fuzzy model of the system is developed using ANFIS (Adaptive Neuro-Fuzzy Inference System), for varying extinction ratio of MZ modulator and performance is evaluated by comparing simulated results with fuzzy model and good correlation is achieved between them.*

Keywords: *WDM-PON, NRZ, ONU, OLT, AWG, Fuzzy Logic, ANFIS*

1. Introduction

The bandwidth demand has been increasing rapidly in the access networks and if this growth increases continuously, it is estimated that bandwidth demands could soon reach to 100Mb/s for residential users and 10Gb/s for business users. WDM-PONs have evolved to provide much higher bandwidth in the access networks. As WDM-PON supports high bandwidth and splitting ratio and long reach in the access networks therefore carriers are able to eliminate unnecessary switching and routing equipments. Time Division Multiplexer(TDM) based technologies like Ethernet PON (EPON), Gigabit PON (GPON) uses TDM techniques to divide bandwidth among multiple users and WDM-PON provides scalability to use multiple wavelengths over the same fiber infrastructure, is inherently transparent to the channel bit rate, and it does not suffer power-splitting losses [1-2]. The WDM-PON increases both upstream and downstream bandwidth available to each user.

A PON is a point-to-multipoint optical network, where an Optical Line Terminal (OLT) at the Central Office (CO) is connected to many ONUs at remote nodes through one or multiple 1:N optical splitters. PONs use a single wavelength in each of the two directions downstream (CO to end users) and upstream (end users to CO) and the wavelengths are multiplexed on the same fiber through WDM [3-4]. In the downstream direction of the WDM-PON, the wavelength channels are routed from the OLT to the ONUs by a passive Arrayed Waveguide Grating (AWG) router, which is deployed at a Remote Node (RN) where the passive splitter is used in a TDM-PON. Bock et al. [3] described WDM/TDM-PON architecture by using Free Spectral Range (FSR) periodicity and AWG. Transmission test showed correct operation at 2.5Gb/s up to 30km. By mean of optical transmission test the authors demonstrated that this architecture was feasible and offered good performance with low optical losses as compared to other PON architectures. Calabretta et al. [4] presented an innovative architecture to realize a single feeder bidirectional WDM/TDM-PON on modified NRZ (DPSK)downstream signals at 20kb/s and narrowband AWG. In this, remodulated upstream signals were obtained at 1Gb/s. Feny et al. [5] discussed a scheme in which modified NRZ format was used to realize multicast WDM-PON by adjusting downstream extinction ratio and achieved good BER rate performance for upstream signals. Han et al. [6] proposed a

WDM-PON model with multicast capability like high scalability multiwavelength converter and single copy broadcast capability by employing multistage AWGs at remote node.

However, the viability of the WDM-PON for bit rate > 1Gb/s and transmission distance > 30km is not available as such in the literature. So, here we investigate the performance of 2.5Gb/s WDM-PON system for varying extinction ratio of the modulator (2 -22dB) upto 60km. Further, the simulated results have been confirmed by using ANFIS fuzzy model. Here, in section 2, the system description and simulation parameters have been described. In section 3, the fuzzy model has been discussed. In section 4, comparison of results of the simulated system and the fuzzy model has been reported for varying extinction ratio and finally in section 5, conclusions are made.

2. System Description and Simulation

The schematic of optical communication system simulation setup is shown in Figure 1. Pseudo-Random Bit Sequence (PRBS) generator with at bit rate 2.5Gb/s has been used**.** The PRBS logical signal is converted into electrical signal using NRZ electrical pulse generator. It is further modulated by Mach-Zehnder (MZ) modulator modulates with varying extinction ratio (2 - 22dB) and CW DFB laser optical source operating at 1550nm with line width = 10MHz and input power = 10dBm. The signals from 8 channels are then fed to WDM multiplexer operating at 1550nm with bandwidth = 10GHz and channel spacing = 100GHz. An Erbium Doped Fiber Amplifier (EDFA) with gain=17dB and noise figure = 6dB is used at the transmitter section to boost the optical signal to the desired power level followed by power splitter, upstream circulator with return loss and isolation of 60dB. AWG (8x8) with frequency = 193.4THz and bandwidth =10GHz is used for upstream and AWG(1x8) with frequency = 1550nm and bandwidth = 10GHz is used for downstream as channel distributors.

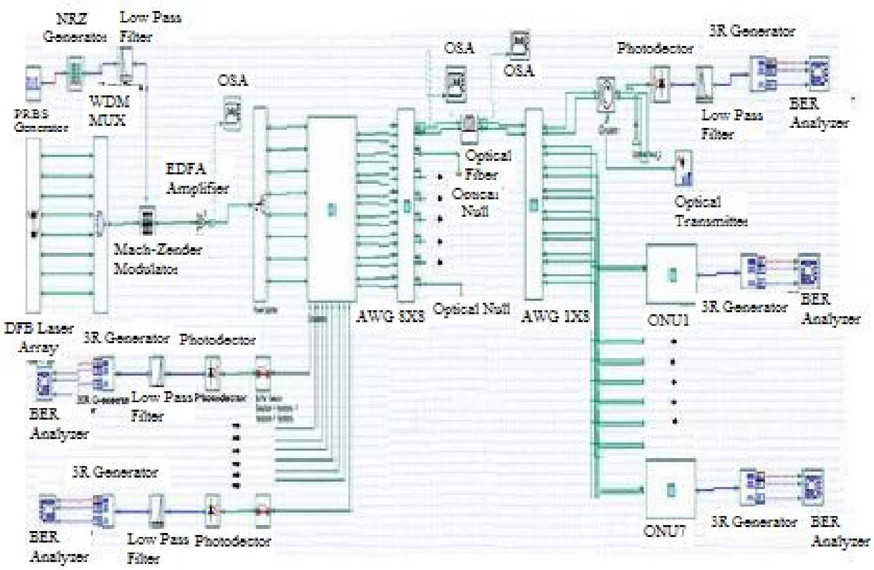

Figure 1 *Simulation Setup of WDM-PON System*

A bidirectional Single Mode Fiber (SMF) parameters include attenuation = 0.24dB/km, dispersion slope = 0.075ps/km-nm^2 and dispersion at 1550nm is 16.75ps/km-nm. At the receiver, the signal is detected by a PIN photodiode (PD). It has responsivity of 0.7A/W and dark current = 10nA having thermal noise 79.99 W/Hz. It is then passed through the low pass Bessel filter with 3dB cut-off frequency = 0.75 × bit rate, order of the filter = 4, depth = 100dB. Thereafter, 3R regenerator is used to regenerate the electrical signal that can be connected directly to the BER analyzer, which is used to measure BER, Q value, eye opening etc. We have also considered the ASE noise, shot noise, thermal noise, estimated receiver noise and ASE-ASE noise effects in the optical receiver.

3. Fuzzy Model

Here, Sugeno fuzzy model of WDM-PON system as shown in Figure 2 is developed using ANFIS (Adaptive Neuro-Fuzzy Inference System) for varying length of the optical fiber (input1) and extinction ratio of MZ modulator (input 2). The Q value[dB] acts as the output of the system.

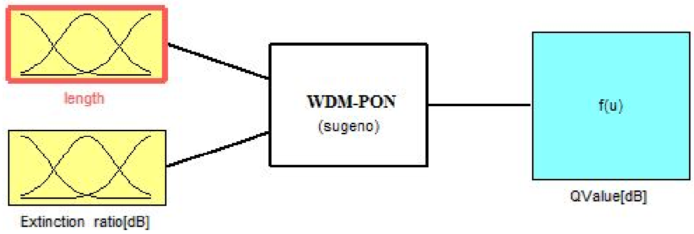

Figure 2 *Sugeno based fuzzy model of WDM-PON system*

The WDM-PON system model uses nine rules for fuzzy model without sub clustering and eighteen rules for fuzzy model with sub clustering [7-8]. Set of linguistic rules for fuzzy model without sub clustering are given below in Table 1:

Table 1 Set of linguistic rules

1	If (length is in1mf1) and (Extinction ratio[dB] is in2mf1) then (Q Value[dB] is out1mf1) (1)
2	If (length is in1mf1) and (Extinction ratio[dB]is in2mf2) then (Q Value[dB] is out1mf2) (1)
3	If (length is in1mf1) and (Extinction ratio[dB]is in2mf3) then (Q Value[dB] is out1mf3) (1)
4	If (length is in1mf2) and (Extinction ratio[dB]is in2mf1) then (Q Value[dB] is out1mf4) (1)
5	If (length is in1mf2) and (Extinction ratio[dB] is in2mf2) then (Q Value[dB] is out1mf5) (1)
6	If (length is in1mf2) and (Extinction ratio[dB] is in2mf3) then (Q Value[dB] is out1mf6) (1)
7	If (length is in1mf3) and (Extinction ratio[dB] is in2mf1) then (Q Value[dB] is out1mf7) (1)
8	If (length is in1mf3) and (Extinction ratio[dB]is in2mf2) then (Q Value[dB] is out1mf8) (1)
9	If (length is in1mf3) and (Extinction ratio[dB]is in2mf3) then (Q Value[dB] is out1mf9) (1)

Further, the ANFIS model structure for WDM-PON system without and with sub-clustering is represented in Figure 3(a) & (b) respectively.

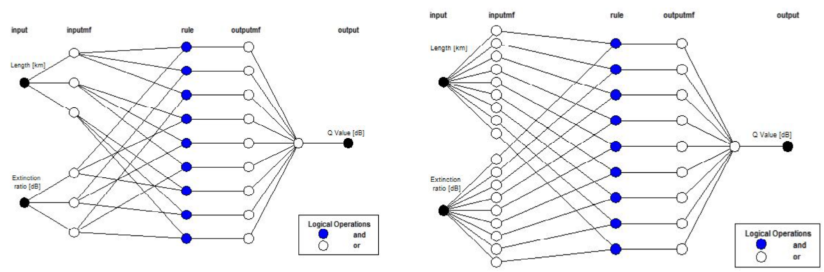

Figure 3 *ANFIS model structure (a) Without sub-clustering (b) With sub-clustering*

4. Results and Discussion

To estimate the performance, the BER and Q value [dB] from the eye diagrams of electrical scope have been considered for channel 4 of WDM-PON system. Figure 4 shows the graphical representation of Q value[dB] as a function of extinction ratio of the MZ modulator ranging from 2 to 22dB and P_{in}=10dBm for NRZ downstream DataStream. It is quite evident from the Figure 4 that Q value decreases with the increase in length of the fiber and the system performance improves with the increase in the extinction ratio of the modulator. WDM-PON system gives optimum performance at ζ= 20dB beyond which also the results are same and the modulator saturates at ζ=20dB

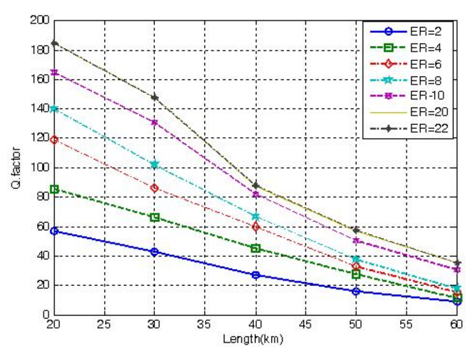

Figure 4 *Q Value[dB] versus fiber length[km] of downstream signals for varying extinction ratio [2-22dB] at Channel 4, P_{in} =10dBm at 2.5Gb/s*

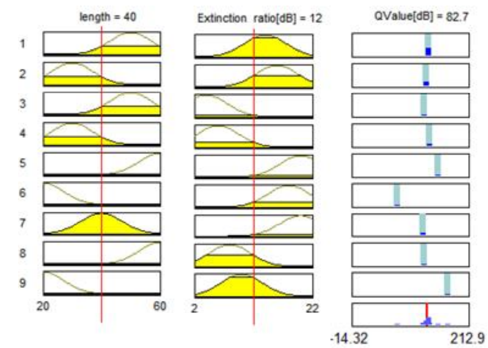

Figure 5 (a) *Rules viewer of Q Value[dB] for extinction ratio & length without sub clustering*

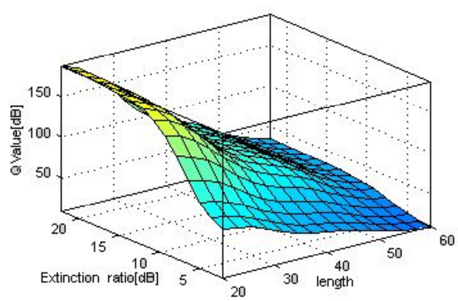

Figure 6(a) *Surface representation of Q Value[dB] for extinction ratio & length without clustering* ***Figure 5(b)*** *Rules viewer of Q Value[dB] for extinction ratio & length with sub-clustering*

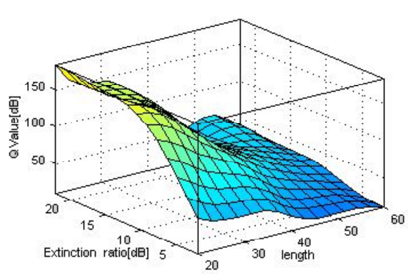

Figure 6(b) *Surface representation of Q Value[dB] for extinction ratio & length with sub-clustering*

Figure 5(a) shows the rule viewer of fuzzy system without sub-clustering for a specific case when fiber length = 40km and the extinction ratio= 12dB, the output Q value [dB] obtained is 86, which is close to the Q value = 83 obtained by simulation (for length = 40km and extinction ratio = 12). Figure 6(a) showing the surface plot for fuzzy system without sub-clustering endorses the results obtained from simulation. Also, the system performance is observed from the rule viewer of fuzzy system with sub-clustering for a particular case when fiber length = 40km and the extinction ratio = 12 dB as shown in Figure 5(b). The output Q value[dB] for this case is 82.7, which is very near to the value of 83 obtained by simulation. Similarly, Figure 6(b) illustrates surface of the system for Q value showing variation in extinction ratio and length of the fiber with sub-clustering. It can be clearly seen that the fuzzy model with sub-clustering gives outperforms the fuzzy model without sub-clustering. As the numbers of rules have been increased in the fuzzy model using sub clustering, this increases the number of parallel computations and thus accuracy.

The results obtained using ANFIS fuzzy model endorse the outcome of the simulated optical model of WDM-PON system.

5. Conclusions

The simulated Q values [dB] for varying fiber length and extinction ratio have been obtained for 8 channel 2.5Gb/s WDM-PON system using NRZ format and AWG for downstream data transmission. It is observed that with the increase in extinction ratio (ζ) of the modulator from 2 to 22dB, and Q value improves for WDM-PON system up to 20dB beyond which it saturates. This paper presents a comparison of the simulated data with the results obtained from ANFIS fuzzy model and it is observed that the findings of simulated optical model are quite close to the ANFIS based fuzzy model.

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