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Performance Comparison of a WDM PON with TDM PON At 10 GBPS

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Recent developments in optical technologies have realized wavelength division multiplexed passive optical network (WDM PON) as a promising and a cost-effective solution for the next generation networks. Due to the intrinsic optical transparency and extremely high transmission capacity, WDM PON is considered more future oriented than conventional TDM PON. In this paper we compare an eight channel WDM PON with an eight channel TDM PON, both operating at 10 Gbps data rate. Network parameters like input laser power, optical fiber length and optical amplifier gain are varied and their impact on performance parameters i.e. Q-factor, BER, OSNR, Eye opening and Extinction ratio penalty is recorded. Results reveal that WDM PON exhibits superior performance than TDM PON in each case.

Keywords: Optical fiber access network, Passive optical network, Remote node, Arrayed waveguide grating, Passive star coupler

1. Introduction

Development of high definition Multimedia applications such as video telephony, video conferencing and IP TV alongwith data services like ADSL, VDSL, HDSL require large amount of bandwidth. Copper based Access Networks have a bottleneck in providing such high bandwidth demanding multimedia applications to the end user. High capacity networks are therefore, required. Optical fiber access network (OFAN) has emerged as a proven solution to this problem. It can carry huge amount of data effectively to much longer distances than copper based access networks.

Several OFAN architectures have been developed e.g. point to point (P2P), active optical network (AON) and passive optical network (PON). Among these, PON is found most efficient because of its all optical nature and low operational cost [1]. PONs are further divided into Time Division Multiplexed passive optical network (TDM PON), Wavelength Division Multiplexed passive optical network (WDM PON) and hybrid wavelength/time division multiplexed passive optical network (WDM/TDM PON).

Presently PONs offer a capacity of 1.25 Gbps for Ethernet PON (EPON) and 2.48832 Gbps for Gigabit (GPON). Efforts are being made to evolve the recently available capacity of PONs upto 40 Gbps in the next generation of PONs (NG PONs) [8, 9].

2. WDM PON Network Architecture

Schematic of WDM PON is shown in Figure 1.

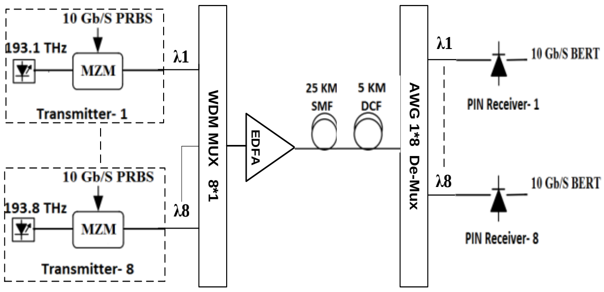

Figure 1. WDM PON architecture.

Separate wavelength is allocated to every channel in the WDM PON under discussion. Each wavelength is capable of operating at 10 Gbps. Mach–Zehnder interferometers are used to externally modulate every continuous wave (CW) laser source as shown in Figure 2 [12].

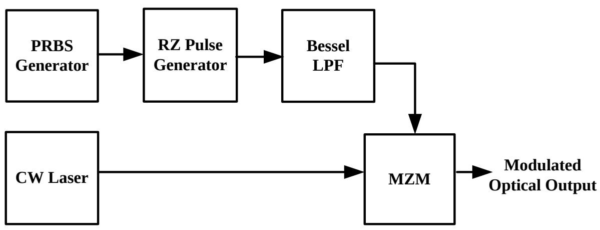

Figure 2. External modulation scheme.

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Eight signals with frequencies ranging from 193.1 THz to 193.8 THz with an increment of 0.1 THz are generated by the sources. These frequencies are selected confirming to ITU-T recommendations G.692 defined for optical interfaces for multichannel optical systems [3]. An EDFA with a gain of 22 dB and Noise Figure (NF) of 6 dB (maximum for EDFA) is selected. Maximum NF for EDFA is selected in order to analyze the worst case scenario.

A dispersion compensation fiber (DCF) is used to counter the dispersion effects on the transmitted signal. Assuming length of DCF to be 5 km and dispersion parameter of Single Mode Fiber (SMF) as 16 *ps/nm/km*, a DCF with dispersion parameter of −80 *ps/nm/km*, will fully neutralize the dispersion effect on our original signal over a length of 25 km.

At the Remote Node (RN), an Array Waveguide Grating (AWG) serves as a 1×8 de-multiplexer. Reference frequency of AWG is set to 193.1 THz. So by making use of cyclic property of AWG, our de-multiplexed stream appears at output ports in an ordered pattern [4, 6]. λ_1 centered at 193.1 THz is mapped to output port 1; λ_2 centered at 193.2 THz is mapped to output port 2 and so on. Finally λ_8 centered at 193.8 THz is mapped to output port 8.

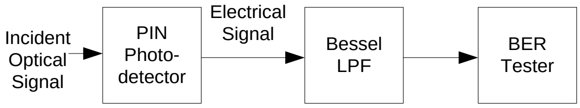

Figure 3. WDM PON receiver circuitry.

Receiver circuitry, shown in Figure 3, is designed using PIN photodiode. A low pass Bessel filter removes noise from the detected signal. Finally this signal is fed to a Bit Error Rate (BER) tester for analysis. Star topology is used in the design of WDM PON schematic. Due to a single split point at RN almost equal power is distributed among all receivers. Hence, it is easier to maintain system power budget [1].

3. TDM PON Network Architecture

TDM PON schematic is shown in Figure 4.

A CW Laser generates a single wavelength channel of 1550 nm. Our transmitter consists of a Pseudo Random Bit Sequence Generator (PRBS), a return to zero (RZ) signal generator and an Amplitude Modulator (AM). Here any modulation scheme like Frequency Modulation (FM) or Phase Modulation (PM) could have been used but Amplitude Modulation (AM) is selected, being easy to implement.

Bit rate of each transmitter is set to 1.25 Gbps. 8 such transmitters sharing the same wavelength channel (1550 nm) are optically multiplexed to form a composite bit stream at a rate of 10 Gbps. Delay line technique is used as the multiplexing technique [11]. In this scheme bit stream in the nth branch is delayed by an amount,

$$(n-1) /NB$$

Where n = 1, 2, ----, N and N is the total number of channels i.e. 8 in our case. To ensure that time interleaved pulses must fit into their allocated time slots, our laser should be capable of producing pulses of width *Tp*, such that,

$$T_p < T_b = 1/NB$$

where, T_b is the bit duration.

A power combiner is used to multiplex these delayed bit streams on to a single channel. Parameters for SMF, DCF and EDFA are set with the same values as in case of WDM PON so that characteristics of transmission channel remain the same in both cases.

AM, FM and PM require coherent demodulation. Same is true for our AM demodulator. For the purpose we use a clock generator that has the same bit rate as that of our transmitters. An RZ pulse generator will convert this clock signal into RZ pulses which are fed to an AM demodulator. AM demodulator extracts the original information from the composite signal. Finally, the extracted signal is projected to the receiver circuitry. Receiver circuitry used here is the same as discussed in our WDM PON schematic.

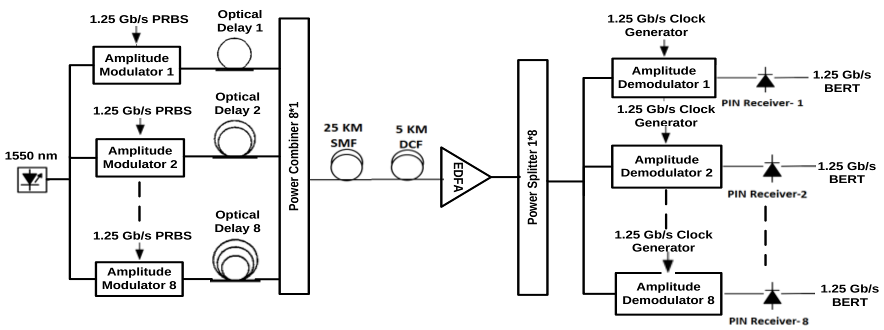

Figure 4. TDM PON architecture.

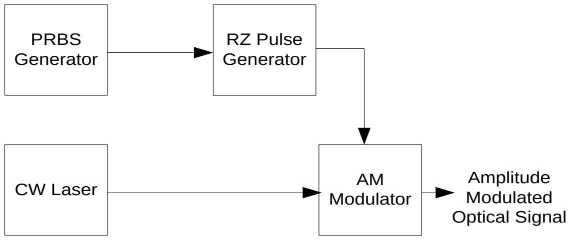

Figure 5. TDM PON transmitter.

4. Experiments and Results

Simulations are performed on physical layer using Optisystem-10 software. Performance of both circuits is compared by varying three network parameters,

1. Decreasing Input Laser Power from 0 dBm to −20 dBm in 10 steps
2. Increasing Optical Fiber Length from 25 KM to 100 KM in 4 steps
3. Decreasing EDFA Gain from 22 dB to 13 dB in 10 steps

The resultant Q–factor, BER, Eye Height, OSNR and Extinction Ratio Penalty are recorded. According to ITU recommendations G.692 & G.957, light wave systems are designed to tolerate a maximum BER of 10^{-12} and system OSNR should be at least 20dB or better. In order to maintain BER of 10^{-12}, the set value of Q should be greater than or equal to 7. Likewise, Extinction Ratio penalty should not exceed –12 dB.

The results have been noted only for the 1st channel of both TDM and WDM PONs. Similar results can be obtained for other channels as well.

4.1. *Decreasing Input Laser Power*

Total number of iterations is set to 10. Parameter "Power" of all the CW Lasers is linearly decreased from 0 dBm to –20 dBm in 10 iterations.

Respective graphs elaborating the comparison between Input Laser Power and subject parameters are plotted in Figures 6 – 10:

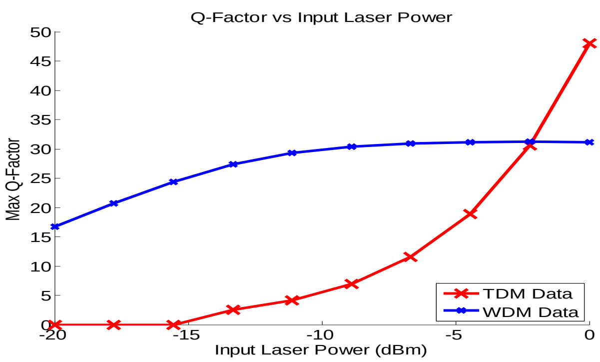

Figure 6. Max Q-factor versus input laser power.

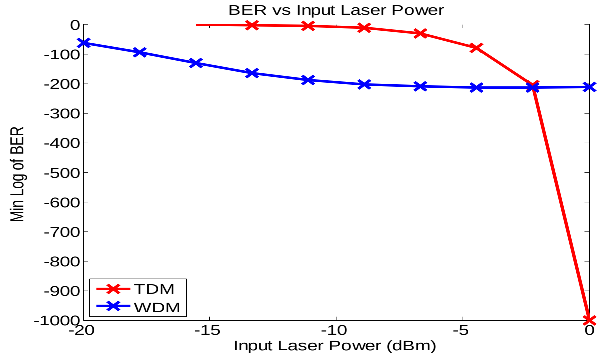

Figure 7. BER versus input laser power.

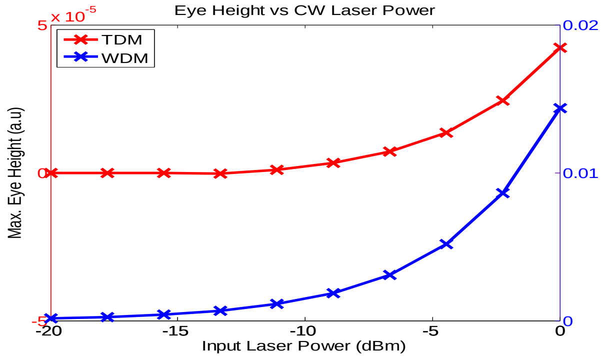

Figure 8. Eye height versus input laser power.

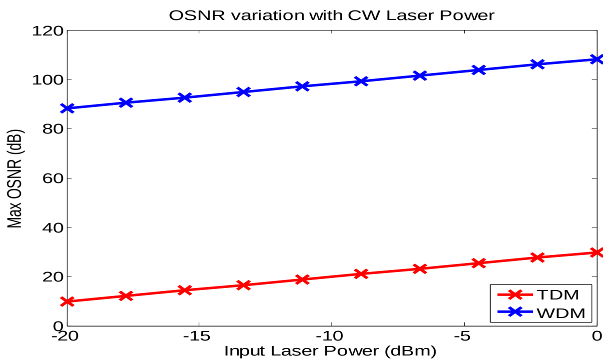

Figure 9. OSNR versus input laser power.

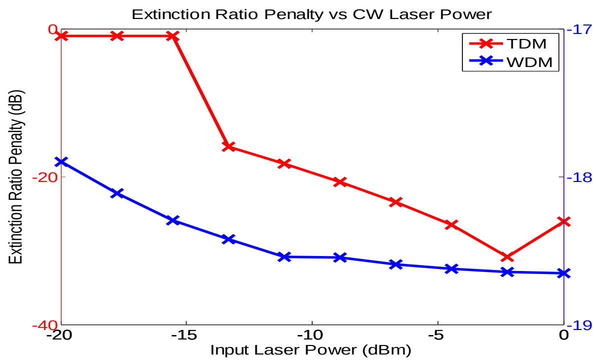

Figure 10. Penalty extinction ratio versus input laser power.

The results show that an acceptable quality signal for TDM PON is not received even at an input laser power of –11.111 dBm. At this stage BER is 1.47952 e −05 which is below the maximum tolerable limit of 10^{-12}. OSNR is 18.7437 which is also below the minimum limit of 20 dB. Q-factor reaches a very small value of 4.17577 and eye opening is also negligible (9.7238e −007). A smaller eye opening alternatively means that it is difficult for the decision circuitry to distinguish between '1' and '0' at the receiver end. Hence there is an increase in the bit error rate. On the other hand, even at very low laser power of –20 dBm, we receive a good quality signal in WDM PON. For sure this power level can be dropped down further to check the cut-off limit.

Respective graphs reinforce our discussion. For our TDM PON Q-factor and BER rapidly increase or decrease with changing power levels whereas in case of WDM PON these parameters remain relatively stable.

Penalty extinction ratio shows a rapid and haphazard decrease with decreasing laser power in TDM PON whereas in case of WDM PON there is a smooth and minute decrease in extinction ratio penalty. Therefore, in WDM PON this power penalty can be overcome by introducing extra amount of power equal to the power penalty. While, in case of TDM PON, the behavior of this power penalty is unpredictable.

Lastly, Eye Height and OSNR values of WDM PON are much superior to the corresponding values of TDM PON.

4.2. Increasing Fiber Length

Total iterations are set to 4. Parameter "Length" of single mode optical fiber is increased from 25 km to 100 km in 4 equal steps. Length of DCF is also adjusted accordingly to provide dispersion compensation to the signal.

The results reveal that in TDM PON an acceptable quality signal is not received, even at 75 km of fiber length. At this stage BER of received signal is much below 10^{-12}. Also its OSNR goes below 20 dB, and for the fiber length of 100 km, the signal is completely lost. While in case of WDM PON a very high quality signal is received even at 100 km fiber length. For sure, it can be transmitted farther than 100 km. Length of optical fiber can be increased further to check the cut-off limit for our WDM PON.

4.3. Decreasing EDFA Gain

Total iterations are set to 10. Parameter "Gain" of EDFA is linearly decreased from 22 dB to 13 dB.

Results show a decrease in the signal quality with the decrease in EDFA gain but, for TDM PON this degradation of signal parameters is very rapid as compared to WDM PON. At lowest EDFA gain of 13 dB, an acceptable quality signal in TDM PON is hardly received, at the verge of lower acceptable limits. Here, BER is 7.0323e −12 and Q-factor has very low value of 6.7522 whereas, in WDM PON at 13 dB EDFA gain, a signal with high quality parameters is received.

5. Conclusion

From above discussions, we conclude certain advantages of WDM PON over TDM PON.

Our WDM PON is suitable to operate at low laser powers, thus avoiding non-linear effects and permanent refractive index changes in optical fiber caused by high powered lasers. It covers much longer distances than TDM PON. It has much better reception at low EDFA gains, thus reducing Amplified Spontaneous Emission (ASE) noise in the system, which is an inherent characteristic of EDFAs.

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