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Performance analysis of Hybrid WDM-TDM Passive Optical network (PON) and TDM NG-PON

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***Abstract*— Current passive optical networks like Gigabit PON (GPON) and Ethernet PON (EPON) and next generation PON (NG-PON) (e.g. 10 Gigabit Ethernet-PON (10G-EPON)) have their limitations, and have low flexibility as they are based on time division multiplexing (TDM) PON architecture. This paper proposes a hybrid TDM-WDM PON (H-PON) architecture which is analysed and compared with the TDM-PON architecture. The H-PON has higher scalability and hence is flexible, and has a longer reach than 10G TDM-PON. Using simulation, the performance is analysed for various fiber distances, using Q-Factor parameter and eye-diagrams in case of both H-PON and TDM-PON for 32 users, for 2.5 Gbps and 10 Gbps data rates.**

Optisystem simulation software package, which is an excellent tool, is used for simulating results, without the need for expensive equipment and complex setup.

***Index Terms*— passive optical network, PON, WDM, TDM, hybrid WDM-TDM, next generation PON, NG-PON, Q-factor, eye diagram.**

I. INTRODUCTION

NG-PON systems may suffer bandwidth limitations in the future, and they do not make use of the full optical bandwidth [5]. There are two 10 Gb/s PON systems recently standardized to extend current PONs and to satisfy the requirements of NG-PON1. These standards, defined by both IEEE and ITU-T, allow backward compatibility and coexistence with the current generation PONs (GPON and EPON). The IEEE and the ITU-T with the Full Services Access Network (FSAN) group, have defined their respective 10 Gb/s solution, namely 10 GE-PON and ITU-T XG-PON [4].

All these standards are based on TDM-PON which has its limitations. Using one wavelength for downstream and one for upstream data limits the average bandwidth per user and the available bandwidth of a single fiber is wasted. Also, it limits the system reach due to the high required splitting ratio (32, 64 or 128). [3]

A. WDM-PONs

TDM-PONs combine the high capacity provided by optical fiber with the low installation and maintenance cost of a passive infrastructure. The optical carrier is shared by means of a passive splitter among all the subscribers. Therefore, the number of ONUs is limited because of the splitter attenuation and the working bit rate of the transceivers in the central office (CO) and in the ONUs. Earlier GPON specifications allow for 32 ONUs at a maximum distance of 20 km from the OLT and 64 ONUs at a maximum distance of 10 km from the OLT. [6]. A multiwavelength source at the OLT is used for transmitting multiple wavelengths to the various ONUs. For the upstream direction, the OLT employs a WDM demultiplexer along with a receiver array for receiving the upstream signals. Each ONU is equipped with a transmitter and receiver for receiving and transmitting on its respective wavelengths. In the proposed architecure, the downstream and upstream transmissions occur in different wavelength windows.

B. Current PON Standards

Current passive optical networks (PONs) (Gigabit PON (GPON) and Ethernet PON (EPON)) will run out of bandwidth sooner or later due to the ever increasing bandwidth demand. Hybrid TDM-WDM PON architecture is able to meet the requirements of NG-PON. Hybrid TDM-WDM PON architecture has longer reach than 10G TDM-PON and has high scalability.

II. PROPOSED HYBRID ARCHITECTURE

The proposed H-PON architecture employs a different set of four wavelengths in both directions to increase the network capacity as is shown from Fig.1. Coarse-wavelength division multiplexing (CWDM) technology is used in the upstream, (with a wavelength spacing of 20 nm), because of their lower cost than dense-wavelength division multiplexing (DWDM) transmitters. DWDM is used with a channel spacing of 0.8 nm in the downstream (optical line terminal (OLT) side) because of the narrow frequency band that is defined by GPON standard.

In hybrid TDM-WDM PON each group of users share one wavelength in the time domain. In the case of four wavelengths (λ=4), for 32 users, each group will comprise of 8 users. The system transceivers capability is 2.5 Gbps, considering the existing GPON transceivers. Typically the input power is between 0 dBm to 5 dBm.

Table 1: Downstream and Upstream wavelengths for H-PON

Downstream Wavelengths (nm)	Upstream Wavelengths (nm)
1496.0	1270
1496.8	1290
1497.6	1310
1498.4	1330

In [3], the authors propose a Hybrid WDM-TDM PON system to obtain a better performance than TDM PON. The hybrid architecture combines TDM and WDM technologies. The performance in terms of the highest possible reach and

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data rate is evaluated and compared with traditional TDM-PON, without any amplification.

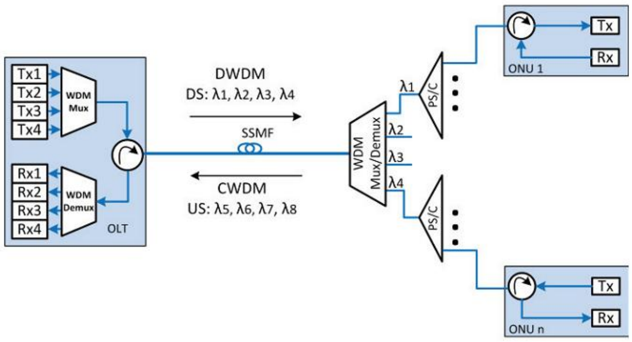

Fig. 1: Proposed Hybrid WDM/TDM-PON architecture as per [3].

III. SIMULATION RESULTS & ANALYSIS

Performance analysis is based on Q-factor. Bit-error rate (BER) and Q-factor can be used interchangeably. Q-factor = 7 is equivalent to BER= 10^{-12}. For Q-Factor (more than 40) the BER will be zero, so we will not have an exact performance indicator [3]. Target Q-factor chosen here is 6. Any Q-factor of less than 5 has degrading performance which shows closing of the eye. Q factor of around 6 with good eye opening is considered fair performance.

This architecture has greater power budget capability due to reduction in the split ratio by four times. (4 wavelengths with four 1x8 power splitters are used). For comparison, TDM-PON architecture is simulated as per [4], with one wavelength for each direction. Analysis is done for 2.5 Gbps and 10 Gbps data rates for both architectures.

A. Simulation

Optisystem 13 software package is used for simulation. Outputs at Transmitter, Fiber etc. are analysed using Optical Spectrum Analyser (OSA) visualizer. Output at Receivers analysed using Bit-error Rate (BER) analyzers. Analysis is done for downstream. NRZ coding is used at transmitters. NRZ is the most suitable format for hybrid PON [7] .

At present, in the ongoing project, same architecture is considered for NG-PON analysis. Simulation is carried out using Optisystem 13 simulation software package. The transmitter, splitter and receiver (ONU) sections are shown in Fig. 4 and Fig. 5. Performance evaluation is based on Quality factor. Eye diagrams at output of ONU are also analysed. Analysis is currently done for downstream direction (OLT to ONU).

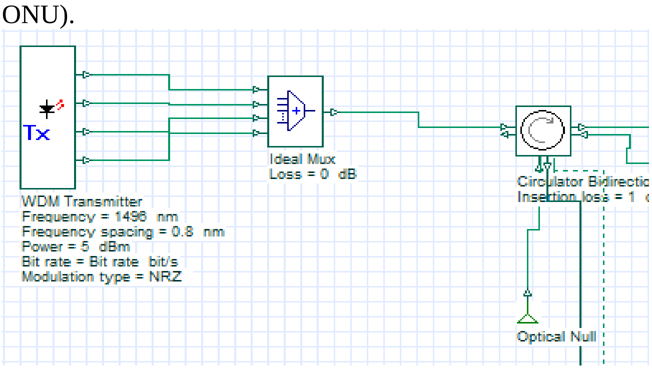

Fig. 4: Transmitter section of H-PON in Optisystem

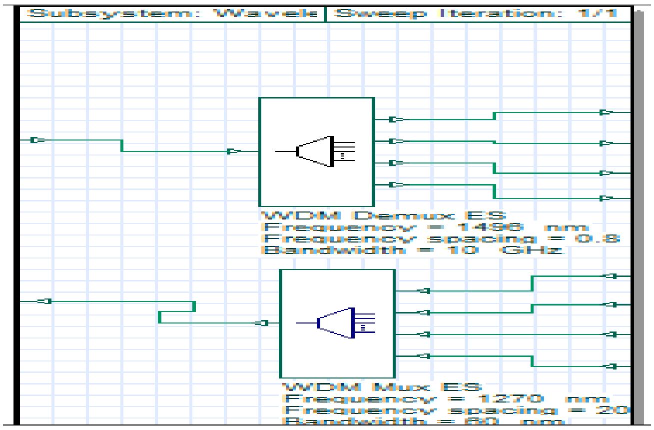

Fig. 5: Wavelength Splitter section of H-PON.

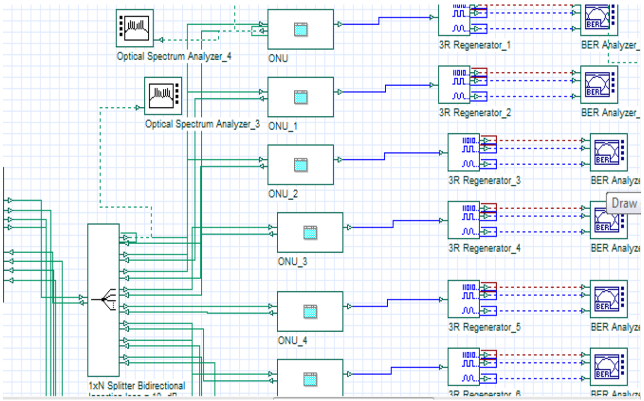

Fig. 6 Receiver ONU section of H-PON.

Following Parameters are used:
Hybrid-PON: 32 ONUs
Coding: NRZ.; Tx-power: +5 dBm, No optical amplifier, Optical fiber: α= 0.2 dB/km, Losses: Circulator: 1 dB, Power splitter (1x8): 10 dB, Mux: 2 dB, Demux: 2 dB.; Fiber length: 20km to 80km;
Approx Loss budget = 30dB

TDM-PON: 32 ONUs
Wavelengths: Upstream: 1496 nm, Downstream: 1270 nm, Coding: NRZ.;Tx-power: +5 dBm, Optical amplifier: +5dB, Optical fiber: α= 0.2 dB/km; Lossses: Circulator: 1 dB, Power splitter (1x32): 16 dB, Fiber length: 20km to 80km

B. Results

The Quality factor (Q-factor) for different fiber distances are tabulated in Table 2, for H-PON and TDM-PON. Figs. 6 a) and 6 b) show the plots.

Table 2: 10 Gbps comparison

10Gbps Hybrid-PON [no Opt. amp]		
Fiber Distance (km)	**Q-factor at ONU-1**	**min BER**
20	**10.5**	3.66e-26
30	**8.57**	4.75e-18
40	**7.86**	1.837e-15
45	**6.11**	4.57e-10
50	**5.66**	<1e-9
60	**4.16**	<1e-6

10G TDM-PON [5dB opt. amplifier after mux]		
Fiber Distance (km)	**Q-factor at ONU-1**	**min BER**
20	**7.983**	7.15e-16
25	**5.62**	9.49e-9
40	**2.37**	0.009

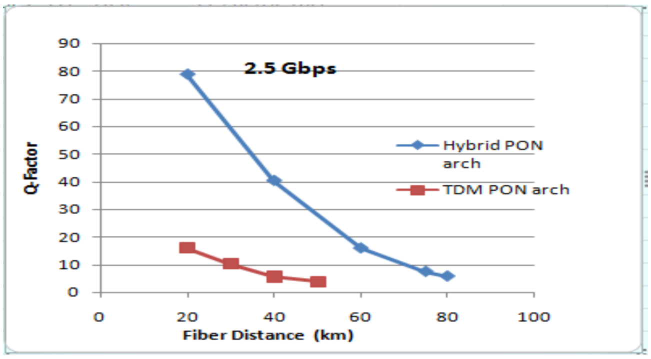

Fig. 7: Fiber distance vs Q-factor comparison H-PON and TDM-PON, for 2.5 Gbps;

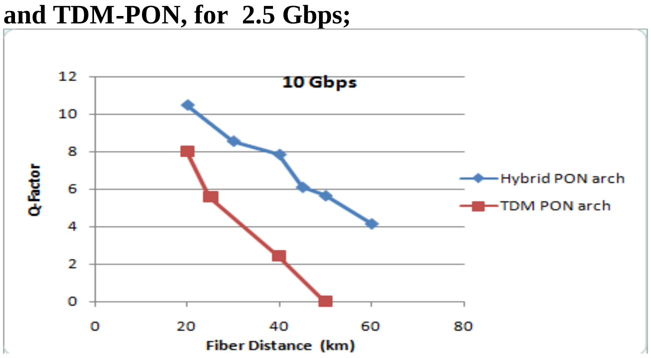

Fig. 8: Fiber distance vs Q-factor comparison, H-PON and TDM-PON for 10 Gbps

Eye Diagrams

Following eye diagrams are for the max distance possible with acceptable Q-factor, with good eye-opening. For smaller distances, the performance, and hence, the eye opening is better, and the results are not shown here

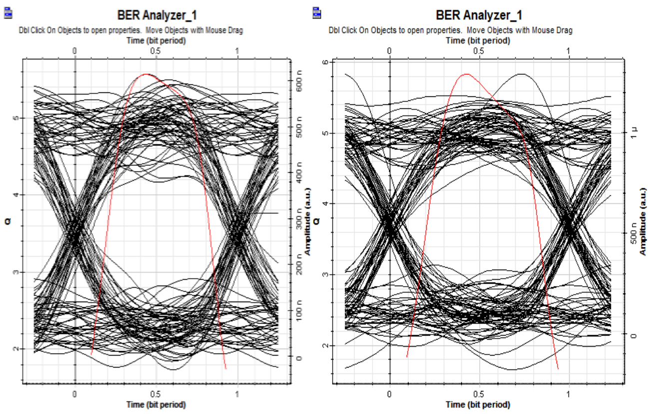

Fig. 9: Eye diagrams; a) Hybrid-arch 2.5 Gbps G-PON; 80km, Q = 5.8 and **b) TDM-arch 2.5 Gbps** G-PON; 40 km, Q = 5.83

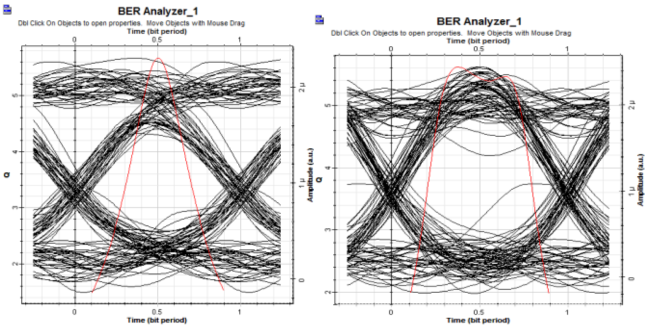

Fig. 10: Eye diagrams; a) Hybrid-arch 10 Gbps G-PON; 50 km, Q = 5.66 and **b) TDM-arch 10 Gbps** G-PON 25 km, Q = 5.62

IV. CONCLUSION

It is seen that the Hybrid PON (H-PON) network offers a longer reach than the existing TDM-PON networks, for similar loss budgets. H-PON offers very good performance at 2.5 Gbps, than TDM-PON architecture, with Q=5.8 for upto 80 km, but TDM-PON cannot sustain beyond 40 km for same Q. For 10 Gbps, acceptable performance in downstream, (Q=5.7 at just below 50 km) is achieved by H-PON, whereas TDM PON performance degrades just before 25 km (Q=5.62) even after using an optical amplifier. Also the H-PON network is highly scalable. Hence H-PON architecture performs better than TDM architecture at the same data rate, without any optical amplification. Further analysis needs to be done for 64 users or more, which is defined by 10 XG-PON standards. Also, research is required for types of receivers to be used at ONUs and OLTs to further extend the reach (>100km) so that it can perform as a long reach (LR-PON), as we can see that the hybrid architecture is very feasible for long-reach PONs.

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