

Performance Evaluation of Next Generation Access Network Architectures

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Abstract

With the emergence of new bandwidth hungry applications, there is a bottle neck in the current access network architecture. This paper gives an overview of what an access network architecture is, the simulation results of different Passive Optical Network architectures currently being used and the requirements of the future generation access network.

Keywords—Access Networks, FTTx, Passive Optical Networks, EPON, WDM-PON, Hybrid PON.

I. INTRODUCTION

Emerging bandwidth hungry applications like video on demand, High definition TV (HDTV), video conferencing, high quality audio transmission and data traffic have tremendously increased the bandwidth demand which cannot be met by the current access network infrastructure. An Access Network encompasses the elements between a local office and the subscriber. We are moving from voice dominated scenario towards high speed data centric network platforms which also require quality of service (QoS) guarantees in terms of packet delays and throughput. The current access network architectures can provide them with a high operational cost, which prohibits the network from delivering integrated services to the end users.

Passive optical networks (PONs), appears to be a promising solution for FTTx (Fiber to the Home, Building or Curb). Due to fiber gain and low cost of maintenance, it is currently employed worldwide [1]. Multiplexing techniques like time division multiplexing (TDM) and wavelength division multiplexing (WDM) methods are currently studied for use with PON.

The existing TDM-PON (Time-Division Multiplexing Passive Optical Network) technologies [2] cannot meet the user demand as the demand exceeds the existing network capability. The best way to tackle this problem is by installation of new fibers in the field to increase PON coverage. This results in wastage of bandwidth available on a single strand of fiber. Also there is a constraint on the ONU splitting ratio and distance between the ONU and OLT. The bandwidth wastage problem can be mitigated by the using WDM (Wavelength Division Multiplexing) technology. This does not require any drastic change in the fiber infrastructure. But this again faces major challenges like high initial cost of set-up, high cost of WDM components and need for temperature control methods as wavelengths tend to drift with

environmental temperatures. Though it provides a larger bandwidth, each and every ONU doesn't have continuous data flow requirement and doesn't need larger bandwidth all the time. From cost point of view, this may not be the optimum solution. Hence, we go in for Hybrid TDM/WDM-PON concept. The hybrid PON concept could fulfill the multi application scenario requirements and can provide a solution for the drawbacks faced by TDM PON and WDM PON.

This paper is organized as follows. Section II gives details on what an access network is and briefly explains the architectures used in the access network currently. Section III gives the simulation results and Section IV discusses the requirements for the future generation access network.

II. OPTICAL ACCESS NETWORKS

An Access Network (or the last mile network) is that part of a network which connects the Central Office (CO) and the Subscriber. A Digital subscriber line (DSL) and cable modem are the more predominant solutions in the access network, but this remains as a bottle neck as users are demanding high bandwidth in an inexpensive manner. The Access network should have high capacity, data rate and should be highly scalable. These requirements are met by Optic Fibre. Thus optical technology has become an attractive physical (layer1) medium for access networks. There are two ways in which a fibre can be used in the Access Network. In a point to point network, a dedicated fibre strand is used between each subscriber and the central office or a single fibre from the central office serves a number of subscribers. This fibre is brought to a neighbourhood where the signals are broken out onto separate fibres that run to the individual subscribers. The signals are split outside using electronic equipment near the subscriber called the Active Ethernet (AE) or the signals are replicated passively by a splitter called Passive Optical Network (PON). There are several advantages of PON

over AE. Since the outside plant has no electronic component PON offers lower cost than AE and it also provides lower operational cost since there is no need for the operators to provide and monitor electrical powering the field or maintain backup batteries. PON also provides higher reliability since the outside plant does not involve any electronic components which are prone to failure. There is transparency in signal format and upgrading to higher bit rates is simpler in PON.

The Various elements in the optical Access network using PON are the Optical Line Terminal (OLT), Optical Network Unit (ONU) and the splitter. An Access network is shown in Fig.1.

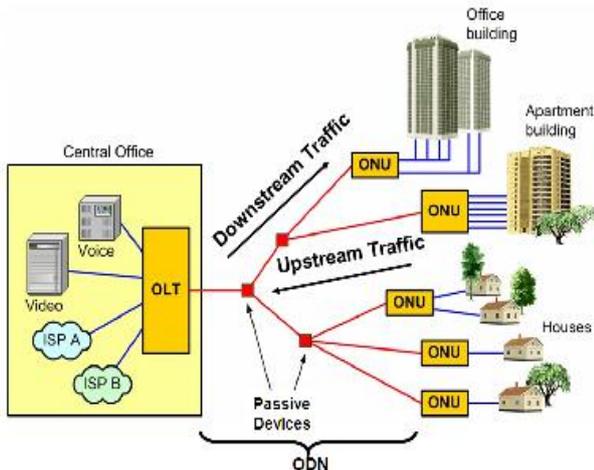


Fig.1 Access Network

The network that lies between the Central Office and the Subscriber is called the Optical Distribution Network (ODN).PON in Access Network is a point to multi point network (P2MP), where one wavelength is used in upstream mode and the other is used in downstream mode. It uses a single trunk fiber that extends from a central office called Optical Line Terminal (OLT) to a passive optical splitter, which then fans out to multiple optical drop fibers connected to subscriber nodes called Optical Network Units(ONU).A PON doesn't have any active element but provides higher bandwidth than the current solutions like DSL and cable modem. A maximum distance of 20 km can be covered by PON from the OLT to the ONU. The number of ONUs that can be connected is based on the splitting loss and decided by the bit rate of the transceivers in the OLT and ONUs. The total user cost is shared by all the subscribers in the network. Various flavors of PON such as APON, BPON, EPON, GPON (1Gbps), GEAPON (10Gbps) and WDM-PON have evolved as demand for bandwidth is growing

A. Ethernet PON (EPON)

EPON combines the benefit of low-cost Ethernet equipment and low-cost fibre infrastructure. This feature makes it the best candidate for the next generation access network [3]-[6]. The downstream

traffic in an EPON where the frames are sent to each of the ONU and the frame specific to the ONU is retrieved by their header information as shown in Fig. 2.

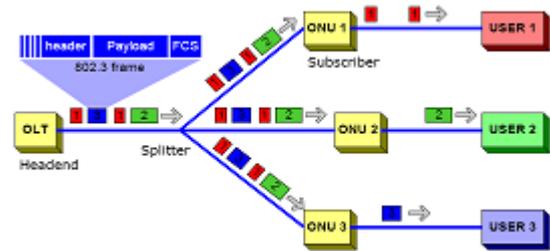


Fig.2 EPON Downstream Traffic

In case of upstream transmission, the frames are transmitted in their allocated time slots so that no collision takes place. Hence this type of PON is a Time Division Multiplexed PON (TDM PON).Fig.3 shows the upstream traffic in an EPON

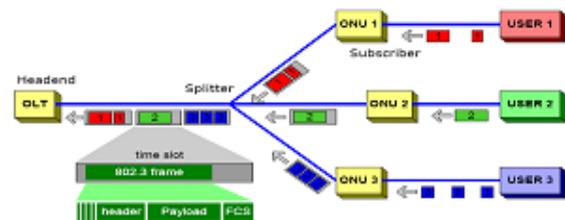


Fig.3 EPON Upstream Traffic

The use of EPON results in higher bandwidth, lower Capex-Opex costs and supports a broad range of services offering higher revenue. Multi point Control Protocol (MPCP) is used for dynamic bandwidth allocation.

B. Wavelength Division Multiplexing PON (WDM PON)

WDM PON is a point to point access Network which uses Arrayed Waveguide Grating (AWG) instead of the passive splitter used in EPON and a dedicated wavelength is assigned to each of the ONUs. Fig.4 shows a WDM PON.

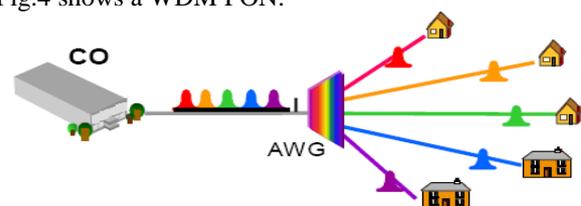


Fig.4 WDM PON

There are a number of advantages when WDM PON is employed

- ONUs can function with different bit rates.
- Each ONU can operate with its full bit rate.
- ONUs need not share Bandwidth.
- Power splitting losses are not present.

- Use of different wavelength improves privacy and reduces security problems.
- Periodic routing pattern of AWG makes WDM scalable.

A number of architectures [7]-[11] are proposed using WDM PON for the Next Generation Networks.

C. Hybrid Access Networks

When the number of users in the TDM PON network increases, upgrading the PON will be a great challenge. New fibre can be installed to meet the growing needs but then infinite bandwidth capacity of each strand of the fibre is wasted. Also TDM PON doesn't offer protection and restoration capabilities. In this context WDM PON is very much ideal. To provide the advantages of WDM PON and to integrate WDM PONs with the existing TDM based PONs, hybrid TDM WDM architectures [15]-[17] have been proposed.

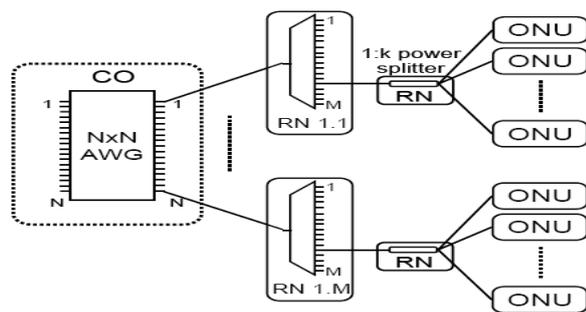


Fig.5 Hybrid PON

The architecture is depicted in Fig.5. Each output port of the AWG is concatenated by a remote node. A remote node contains a passive splitter and is connected to a number of ONU's. The AWG at the CO routes signals from a given laser port to different remote AWGs depending on its incoming wavelength, so each laser serves one TDM-PON sub-segment from a different remote node. And each laser is shared on time basis among all those TDM-PON sub-segments. This offers a very interesting feature to the network, which is to assign bandwidth on demand to specific network nodes depending on the network utilization. The total number of reached users is given by the product of N (ports of central AWG) by M (ports of the remote AWGs) by K (tree splitting ratio).

III. SIMULATION RESULTS

A Comparative study between TDM PON, WDM PON and Hybrid PON was made. EPON, WDM PON and Hybrid PON architectures were simulated and the following results were obtained. Estimating the bit error rate (BER) of an optical communication system currently requires expensive measurement equipment such as serial data analyzer and BER Tester. Besides cost, all this has limited BER estimation based on standard format and is not suitable for custom analysis. Hence in this simulation Q factor

and BER is calculated for different experimental conditions.

Fig.6 and Fig.7 shows the transmitter and receiver section of the EPON and WDM PON. The Electrical signal is modulated by the laser source. In EPON, the signals from different sources are combined by a power combiner which then travels through the optical fiber. At the receiver end the signal is then splitted by a power splitter and reaches several receivers connected to the splitter. Thus a broadcast signal reaches the receivers.

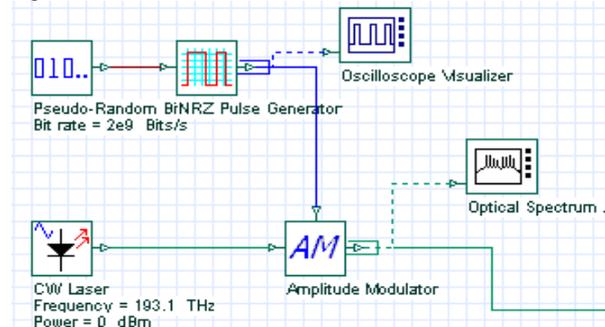


Fig. 6 Transmitter section of an EPON and WDM PON

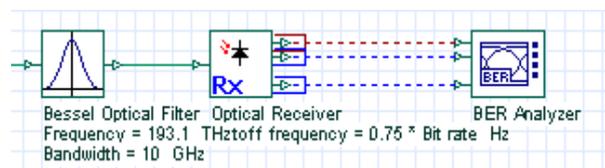


Fig 7. Receiver section of EPON and WDM PON

To combine the advantages of both EPON and WDM PON, many hybrid PON architectures have also been proposed in the architectures[15]-[17]. A simulation of these architectures were also carried out and the transmitter section and one receiver section of a hybrid PON is shown in Fig.8 and Fig.9 respectively. An ONU section has been shown in Fig.10 respectively.

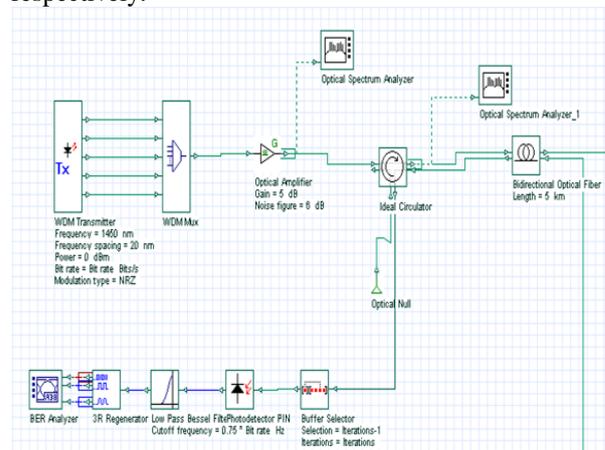


Fig.8 OLT section of Hybrid PON

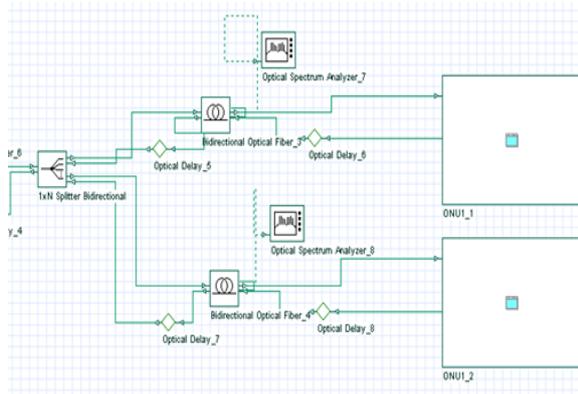


Fig.9 Receiver section of Hybrid PON

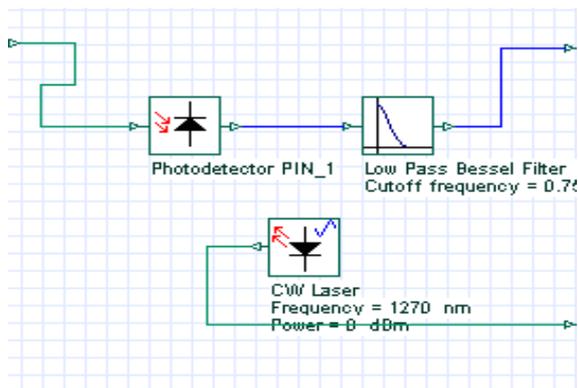


Fig.10 ONU Section of Hybrid PON

Some of the wavelengths from the transmitting section were solely used by an ONU depicting a high Bandwidth consumption user with a high data rate and some of the wavelengths were shared between users, depicting users of different kinds having various usage rates.

In Simulation results, it is observed from Fig.11 that as the data rate of the transmitted information is increased keeping the length, the number of users, power level, losses etc. constant, the Q factor is found to be decreasing for all three architectures. It can also be seen that the performance of the WDM PON is better compared to an EPON with significantly high Q factor and the Q factor of Hybrid PON is the best out of all the three.

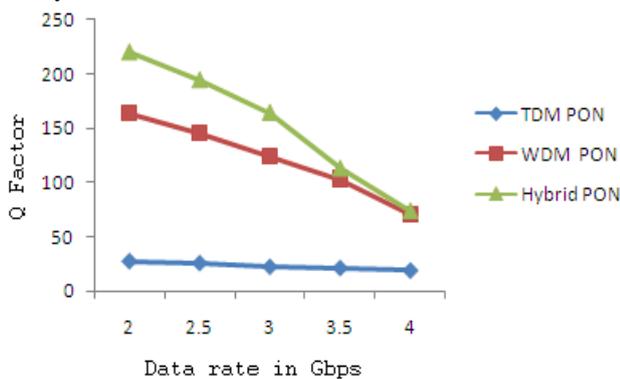


Fig.11 Data Rate Vs Q factor

Keeping the data rate, power level, number of users and other factors constant the same experiment was repeated for different lengths of the fiber. The results are depicted in Fig.12 for TDM PON, WDM PON and Hybrid PON respectively. The results again show that the Hybrid PON Performs better than WDM PON and its performance is better for long distances as compared to TDM PON as the Q factor is more than double the value of Q factor for EPON.

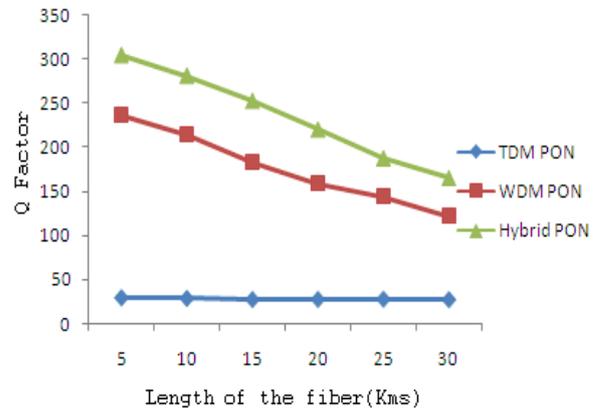


Fig.12 Length of Fiber Vs Q factor

In a similar experimental scenario, the power level of the transmitters is varied and the results do not show any significant improvement in increasing the power level of transmitters in WDM PON and TDM PON. The increase in Q factor of WDM PON is less as compared to increase in Q factor for a TDM PON. However Hybrid PON shows a significant increase in the Q factor value for the increase in Power level and hence provides lesser Bit error rate. This is presented in Fig.13.

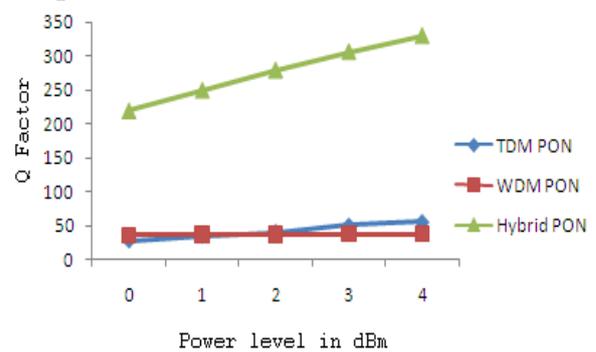


Fig.13 Power Level Vs Q factor

As the number of end terminals increase, again Hybrid PON proves to give better performance compared to WDM PON and EPON. This is shown in Fig.14. It is clear from the graphs that more number of users could be accommodated in Hybrid PON compared to WDM PON and EPON with a high Q factor value and low Bit error rate.

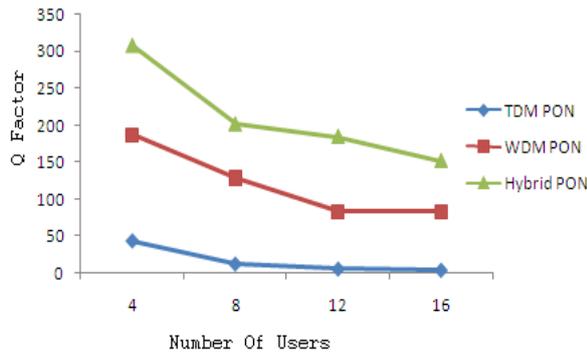


Fig.14 Number of Users Vs Q factor

The losses in the passive splitter were also analyzed. In case of WDM PON, the losses of the demultiplexer and multiplexer were considered. As the loss component increases the BER is found to be increasing, as expected. As the number of splitters is increased in the PON for increasing the range of PON and to support larger number of ONU's, it plays a detrimental role on the Q factor as shown in Fig.15.

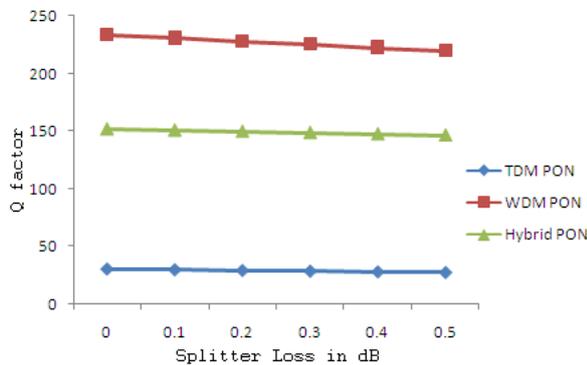


Fig.15 Splitter loss Vs Q factor

IV. NEXT GENERATION ACCESS NETWORKS

The Next Generation Access network (NG-AN) should be designed in such a way that it meets the increased capacity demands by increasing the bit rate per wavelength and also by increasing the number of channels. It should also allow the coexistence of current generation Networks and support heterogeneous access networks. It should also make sure that all these must be incorporated with minimal cost per user and lesser complexity.

The network survivability or the service availability is one of the key issues in high capacity networks. It is true for NG-AN, since the bandwidth will be very high. The protection and survivability against fiber fault will be essential for both business users and home users. Continuous monitoring and fast fault localization are also needed for efficient management. Future access networks must provide data security and integrity to its customers. The terminal equipment should be simpler in terms of administration and configuration as possible.

V. CONCLUSION

Of all the optical Access network Architectures, Hybrid architectures seems to be advantageous as it can combine the advantages of individual networks. It offers the necessary capacity and flexibility to cover the requirements of the future. Infinite bandwidth capacity of each strand of fibre can be well utilized. Depending on the network utilization bandwidth can be assigned on demand, business and home users can also be made to coexist in the same network while bringing down the cost. EPON has been prevalent across the globe and a gradual switch over from EPON to Hybrid PON does not seem to be impossible. These hybrid architectures can also be provided with protection and restoration capabilities and so it seems to be very attractive for the future Next Generation Access networks.

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