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ANALYSIS OF CAPACITY AND DELAY IN PASSIVE OPTICAL NETWORKS (PONS)

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Abstract- With the continuous increase in bandwidth demand generated by consumer and business applications, a new higher capacity access network is required. Today, with the development of electronic media and its usage most of the networks having more number of nodes and as the number of nodes increases in the network the communication over the network also increases. A reliable end packet delivery is the basic requirement of a user as well as network. Heavy traffic over any network gives the problems like congestion, degradation in throughput. There are number of such network in which different kind of data is being transferred in terms of multicast and broadcast. The growing popularity of internet, video on demand, video conferencing, and gaming are the key factor behind the development of new access method which would meet the bandwidth requirement. The Passive Optical Network (PON) and Gigabit Passive Optical Network (GPON) resolve most of the above defined problem. PON can reduce the packet loss and return reliable data transmission over the network. As PON provide large bandwidth

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that it will never gives efficiency problem in the network. The PON can also resolve the bottleneck problem along with the delay analysis over the bottleneck congested network.

Keywords- GPON, packet delay, passive optical network, throughput-delay analysis.

I.INTRODUCTION

The rapid growth of the Internet access and services such as the IP video delivery and voice over IP (VoIP) is accelerating demand for broadband access. While most of the broadband services around the world are delivered via the copper access network, optical access technology has been commercially available for several years and is being deployed in volume in some countries [1]. The rapid growth in both use and size of computer networks (wired/wireless) has sparked a renewed interest for increasing the networks capabilities to deliver more traffic with higher speed. Over recent years, optical communication networks have been deployed widely across the globe. With tremendous bandwidth offerings of optical networks in metropolitan and wide area networks (WANs), there still exists a bottleneck between local area networks (LANs) and the service provider's networks. This has a profound impact on the design of next-generation optical network architectures and technologies.

There are two major set of fiber-based technologies to be deployed in the access networks. One is active optical networks and other is passive optical networks (PONs). The former relies on active components in the subscriber loop (from CO to users) and in PON, there is no active device in the signals path between CO and subscribers. High capacity feature of multi-access optical networks with comparison to other access network technologies like cable, DSL and wireless access is the main motive of passive optical network exploitation [2].

II. EVOLUTION OF PON

Fiber-to-the –home and –business was a consideration from the earliest days of the optical fiber technology development. In the late 1970s point- to- point replacement of copper by the fiber was being

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considered as a way of delivering broadband services to customers. These early system was predicted on multimode fiber technology.

The first consideration of passive optical networks approach for the access network was around 1982 when single mode fiber technology was being seen as a possible new way for a forward optical communications. Single mode fiber offered many advantages as compared to multimode fiber, much greater bandwidth being one of the more obvious. For the future evolution of the optical networking was the ability to make high performance optical components. One component that became available fairly quickly with the arrival of single mode technology was the fused fiber directional coupler. These splitter or couplers can be cascaded and any size of splitter or star couplers can be made. These optical splitters were the key components behind the passive optical network concept. In the first half of the 1980s the passive optical network concept was centered on wavelength switched networks. These used star couplers to interconnect network terminations and wavelength selection to route path [3] across the network. At the same time ideas of using the couplers as simple passive splitters for broadcasting television signal were also being considered [4].

In the mid 1980s BT became interested in the possibilities offered by optical access and this led to a refocusing of passive optical network approach. The operational unit brought a much needed business focus to the research and challenged the research team to develop a system that could be economical for telephony. This was a service with a known revenue structure s opposed to the unknown revenues from future broadband services. This approach became known as “telephony entry strategy” and led to invention and development of “TPON” (telephony over passive optical network) system [5] [6].

TPON was TDM based and the early system had a limited bandwidth of 20 Mbit/s, adequate for telephony and ISDN but not for broadband. Broadband would be added later, as an upgrade, by addition of extra wavelengths. To facilitates this a blocking filter was added to the TPON ONUs, which only pass

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the original TPON wavelength and block all others, enabling addition wavelengths to be added to the PON at a later stage without disturbing the original telephony only customers. However, the system was never rolled out on any significant scale the upgrade system (called BPON at the time) was never developed into a commercial product. At the end of the eighties BT was developing an ATM version of Passive Optical Network called APON. Also around this time optical amplifiers were emerging as a network component. At the end of eighties and early nineties several experiments were performed at BT Labs that demonstrated the real potential of passive optical networking approach and culminated in the publication of initially a 32 million way split network delivering 12 wavelength at 2.5 Gbit/s each [7].

During the early nineties BT continued with the design and development of a practical amplified PON architecture, it became dubbed as Super PON. This examined the design and implementation option of a passive optical network that could service a split of up to 3000 and have a geographical range up to 100 km. The capacity was 1.2 Gbit/s downstream and 300 Mbit/s upstream. At the time these bit rates were very ambitious for optical access and were considered to be the limits for low costs customers equipment.

In the mid nineties BT, Deutsche Telekom and NTT decided, with other operators, to set up a consortium to develop and standardized PON requirements and systems , this forum became FSAN [8].

In recent years, PON systems have continued to be developed, largely along FSAN guidelines and mainly in the small/start -up company arena. More recently Japan, Korea and the US have revitalized interest in the supply industry and PON access solutions are once becoming the access solution of choice as FTTH deployment progresses into 21st century.

III. PASSIVE OPTICAL NETWORK

The Passive Optical Network (PON) is one of the most widely deployed access networks due to its unique benefits, including transparency against data rate and signal format as well as high data rates and

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reliability [9]. The PON is an access network based on Optical Fiber. It is designed to provide virtually unlimited bandwidth to the subscriber. A Passive Optical Network is a single, shared optical fiber that uses a passive optical splitter to divide the signal towards individual-subscribers. Fig1. depicts a common PON architecture supporting different FTTx scenarios. The optical elements used in such networks are only passive components, such as fibers, splitters/couplers and connectors. The optical path that consists of these components is called Optical Distribution Network (ODN). The Optical Line Terminal (OLT) resides in CO, connecting the optical access network to an IP, ATM, or SONET backbone. An Optical Network Unit (ONU) is located at the curb (FTTC solution), or Optical Network Terminal (ONT) is located at end user location (FTTH, FTTB solutions) to provide broadband voice, data and video services with guaranteed quality of services. While FTTB and FTTH solutions have fiber reaching all the way to customer premises, FTTC may be the most economical deployment today [10], leaving room for alternatives technologies such as DSL or even wireless to implement the last drop.

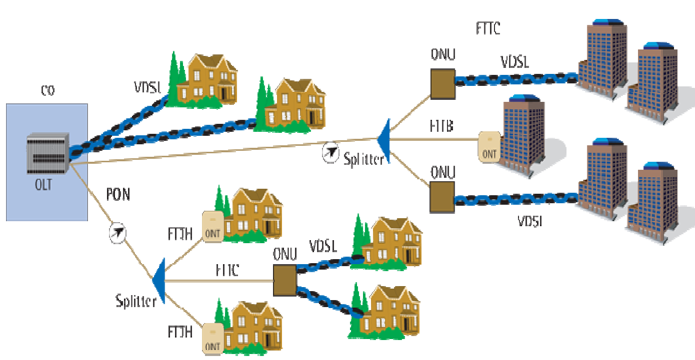

Fig1. PON Architecture

All transmission over the ODN of the PON occurs from or towards the OLT, as ONUs or OLTs do not communicate directly with each other. The P2MP transmission from the OLT to ONUs/ONTs is called

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downstream and the P2MP transmission from the ONUs/ONTs to OLT is called upstream. The downstream and upstream signals are carried on same fiber.

Due to passive interconnection of nodes, and shared medium among users, a multiple access scheme is required to avoid collision. In all networks, multiple access schemes are accomplished by resource sharing in either of space, the time, the frequency, or the code domains. The four basic multiple access techniques that have been extensively investigated and applied to current optical fiber networks are comprised of, Wavelength Division Multiple Access (WDMA), Subcarrier Multiple Access (SCMA), Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) schemes [11]. Multiple access optical networks grasp best of both optical and electrical worlds, i.e. the routing and transport from optics and buffering and processing from electronics.

IV. PON TECHNOLOGIES

There are four types of PON-based technologies namely Broad band PON (BPON), Ethernet PON (EPON), Gigabit PON (GPON) and Wavelength Division Multiplexing PON (WDM PON).

a) **BPON:** The Broadband passive optical network (BPON) was the first attempt towards a PON standard. It is governed by the ITU-T and is designated as ITU-T G.983. It established the general requirements for PON protocols. BPON use Asynchronous Transfer Mode (ATM) as the underlying transport mechanism to carry used data. BPON did not gain much popularity due to lack of bandwidth and widespread use of Ethernet protocol.

b) **EPON:** The Ethernet Passive Optical Network (EPON/GE-PON) is governed by IEEE and is designated as IEEE 802.3ah. EPON is based on Ethernet, unlike other PON technologies which are based on ATM. It provides simple, easy-to-manage connectivity to Ethernet-based IP equipment both at the customer premises and at the central office. It is well suited to carry packetized traffic as

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well as time-sensitive voice and video traffic. It offers 1.25Gbps data rate for both upstream and downstream. EPON supports 1:16 split ratio i.e. 16 ONUs at a range of 20 km can be connected with a single port of OLT.

c) **GPON:** The most recent PON standard is the ITU-T G.984 GPON(Gigabit PON) standard, which offers 2.488 Gbps bandwidth and direct support of both TDM(POTs & E1) and Ethernet traffic at the edge of the network with possible triple play voice, data and video services on the same PON. GPON can support ONUs that are located as far as 30 Km from the OLT. GPON offer higher split ratio of 1: 32/64/128 which results in an OLT reduction by more than a factor of 2 over EPON.

d) **WDM PON:** The wavelength division multiplexing passive optical network (WDM PON) is the next generation in the development of access networks and offers high bandwidth. In WDM PON architecture, ONUs operates on different wavelengths and hence higher transmission rates can be achieved. Much research has been focused on enhancing WDM PONs ability to serve large numbers of customers in an attempt to increase revenue from invested resource. As a result, some hybrid structures have been proposed where both WDMA and TDMA are used to increase the number of potential users. For DWDM, the ONUs requires expensive, frequency stable, temperature -controlled lasers. The OLT puts the entire wavelength on to the feeder fiber and the splitter replicate the wavelengths to each home [12].

V. RELATED WORK

In this section we briefly review the related work on the analysis of passive optical network. Only a few existing studies have attempted to analyze various aspects of PON.

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Yun Wang et al. [13] give a global perspective of multicast capacity and delay analysis in Mobile Ad-hoc Networks (MANETs). Specifically, authors consider two node mobility models: (1) two-dimensional i.i.d. mobility, (2) one-dimensional i.i.d. mobility. Two mobility time-scales are included in this paper: (i) Fast mobility where node mobility is at the same time-scale as data transmissions; (ii) Slow mobility where node mobility is assumed to occur at a much slower time-scale than data transmissions. The delay and capacity tradeoff for Motion cast was studied by Xinbing Wang et al. [14].The author utilized redundant packets transmissions to realize the tradeoff and present the performance of the 2-hop relay algorithm without and with redundancy and find that the capacity of 2-hop relay algorithm is better than that of static networks when k=o(n).

J. S. Vardakas et al. [15] present and analyze three basic dynamic wavelength allocation scenarios for a hybrid wavelength division multiplexing-time division multiple access (WDM-TDMA) PON. Author also presents new tele-traffic loss models for calculating call-level performance measures, like connection failure probabilities (due to unavailability of a wavelength) and call blocking probabilities (due to the restricted bandwidth capacity of a wavelength). The PON accommodates bursty service-classes of ON-OFF traffic and the models are extracted from one-dimensional Markov chains, which describe the wavelength occupancy in the PON, and two-dimensional Markov chains, which describe the bandwidth occupancy inside a wavelength. A new Dynamic Bandwidth Allocation (DBA) called MHPP (Maximum High Priority Proportion) to reduce packet loss rate and packet delay for high priority traffic is proposed by M. V. Dolama et al. [16] MHPP first grants those Optical Network Units (ONUs) that have more high priority traffic in their granted bits. Hence, the order of ONUs is changed in every transmission cycle based on the proportion of high priority data to granted bits. The performance evaluations show that the MHPP algorithm can significantly reduce packet delay and packet loss for high priority traffic.

A dynamic bandwidth assignment protocol is proposed by C. H. Chang et al. [17] that demonstrates impartial and highly efficient bandwidth arrangement for gigabit-capable passive optical networks. In particular the novel algorithm automatically modifies the assigned bandwidth per optical network unit to support quality of service and service level agreement according to maximum network capacity and users' queuing status. Network simulation results have demonstrated superior mean packet delay performance achieving a tenfold reduction of packet delay at high network load when compared to other dynamic bandwidth assignment algorithm. Luo and Ansary [18-19] propose and analyze a DBA scheme with traffic prediction, whereby a prediction error is assumed to be Gaussian. The average delay is expressed in term of Gaussian prediction error distribution.

P. Robert et al. [20] introduce an original MAC protocol for a passive optical metropolitan area network using time-domain wavelength interleaved networking (TWIN). Optical channels are shared under the distributed control of destinations using a packet-based polling algorithm. This MAC is inspired more by EPON dynamic bandwidth allocation than the slotted, GPON-like access control generally envisaged for TWIN. Management of source-destination traffic streams is flow-aware with the size of allocated time slices being proportional to the number of active flows. The proposed MAC is shown to have excellent performance in terms of both traffic capacity and packet latency.

J.S. Vardakas et al. [21] investigate the performance of a simple PON configuration, in term of the end-to-end packet delay. The network supports multiple service-classes with priorities, in terms of the number of packets that can be transmitted in each transmission period and calculate the mean queuing delay of a packet, by taking into account the fact that packets are serviced in batches. The queuing delay is defined through the formulation of two queuing models; an M/D/1 model for the batches, and an M/D/m model for the individual packets. Author also studies the effect of the packet arrival rate of different service-classes, and the effect of the distribution of the packets into a frame, on the end-to-end packet delay.

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V. G. Vassilakis et al. [22] studies the call-level performance behavior of two Passive Optical Network (PON) configurations in the upstream direction: an Optical Code Division Multiple Access (OCDMA) PON and a hybrid Wavelength Division Multiplexing (WDM)-OCDMA PON. Each PON accommodates 2K service-classes, which are grouped in two service priorities.

A plethora of metropolitan area wavelength-division multiplexing networks have been proposed by M. Maier et al. [23] and examined in recent years with the aim to alleviate the bandwidth bottleneck between increasingly higher-speed local/access networks and high-speed backbone networks. Many of the considered metropolitan area networks use the arrayed waveguide grating as an optical building block. Author give an overview of star metro WDM networks that are able to meet modular upgradability, transparency, flexibility, and efficiency, reliability, and protection requirements of future metro networks. AWG-based star networks also enable an evolution path of ring networks toward highly efficient and fault-tolerant hybrid star-ring metro network solutions.

Hyo-Sik Yang et al. [24] studies that both wavelength-division-multiplexing (WDM) networks with ring architecture and WDM networks with a star architecture as solutions to the ever increasing amount of traffic in the metropolitan area. Also evaluate mean aggregate throughput, relative packet loss, and mean delay by means of simulation for Bernoulli and self-similar traffic models for uni-cast traffic with uniform and hot-spot traffic matrices, as well as for multicast traffic.

Kyeong Soo Kim et al. [25] provided two new scheduling algorithms- BEDF and S^3F , providing efficient and fair bidirectional communication between the OLTs and the ONUs in the WDM-PON under the success H-PON architecture. The goal is to overcome the low transmission efficiency and the poor fairness guaranteed between the upstream and downstream traffic flow of original sequential scheduling algorithm. To achieve this goal, batch scheduling mode is adopted in BEDF to do optimization in scheduling with batch of frames. In S^3F, sequential scheduling mode is maintained as in the original

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sequential scheduling algorithms but grants are used for downstream traffic as well, in addition to upstream traffic, together with schedule time framing to reduce the overhead due to framing and guard bands.

VI. CONCLUSION

Among the different optical access architectures, Passive Optical Network provides unique advantage because of its passive nature and reduced operational costs. In this paper we have studied that passive optical network resolves the congestion and degradation in throughput like problems when data is transferred over the network. The architecture of PON is simple, cost effective and offered bandwidth that is not possible by other access methods.

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