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Dynamic Bandwidth Allocation Energy Efficient Operation for WDM/TDM PON Architectures: A Survey

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Abstract

During the past decades, technology has been revolutionized the world in various fields, including networking and communications. With the continuous increase in the number of users (subscribers) of communication technology and development of communication services, led to increase the need for a larger bandwidth in order to send/receive more data with higher speed. Therefore, it was necessary to make a change in the field of networks and communications also and continuously to meet end-users demands and taking the cost in to account. Moreover, energy-efficient networking it's a significant point and should be improved. Providing an efficient usage of PON upstream bandwidth by DBA in PONs presents a main issue during supporting the QoS requirements of various traffic classes. This study will review and investigate the Dynamic Bandwidth Allocation (DBA) energys efficient operation approach for WDM/TDM PON network architectures with a brief discussion of its related technologies and techniques as well as technical characteristics and its deployment in order to increase the efficiency of the access network

Keywords: Dynamic Bandwidth allocation, WDM, TDM, PON, ONU, OLT, FTTH, APON, EPON, GPON.

1. Introduction

The development of communication technology and its services in different aspects of life, led to enormous increasing in the number of users continuously. Moreover, this needs a larger bandwidth to transmit more data in a higher speed in order to accommodate all users demands. Hence, the next-generation of PON technologies became more popular research topic in the recent years and the optical access networks that based on PON technologies is increasing rapidly in worldwide deployment [1]. However, the basic requirements for the end user and the network is reliability in delivering data. There are many reasons which causes losing data during transmission over the network such as congestion [2].

One important point of the research topic is allocating network resources efficiently. However, managing resources is a challenge in PONs, which made a lot of attention [3], [4] . Minimizing energy should be considered in managing resources scheme, as it could be seen in communication network a part of the overall energy is consumed in access networks [5]. It is expected to rely the wavelength division/time division multiplexing (WDM/TDM) techniques to increase the capability of the PONs. However, this will improve managing wavelength resources as well as bandwidth, but a new challenge will present to the previous techniques as cutting down consumption of energy is still desirable[6] .The main idea here is to review, investigate and make a comparison of different PON standards as well as WDM/ TDM which emerged using various characteristics in order to increase the efficiency of the access network.

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2. Literature review

Rini T. Jacob and Vidya Raj conduct the Unidirectional TDM PON and WDM PON performance assessment. The optical fiber is expected to support many consumers with passive components. Different PON-unidirectional technologies, such as Time Division Multiplexing Passive Optical Networks (TDM PON), and the Wavelength Division Multiplexing Passive Optical Networks (WDM PON) are simulated, using software OptiSystems 12.0 based on the consistency factor (Q) and the Bit Error Rate (BER). In the study, the efficiency of the 2-user systems symmetric WDM PON was higher than the 2 user systems of the TDM PON system with a high Q factor and low BER [2] . Felix Obite et al. examined trends in the Ethernet Passive Optical Network (EPON) and future trend by reviewing existing implementation procedures for future high-rate access networks such as Next-Generation Passive Optical Network Stage 2 (NG-PON2), Multiplexing Wavelength (WDM) PON, and O. The Ethernet Passive Optical Networks (EPON2) were also addressed. This thesis concludes with proof that optical technology continually develop in the direction of faster speeds, expanded wavelength and higher budgets for loss [7]. Jawad Mirza & al estimates the cost-effective and efficient single-mode, hybrid 32x5 Gbps, hybrid 32x5 Gbps ultra-dense multiplexed-passive optical grid architecture utilizing optical comb and polarization multiplexing to transfer wired grid traffic over an existing passive optical network to the next generation It was observed that the recipient resistance to a 0.06 ps.km-0.5 dispersion is approx. -22 dBm in polarization mode and approximately -20 dBm in heavy turbulence [8] . The GPON and EPON transmission, based on the standard VPON OLT management framework, is assisted simultaneously by GPON and EPON in the metro-access optic network of Yuchao Zhang et al. Digital access mechanisms are developed to dynamically change the configuration of VPON. The authors plan to delegate bandwidth to GPON and EPON subnetworks equally. This algorithm will avoid hegemony of high-load sub-network bandwidth when load of one sub-network is far higher than the other to support 2 different standards, compatible multi-standard management mechanisms for VPONs and the system and algorithm are known to be strong in their efficiency [9]. Two bandwidth-management strategies have been researched to improve the proposed algorithm aimed at future relocation of end-user equipment (OPU, UN) in an effective allocation of ONU per pair of wavelengths as far as is possible (downstream-upstream). By proposing the TWDM-PON methodology, which incorporates three solution lines. As a result, certain control interfaces can be turned off and a level of energy conservation is ensured. In parallel, two methods have been introduced for having a U.N. adaptive record to enhance the efficiency of the UNs who move and/or join the network, thus preventing collisions and increasing their probability of being registered at the OLT [10]. Also C. Christodoulou et al. have carried out scheduling algorithms for converged WDM-PON ring-based cell backhaul travel and have suggested d for downstream Wavelength preparation in ring-based WDM-PON traveling reverse-control networks, where optical networking units (ONUs) have been built into base stations (BSs). Dynamic wavelength preparation and sharing in a converged WDM-PON access architecture take the goals of the data forwarded and even the field of collaboration between neighboring ONUs and BS users into account. In order to assess the network output with a maximum time for the packet delivery[11], they tested l-heuristic algorithms and optimization algorithm d under various traffic load and queue scenarios. OLT Architecture Strategy for Resilient Expanded PON with OBS Dynamic Bandwidth Allocation Sharing the Fiber-To-The Home (FTTH) for OLT and Josep Segarra and others are exploring and proposing potential connectivity networks for the next decade. It is built on a versatile Hybrid WDM/TDM architecture that provides resilience with Remote Nodes (RNs). It was analyzed and observed that simulations of SRD and LRD traffic and priority queuing were tested on all OLT principles. Two TLDs have been simulated with the configuration with TLDs in the optical regions and evenly distributed to various tPONs. The findings show that the use of common TLDs does not dramatically increase the time lag, while improving network performance and security failures [12] . Cost-efficient introduction and power-efficient operation of long-range wda-multi and time split wavelength multiplex wavelength and time division multiplex passive network systems with long-range WDM/TDM PON systems by Hao Feng et al. The result was a saving in energy of up to 35 percent at minimum traffic requirements. Furthermore, we can achieve a typical 20 percent energy savings compared with traditional fully operating systems on a daily basis in terms of energy consumption[13] . Also Dibbendu Roy et al. conducted A Cost-efficient Bandwidth Allocation Protocol for Fog Computation over EPON for traditional dynamic bandwidth allocation (DBA) systems for PON. Before the upstream propagation of all other UNs shows poor usage, the transmitter stays idle for a UN (ONU) During these free cycles the arranging of fog services will result in increased transmitter use. Authors proposed to allow fog facilities, a DBA protocol and its architecture. Our design uses a single line card at the United Nations which provides significant cost and energy savings. The authors find it possible to slash costs per UNU by $87 and conserve electricity of 5W per UNU in contrast to offers with different transceivers in the UN. The proposed DBA increases the load resistance by around 300%, which is very desirable for a retarding fog network, to retain a 10 ms delaying binding and an increase in the efficiency by around 20% at high load. The location of the fog node in a remote node allows the fog node to function in larger loads while holding the late position at OLT tied [13] . Md Shahbaz Akhtar et al. carried out an effective TDM/TWDM PON modeling approach based on ILP CapEx and OpEx to identify processes and algorithms to simplify the network architecture and preparation so as to minimize as much as possible the total costs due to the capital investment and operating expenses. To minimize overall costs. The model selects the number, form, splitting ratio and position of passive devices based on a number of connected users in optical network units (NUs), need of user bandwidth, power budget, maximum distance from the optical terminal (OLT) to user, number of wave lengths and OLT ports and particular region of UNOs, the OLT and RNs. Optimum PON architecture is properly known as multiplexing time division or wave-length multiplexing (TWDM). It offers detailed connectivity information for all network devices, total cost, and number of OLT ports, number and related wavelength data speeds. They present detailed data for two urban and rural areas with separate UNO numbers and bandwidth demands from consumers. They also present findings from selected OLT, ONUs and RNs positions from Google map [13].

3. Passive Optical Network (PON)

A PON refers to a fiber-optic access network which is using a topology point-to-multipoint as well as optical splitters in order to deliver the data to multiple users' endpoints from a single transmission point. Passive, which means no source of power is used in the fiber components (splitting/combining). It requires electrical power only at the sending and receiving points. Consequently, it makes PON inherently efficient from the viewpoint of operating cost. Basically, the PON consist of many Optical Network Units (ONUs) close to end users and an Optical Line Terminal (OLT) in the central office. PONs used to transmit the signals simultaneously in both direction upstream and downstream to and from the user's locations [1].

OLT is a hardware device that located at in the end point of PON system. It performs two essential functions: first, it converts the fiber optical service standard signals into a kind of frequency and frames which used by PONs system. Second, coordinate multiplexing among conversation devices which used in the other end points of the network, it could be OLTs or ONUs[14].
ONUs located in the other end points (end users), it collaborates with OLT to control and monitor PONs transmission and it provide services to the end users (sorting packets according to users)[15].
Optical Distribution Points (ODP) provides a connection point at the user's access point (pole or building or outdoor wall) between distribution cables and drop cables which provided by splitters in fiber optic network[16] . Figure 1 shows the basic design of PON architecture

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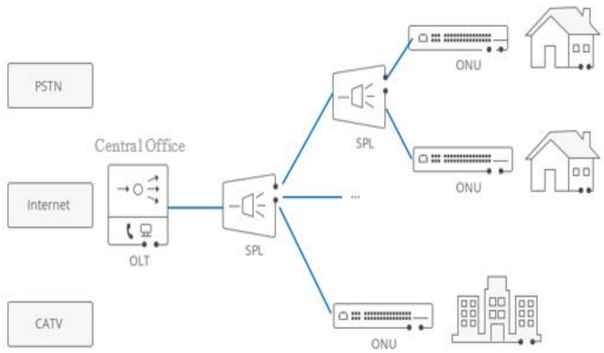

Figure 1. Basic PON architecture

4. WDM/TDM PON

For improved resource utilization and power, TDM and WDM techniques are implemented in PON, resulting respectively in TDM-PON and WDM-PON. The TDM-PON bandwidth for the data program is much higher, but it has reduced end-user availability. WDM PON can solve problems in TDM-PON by assigning each subscriber a specified wavelength. Therefore, each subscriber has a different, stable P2P channel with a fast data rate. This article offers you a description of the TDM-PON and WDM-PON applications and the joint program, TWDM PON.

4.1 Wavelength Division Multiplexing (WDM)

According to [1], [13] Wavelength-Division Multiplexing Passive Optical Network (WDM-PON) is a technology that assigns specific wavelengths to each PON network, allowing Optical Network Units (ONUs) to transmit light at different wavelengths over the same fiber. This approach enhances network capacity and increases the number of connected users in the optical access network. Depending on the communication mode, WDM-PON can be configured as point-to-point, point-to-multipoint, or a hybrid solution. In point-to-point mode, no complex resource allocation is required, while point-to-multipoint combines WDM and Time Division Multiplexing (TDM) to achieve higher resource efficiency. Unlike TDM PON, which uses a single wavelength for multiple channels with modest bandwidth, WDM PON employs multiple wavelengths to expand bandwidth without increasing the data rate. Both approaches are valid and require careful evaluation based on network requirements.

WDM-PON has been researched for over a decade, with various architectures proposed to improve broadband connectivity. A typical WDM-PON architecture links a central office to distribution points using Single Mode Fiber (SMF) and passive splitters, multiplexers, and de-multiplexers. Reducing active components in these networks offers cost advantages since power consumption and maintenance are significant expenses for service providers.

Wavelength-Division Multiplexing (WDM) enhances fiber capacity by separating and multiplexing different light wavelengths (colors), enabling the transmission of multiple channels—each capable of speeds up to 10 Gbps—through a single fiber. Modern interfaces can even support up to 100 Gbps. This technology is highly beneficial for carriers and data centers. Meanwhile, Passive Optical Networks (PON) and fiber-powered microswitches simplify fiber deployment within businesses or campus environments by integrating with traditional cabling standards. Fiber optics reduce the need for multiple wiring rooms or closets in buildings due to their longer transmission distances, higher data rates, and lightweight structure, resulting in significant savings in space, cooling, energy, and maintenance costs..

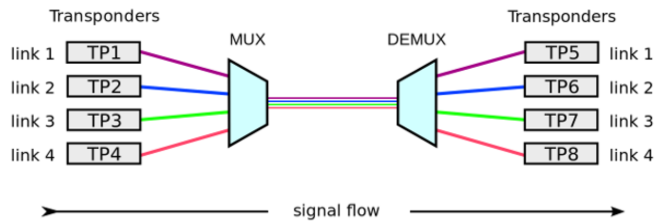

Figure 2: Wavelength Division Multiplexing

Figure2 represent the n channel path through multiplexer and joined in a single optical cable and de-multiplexing the signals to different n channels again using the color of light. Other technical multiplexing innovations such as multiplexing optical time division (OTDM), WDM (optical wavelength division multiplexing) and OFDM (optical frequency division multiplexing) and Subcarrier Multiplexing (SCM) have also evolved as well as the well-known technology for multiplexing time division (TDM). Here we identify primarily WDM's fundamental technology [12]. The WDM system typically comprises predominantly of the following five components: optical transmitters, optical relay amplifiers, optical receivers, optical channels and network control systems.

The WDM system center is the optical transmitter. In addition to the special specifications for the center wavelength of the transmitting laser inside the WDM system for the ITU-T recommendations and standards, it also must be focused on the various implementations of the WDM System mainly the type of transmission fiber and the transmitting distance of the electric relay) to choose a transmitter with certain chromatic tolerance. At the transmission stage, the optical signal output from the terminal system (such as the SDH terminal) is transformed first by an Optical Transform Unit (OTU) that complies with Recommendation G.957 into an Optical signal with a stable particular wavelength. A multiplexer synthesizes the multi-path optical signal and then raises and performance by a booster amplifier (BA).

The key function of the optical monitoring channel is to monitor each channel's transmission status. At the transmission end, insert an optical control signal produced by this node with a wavelength of 1510nm and combine the output with the main channel's optical signal. At the receiving point, the optical signal is de-multiplexed and an optical wavelength tracking signal (1510 nm) and a service channel optical signal is output respectively. The optical control canal transmits frame timing bytes, operation bytes and overhead bytes used for network administrators [5], [13], [17].

4.2 Time-Division Multiplexing TDM-PON

TDM/TDMA (Time-Division Multiplexing/Time Division Multiple Access) transmission techniques represent as the basis of PON standards. For the upstream direction the TDMA is used to deny any collisions on the PON. For the downstream direction TDM allocates the data to ONU which controlled by OLT[18] . TDM-PON has many types such as APON, BPON, EPON and GPON. The Ethernet PON (EPON) and Gigabit PON (GPON) optical networks are commonly used[13].

a) APON: It was proposed in the mid of 1990 by International Telecommunication Union (ITU) using synchronous transmission mode (ATM) for packet communication. APON used the combination of passive splitters with statistical and centralized multiplexing ATM which reduced the cost up to 20-40%. APON later replaced with Broadband PON (BPON) as the Ethernet technology is developed rapidly and due to less efficiency of data transmission and its complexity[19].

b) Ethernet PON (EPON): It is a PON network that carries Ethernet frame encapsulated data traffic (defined in the IEEE 802.3 standard). A standard EPON system contains three components: the Optical Line Terminal (OLT), the ONU and the Optical Delivery Networks (ODN). EPON's topological structure to achieve Ethernet connectivity is fitted with the dual advantages of PON and Ethernet, including low cost, high bandwidth, high scalability, decent Ethernet compatibility, etc.

c) Gigabit PON (GPON): The most advanced PON solution is Gigabit PON (GPON) and widely used by US and European service providers. The data encapsulation and various network protocols including ATM, Ethernet and IP. It is based somehow on the former ATM Control Network (APON, BPON). GPON system Consist of three parts: optical terminal line (OLT), the ONU network terminal, optical distributer network (ODU) and the splitter . GPON has advantages of high bandwidth, high performance, wide coverage, comprehensive user interfaces, etc [13].

The following table 1 represents the comparison between the three types of PON technologies

Table1: Comparison of various PON technologies [20]

PON Technology	**APON**	**EPON (GEPON)**	**GPON**
Standard	ITU G.983/ FSAN	IEEE 802.3ah	ITU G.984
Maximum Bandwidth	622 Mbps	1.2 Gbps	2.4 Gbps
Maximum Downstream Line Rate	622 Mbps	1.2 Gbps	2.4 Gbps
Maximum Upstream Line Rate	155/622 Mbps	1.2 Gbps	1.2 Gbps
Wavelength	and 1550 nm	1550 nm	1490 and 1550 nm
Upstream Wavelength	1310 nm	1310 nm	1310 nm
Traffic Modes	ATM	Ethernet	ATM Ethernet or TDM
Video	RF/IP	RF/IP	RF/IP
Max PON Splits	32	32	64
Max Distance	20 km	20 km	60 km
Average Bandwidth per User	20 – 40 Mbps	30–60 Mbps	40 – 80 Mbps
Cost High Very high	Low	Low	Medium

4.3 Optical Line Terminal (OLT)

OLT is the endpoint hardware unit in a passive optical network is an OLT terminal (PON). OLT supports the allocation of bandwidth and facilitates seamless transmission of data to the OLT, which normally happens in customer bursts. It has two main functions:

- Transferring the FiOS service provider's regular signals into the frequency and framing of the PON system.
- Coordination of multiplexing between conversion devices on customer-specific Optical Network Terminals (ONTs).

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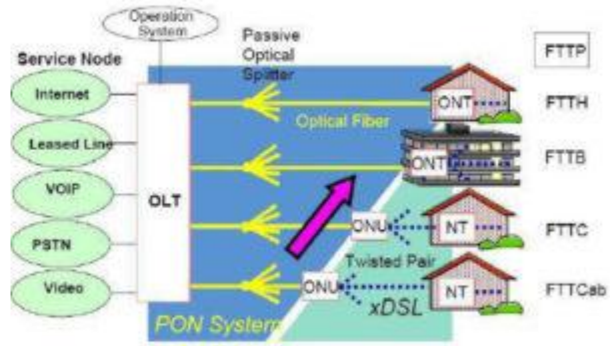

Figure 3. OLT representing in PON [17]

4.4 Optical Network Unit (ONU)

ONU transforms optical signals to electric signals emitted by cable. Those electrical signals are then forwarded to individual customers. Generally, a gap or some other access network occurs between the UN and the property of the end user. In addition, ONU can email, aggregate and archive various types of data from the customer and send it to the OLT upstream. Grooming is the process which optimizes and rearranges the data stream to produce it more efficiently [17].

5. Conclusion

Telecommunications providers use PONs to provide customers with triple play networks including TV, VoIP and telephone. The advantage is much higher data speeds which are important for video and other Internet services. The low cost of passive components means simpler systems with less defective or maintenance components. The biggest drawback is the smaller size, typically not more than 20 km or 12 miles. As demand for quicker internet services and more video increases, PONs are becoming increasingly popular. GPON is the most common machine in the U.S., like Verizon's Foist. In Asia and Europe, EPON systems are more prevalent[13].

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