The Next Generation Passive Optical Network: A Review

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Abstract – In this a review is given on the Next Generation Passive Optical Network (NG-PON). Recently, a WDM-PON system has gained significant attention to support high data rate transmission. To overcome the several effects occurring in optical transmission, OFDM has been introduced to improve the overall performance of the system. In this paper, NG-PON1 and NG-PON2 technology has been reviewed and studied their compatibility with the deployed networks, bandwidth efficiency, capacity and its efficiency for the cost. In it , the design principles and prospective technologies for NG-PONs has been described which introduced a views of NG-PON evolution, by focusing on the discussion and evaluation of various technologies. The discussion have been taken under the FSAN and ITU-T framework of NG-PON recommendations.

Index Terms – Passive Optical Network (PON), Orthogonal Frequency Division Multiplexing (OFDM), Next Generation Passive Optical Network (NG-PON).

1. INTRODUCTION

Passive Optical Network (PON) is a telecommunications technology that implements a point-to-multipoint architecture, in which Fiber Optic Splitters are used to enable a single optical fiber to serve multiple end-points such as customers, without having to provision individual fibers between the hub and customer and these splitters are unpowered. Passive optical networks has many applications, one of its application is that it is used for reduction in number of optical transceivers which are used in FTTC, Passive components are used such as splitters, combiners, AWG etc. The PON evolution has occurred in two stages: The next generation PON1 (NG-PON1) and NG-PON2. The next-generation passive optical network stage 2 (NGPON2) project has been initiated by the full-service access network (FSAN) [1] community in 2011, which investigates on optical fiber network technologies to enable a bandwidth increase beyond 10 Gb/s in the access network so as to provide a better communication. Operators' requirements for NG-PON2 included a set of access performance descriptions. There are some standards which are described by International Telecommunication Union (ITU) for PON are the Broadband PON (BPON) ITU-T G.983, Gigabit PON (GPON) ITU-T G. 984.

(i) BPON (Broadband PON)

BPON is the advanced version of APON with the transmission speed up to 622 Mbps with having the dynamic bandwidth distribution, protection and some other functions. The downstream capacity of APON/BPON systems typically have 155 Mbps or 622 Mbps [2].

(ii) EPON or GEPON (Ethernet PON or Gigabit Ethernet PON)

EPON is an IEEE standard 802.3 and support point to multipoint (P2MP) subscriber access network topology. P2MP network topology is usually used to establish a long-range of wireless backhaul solutions for various sites, and private business connectivity to offices in remote locations. These P2MP networks are provided distribution facilities in the field of huge corporate campuses, school districts, public safety applications, etc. The point-to-multipoint topology includes a central base station that supports several subscriber stations which provide network access from a single location to multiple locations and allowed a access them to use the same network resources between them. The bridge which is called the base station bridge or Root Bridge, is located at the central location. All data which has to send or receive should passes between the wireless bridges clients should firstly go via the root bridge. This network can be easily deployed when compared to the deployment of a point-to-point network but the only condition is that all the remote sites must come under the range of the base station and within their visibility. The obstructions like Hills, trees and other kinds make point-to-multipoint nods unsuitable for office and residential coverage. P2MP systems are divided into single system and bi-directional systems. It is used for customers that are in need of a high-speed, reliable connection, but worried about paying. The only drawback of point-to-multipoint node topology is that its do not have ability to make connection with other nodes due to the directional antenna which it have been used [9]. PON basically increase the capability of network in PON system by using a less number of components at very low operation and maintenance cost [3].

(iii) GPON (Gigabit-capable Passive Optical Network)

GPON is defined by ITU-T recommendation series G.984.1. It is an advanced version of capability as compared to APON and BPON. The data rate used by GPON is from 1.2 Gbps to 2.5 Gbps for downstream and for upstream, different data rates of 155 Mbps, 622 Mbps, 1.25 Gbps or 2.5 Gbps can be used [4]. It uses different protocols like ATM, Ethernet and TDM protocol. GPON is better than other PON techniques but it is more complex as compare to the other techniques of the PON

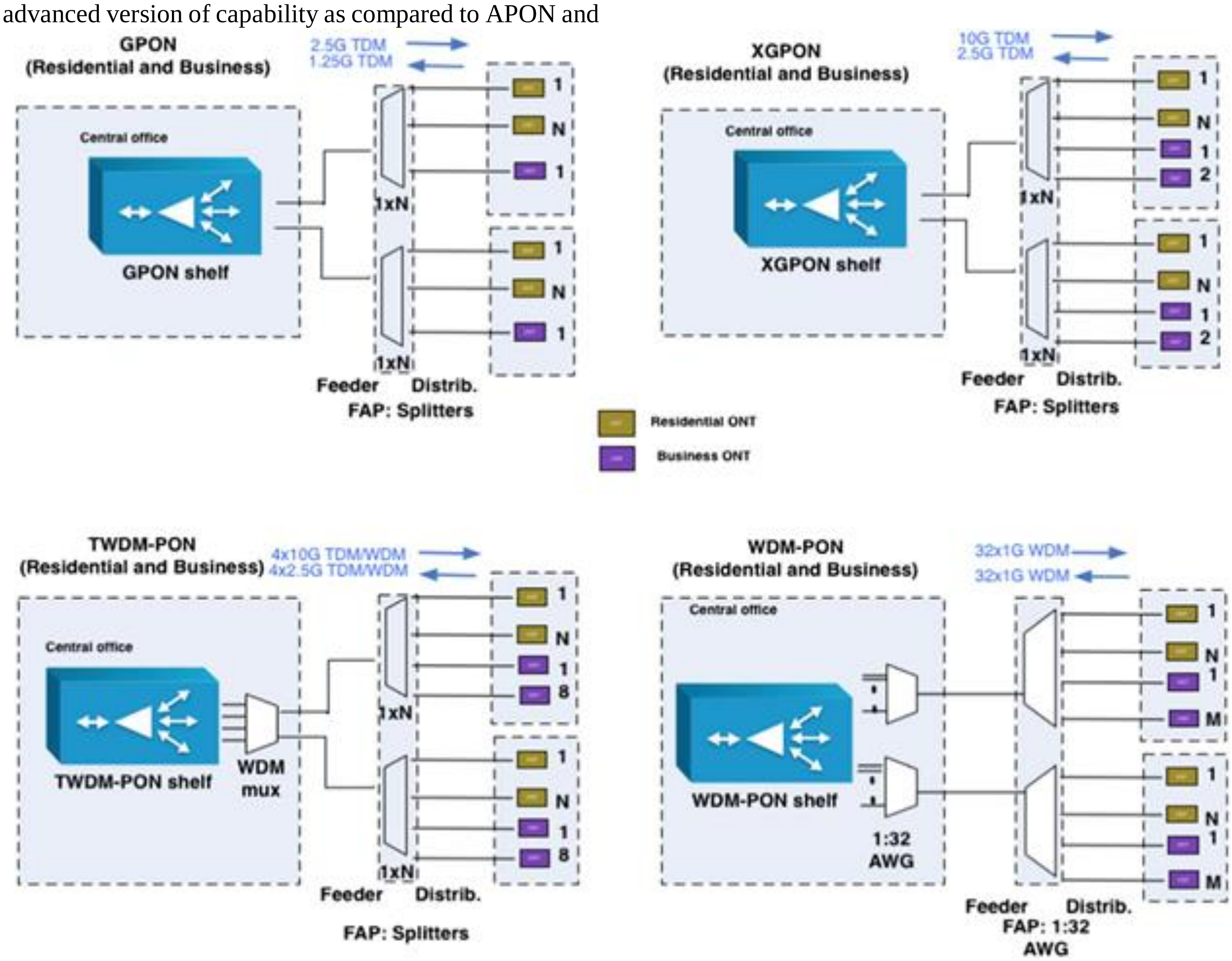

Fig. 1. Taxonomy of PON fiber-access protocols (i) GPON (ii) XGPON (iii) TWDM-PON (iv) WDM-PON [7]

2. PON ARCHITECTURES

(i) Time Division Multiple Passive Optical Network (TDM PON)

TDM PON plays an important role in all access networks of the PON. The protocol used by TDM PON is the time multiplexing protocol, in which the users can transmit and / or receive data according to the assigned time slots, so the users can utilise the whole bandwidth, which help to increase the number of users. For its synchronisation pupose, it uses power splitters. A TDM PON architecture using power splitter is shown in the Figure 1. [5]

(ii) Wavelength Division Multiplexing PON (WDM PON)

With the rapidly increase in the use of internet the demand of high speed increases so the demand of higher data rates also increases & for this, there is need to achieve higher bandwidth or capacity. To find the solution of this problem, WDM comes into play an important role. By using it, multiple users can share different wavelengths on a single fibre which help to increase the number of users, and therefore it makes the system less costly because of reduction in cost per user. WDM PON provides a high efficient system, fast response to the problem, and more secure bandwidth allocation in PON [6]. A WDM PON architecture using WDM coupler is shown in the Figure 1.

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TABLE I
SUMMARY OF FEATURES FOR PON TECHNOLOGIES

	GPON	XG-PON	TWDM-PON	WDM-PON
Standard	ITU-T G.984	ITU-T G.987	ITU-T G.989	ITU-T G.698.3
Availability	In market	In market	In-progress	In market
Feeder rate (C_{DL}/C_{UL})	2.5G/1.25G	10G/2.5G	40G/10G	32G/32G
Security	No	No	No	Yes
Outside Plant	Splitter	Splitter	Splitter with WDM mux	AWG
Price	Lower	Medium	Medium	Higher
Power budget (dB)	28 (B+)	35 (E2)	38.5	15

3. EVOLUTION

The co-existence and an ultra-broadband with existing technologies are basic requirements from operations of the network to provide direction for PON evolution. Recently, the worldwide operators are finding to increase th consumption of the full bandwidth services [8]. An example of its service is HDTV, which requires about 20 Mbit/s per channel. But in the near future, new business models, such as home video editing, interactive E-learning, online gaming, remote medical services, and next-generation 3D TV will rapidlly increase bandwidth demand. After GPON recommendations were done, FSAN and ITU-T continued the study of NG-PONs and defined the first phase of NG-PONs as systems which provide a large capacity, wide coverage, low costs, full service, and interoperability with existing technology. FSAN and ITU-T members also agree that for a long-term PON evolution, the new scenarios will be driven, if coexistence with legacy systems is not required. Based on the current demand of applications and technological maturity, FSAN divides NG-PONs into two phases shown in Figure 2. FSAN divide NG-PON evolution into stages i.e. NG-PON1 and NG-PON2. NG-PON1 is a mid-term upgrade, which is compatible with legacy of GPON ODNs, while NG-PON2 is a long-term solution in PON evolution which can be deployed over new ODNs, independent of GPON standards.

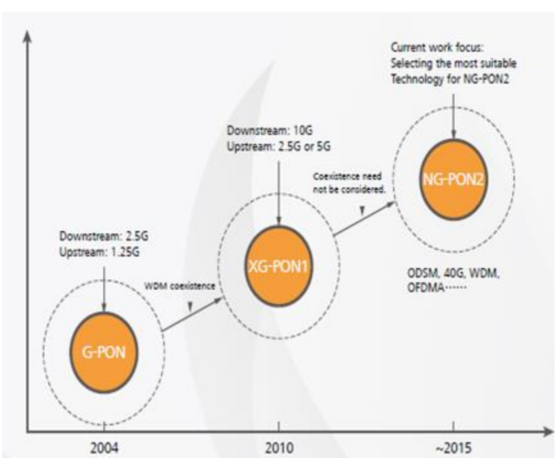

Fig 2. NG-PON roadmap by FSAN [8]

Unlike NG-PON1, there are different types of technologies that can be adopted for NG-PON2, which help it to make better technology. Among these prospective technologies, a suggested baseline is given to improve the rate from 10Gbps to 40Gbps by following the TDM Technology. The another method is the employment of wavelength division multiplexing (WDM) PON to achieve 40Gbps access, and for this, the most possible multiplexing schemes must be coarse wavelength division multiplexing (CWDM) or dense wavelength division multiplexing (DWDM). The another topology, ODSM PON topology based on TDMA+WDMA is also suggested, which dynamically manages user spectrum. The next part has included OCDMA-PON, which uses code division multiple access (CDMA) to encode ONU signals, so help to avoid the timeslot assignment for data transmission which were required by a time division multiple access (TDMA) systems. The O-OFDMA PON topology is a better option because it uses orthogonal frequency division multiple access (OFDMA) technology to differentiate ONUs, so help to improve bandwidth usage. However, still the most of these technologies are in the research phase. It require more study and test desired to promote them as industry standard. The specified NG-PON1 system is known as XG-PON1. In an XG-PON1 system, the downstream rate is 10Gbps and the upstream rate is 2.5Gbps. Therefore, the downstream bandwidth of XG-PON1 is four times as that of GPON, while the upstream bandwidth of XG-PON1 is twice as that of GPON. A smooth evolution from GPON to XGPON1 can be achieved, which completely leverages the value of GPON ODN after a 10Gbps interface board has added to the OLT.

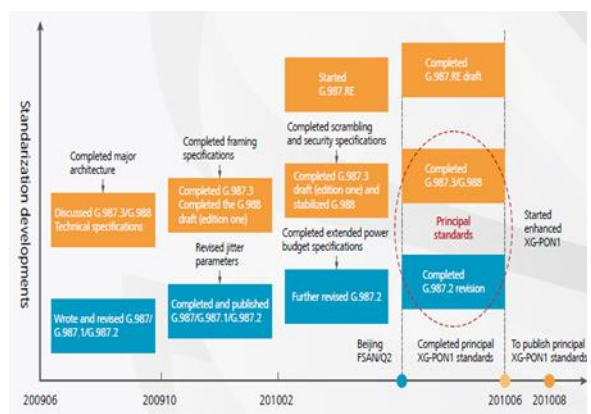

Fig 3. XG-PON1 standardization developments [8]

An afterward thought was power saving in GPON, and for this, the ITU-T published [G.sup45] on saving power with multiple modes at the chip level. Here, the operators propose mandatory regulations and improvements on XG-PON1 to promote power saving worldwide. Some modes are given by ITU-T, in which XG-PON1 supports doze mode and cyclic sleep mode specified in [G.sup45]. The draft of XGTC layer standard was completed in April 2010, while the ITU-T Recommendation [G.987.3], aka: the XG-PON1 TC layer standard was officially approved in June 2010.

4. BANDWIDTH REQUIREMENT FOR NG-PON

Because PON technology advances from 1Gbps to 10Gbps and even higher rates, operators are gearing up for a future user bandwidth requirement to 100Mbps and even 1Gbps. So, in the next 5–10 years, the target for mainstream bandwidth requirement is 100Mbps for residential users and 1Gbps for commercial users. The following figure forecasts the bandwidth requirement increase for FTTB/C and FTTH scenarios.

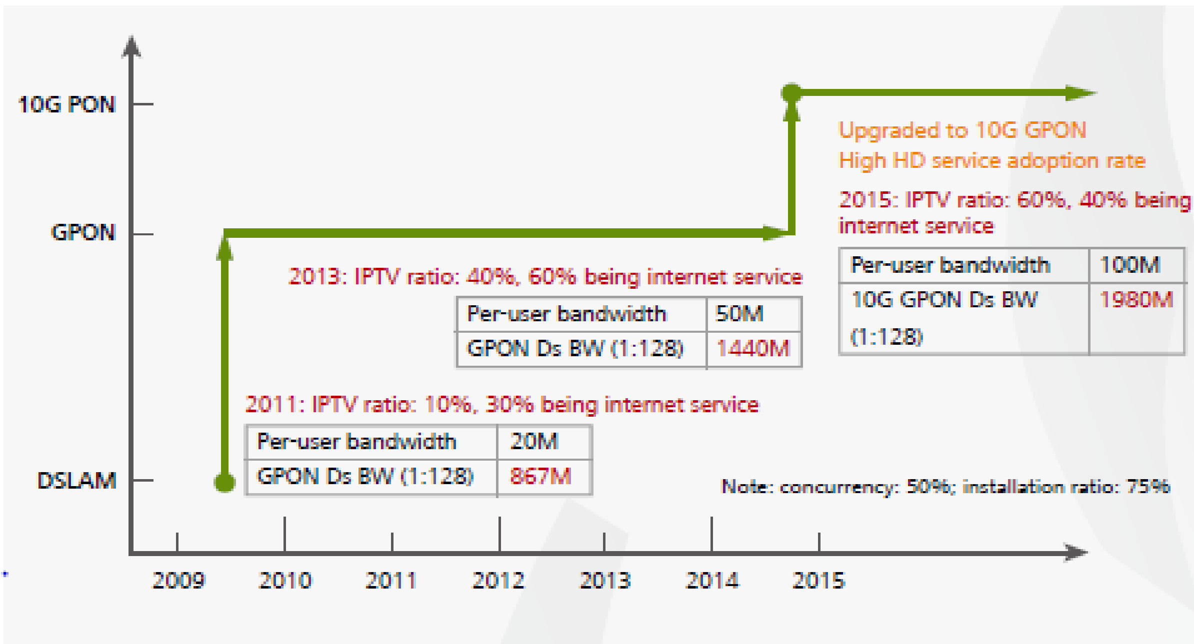

Fig 4. Roadmap of rate-rise for FTTH [8].

10G PON raises new challenges on the performance of the OLT and the system architecture design. The drawback of the OLT must evolve smoothly to protect existing investments of operators, and for the per-slot bandwidth needs to be increased from the current GE/10GE to 40Gbps/80Gbps. It is to address the bandwidth requirements of future optical access. For higher network flexibility, 10G PON line cards can be compatible with current PON line cards and for network maintenance and management, the unified network management system (NMS) has been required to manage PON ports and higher efficiency. At the end to sum up the whole discussion, large capacities, unified network management systems and shared platforms , will be the trends in 10G-PON equipment developments so that vendors are striving to fulfill their communication need [8].

Chi-Wai Chow et al. [10] in this paper, they propose a bidirectional network combining the VLC access network and the time–wavelength-division-multiplexed passive optical network (TWDM-PON). Orthogonal frequency division multiplexed modulation was used because it offers high spectral efficiency for both the TWDM-PON and the VLC access network. In this paper, the researchers used a Low-cost phosphor-based white-light, light-emitting diodes (LED, s); which help the VLC access network to combine with the lighting systems. A Gateway was proposed which provide the interface between the inside and outside of the building. In the TWDM fiber access part, a net data rate of 20.2 Gbit/s at each wavelength was experimentally achieved with 256 ODN split-ratios and after 40 km SMF transmission. In the VLC access network, with direct modulation bandwidth of ~1 MHz phosphor-based while-light LEDs were used. They provided an electrical equalization scheme, which were implemented in the driving circuit of the LED lamp; a 30 MHz 3-dB modulation bandwidth can be achieved. Data rate of 190 Mbit/s−84 Mbit/s. The uplink multiple accesses in the VLC network were based on using different up converted frequencies. In the proof-of-concept demonstration, three Mobile Units (MU) were used, and each MU transmitted a particular frequency up-converted OFDM band. H. Ou et al. [11] in this paper, they proposed a dynamic bandwidth allocation framework that was suitable for application to a layer-2 switch. The performance of the proposed scheme was evaluated by both computer simulations and experiments, and it was shown that the proposed scheme provides better performance than the conventional scheme with regard to buffer size with high bandwidth efficiency. This paper proposed a novel DBA framework for integrated DBA. Integrated DBA can reduce the aggregation buffer size in an L2SW because the L2SW controls the upstream transmission from ONUs. The proposed approach utilizes the advantage that there were multiple PON links, and overlaps the overheads and the data frames. Numerical analysis showed that the proposed approach can achieve almost 100% of the bandwidth efficiency, while it reduces the required buffer size by 10−6 times compared with the conventional architecture. Moreover, the feasibility was studied experimentally in terms of buffer usage, bandwidth usage, latency, and long-term stability. Yuanquan Wang et al. [12] propose and experimentally demonstrate a full-duplex integrated passive optical network (PON) and indoor optical wireless communication (OWC) system. For the PON part, an external cavity laser (ECL) and a directly modulated laser (DML) were used as optical sources for downlink and uplink, respectively. The OWC subsystem utilizes a visible light-emitting diode (LED) for downlink and an infrared LED (IR-LED) for uplink transmission. To enable high spectral efficiency (SE), high-speed transmission, and flexible multiple access with simplified optical network unit (ONU)-side digital signal processing (DSP). As a proof of concept, an integrated system of symmetrical full-duplex 5 Gb/s PON and 250 Mb/s OWC at each direction for three wired users and one wireless user was successfully achieved. The main purpose is that it can provide multiple services to one wireless and three wired users originating from the Central Office. The crosstalk between different services was analyzed, which demonstrated to be very small. This is the first time, where different services over such an integrated full-duplex PON and OWC network have been simultaneously analysed and supported. Yunxin Lv et al. [13] in this work, a novel energy-efficient scheme named LASA has been proposed and numerically investigated. By properly arranging the polling sequence, ONUs in the network can obtain a longer total sleeping time, and the network becomes more energy efficient. The added label in the gate/report message and the idle time arrangement offer the main help in arranging the polling sequence. Simulation results intuitively show the energy-efficient advantage of the LASA scheme. Compared to the traditional fixed polling sequence scheme, the proposed LASA scheme can additionally save energy up to 18% without extending the average polling cycle time. M. Pubuduni Imali Dias et al. [14] for the first time, an energy-efficient framework that optimizes the number of active wavelengths and uses sleep/doze mode to improve the energy savings of a delay-constrained time and wavelength division multiplexed passive optical network was presented. In the proposed framework, the optical network units (ONUs) operate under the maximum polling cycle time that satisfies a given delay constraint to achieve maximum possible energy savings at the ONUs. Conversely, when the bandwidth requested by an ONU was small, idle wavelengths were switched off to increase energy savings at the optical line terminal (OLT). For a given delay constraint and network load, the framework determines 1) the number of active wavelengths required to maintain this delay and 2) the sleep or doze time of the ONUs. The framework achieves energy savings at the OLT by switching off idle wavelengths and at the ONUs by transitioning the ONUs to sleep or doze mode during their idle time. The analytical and simulation results indicate that using the proposed framework, a TWDM-PON can maintain the average delay of the network under a given delay constraint while achieving significant energy savings at both the OLT and the ONUs. Hakjeon Bang et al. [15] proposed that in a 10-gigabit-capable passive optical network (XGPON) system, a power management function such as cyclic sleep mode can be implemented to increase energy efficiency of an optical network terminal (ONT). To optimize power saving with the cyclic sleep mode, they proposed an analytic model to determine required ONT buffer size for incoming traffics from user network interface (UNI) when the ONT is sleeping, and to evaluate performances such as power consumption and delay, in accordance with buffer sizes, sleep periods, and arrival rates. From the results, they found that the buffer size should be increased to support long sleep periods, and that a sleep period of over 40ms or 50ms was not effectively reduce consumed power if the buffer size of the ONT system with the cyclic sleep mode was enough to queue incoming traffics from UNI. Furthermore, the model can be extended to doze mode of the XG-PON power management function, and obtained results can be used to increase energy efficiency with the supports of hardware system functionalities or network designs such as scheduling and bandwidth allocation on physical or MAC layers. As such, it was expected that this model can be utilized for the analysis of the power management function and for the system design with the optimal power saving. Jongdeog Kim et al. [16] in this paper evaluated the design and performance of the suggested Cu-XG-PON architecture with a first demonstration of the upstream physical layer specification for the extended class in ITU-T G.987 standard recommendation. Here a new scheme has been proposed bby them, for a passively extended XG-PON having 8 CWDM channels ranging from 1270 to 1450 nm, which were referred to as Cu-XG-PON. This has been attempted to improve the length of the fiber and split ratio which has been limited mostly by the upstream characteristics in the XG-PON, the current standard. In most of the cases, for an arbitrary data packets, the demonstrated upstream scheme uses a single BMRx within an OLT for the CWDM wavelengths from ONTs. So, from the analytically experiment, 2.5 Gbit/s BMRx has been developed, and also they obtained a -34.5dBm OLT Rx sensitivity at a 10^{-4} BER in burst-mode operation by using 4 ONTs, which operated for 1270 and 1310 nm wavelengths. After these practical results, they has been expected that the Cu-XG-PON can be extended to 256 ONTs and 28 km, or 64 ONTs and 42 km at least and that further reach extensions will be developed in the future.

However, its drawback was the low bandwidth efficiency in the uplink of the L2SW due to overheads, which were only used in PON systems. Furthermore, the jointly working scheme of LASA-FMT has been derived to improve the performance of the LASA scheme under the low-traffic scenario, and simulation results show that it could save a large amount of energy under any traffic load. The investigations on the packet delay of both the LASA and the LASA-FMT schemes indicate that the proposed schemes do not induce obvious delay, which means that they can afford delay sensitive services in general. Moreover, the two schemes are both able to support the loss of the signal alarm protection mechanism, and they can also be further applied in a TWDM-PON system to help save energy costs on ONUs that are sharing the same wavelength. Also the delay of data is more in the LASA schemes. Much higher driving power can be used before the LED response becomes nonlinear. The BER has been high and also power consumption high. The deployment of tunable transceivers increases the cost of the access network and facilitate wavelength optimization at varying network loads for improved energy efficiency. Bandwidth updates were performed at a less frequent rate than one update per frames.

5. ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS (OFDMA) ACCESS NETWORKS

Originally used as a modulation method for copper and radio OFDM is currently being considered by many research groups as one of the strongest candidate for future PON implementation due to its attractive features that satisfy the needs of next generation access networks [17], [18]. In OFDM, multiple low bit rate orthogonal subcarriers carrying different QAM symbols are simultaneously transmitted in parallel. A major benefit of OFDMA is that the complexity of transmitters and receivers is transferred from the analog to the digital domain using advanced DSP [19]. For example, practical and cost-efficient implementation of the orthogonal subcarriers is achieved at the transmitter via the Inverse Fast Fourier Transform (IFFT) algorithm and at the receiver via FFT algorithm [19]. Another advantage of OFDM lies in the orthogonality of low bit rate subcarriers, thus allowing high spectral efficiency. A high aggregate transmission bandwidth can be maintained using low bandwidth transceivers. Further, advanced modulation formats can be implemented to achieve high-speed transmission [20].

6. CONCLUSION

In this paper, a reviewed for NG-PON and its critical features to meet the NG-PON2 requirements has been given. Now a days, PON industry try to reach an aggregate access rate of 40 Gb/s by using four XG-PONs. Because of the primary solution to NG-PON2, TWDM-PONhas been used to maintain balance with the network upgrade requirements and the cost model consideration in the access network market. Here, the major wavelength plans have been discussed and their loss budgets have been evaluated for the NG-PON, and according to the research reaches to the state that there are different candidate technologies which provide a way to see the network in different scenrios; if one technology does not perform to expectation, there are always other options to implement the required functions. It is a prototype that shows commercial components to provide 40 Gb/s in downstream and 10 Gb/s in upstream. 40 dB power budget in the downstream and 38 Db power budget in the upstream have been achieved by the researchers. For the future research on TWDM-PON , a further the TWDM-PON wavelength plan options have been explored. For it, relevant factors such as fiber loss and chromatic dispersion would be thoroughly investigated, and a single wavelength plan should be selected for the purpose of standardization. The loss budget investigation would also be investigated which includes the study of OLT and ONU transmitter launch power, the OLT and ONU receiver sensitivity, optical path penalty, and signal loss in connectors, coexistence filters, splitters, and WDM Mux and DeMux. Also the main focus would on the low cost tunable ONUs research. Among the enabling technologies of Tunable transmitters and tunable receivers. So solutions with low-cost should to be further explored with high priorities.

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