A REVIEW ON PASSIVE OPTICAL NETWORK WITH COLORLESS ONU TECHNOLOGY

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Abstract

Next-generation passive optical network stage 2 (NG-PON2) is the result of development in PON technology towards achieving higher data rates, and higher split ratios. Time and Wavelength Division Multiplexing (TWDM) represents the most promising and efficient technology for the NG-PON2 network as per ITU-T G.989 recommendation. To make the system cost-effective the wavelength reuse scheme can be used which eliminates optical sources from the ONU. In this review article, the different wavelength reuse schemes to make colorless light-source of the recent TWDM PON systems are discussed.

Keywords

PON, TDWM, Colorless ONU, RSOA.

1. Introduction

Nowadays the copper wires or electric cables cannot satisfy higher bandwidth and are being replaced with optical fiber because of their advantages over copper wire [1]. Therefore, optical fiber became a key component or media in the optical access network. Fiber to the home (FTTH) technology is used nowadays where a fiber is present between the central office (CO) to the end user. Passive optical network (PON) is an emerging technology in FTTH, which provides higher bandwidth and also low loss which is required [2][3]. PON provide advantages of high bandwidth, lower cost, high quality of service flexibility and scalability. PON is a broadcast network that provides services to multiple users. It can be a point to point and point to multipoint network. Point to the multipoint network provides advantages over point to point because in this there is only a single fiber required to broadcast the data. In the PON network, all components used are passive e.g., optical splitters/combiner to deliver the data in both directions [4]. A PON consist of optical line termination (OLT) which is at CO side, an optical network unit (ONU) which is present at user premises and the optical distribution network (ODN) which consist of all passive components between OLT and ONU. In general, a section between the OLT and ONU is called ODN, which consist of fiber, splitter, combiner, and coupler [2][5]. This paper is organized into five sections. In section 1, the introduction of PON and its components is presented. PON standards are explained in section 2. The state of the art of PON using different remodulation techniques are discussed in section 3. The conclusions from the results and discussion are made in section 4. At the end of the paper, the cited references are listed in last section 5.

2. PON Standards

The ITU has defined PON standards, the first significant PON standard was the broadband passive optical network (BPON) which soon was upgraded to gigabit passive optical network (GPON). The GPON supports 2.5Bbps an up[grade to the GPON was proposed by ITU in form of a 10-gigabit-capable passive optical network (XG-PON). As compared to the previous PON standards, the NG-PON2 is the more capable PON proposed by ITU. Following are the detail of each PON standard.

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2.1. Asynchronous Transfer Mode (ATM PON)

This is the very first of the PON standards and was based on ATM with standard ITU T G.983. The original APON system only standardizes the 155Mbit/s. This standard uses the asynchronous time-division multiplexing technique. Downstream and upstream transmission via a single fiber facility can also be achieved using independent wavelengths (1490/1310 nm) for each direction. ATM PON is a point-to-multipoint, cell-based, optical-access network that facilitates broadband communications between an OLT and multiple ONUs over a passive optical distribution network with a reach of up to 20 km and a split ratio of 1:16 or 1:32 maximum [6].

2.2. Broadband Passive Optical Network (BPON)

After the APON standard, BPON comes into the picture. BPON is the upgraded version of APON which is recommended by ITU-T G.983.1.The wavelengths allotted by the G.983.1 recommendation for upstream and downstream signals are 1310 and 1490 nm respectively. The BPON standard working on 155 Mbps for upstream transmission and 622 Mbps for downstream transmission. The split ratio for this standard can be 1:16 or a maximum of 1:32 [6][7].

2.3. Gigabit PON (GPON)

With the increase of demand in higher bandwidth, ITU-T G.984 recommends the next standard that is GPON, which is capable to transmit the data rate of 2.488 Gbps or 1.25 Gbps downstream and upstream respectively.GPON is the enhanced version of BPON. It supports a split ratio of 1:16, 1:32 or1:64 or more. It is widely deployed all over the world. OLT in the central office can support various split ratios (1:16, 1:32 or 1:64 or more), depending on the desired reach as in this case maximum reach is 20 km. A higher split ratio means lower reach and vice versa. The downstream transmission in a single-fibre system operates at the wavelength of 1490 nm and the upstream transmission at a wavelength of 1310 nm [8].

2.4. Next-Generation PON (NG-PON1)/XG-PON

The downstream transmission of NG-PON is 10 Gbit/s and the upstream transmission is 2.5/10 Gbps. To fulfil the demands of higher data rate, the FSAN/ITU- T group recommended the 1577 nm for the downstream and 1270nm for the upstream transmission of data respectively [9]. OLT in the central office can support various split ratios (1:32 or 1:64 or more), depending on the desired reach as in this case maximum reach is 20 km. A higher split ratio means lower reach and vice versa [10][11].

2.5. Next-Generation PON stage 2 (NG-PON2)

The FSAN/ITU-T group has still not achieved consensus and clear cues regarding the next stage of the NG-PON1 system called as NG-PON2 system with standard ITU TG-989. NG-PON2 can provide up to 40 Gbit/s data rate to the entire optical network system with a reach distance from 20km to 60km. Wavelength allocations are as 1524 nm to 1535 nm for uplink and 1596 nm to 1600 nm for downlink with a split ratio of 1:64 to 1:128 [12]. Table 1 represents the comparison of different PON standards.

Table 1 Different PON standard comparison.

Characteristics	APON ATM PON	BPON	GPON	XG-PON/NG-PON1	NG-PON2
Standardization	ITU-TG.983	ITU-TG.983.1	ITU-TG.984	ITU-TG.987	ITU-TG.989
Upstream data speed	155Mbps	155Mbps	1.25 Gbps	10Gbps	40Gbps
Downstream data speed	622Mbps	622Mbps	2.5 Gbps	10Gbps	40Gbps
Maximum split ratio	1:32	1:32	1:128	1:256	1:256
Down/Up Wavelength	1490/1310nm	1490/1310nm	1490/1310nm	1577/1270nm	1600/1535nm
Maximum reach	20Km	20Km	20Km	60Km	100Km

3. State of Art

According to different implementations discussed here for PON standards, NG-PON is the most recent and with TWDM, colourless ONU is most promising. The communication between OLT and ONU units depends on the reach distance and the technology used. For cost-effective user's ONU, the colorless ONU are the main challenge in the PON network. In this section we have covered how PON technology emerged as the main broadband technique it is also discussed that how over the years the PON technology got to upgrade. The PON architecture has been explained along with the detail of components used in typical PON.

3.1. Colorless ONU

The next-generation PON uses the TWDM technique. TWDM is the most promising technology for present and future applications because it can coexist with the legacy TDM PON technology [13][14]. WDM technique is used in downstream transmission. To make the network colorless the tunable lasers at each ONU is assigned to respective wavelength in upstream transmission. TDM for upstream direction is done with the help of lasers at each ONU. As the wavelengths used for the downstream and upstream are different in the case of ONU the cost of the lasers is huge on the large-scale deployment. The ONUs in future PON should be preferred as independent of wavelengths called colorless ONU, in future PONs.[4][15].

To overcome the higher system cost problem, the transceiver must be colorless. To ease the operation, maintenance and to reduce cost, a colorless ONU independent of wavelength is required. Various creative and innovative transceivers are there for this purpose. One of the schemes is to use a transmitter based on the broadband light source and by spectral slicing at the remote end. However, there are many obstacles to this approach that hinder the performance which are power loss and dispersion [16].

Advantages of using colorless ONU in PON

- Low cost
- High bandwidth
- Low loss
- Complexity
- High capacity
- Reliable

FTTH technology is upgrading day by day. For the development and growth of optical access networks, cost-effective (reductive) solutions should be there to offer broadband services to subscribers while maintaining a low cost. The ONU has a direct effect on the cost of the user in the whole optical access network. Josep Prat et.al [17] presented a colorless 1.25 Gbps PON network based on a reflective semiconductor optical amplifier (RSOA). The system was capable of up to 30-km reach with RSOA and electro-optic transceiver at the ONU side. It performs both the operation of modulation and detection. The light from the CO is modulated by RSOA in the upstream direction and operates as a photodetector for downstream data. The light source at the CO used was a tunable Fabry Parot laser. Mach Zehnder modulator is used to modulate the downstream data at 1.25Gbps. The RSOA is InP–InGaAsP metal-organic chemical vapor deposition grown. There is only one optical component which is RSOA in the access network and it acts as a modulator and photodetector. An interface circuit for the RSOA was implemented to separate the received downstream signal and the ONU upstream data via an electrical switch that activates the receive or transmit mode at the respective time. An RSOA as ONU has been presented as an effective cost reduction technology for optical access network with bidirectional operation along with single fiber use.

Tae-Young Kim et.al [18] presented the WDM-PON where the RSOAs were used. They modulated baseband signal and subcarrier multiplexing (SCM) signal simultaneously using a single laser diode (LD), this makes the system cost-effective. A symmetric 1-Gb/s PON system was achieved with a 20-Mb/s SCM signal at 2.2 GHz for broadcasting. The WDM-PON based on the colorless ONU is possible with the multi-wavelength source, tunable source, AWGs and RSOAs, The RSOA does two tasks one is to provide the gain to the signals and to modulate the data at 1.25Gb/s. The RSOAs when operated in saturated mode provides the full remodulation effective and possible. The solution to the saturation problem is to use the optical line coding like Inverse RZ (IRZ) or Manchester coding for the downstream and for the upstream Non- Return-to-Zero (NRZ) coding should be used. Moreover, Mach-Zender modulators (MZM) is used in most of the demonstrations related to IRZ modulation in the downlink, this is difficult to implement in the practice, it is because the MZM has polarization-dependent properties. The solution to this is the electro-absorption modulator (EAM) which is polarization independent. But the use of EAM affects the PON power budget to a large extent. It happens because of high insertion loss. Marco Presi et.al [19] proposed a novel method of dual coding system where they proposed the use of IRZ for downstream and RZ for upstream). With the proposed approach the reach of WDM PON based on RSOAs increases without the inline amplifier. Bidirectional full-duplex error-free transmission with RSOA at 1.25Gbps data rate was carried out with a reach distance of 80km.

Yue Tian et. al [20] have proposed a WDM-PON technology for downstream multicasting over the conventional unicast data service without the use of an additional light carrier. No light source and colored components are required in ONU which helps to reduce the cost of the system. There are many cost-effective solutions investigated and implemented. For example, different schemes based on a single optical source using both a reflective semiconductor optical amplifier (RSOA) and an injection-locked Fabry–Perot laser were presented. The crosstalk effect is present on an upstream signal due to the downstream one. Relatively complex OLT and remote node, which can generate downlink and uplink light simultaneously in order to avoid the power penalty of uplink signal due to the downlink one. However, these schemes can be far away from a cost-effective solution because additional optical devices are required to enhance the channel capacity. It is here important to implement and deploy a system, capable of both generating upstream and downstream optical signals simultaneously and can be a relatively cost-effective one.

Yong-Yuk Wonet. al [21] [22] presented a 1.25Gbps capable WDM-PON which was able to support bidirectional traffic. They proposed to use the direct modulation for the downstream and optical carrier suppression for the upstream. They observed no crosstalk effect and the BER was under limits. With the 1.25Gbps the error-free transmission for the 23km fiber length was achieved. The cost of the proposed system was low as the single light source was utilized to generate the signal for both upstream and downstream. The signal for the downstream is produced by utilizing the concept of the carrier suppression and injection locking of FP laser. the signal for the upstream was generated by splitting the portion of the power of the laser. The proposed ONU was wavelength-independent, The emission wavelength is dependent on the tuned wavelength of FP laser. An RSOA was used for the colorless ONU operation. The error-free transmission was observed with the proposed method.

Luca Banchi et.al [23] reported the distributed Rayleigh scattering based reflections from the fiber ends at the ONU, the reflected signal can be called a Rayleigh backscattered signal. The reflections can be classified into two types type -I and type-II. The RBS of seeding light in the fiber is the result of type -I reflections. The type-II reflections are due to the RBS of the upstream signal, but they are directed to the ONU where they got to mix with the upstream signal in the reflective modulator. The reflections result in the crosstalk effect which leads to the distortion of signals and degradation of system performance. The in-band crosstalk in colorless ONU is an unwanted effect and there are many methods to reduce this effect. The DC block-based model was proposed which blocks most of low-frequency beat signals which are the result of the photodetection and filtration process. Another way of reducing the crosstalk is by broadening the transmitted optical spectrum. The RZ with RSOA was found to broaden the spectrum of the upstream signal.

Bo-Hun Choi et.al [24] presented the method where the single broadband signal is split into many parts by spectrum slicing of the broadband signals. The femtosecond mode-locked laser are capable of this task but the cost of these sources is very high. Apart from the cost, these sources are very costly and the maintenance is very difficult. The lower cost can be achieved with incoherent light sources like EDFAs, LEDs etc. These components are cheaper as compared to the coherent sources, which makes incoherent sources suitable in cost-sensitive access network applications.

L. Xu et.al [25] presented the transmission of a 10Gbps signal carried out by a 40Ghz mm-wave carrier using SCM with colorless ONU. They observed that the effect of dispersion decre4ases by a large extent by the use of the SCM technique. For the remodulation and upstream transmission, the differential phase-shift keying (DPSK) remodulation was proposed. Avneet Kaur et.al [26] focuses on a re-modulation scheme based on TWDM orthogonal frequency division multiplexing (TWDM-OFDM- PON). A cost-effective solution of TDWM PON is done with the help of sharing of optical wavelength and the deployment of colorless ONU. They used a 25 Gbps data rate for downstream transmission and a 10 Gbps data rate for upstream transmission with the help of an Electroabsorption modulator (EAM).

The use of this OFDM gives better chromatic dispersion tolerance and also the bandwidth allocation to passive optical network users become flexible. This provides a good tradeoff between the data rate supported by the system and the reach supported by PONs. They observed the results of the system in terms of Quality factor and bit error rate (BER), the better results were observed in the case of the proposed method for the lesser amount of transmitted power.

Zhengxuan Li [27] have presented a hybrid TDM/WDM-PON scheme, they proposed the use of hybrid TDM/WDM along with the traditional TDM. They proposed to use the directly modulated tunable fiber ring laser based RSOA as the upstream source. The downstream wavelength selection was done by the Tunable optical filter (TOF). The TOF seeds the RSOA for upstream. With the proposed method the backscattering and Rayleigh scattering reduction was reported. The capacity of the system could be further improved by using a greater number of wavelengths and by tuning the operating wavelength of the ONU as per demand. Lilin Yi [28] presented colorless PON by using RSOA and TOF based on directly modulated laser (DML). Respective ONU can tune its wavelength as per their high bandwidth demand by tuning the central wavelength which enhances the system capacity of the network.

Fady El-Nahal et al. [29] presented in their paper the scheme to use colorless ONU with the help of FPLD. The fabry parot laser diode (FPLD) is an oscillator laser. They presented that the FPLD is capable of acting as the colorless transmitter of the upstream and for the downstream transmission the injection locked FPLD can be used at the ONU. The oscillation wavelength of the FPLD gets locked to injection mode in the case where the downstream signal gets injected in the FPLD. Qian Deneil et al. [30] proposed the use of RSOA. They mentioned that the modulation speed can be increased by reducing the reflection of the end facet with improved fabrication. They proposed a WDM-PON based which was based on the RSOA enabling the wavelength reuse. The RSOA does two tasks firstly it acts as an uplink colorless transmitter and it also acts as a modulator in the ONU. Also, there are many advantages of RSOA like its optical gain and wide optical bandwidth. With the RSOA the use of EDFAs from the system can be reduced as the RSOA provides much gain to the signals. TLD require an additional wavelength control method to achieve colorless operations [31]. Figure1 describes the different colorless techniques for NG-PON2.

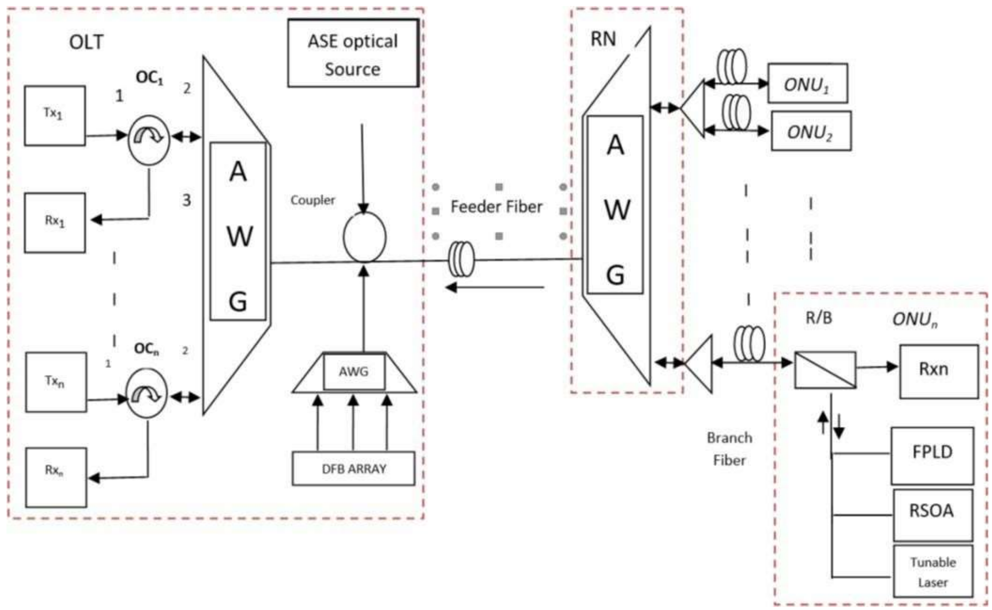

Figure 1: Different colorless techniques for NG-PON 2

Where,
Tx –Transmitter
Rx- Receiver
OC- Optical coupler
ASE-Amplified spontaneous emission
RN- Remote node
ONU- Optical network unit
AWG-Arrayed waveguide grating
DFB- Distributed feedback laser

4. Conclusion

TWDM based NG-PON2 is the most promising technology in PON standards. In this paper, we have studied promising developments of various standards with their characteristics and also we have reviewed the tunable laser technologies. Colorless ONU with low power consumption and low system cost can be achieved with the use of a wavelength reuse scheme. From the literature, it has been found that the FPLD and RSOA are the most promising components for the realization of colorless ONUs, apart from these the SOA-REAM, and TLD are also potential candidates for use in colorless ONUs. From the literature survey, it has been observed that the most suitable technique for colorless ONU is by using FPLD and RSOA in the TWDM NG-PON2 system.

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