Wavelength Division Multiplexing Passive Optical Network: review paper

[1]Chinky rani ,[2] Kulwinder Singh , [3]Bhawna utreja ,Punjabi university Patiala

Abstract: **A passive Optical network is a single, shared optical fiber that uses a passive optical splitter to divide the signal towards individual subscribers. The performance of WDM-PON can be improved by using various technologies. However, the transmission distance can be extended by using forward error correction codes and line coding greatly suppresses the interference between the downstream and upstream signals.**
Keywords: **Passive Optical Networks(PON), Wavelength Division Multiplexing Passive Optical Network(WDM PON)**

I. INTRODUCTION

The access network, also known as the "first-mile network," connects the service provider central offices (COs) to businesses and residential subscribers. This network is also referred to in the literature as the subscriber access network, or the local loop. The bandwidth demand in the access network has been increasing rapidly over the past several years. Residential subscribers demand first-mile access solutions that have high bandwidth and offer media-rich services. The predominant broadband access solutions deployed today are the digital subscriber line (DSL) and community antenna television (CATV) (cable TV) based networks. However, both of these technologies have limitations because they are based on infrastructure that was originally built for carrying voice and analog TV signals, respectively; but their retrofitted versions to carry data are not optimal. Currently deployed blends of asymmetric DSL (ADSL) technologies provide 1.5 Mbits/s of downstream bandwidth and 128 Kbits/s of upstream bandwidth at best. Moreover, the distance of any DSL subscriber to a CO must be less than 18000 ft because of signal distortions. Although variations of DSL such as very-high-bit-rate DSL (VDSL), which can support up to 50 Mbits/s of downstream bandwidth, are gradually emerging, these technologies have much more severe distance limitations.

One of the new technologies that have emerged in recent years is Passive Optical Networks. Passive optical Network (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, optical fiber that uses a passive optical splitter to divide the signal towards individual subscribers. PON is called passive because other than at the central office there are no active element within the access network. A PON enables an service provider to deliver a true triple play offering of voice, video and data, an important component of the data offering can be IPTV. PON are getting more widespread in rollout of Fibre To The Home(FTTH) infrastructure.

A PON is a point-to-multipoint optical network, where an optical line terminal (OLT) at the CO is connected to many optical network units (ONUs) at remote nodes through one or multiple 1:N optical splitters. The network between the OLT and the ONU is passive, i.e., it does not require any power supply. PONs use a single wavelength in each of the two directions—downstream (CO to end users) and upstream (end users to CO)—and the wavelengths are multiplexed on the same fiber through coarse WDM (CWDM).

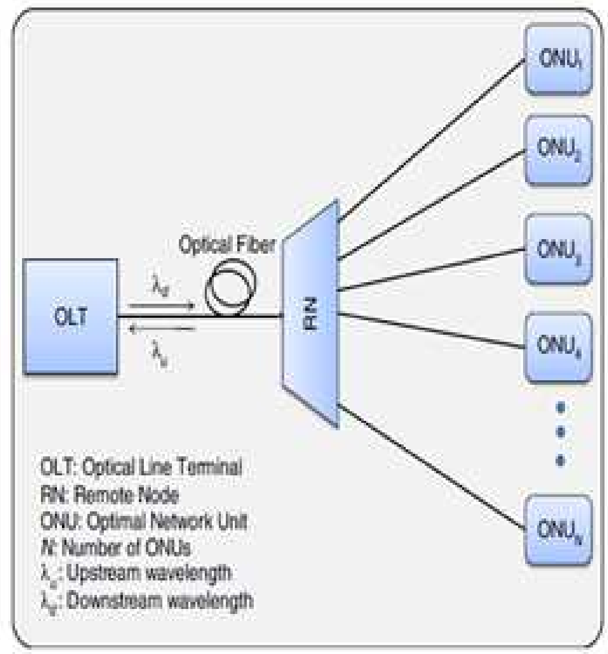

Fig.1 Passive optical network

II. Wavelength Division Multiplexing Passive Optical Network

Traditional single-wavelength PONs combine the high capacity provided by optical fiber with the low installation and maintenance cost of a passive infrastructure. The optical carrier is shared by means of a passive splitter among all the subscribers. As a consequence, the number of ONUs is limited because of the splitter attenuation and the working bit rate of the transceivers in the central office (CO) and in the ONUs. A WDM-PON solution provides scalability because it can support multiple wavelengths over the same fiber infrastructure, is inherently transparent to the channel bit rate, and it does not suffer power-splitting losses.

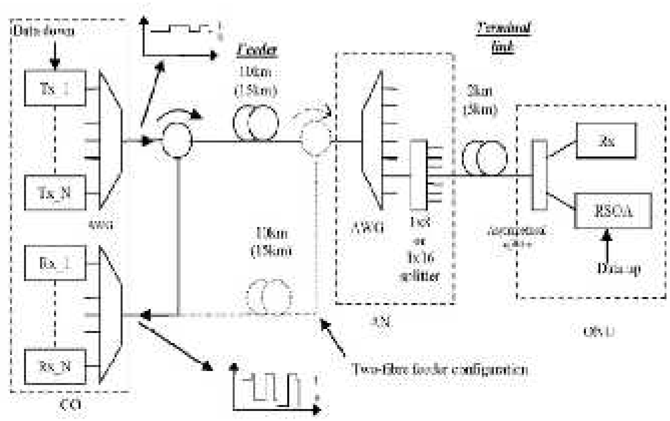

Fig. 2 WDM Passive optical network

The straightforward approach to build a WDM PON is to employ separate wavelength channels from the OLT to the ONUs in the downstream direction which called downlink wavelengths (¸*d*1¸*d*2, *: : :*, ¸*dN*). In upstream direction, the uplink wavelengths (¸*u*1, ¸*u*2, *: : :*, ¸*uN*) pass from the ONUs to the OLT. An efficient bi-directional broadband optical networks using dense wavelength division multiplexing (DWDM) technology is proposed . The proposed DWDM PON scheme is implemented using optical carrier suppression and separation (OCSS) technology to generate a down/uplink wavelength pair from a single laser source at the central office. This method enables the co-location of both upstream and downstream DWDM transmitters in the central office.

In WDM system multiple semiconductor lasers ,each at unique wavelength are combined on to single optical fiber cable using a wavelength multiplexer. Multiple optical signals propagate through fiber cable together until they are demultiplexed at destination and receivers by photodetectors. Wavelength demultiplexing at the central office (CO) provides full-duplex point–point connections.

III. Components of WDM-PON

A PON basically consists of an OLT at the central office which transmits traffic received from the access network to the Internet and vice versa, an remote node (RN) which contains passive splitters/couplers for demultiplexing the downstream traffic received from the OLT and multiplexing the upstream traffic to the OLT, and multiple ONUs close to user's premises which receive the downstream traffic from the RN and generate the upstream traffic to the RN.

A. Optical Line Terminal: Optical Line Terminal is basically transmitter placed at central office which transmits traffic received from the access network to the Internet and vice versa. It consists of various optical sources. Optical sources are classified into four groups , depending on the way wavelengths are generated. These are (1) a wavelength-specified source, (2) a multiple wavelength source, (3) a wavelength-selection-free source, and (4) a shared source. The multiple-wavelength source is applicable only to the OLT, the shared source is applicable to the ONU, and the remaining two are applicable to both. Various optical sources explained as follows:

(a)Tunable Lasers: the tunable laser is attractive if it can be used for several WDM channels. A mechanical-type laser, also called an external-cavity laser, is implemented by external grating or Fabry–Perot (FP) cavity, which is controlled mechanically. Because of its wide tuning range of up to 500 nm and good wavelength accuracy, it can be used for instrumentation purpose. However, the external-cavity tunable laser requires an external modulator for high-speed modulation because of its long cavity length. A thermally tunable DFB uses the wavelength-shift property of the DFB LD because of its cavity-index change with temperature.

(b)Distributed Feedback (DFB) Laser Diode (LD): As a most common scheme for obtaining a single optical longitudinal mode, distributed Bragg gratings are etched inside the cavity of a DFB LD, which allows only the wavelength-matching gratings to be lasing . If the grating is outside the cavity, it is called a distributed Bragg reflector (DBR) LD. Since there may occur a wavelength shift of _ 0.1 nm/°C, these LDs usually require a thermoelectric cooler (TEC) for stable operation as a WDM source. In addition, a wavelength locker, which helps the LD to lock exactly to its assigned wavelength, is needed. The DFB LD can be modulated directly for a WDM-PON deployment, where the distance is often less than 20 km. And it has good high-speed modulation property because of its narrow linewidth of less than a few MHz.

(c)Vertical-Cavity Surface-Emitting Laser (VCSEL) Diodes: VCSELs with 850 nm and 1310 nm wavelengths are commercially available and widely used for LAN applications. But the VCSEL at 1550 nm wavelength is at its early stage of development because of poor optical and thermal properties of the laser material. Although it cannot be used as a WDM-PON source today, it can be adopted as an upstream source in a composite PON (CPON).

(d) Gain-Coupled DFB LD Array: Another possible way of integrating multiple wavelength sources is to implement DFB LD arrays by combining a gain-coupling mechanism and a tuning capability in one LD module. Thin-film resistors are integrated for tuning wavelengths by controlling the temperature. The advantages are compact size and high speed modulation. But it is difficult to accurately maintain every channel at the correct wavelength, since each lasing wavelength is determined by an independent filter.

Considering that different types of gratings are etched inside a chip, this scheme is more realizable for a small number of channels.

C. RN (Remote Node)

The remote node (RN) in a PON can be made of either a power splitter or a passive wavelength router. A power splitter distributes all incoming signals evenly into all output ports, requiring a wavelength filter at each ONU. Insertion loss, uniformity, return loss, and operating temperature are important features for its selection. Although the splitter is a simple, low-cost, distribution structure, it requires optical filters with different center wavelengths at ONUs. Also, more signal loss occurs with a splitter than with a wavelength router. There are various types of remote node but most commonly used is array wave grating(AWG) .The AWG has been a successful device in WDM industry. It has been used in many long-distance WDM systems as a multiplexer/demultiplexer and as an add-drop multiplexer (ADM). It routes each specific wavelength to a unique output port, separating multiple wavelengths at the same time. Its cyclic wavelength property enables the AWG to be used at the RN, both as multiplexer and demultiplexer at the same time. When the upstream transmitters use wavelengths that differ from the downstream in integral multiples of the free spectral range (FSR) of the AWG, the same AWG output port can be assigned for both upstream and downstream transmission.

There is another common scheme for multiplexing/demultiplexing wavelengths, called thin-film filters or multilayer interference filters. By positioning cascaded filters in the optical path, wavelengths can be demultiplexed, and vice versa. Each filter is designed to transmit a unique wavelength while reflecting others. This type of filter is better for CWDM while AWG is good for implementing large channel counts. Recently, a new type of wavelength router, called a bulk grating, has been suggested for use in a DWDM system. This bulk grating is based on a bulk-type diffraction grating and is reported to have less insertion loss of sub-3 dB.

C. Optical network unit: there are multiple ONUs close to user's premises which receive the downstream traffic from the RN and generate the upstream traffic to the RN.ONU can also be called receiver in passive optical network. A receiver module consists of a photodetector (PD) and its accompanying electronics for signal recovery. Common PDs are positive-intrinsic-negative (PIN) and avalanche photodiode (APD), which find different applications according to the required sensitivity. Electronic parts, usually composed of preamplifier, main amplifier, and clock and data recovery circuits (CDRs), depend on the protocol used on each wavelength. Since each wavelength can work separately in a WDM-PON, each receiver can be configured differently. The power of the optical signal that reaches a receiver module is determined by its transmission distance and splitting ratio.Most commonly receiver used in WDM-PON is PINreceiver. A PIN-type PD, so called because it is composed of P-doped, intrinsic, and N-doped semiconductors, is very common because of its simple structure, ease of use, and low cost. As transmission loss becomes larger and the received optical power does not satisfy the receiver sensitivity of the PIN PD, it should be replaced with an APD that has _ 10 dB higher sensitivity at the cost of a higher price. The better performance originates from its internal amplification process called the avalanche effect. Various combinations of LDs and PDs may be taken into consideration. If a highpower OLT is used, then a cheap PIN PD can potentially be a better candidate at the ONU. But, for the upstream case, having a high-power source at each ONU may be quite costly. Therefore, to have an APD at the OLT with a low-power ONU can be a better solution.

IV. Various techniques used in WDM-PON

A. RSOA based WDM-PON

In fiber optic communication, there is degradation of transmission signal with increased distance. To remove loss limitations, optical amplifiers are used which directly amplify the transmitter optical signal without converting it into electric forms. The optical amplifiers are used in linear mode as repeaters, optical gain blocks and optical pre-amplifiers. unlike semiconductor lasers, the frequency response of the RSOA has a smooth rolloff with no relaxation oscillation peak, while its modulation has a good linearity similar to the laser diode.Wavelength-division-multiplexed (WDM) passive optical networks (PONs) offer large capacity, high network security, protocol transparency, and easy upgradability.

The wavelength-shared scheme using reflective semiconductor optical amplifiers (RSOAs) can be a promising solution for cost-effective implementation of these networks . Not only does the scheme utilize a single light source per ONU for bidirectional transmission, but it also provides colorless operation of the ONU, greatly relieving the inventory problem. However, the modulation bandwidth of the RSOA, limited by carrier lifetime, is only about 2 GHz. Thus, it is nearly impossible to modulate such a device at 10 Gb/s. Also as we decreased the optical power incident on the RSOA, the receiver sensitivity was also degraded, due to which there was no eye opening at decision point.

B. Electronic equalizer technique in WDM-PON

Electronic equalizer is an electronic device made of filters and amplifiers, used to alter the relative strengths of different frequencies in an electronic signal. Equalizers are used primarily for fine-tuning of the signal to compensate for distortions such as weak response or over sensitivity at various frequencies. Electronic equalization using the decision feedback equalizer (DFE) consisting of feed forward and feedback filters.

Thus, despite its extremely limited bandwidth, it is possible to operate the RSOA at 10 Gb/s by using the electronic equalization technique. Power penalty caused by the limited bandwidth of the RSOA can be suppressed by using electronic equalizers. Clear eye opening was recovered by the equalizer. we can achieve the nearly optimal performance by using 12-tap feed forward and two-tap decision-feedback sections.

C. Forward error correction code technique in WDM-PON

Forward error correcting (FEC) codes are proposed €or use in PON to relax the requirements on laser sources. They can also be used to improve the system power margin to increase the reach **of** PON or the number of users that can be supported by PON systems**.** wavelength-division-multiplexed passive optical network (WDM PON) has long been considered as an ultimate solution for the next-generation broadband access network capable of providing 10-Gb/s data to each subscriber. However, in practice, it is not easy to increase the operating speed of the WDM PON to 10 Gb/s due to the slow dynamics of the colorless light sources used at the optical network units (ONUs) such as the reflective semiconductor optical amplifiers (RSOAs). This problem can of course be resolved simply by utilizing high-speed external modulators at the outputs of the colorless light sources. However, this solution is not realistic for use in cost-sensitive access networks.

Therefore to improve the power budget for the proper operation of the 10-Gb/s WDM PON and the excessive penalties resulting from the utilization of bandwidth-limited light sources forward-error-correction (FEC) codes are used. There are various types of forward-error-correction (FEC) codes e.g. Reed-Solomon (RS) (255, 239), Bose-Chaudhuri-Hocquenghem (BCH) (4359, 4320), low-density parity-check (LDPC) (1908, 1697), and the concatenated scheme using BCH(3860, 3824) as outer and BCH(2040, 1930) as inner codes could increase the maximum reach of the WDM PON to 20 km.

D. Coding techniques used in WDM-PON

The wavelength-shared (λ-shared) scheme using reflective semiconductor optical amplifiers (RSOAs) can be a promising solution for cost-effective implementation of these networks. In Wavelength sharing scheme, the upstream performance can be severely degraded by the interference between the downstream and upstream data at the central office (CO). Power budget and scalability of the wavelength-division-multiplexed passive optical network (WDM PON) implemented by using reflective semiconductor optical amplifiers (RSOAs) can be significantly improved by modulating the downstream signals in coding format. A proper choice of line coding can also greatly reduce the interference between the downstream and upstream transmission. For example, Manchester coding can deplete the signal contents at low frequencies and thus allows the low-data-rate upstream signals to reside at these frequencies without interfering with the downstream signals . However, Manchester coding doubles the bandwidth of the signals, which limits the downstream data rate and also makes the signals more susceptible to fiber dispersion. But DC-balanced line coding for a cost-effective implementation of 10-Gbps downlink/2.5-Gbps uplink WDM-PON system using a directly modulated laser (DML) and an RSOA can be used to improve both the downstream and upstream performance. At last, we can say that line coding is best technique used in WDM-PON because it improves both downstream and upstream performance.

V. Conclusion

In this paper, we presented a comprehensive review on various technologies used to improve the performance of WDM-PON systems. We focused on various aspects of device technologies and network components. The performance of WDM-PON can be improved by using various technologies. However, the transmission distance can be extended by using forward error correction codes and line coding greatly suppresses the interference between the downstream and upstream signals.

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