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Review on Indispensable Internetworking Architectures in Passive Optical Networks

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Abstract - *For the ever increasing bandwidth hungry applications, Passive Optical Network (PON) is assumed to be an effective solution. It is a system which leads optical fiber cables and signals all or most to the end user. It is a technology of telecommunication that implements a point to multipoint architecture and utilizes unpowered components to enable a single fiber to serve multiple end users without the need of having individual fibers between the customer and the hub. We in this review article summarize different kinds of internetworking architectures in passive optical networks with specifications and applications.. The PON (Passive Optical Network) is a passive optical network that is classically installed in a point-to-multipoint fashion alike to a star network. The single fiber leaving the central office is characteristically split, using a power splitter or many power splitters dispersed along the fiber.*

Key Words: Passive optical network (PON, Optical network unit (ONU), Bandwidth, BER (bit error rate))

1. INTRODUCTION

Passive Optical Network (PON) [1-3] consist 3 portions namely an Optical Line Terminal (OLT) or Central Office (CO), Remote Node (RN) or Optical Distribution Network (ODN) at mid-path and an Optical Network Unit (ONU) or Optical Network Terminal (ONT) at end user [4]. An OLT acts as the endpoint hardware device in a PON. It includes a gateway router (GWR), central processing unit (CPU), PON cards and a voice gateway (VGW) uplink cards. Equipment at the customer end is called ONU. In PON, only OLT and ONUs use active (powered) components while the RN used passive (unpowered) components like Power Splitters (PSs), Power Combiners (PCs), Arrayed Waveguide Grating (AWG), Fiber Bragg Grating (FBG), etc. and hence it is called passive network. Due to the use of passive components and avoidance of active components like electronic amplifiers and regenerators between OLT and RN, these networks are energy efficient networks with significantly reduced cost. The fiber between OLT and RN is called feeder fiber which ranges from 20 km or more while that between RN and ONUs is called distribution fiber which usually ranges several kilometres. PON is a single point to multi-point network which lessens the length of fibre needed and OLT equipment as compared to point to point network. The transmission from ONUs to the OLT is called upstream transmission and that from the OLT to ONUs is called downstream transmission. In the downstream, the traffic is broadcasted while in the upstream it is time division multiplexed. In PON, TDM-PON [7] is a concept used for access and long haul networks in order to accommodate more number of users in a network. In the uplink, all ONUs share the same fibre through Time Division Multiple Access (TDMA) by transmitting the signal in specified time duration, for downlink direction, the OLT coordinates the ONUs to pass frames specified for particular ONU for specified time interval. To avoid collisions in the upstream some point to multipoint media access protocols are to be used. At RN, the downstream signal is split via power splitter and the same signal is received at each ONU in the network. Each ONU detects the signal intended for it according to the specific time slot [5].

In this PON, all ONU have identical transceivers and TDMA is implemented in electronic domain, this method has been practical and effective solution for the access networks over the globe. But such a strategy faces problems as the varied distance between various ONUs and RN, therefore, different delays do happen in upstream direction, capacity issues due to time sharing, security issues as power split signal is received by all ONUs, requirement of burst mode receiver, etc. The problem of different delays is mitigated through implementation of a procedure termed as ranging [6] where the distance of the ONUs from OLT is decided by exclusive control frames [6]. Predominantly, due to the time sharing and power splitting mechanism, TDM-PON foists some limitations on flexibility and privacy of the network. These issues can be relieved by introducing new technology named Wavelength Division Multiplexing in PON (WDM-PON). In PON, WDM-PON [7] [8] [9] is an innovative concept for access and long haul networks. It provides a logical point-to-point architecture by using multiple different wavelengths in the fiber infrastructure that contains no active component in order to increase capacity. In WDM-PON upstream is transmitted on different set of wavelengths and downstream traffic is also transmitted on different set of wavelengths. For this purpose, a number of transceivers operating at different wavelengths are employed at the OLT and at ONUs, a set of transmitter and receiver with specific wavelength is employed. AWG [10] or thin film filter is generally used as multiplexer. For the downstream transmission, the signal at

different wavelengths are generated at the OLT, multiplexed and travels through the feeder fiber, on reaching at RN, gets power split and received by all ONUs via filtering and detection process. For the upstream transmission, signals at different wavelengths from different ONUs are multiplexed at RN and gets transmitted to OLT traveling distribution fiber, RN and feeder fiber. This method has a certain guaranteed QoS for broadband services. Important to mention that there is no problem of range security and power. It simplifies the control and electronics in the network. However, the cost for dedicated transceivers is still high as compared to TDM-PON, the subscribers can be benefited from extra high available bandwidth. In future, with the research in innovative WDM architectures with colourless ONUs and advancements in the technology, we can expect that the problem of cost will also get partially alleviated. Here in we report the background literature in the area of research in ONU-internetworking. It is focused on fundamental concepts on ONU-internetworking. It also explains the role of ONU-internetworking and benefits.

2. TYPES OF INTERNETWORING ARCHITECTURES

In the current trend, end users are heading towards owning their own private network in conjunction with the public network for rapid transmission of information. Consumers residing in one building or area are generally liable to own personal and private networks for security and privacy considerations. It is mandatory for above mentioned networks to have considerations that include low latency along with high throughput while consuming minimum power. Especially for optical networks (PONs), the networks like that are generally referred to as VPGs and the data traffic for such networks is termed as inter-ONU traffic. ONU-internetworking is the communication of information with different ONUs pertaining to a particular VPG. Due to this the communication between ONU cannot be intervened by an OLT which is a desirable feature of such communication system. As far as classical approach of TDM-PON, the ONUs is not able to communicate directly among one another.

The provision of direct network to end users has two fold advantages in which the service provider as well as end user is benefited. From network providers perspective, direct or wired connections are mandatory for ONUs without employing complex centralized protocols for routing. This makes it easy for service providers to facilitate services to end users. It is due to this reason that for both cases of upstream and downstream, the bandwidths can be used for other services that may include service like high-value broad-bands, IPTV, high definition TV. The security in such communication systems is owed to direct or wired communication networks maintaining the data privacy for the end user. Security is one of the major challenges faced by various low to high end network applications which makes the ONU network more desirable and preferable option for customers. ONU-networking is an efficient solution to classical challenges faced by conventional networks that include reduced latency, in-efficient band width usage, high processing and scheduling time. In ONU-network data traffic at first is transmitted to OLT and then re-routed to target ONU.

2.1 ONU Internetworking Methods

ONU-internetworking can be done in many different ways. But it can be generally categorized into two techniques:

1. Inter-ONU Broadcast
2. Formation of VPGs of ONUs

Inter-ONU Broadcast: As far as inter-ONU broadcast is concerned, the ONU can communicate to their OUNs, directly within the network without the need of being coordinated by the OLT. Thus, the traffic which is intended for inter-ONU communication is redirected back from the RN, broadcast to the entire ONUs available in the network. Hence, the traffic is received by the entire ONUs.

Formation of VPGs of ONUs: In case of some practical scenarios, inter-ONU communication is required to be done in few ONUs forming a group. Thus, by formation of VPGs/VPNs of ONUs, virtual groups of like users are formed and traffic is broadcast to the particular group only. In this, the traffic is received by a specific group of ONUs only. In this case, ONUs in other groups will not be able to receive the inter-ONU traffic. Due to this, the privacy is maintained. The majority of researches on this topic are focused on development of practical and feasible internetworking architectures for the access networks. So many architectures have already been proposed. Besides, there are also some research interests that try to minimize the number of transmitters and receivers required, minimize the losses, maximize the power budget, improves security and for cost reduction of ONU.

Here, we will present a critical review for most of the pre-existing projected internetworking architectures by classifying them in architectures capable of inter-ONU overall broadcast and architectures capable of inter-ONU VPG broadcast communication.

Based on ONU-internetworking, there are a number of techniques that include virtual ring network [11], reflection mechanism using FBG [12], [13] loop-back mechanism [14], [15], use of RF carrier [16], reflective waveband grouping [17], Electronic-code division multiple access (E-CDMA) [18], Sub Carrier Multiplexing (SCM) technique [19], Dynamic waveband reflection, two stage PONs [20] and many more have already been employed. Let us review all of these methods one by one. First of all, the broadcast methods have been discussed and then VPG communication methods have been discussed.

2.2 Inter-ONU broadcast Methods

Reflection mechanism using FBG: In this method, an FBG is placed near the star coupler (SC) as shown in the Figure 1, which reflects the inter-ONU traffic and hence it is broadcast in the whole network. In this, two wavelengths are used, $\lambda 0$ for regular upstream traffic and $\lambda 1$ for inter-ONU traffic. Downstream transmissions follow TDM and upstream

transmissions follow TDMA [10]. The Bragg wavelength of FBG is λ1 and due to this, it reflects that wavelength while passing the regular upstream traffic freely, experiencing a small amount of insertion loss of 0.62 dB.

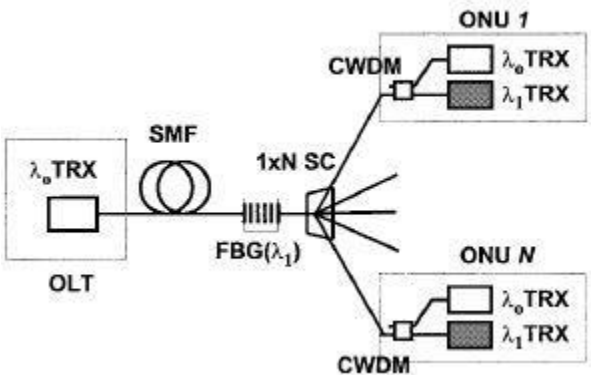

Fig. - 1 Reflection mechanism using FBG [14]

When any one of the ONUs sends its traffic using the λ1 transceiver, that wavelength is reflected by the FBG after traveling the CWDM and the SC. No signal with this wavelength is transmitted to OLT. By the SC, this signal power gets split into two parts and gets conveyed to each ONU to detect the data. For this purpose, different MAC protocols can be used [2], [15], [16]. Although it provides a simple inter-ONU communication, a wavelength specific extra transceiver is required at each ONU and it also imposes limitation on power due to high splitting loss [14].

ONU-Internetworking Capability Among Users using CSMA/CD:

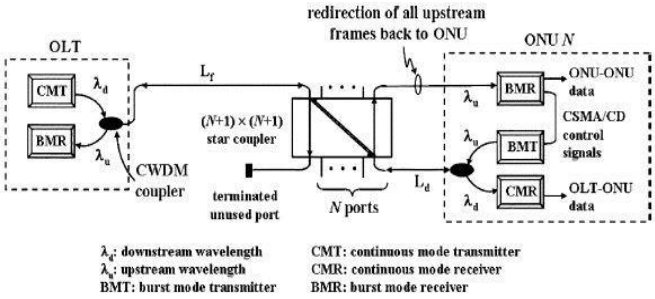

Fig. - 2 ONU-Internetworking using CSMA/CD [17]

A mechanism of loop-back was projected so as to obtain the ONU-broadcast proficiency for TDM-PONs in [17], [18]. The (N+1) x (N+1) SC has been employed at the RN to communicate the inter-ONU traffic signal to all ONUs present within the network as shown in Figure 2. If we compare with the previous mechanism in which reflection is centred on a FBG, the inter-ONU traffic does not result in elevated insertion loss by the round trip transmission over and done with star coupler. Hence, it can majorly ease the problems of limited power in such a technique so as to ensure high speed rate of data transmission. Though, the technique is appropriate only for the TDM-PON [17].

LAN Emulation Technique using RF carrier: In this technique, inter-ONU i.e. LAN emulation is obtained by using an FBG before SC and RF modulation of inter-ONU data. The only difference with inter-ONU data is that first of all it is amplitude modulated on an radio frequency (RF) carrier which is chosen such the it is from upstream data using low voltage controlled oscillator. The up converted RF inter-ONU data and upstream data are electrically combined and modulated onto the same wavelength λu and transmitted. The narrow band FBG placed near SC has Bragg wavelength as it reflects one of the optically modulated sidebands and it is broadcast for ONUs as shown in Figure 3. With escalation in ONUs in this, required splits at Star Coupler (SC) escalates resulting in increased splitting loss and reduced power margin for each signal [19].

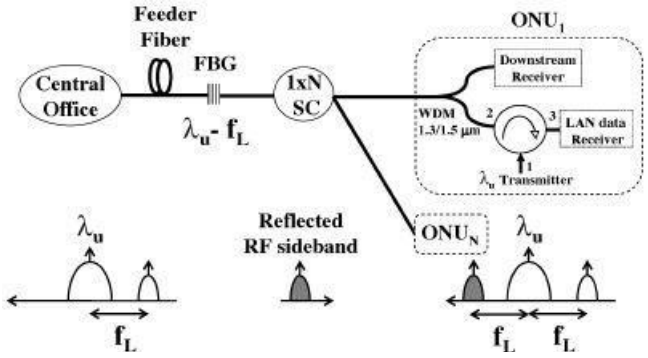

Fig. - 3 LAN Emulation Technique using RF carrier [19]

WDM-PON Network for Simultaneous Upstream Transmission with ONU Interconnection Capability: In this architecture, at remote side, 1xN AWG is involved for de-multiplex the downstream signals. A center frequency of 193.1 THz exists for AWG with wavelength spacing of 100 GHz between the two ports. Cascading of a 50 GHz inter-leaver has been done for every output port of 1 x N AWG as shown in Figure 4. These are used to separate out the even and odd multiple of 50 GHz signals into two paths. Each of the even wavelengths are directed towards ONUs and all odd (shifted by 50 GHz) wavelengths are directed towards N x N splitter. The splitter is linked in parallel among the RN inter-leavers and ONUs. The resolve of this splitter is to deliver the straight intercommunication of each ONUs instead of OLT. The downstream and upstream transmissions are done for even wavelengths, and inter-ONU communications are at 50 GHz shifted odd wavelengths [20].

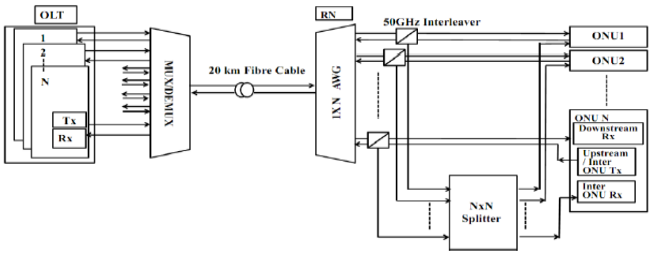

Fig. - 4 WDM-PON Network for Simultaneous Upstream Transmission with ONU Interconnection Capability [20]

2.3 Formation of VPGs of ONUs

Bandwidth-Efficient PON System for Broad-Band Access and Local Customer Internetworking: As shown in the above Figure 5, if Optical Switch 1 (OSW1) is in bar state and

OSW2 is in cross state, the PON system is in the internetworking mode. The downstream signals reaching on OSW2 gets routed to the antireflection treated port. This enables ONUs to send internetworking data securely [18].

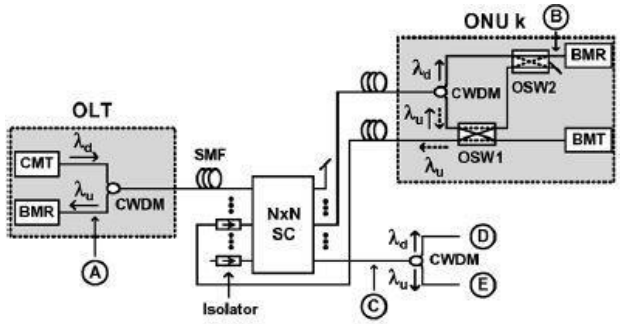

Fig. - 5 Bandwidth-Effective PON for Broadband Access and Local-Customer Internetworking [18]

Internetworking among ONUs in EPON Using OCDMA Technique: Optical CDMA (OCDMA) technique enables different users to admit the transmission medium by conveying various optical code words to multiple end users. A specific code is assigned to each user to encode the data bits. The encoded data is transmitted and received by a designated receiver. By using this technique multiple private networks can be established on EPON. By using an FBG before SC as shown in Figure 6, a specific wavelength which is taken for VPG communication can be reflected towards ONUs. This method requires installing multiple private networks through EPON by using a particular code for particular network [21].

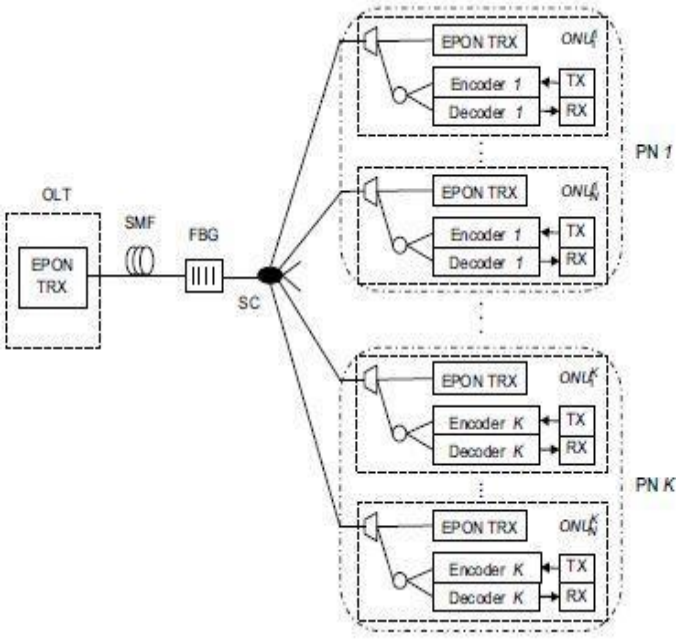

Fig. - 6 Internetworking in EPON Using OCDMA Technique [21]

Passive Virtual Optical Networking Technique Using a Cyclic N*N Arrayed Waveguide Grating for Multiple Multi-hop Ring Network: With the use of cyclic property of AWG, a more flexible solution to the multilayer internetworking has been found. The virtual ring network requires only a single fiber between two nodes is required, provides protection in case of fiber cut and it is flexible to be adjusted with changing network size. In reference to access networks customers can select self decided protocols for control and also can manage their VPN. While the demand is increasing, a single ring network won‟t be able to serve the purpose of high speed networking. Hence it may be necessary to introduce a multilayer networking to meet the demands. This will lead to more than one VPN for the same group of users. The group size and number of users may vary in a VPN. The use of AWG results in flexible VPN on star configured optical network with legacy and advanced ring network protocols. This method is useful for interconnection of gigabit routers in the metropolitan area and high speed device in large buildings [22].

Packet-Switched Waveband-selective PON Enabling Optical Internetworking among ONUs: In this, a waveband selective PON has been proposed that enables ONU-internetworking within the same waveband (WB). A single pair transmitter/receiver is needed at each ONU. ONUs is grouped and form VPNs based on WBs assigned to them. The VPNs are executed by adjusting a WB reflector, dynamically at the OLT to achieve flexible arrangement. As shown in Figure 7, the transmitter at ONU is having an explicit wavelength and end-to-end wavelengths are grouped to form a WB. The receiver at ONU consists of WB filter that covers VPN wavelengths. Hence, the signal from an ONU can be transmitted to different ONUs in same VPN if WB reflector is used at OLT. The WB can be reconfigured dynamically to handle rapid traffic [5].

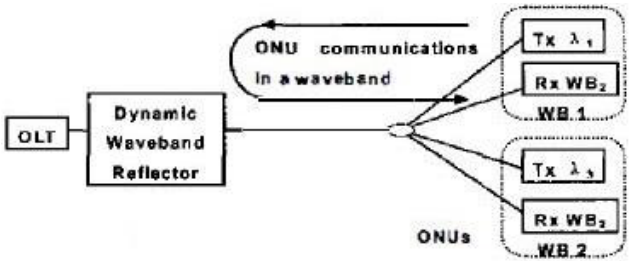

Fig. - 7 A Packet-Switched Waveband-selective PON Enabling Optical Internetworking [23]

Multiple Secure VPNs Using Electronic CDMA: In this technique, each ONU is alloted a specific E-CDMA code, that is multiplexed through data that is intended for the VPN and decoded by the one who has that unique code. As shown in the Figure 8, the system uses (N+1) x (N+1) SC to which N ONUs are connected via 2 circulation fibers. The transmitted E-CDMA signal is redirected to each ONU via second distribution fiber. The upstream transmission takes place at 1.3 μm while E-CDMA signal is transmitted at 1.5 μm.

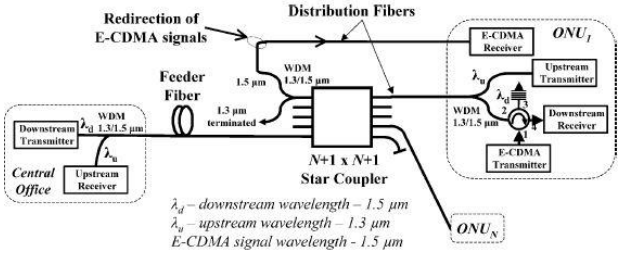

Figure 8 Multiple Secure VPNs Using Electronic CDMA [24]

3. CONCLUSIONS and SUMMARY

This review article delivers a literature survey of research into potential methods for next generation PONs. The article show-cases the required modifications for each standard in terms of the physical layer. In accumulation, this review highlights the necessities and the multiplexing methods for PONs and identifies the pros and cons. Furthermore, hybrid technologies that are being used to fulfil the requirements set for NG-PON2 are also discussed .Despite the work and the effort that have been invested to improve PON performance, challenges remain and should be explored in future studies.

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