

# Department of Electrical Engineering

## Assignment

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### Final paper

<b>Course Title:</b>	<b>Mobile and Broadband Networks</b>	<b>Module: 3<sup>rd</sup></b>
<b>Instructor:</b> <b>pir mehar ali shah</b>	<b>Total Marks:</b>	<b>50</b>

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**Q1. Passive Optical Network is a promising broadband Access Technology that provides many advantages such as high-quality triple play service in a cost effective manner. PON technologies have been developed with different architectures and standards over the past few decades. IEEE and ITU are the standardization bodies that have proposed their own versions of PON's. Support you answer to explain the PON Architectures proposed by ITU and IEEE in terms of its FRAME STRUCTURES (DATA LINK LAYER).**

## **Passive Optical Network:**

A PON is a fiber network that only uses fiber and passive components like splitters and combiners rather than active components like amplifiers, repeaters, or shaping circuits. Such networks cost significantly less than those using active components. The main disadvantage is a shorter range of coverage limited by signal strength. While an active optical network (AON) can cover a range to about 100 km (62 miles), a PON is typically limited to fiber cable runs of up to 20 km (12 miles). PONs also are called fiber to the home (FTTH) networks.

The term FTTx is used to state how far a fiber run is. In FTTH, x is for home. You may also see it called FTTP or fiber to the premises. Another variation is FTTB for fiber to the building. These three versions define systems where the fiber runs all the way from the service provider to the customer. In other forms, the fiber is not run all the way to the customer. Instead, it is run to an interim node in the neighborhood. This is called FTTN for fiber to the node. Another variation is FTTC, or fiber to the curb. Here too the fiber does not run all the way to the home. FTTC and FTTN networks may use a customer's unshielded twisted-pair (UTP) copper telephone line to extend the services at lower cost. For example, a fast ADSL line carries the fiber data to the customer's devices.

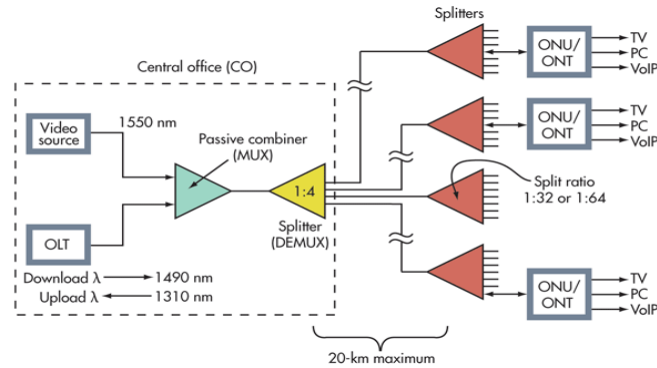
The typical PON arrangement is a point to multi-point (P2MP) network where a central optical line terminal (OLT) at the service provider's facility distributes TV or Internet service to as many as 16 to 128 customers per fiber line. Optical splitters, passive optical devices that divide a single optical signal into multiple equal but lower-power signals, distribute the signals to users. An optical network unit (ONU) terminates the PON at the customer's home. The ONU usually communicates with an optical network terminal (ONT), which may be a separate box that connects the PON to TV sets, telephones, computers, or a wireless router. The ONU/ONT may be one device. In the basic method of operation for downstream distribution on one wavelength of light from OLT to ONU/ONT, all customers receive the same data. The ONU recognizes data targeted at each user. For the upstream from ONU to OLT, a time division multiplex (TDM) technique is used where each user is assigned a timeslot on a different wavelength of light. With this arrangement, the splitters act as power combiners.

The upstream transmissions, called burst-mode operations, occur at random as a user needs to send data. The system assigns a slot as needed. Because the TDM method involves multiple users on a single transmission, the upstream data rate is always slower than the downstream rate.

## **GPON:**

Over the years, various PON standards have been developed. In the late 1990s, the International Telecommunications Union (ITU) created the APON standard, which used the Asynchronous Transfer Mode (ATM) for long-haul packet transmission. Since ATM is no longer used, a newer version was created called the broadband PON, or BPON. Designated as ITU-T G.983, this standard provided for 622 Mbits/s downstream and 155 Mbits/s upstream. While BPON may still be used in some systems, most current networks use GPON, or Gigabit PON. The ITU-T standard is G.984. It delivers 2.488 Gbits/s downstream and 1.244 Gbits/s upstream. GPON uses optical wavelength division multiplexing (WDM) so a single fiber can be used for both downstream and upstream data. A laser on a wavelength ( $\lambda$ ) of 1490 nm transmits downstream data. Upstream data transmits on a wavelength of 1310 nm. If TV is being distributed, a wavelength of 1550 nm is used. While each ONU gets the full downstream rate of 2.488 Gbits/s, GPON uses a time division multiple access (TDMA) format to allocate a specific timeslot to each user. This divides the bandwidth so each user gets a fraction such as 100 Mbits/s depending upon how the service provider allocates it.

The upstream rate is less than the maximum because it is shared with other ONUs in a TDMA scheme. The OLT determines the distance and time delay of each subscriber. Then software provides a way to allot timeslots to upstream data for each user. The typical split of a single fiber is 1:32 or 1:64. That means each fiber can serve up to 32 or 64 subscribers. Split ratios up to 1:128 are possible in some systems. As for data format, the GPON packets can handle ATM packets directly. Recall that ATM packages everything in 53-byte packets with 48 for data and 5 for overhead. GPON also uses a generic encapsulation method to carry other protocols. It can encapsulate Ethernet, IP, TCP, UDP, T1/E1, video, VoIP, or other protocols as called for by the data transmission. Minimum packet size is 53 bytes, and the maximum is 1518. AES encryption is used downstream only. The latest version of GPON is a 10-Gigabit version called XGPON, or 10G-PON. As the demand for video and over the top (OTT) TV services has increased, there is an increasing need to boost line rates to handle the massive data of high-definition video. XGPON serves this purpose. The ITU standard is G.987. XGPON's maximum rate is 10 Gbits/s (9.95328) downstream and 2.5 Gbits/s (2.48832) upstream. Different WDM wavelengths are used, 1577 nm downstream and 1270 nm upstream. This allows 10-Gbit/s service to coexist on the same fiber with standard GPON. Optical split is 1:128, and data formatting is the same as GPON. Maximum range is still 20 km. XGPON is not yet widely implemented but provides an excellent upgrade path for service providers and customers.



Most PONs are configured like this. The number of splitters and split levels varies with the vendor and the system. Split ratios are usually 1:32 or 1:64 but could be higher.

## EPON:

The Institute of Electrical and Electronic Engineers (IEEE) developed another newer PON standard. Based on the Ethernet standard 802.3, EPON 802.3ah specifies a similar passive network with a range of up to 20 km. It uses WDM with the same optical frequencies as GPON and TDMA. The raw line data rate is 1.25 Gbits/s in both the downstream and upstream directions. You will sometimes hear the network referred to as Gigabit Ethernet PON or GE-PON. EPON is fully compatible with other Ethernet standards, so no conversion or encapsulation is necessary when connecting to Ethernet-based networks on either end. The same Ethernet frame is used with a payload of up to 1518 bytes. EPON does not use the CSMA/CD access method used in other versions of Ethernet. Since Ethernet is the primary networking technology used in local-area networks (LANs) and now in metro-area networks (MANs), no protocol conversion is needed.

There is also a 10-Gbit/s Ethernet version designated 802.3av. The actual line rate is 10.3125 Gbits/s. The primary mode is 10 Gbits/s upstream as well as downstream. A variation uses 10 Gbits/s downstream and 1 Gbit/s upstream. The 10-Gbit/s versions use different optical wavelengths on the fiber, 1575 to 1580 nm downstream and 1260 to 1280 nm upstream so the 10-Gbit/s system can be wavelength multiplexed on the same fiber as a standard 1-Gbit/s system.

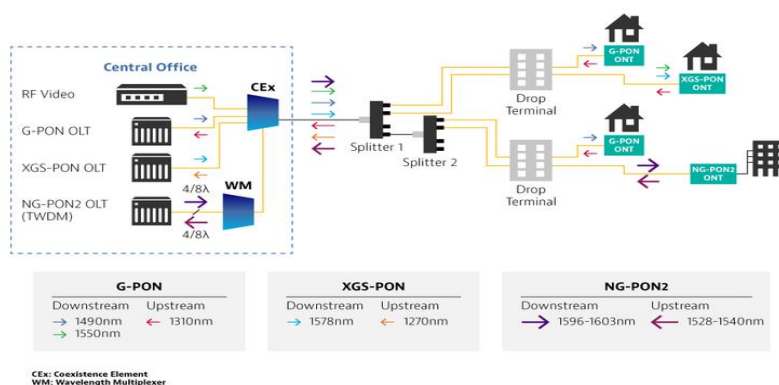
## Passive Optical Network Architecture:

PON networks adopt a Point-to-multipoint (P2MP) architecture which utilizes optical splitters to divide the downstream signal from a single OLT into multiple downstream paths to the end users; the same splitters combine the multiple upstream paths from the end users back to the OLT.

Point-to-multipoint was selected as the most viable PON architecture for optical access networks with the inherent efficiencies of fiber sharing and low-power consumption. This architecture was standardized in 1998 via the ATM-PON G.983.1 specification.

Today, the ITU-T G.984 standard for G-PON has supplanted the ATM standard, since Asynchronous Transfer Mode (ATM) is no longer utilized.

A PON network starts with the optical line terminal (OLT) at the service provider source location typically known as a Local or Central Office, or sometimes referred to as an exchange or headed. From there, the fiber-optic feeder cable (or feeder fiber) is routed to a passive splitter, along with a backup fiber if one is used. Distribution fibers then connect from the splitter to a drop terminal, which can be located in a street cabinet or in a ruggedized housing mounted in a pit, on a telegraph pole or even on the side of buildings. Drop fibers then provide the final one-to-one connection from drop terminal port to an end user ONT/ONU. In some cases, more than one splitter is used in series; this is referred to as cascaded splitter architecture.



The signals carried on the feeder fiber can be split to provide service to as many as 128 users with an ONU or ONT converting the signals and providing users with internet access. The number of ways the downstream OLT signal is divided or split before reaching the end user is known as the splitter or split ratio. In more complex configurations where RF video is being broadcast in parallel to the PON data service or additional PON services co-exist on the same

PON network, passive (MUX) combiners are used at the central/local office to merge the video overlay wavelength and additional PON service wavelengths onto the outbound OLT feeder fiber.

### **IEEE:**

In 2004, the Ethernet PON (EPON or GEPON) standard 802.3ah-2004 was ratified as part of the Ethernet in the first mile project of the IEEE 802.3. EPON is a "short haul" network using Ethernet packets, fiber optic cables, and single protocol layer. EPON also uses standard 802.3 Ethernet frames with symmetric 1 gigabit per second upstream and downstream rates. EPON is applicable for data-centric networks, as well as full-service voice, data and video networks. 10 Gbit/s EPON or 10G-EPON was ratified as an amendment IEEE 802.3av to IEEE 802.3. 10G-EPON supports 10/1 Gbit/s. The downstream wavelength plan support simultaneous operation of 10 Gbit/s on one wavelength and 1 Gbit/s on a separate wavelength for the operation of IEEE 802.3av and IEEE 802.3ah on the same PON concurrently. The upstream channel can support simultaneous operation of IEEE 802.3av and 1 Gbit/s 802.3ah simultaneously on a single shared (1310 nm) channel.

In 2014, there were over 40 million installed EPON ports, making it the most widely deployed PON technology globally. EPON is also the foundation for cable operators' business services as part of the DOCSIS Provisioning of EPON (DPoE) specifications.

10G EPON is fully compatible with other Ethernet standards and requires no conversion or encapsulation to connect to Ethernet-based networks on either the upstream or downstream end. This technology connects seamlessly with any type of IP-based or packetized communications, and, thanks to the ubiquity of Ethernet installations in homes, workplaces, and elsewhere, EPON is generally very inexpensive to implement.

### **DATA LINK LAYER:**

The EPON frame structure which uses the native Ethernet frame to transmit traffic. The downstream MAC layer has the same operation as a standard Gigabit Ethernet MAC (GbE MAC), where the traffic is broadcast to all users. In the downstream frame, the preamble field contains a logical link identifier (LLID) which is a unique identifier assigned by the OLT to each ONU. The ONUs identify received traffic by matching the LLID of the received frame with its own LLID and if there is a match then it will accept the received frame, otherwise it is discarded. For upstream traffic, the MAC layer has been modified by the IEEE to operate using a TDMA approach, where the OLT assigns a specific time slot to every ONU taking into account the distance between each ONU and the OLT. Shows the frame structure of GPON. The downstream MAC layer operates in the same manner as a GFP-framed SONET. It supports a frame of 125 ms long that uses TDM to divide the available bandwidth among the users, whilst the upstream MAC layer is based on TDMA. GPON supports two layers of encapsulation where the Ethernet frame is encapsulated into a GPON Encapsulation Method (GEM) frame which is encapsulated again into a GPON Transmission Convergence (GTC)

frame. The GTC frame also includes pure ATM cells and TDM traffic. The downstream frame is broadcast to every ONU and the ONUs use the information in the Physical Control Block downstream (PCBd) field to extract its own data. In case there is no data to be transmitted, the downstream frame will be transmitted continuously and utilized for time synchronization. The upstream frame contains multiple transmission bursts arriving from the ONUs. Along with the payload, each of the upstream burst frames consists of the Physical Layer Overhead (PLOu), a bandwidth allocation interval which contains the Dynamic Bandwidth Report upstream (DBRu), and allocation identifiers (Alloc-IDs). When traffic reaches the OLT, ONU traffic is queued based on Classes of Service (CoS) with a diverse QoS dependent on the type of the Traffic Containers (TCONTs) that is specified in the Alloc-ID. GPON introduces five types of T-CONTs that provide QoS in the upstream direction. The T-CONT frame is used in GPON to establish a virtual connection between ONU and OLT as well as to manage fragment transmission.

### **1) T-CONT type 1**

supports fixed bandwidth that is sensitive to time. The jitter of T-CONT type-1 is 0 which enhances the suitability it has for Constant Bit Rate (CBR) traffic.

### **2) T-CONT type 2**

This type supports Assured bandwidth where it has a higher delay than T-CONT 1. It is used with Committed Information Rate (CIR) traffic.

### **3) T-CONT type 3**

Supports assured and non-assured bandwidths providing a guaranteed minimum CIR and surplus Excess Information Rate (EIR). This type is appropriate for Variable Bit Rate (VBR) traffic that does not guarantee delay.

### **4) T-CONT type 4**

Supports Best-Effort services such as Internet browsing, SMTP and FTP.

### **5) T-CONT type 5**

This type is a mix of all the above T-CONT types. It is appropriate for general traffic flows; ONUs are located at different distances from the OLT. When each ONU transmits its upstream traffic during the assigned time slot, there is a possibility that frames from different ONUs collide at some point due to the difference in propagation delay. In order to guarantee that the upstream transmissions do not collide, a ranging process is performed by the OLT during the activation and registration of the ONUs. The ranging process is based on calculating a specific delay time for each ONU according to its distance from the OLT to equalize its transmission delay with other ONUs. This delay is called Equalization Delay (ED). Each ONU will store and apply its ED to all the upstream transmissions. The ED values are broadcast to other ONUs using Physical Layer Operations and Maintenance (PLOAM) messages and each ONU resumes its transmission based on the ED. Shows an ONU in a ranging state. While one ONU is active and sending traffic, transmissions from other ONUs must be suspended. Multipoint control protocol (MPCP) has been introduced to facilitate dynamic bandwidth allocation process.

This is executed at the MAC layer. For EPON, MPCP can be run in one of the two modes. Firstly, in the normal mode, it makes use reporting Dynamic Bandwidth Allocation (DBA) and traffic monitoring DBA. In the case of status-reporting DBA, each ONU directly sends status report information to the OLT. Whereas, in the traffic monitoring DBA, the inference of the T-CONT's buffer status at the OLT is reliant on the historical information of bandwidth use and the amount of defined bandwidth. The header in the downstream frame includes the upstream bandwidth map (BW map) field that depicts the start and end time for upstream transmission for each ONU.

**Q2. Due to Bandwidth Hungry Applications like Video on Demand, Online Gaming and other multimedia services, the demand for high bandwidth is increasing day by day. Apart from that, multiple users are adding to that network which increases the network capacity. In order to accommodate more users to the network and provide these users with a high bandwidth, a strong Broadband Access Network is required. Passive Optical Networks have the ability to provide high bandwidth as well as it accommodates more users to the network. Support your answer to Explain different types of PON Networks along with its Architecture that are in use to provide the scalability and High bandwidth to their users?**

Next generation passive optical networks (NG PONs) are the natural development of PONs toward achieving higher data rates, larger counts of wavelength channels, and longer fiber ranges. NG-PON can be implemented as high speed time division multiplexing (TDM), wavelength division multiplexing (WDM), Hybrid TDMIWDM, optical code division multiplexing (OCDM) PON. Many enhancements and adaptations are occurring in order to offer higher bandwidths with higher number of subscribers. This includes coverage area that is increasing to reach of 100km and more, e.g. the LR-PON. In addition, the wireless access network is gradually going to be integrated with PON systems, e.g. FiWi network.

4. ING-PON2 pure technologies:

Studies have been conducted for several NG-PON2 technologies that offer up to 100 Gbps. This includes high speed TDM-PON, WDM-PON, OCDM-PON, OFDM-PON, and hybrid technologies.

#### **High speed TDM-PON:**

TDM-PON allows multiple users to share the same bandwidth using a single wavelength. A typical TDM-PON structure is shown in Fig. 8. The downstream traffic is broadcast to all users



and a specific time is assigned by the OLT to every ONU to control upstream transmissions. These time slots are allocated in downstream and upstream frames where a complex algorithm is required to arrange and assign the bandwidth in order to avoid collisions. TDM-PON is a simple and cost effective technology, however; it has limited scalability due to the fact that ONUs share bandwidth. Increasing the bit rate for all of the users will be a challenging task because every ONU receiver operates at a bit rate that is higher than the bit rate assigned per ONU. Utilizing a high speed digital signal processor and field-programmable gate array to increase the bitrate to higher than 10 Gbps increases cost and complexity. In addition, TDM-PON is not very secure due to the shared infrastructure which opens the possibility of eavesdropping and other attacks. Moreover, the variation in the distance between ONUs and the OLT is another drawback that causes variation in the optical power and consequently, the OLT receiver operates in burst mode. In order to upgrade the current TDM-PON to meet the NG-PON2 requirements, a number of approaches have been investigated to increase the capacity of TDM-PON, including:

Conventional ON OFF Key (OOK) systems: Applying OOK is the easiest way to increase the capacity of TDM-PON. However, this solution is not favorable for future PONs because it requires a 40 Gbps burst-mode receiver, high cost 40 GHz electronics and photonics as well as it requires highly sensitive receivers. Due-binary modulation: this scheme is similar to the deployed PON system that uses one wavelength for downstream and another one for upstream. Invest such modulation in the downstream grants the ONUs with 20 GHz bandwidth and reduce the disruption. Bit interleaving: This approach employs two wavelengths, one for downstream that supports a 40 Gbps signal and another wavelength for upstream transmission that supports 10 Gbps. Bit interleaving is introduced in the downstream frame where each ONU is pre-assigned an offset and an interval. This technique requires the ONU receiver operating at a rate lower than 40 Gbps. It simplifies the transmission process, reduces power consumption, and reduces the electronic circuitry of the ONU receiver.

Serial 40G NRZ- 40G serial Non-Return-To-Zero (NRZ): is another approach that has been investigated to increase the capacity of legacy TDM-PON. However, it has a transmission distance limitation due to chromatic dispersion and the associated optical power requirement at the receiver.

### **WDM-PON:**

WDM-PON has been considered as an alternative technology to TDM-PON. A typical WDM-PON structure is shown in Fig. 9. It provides a virtual point-to-point connection between the OLT and several ONUs; where, each ONU is assigned a different wavelength for transmission.

The major difference between the implementation of WDM-PON and TDM-PON is that WDM-PON employs a WDM device in the ODN such as an Array Wavelength Gratings (AWG) instead of a power splitter. This leads to dramatic reduction in the power loss and consequently supports a large number of ONUs. This type of WDM is called Wavelength routed. Each port of the AWG is assigned to a specific wavelength; each transmitter at the ONU transmits a signal on the wavelength that is specified by the port. This architecture offers lower insertion loss and

a simple ONU receiver structure. However, the OLT is required to install a standard receiver and a wavelength de-multiplexing device.

Upstream transmission in a WDM loop back structure is achieved by utilizing a single or two fiber links. In the case of a single fiber link, bidirectional transmission of the light and the modulated signal leads to Rayleigh Backscattering (RB) noise. This issue affects the performance of downstream and upstream transmissions and consequently degrades the transmission distance and the receiver sensitivity.

**There are several schemes that can be used to mitigate RB noise, for example:**

Using phase modulation. In the authors claim that the RB noise can be reduced by using Wavelength Shifted amplitude-shift keying (WS-ASK) modulation. In addition, the role of phase modulation non return to zero (PM-NRZ) modulation format has been investigated in to reduce BR noise which can be farther reduced by utilizing an optical filter.

Using dual parallel Mach-Zander modulator (DP-MZM) Four-wave mixing (FWM).

A key advantage of WDM-PON is that it allows every ONU to transmit at the peak speed as the OLT bandwidth is not shared. Thus, it is capable of supporting a higher data rate. Another type of WDM-PON is based on splitter and known as WDM-PON wavelength switched in which the power splitter is implemented to distribute incoming signals equally into all ONUs. However, each ONU is required to equip with a wavelength filter to select specific wavelength. Although wavelength switched PON considers simple and distributed structure, its signal loss is higher than wavelength routed PON .WDM-PON is classified into two classes based on the number of wavelengths supported and the wavelength spacing between the individual wavelengths transmitted over a single fiber. The first class is Dense WDM (DWDM) and its wavelength plan is defined by ITU-T G.694.1 and the second class is Coarse WDM (CWDM) and its wavelength plan is defined by ITU-T G.694.2. The main objective of DWDM is to increase the network capacity by minimizing the wavelength spacing; CWDM aims to reduce the cost where the wavelength spacing is sufficiently high to permit the transmitters to be more accurately controlled.

In the literature, there are number of approaches that have been proposed to be implemented in WDM-PON. The approaches are discussed below.

**1)** externally seeded WDM-PON In a wavelength-splitter based ODN, a light source is splitted spectrally and distributed to reflective ONUs. This approach is mature and available with the commercially existing systems. However, the commercially available systems require that the wavelength splitter operate over the power splitter, which imposes the major challenge in terms of link budget. Additionally, the possibility of attaining more than 1 Gbps of data rate is not clear as it exceeds the capability of the current system.

**2)** Wavelength re-uses WDM-PON this approach assigns a wavelength to each user for downstream and upstream transmission. The re-use of the wavelength is enabled by the transmitter based on semiconductor amplifier. This amplifier modulates the downstream signal in inverse Return to-Zero formats and the upstream signal in Return-to-Zero format.

3) Tunable WDM-PON. This approach is based on a low cost tunable transmitter module instead of the conventional module. The reduction of the cost is achieved by removing thermoelectric coolers and the wave-lockers from the conventional modules. Tuning at the upstream is performed utilizing the shared OLT based wave-locker. However, tunable receivers are needed at each ONU to perform colorless function.

4) Ultra-dense Coherent WDM-PON. This approach is based on coherent detection where the channels are tightly spaced (around 3 GHz). 1 Gbps data rate is allocated to every user utilizing dedicated Quadrature Phase Shift Keying (QPSK) modulated wavelength. However, the transmitters and the receivers are very complex systems and expensive. Thus, more improvements in photonic integration are essential to be used in practical implementation.

5) Self-seeded WDM-PON In this scheme, the seed light of the ONU is self-generated by a reflector at the common port of the wavelength splitter. However, the length of the drop fiber (the fiber between the splitter and the ONU) is limited.

### **OCDM-PON:**

Introducing OCDM-PON technology leads to considerable improvements for NG-PON2. The advantages include highly efficient use of bandwidth, good correlation performance, asynchronous transmission, flexibility of user allocation, low signal processing latency as well as improving network security.

OCDM can be classified into two main categories: coherent system and incoherent system. In coherent system, OCDM is implemented through a bipolar approach that requires information about the phase of the carriers. On the other hand, the incoherent system is implemented through a unipolar approach. Owing to the simplicity of incoherent hardware as well as its no reliance on phase synchronization detection, incoherent system has emerged as the preferred detection scheme. The basic structure of the OCDM network, which has four main components including transmitter, encoder, decoder, and the receiver. At the transmitter, an information source provides a data bit for a laser at every  $T$  second. The encoder then multiplies the data bit "when it equals 1" by a code-word. The code-word can be formed by one-dimensional encoding using the time or wavelength domain or by a two-dimensional encoding scheme, which is a combination of both domains. Yet, recent studies have shown advantages of three dimensional codes. The pulses generated are referred to as chips and have duration of  $T_c = T/n$ , where  $T$  donates the duration of each bit and  $n$  denotes the code length.

The multiplexed signal is broadcast to all of the users. The signal arrives at the receiver and passes through the decoder. The decoder matches the code and accepts only the intended user's signal. Then the output of the decoder passes through photo detection and integration. Later, the output power is sampled for each bit interval and compared to the threshold value to provide an estimation of the transmitted bit. The performance of the OCDM network is reliant on the performance of the address codes that have been designed to be orthogonal in order to reduce Multiple-Access Interference (MAI) and performance of the receiver structure that must successfully operate in an environment including various noise sources.

Various types of codes have been investigated and the codes and corresponding coding devices.

### **OFDM-PON:**

OFDM-PON is considered as the most attractive system because of its scalability and ability to provide bit rate up to 40 Gbps per user. OFDM for NG-PON2 is used as multiplexing technique as it is spectrally efficient modulation method. OFDM technique offers flexibility on dynamic bandwidth allocation, enables multiple services, and attains high spectral efficiency. OFDM utilizes a large number of orthogonal subcarriers that are closely-spaced in order to carry traffic. These subcarriers are modulated at a low symbol rate utilizing conventional or advanced modulation techniques.

FDM-PON architecture is similar to the conventional PON. It utilizes two different wavelengths for downstream and upstream transmissions. The OLT generates multiple orthogonal subcarriers that are assigned to different ONUs. Each subcarrier is divided into different time slots. The OLT performs the partitioning process and distribute the total bandwidth over the subcarriers, over the timeslots or on both to different ONUs according to their demand. For downstream transmission, each ONU recognizes its own OFDM subcarriers and/or time slots based on information obtained by the OLT's schedule. For upstream transmission, the OLT works to assemble the sub-frames coming from different ONUs to generate a complete OFDMA frame.

Various benefits can be achieved by applying the OFDM multiplexing technique. Firstly, the total cost is reduced because of the cost of the complex optical modulation at the OLT can be shared between the users. In addition, the ONU implements a simple and inexpensive optical modulation in order to identify data for that ONU. Moreover, OFDM-PON technology helps to reduce the cost by using cost-effective electronic devices instead of optical devices. The overlapping characteristic of OFDM produces no interference which results in the effective utilization of the spectral resources. Furthermore, in comparison with other technologies, OFDM-PON provides a two dimensional bandwidth map with finer granularity, offering flexibility for assigning the bandwidth at different levels.

Despite the enormous advantages of OFDM, some limitations have been identified. OFDM-PON requires complex receivers that are reliant on high speed DSP and FPGAs. Furthermore, OFDM-PON is disadvantaged by noise and a high Peak Average Power Ratio (PAPR). The PAPR issue appears as a result of sinusoidal signals from multiple OFDM subcarriers that interfere constructively in the time domain. This generates a higher amplitude value than the average amplitude value of the signal. The noise is generated as a result of interference when multiple signals from multiple users are detected on the photodiode at the OLT. Such interference leads to performance degradation. Frequency offset is also a disadvantage of OFDM technique which occurs due to mismatch of carrier frequencies.

### **UNI-PON:**

High costs, wastage of resources are the main limitations in the existing multiplexing techniques insist researchers to think about more appropriate and effective methods. Some researcher's came up with the idea of UNI-PON (Cloud-Radio Access Network).

In UNI-PON data manipulation is done at OLT using cloud computing. The advantages of UNI-PON include access of all services for all users, lower cost, and connectivity of radio remote units, multi-rate adjustment, and dynamic bandwidth allocation. In a physical layer adaptive algorithm is used to attain multi-rate and dynamic bandwidth allocation. With the rapid advancement in technology the systems should be resilient to adopt future changes. Therefore, UNI-PON can be a suitable choice for future networks.

### **XDM/WDM hybrid technologies:**

#### **OCDM/WDM-PON :**

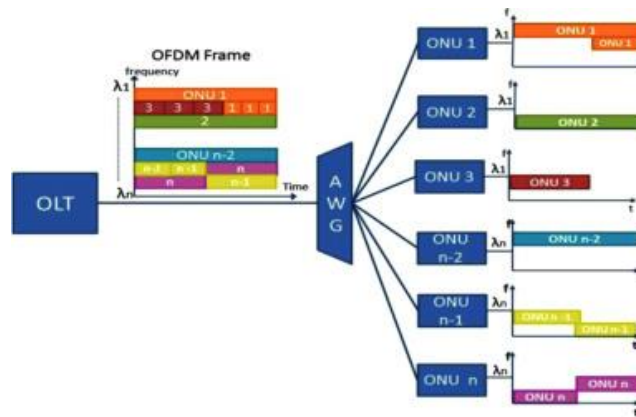
The combination of WDM and OCDM introduces advantages to the network including asynchronous multiplexing, high transmission speed, simplifying the management of the network, supporting a large number of users up to 3000 , reduction in the cost, expand coverage up to 100 km and improvement in the security. Another advantage of OCDM/WDM-PON technology is that it reduces circuitry by eliminating the need of encoder and decoder at each ONU. As it requires just one pair of encoder/decoder at ONU and OLT sides

**OCDM/WDM-PON** was proposed as a system that offers symmetric transmission shows the basic architecture of OCDM/WDM-PON, which works by superposing OCDM channels over WDM channels. With every WDM grid (1–N), M users could be added using various optical codes. Thus, the total number of users in the network will be N M. The bandwidth offered by one wavelength can be shared between M users and every code in each wavelength can be repeated. However, implementation of such a system would need to upgrade all ONUs generate cost-effective optical orthogonal code, manage MAI and reduce the spectral due to increment in the network capacity.

In a new architecture of OCDM/WDM-PON has been presented based on Differential Quadrature Phase shift Keying (DQPSK). Few advantages of the DQPSK method are large dispersion tolerance, PMD and nonlinearity tolerance, high spectral efficiency, narrower spectrum width, and strong crosstalk resistant capability. The proposed system shows less complex integration process, reduced number of decoder and encoder, smooth upgrade, and seamless integration.

#### **OFDM/WDM-PON:**

In OFDM/WDM-PON configuration, a group of OFDM subcarriers are transmitted over a group of wavelengths to different users as shown in Fig. 16. OFDM/WDM-PON is able to increase the capacity of the system up to few Tbsp. over a long distance providing services for multiple users and offering an efficient use of the bandwidth. In such a system, the generated OFDM subcarriers are modulated optically using a continuous wave (CW).



In downstream transmission, all the wavelengths are multiplexed and transmitted through the fiber. A Local Exchange (LE) is needed in order to route and amplify the signals. At the ONUs side, every ONU is tuned to a wavelength, and an OFDM subcarrier. In the upstream transmission, the OFDM subcarrier is tuned to the upstream wavelength. All the wavelengths are integrated and amplified at the LE and transmitted to the OLT.

The challenges in implementing OFDM/WDM-PON are the need for advanced digital signal processing at the transceivers, a high speed converter (Analog to Digital/Digital to Analog), and a fast radio frequency.

The bidirectional hybrid OFDM/WDM-PON presented in has advantages of high bit rate, high spectral efficiency, low effect of RB, and power fading. For downlink, the system uses single side band OFDM. Whereas, for uplink transmission RSOA re-modulation is used. Another approach presented in describes the experimental results of compatible single side-band (SSB) based technique by using mode locked combo source.

The performance of this technology can be enhanced by decreasing the tunable mode-locked laser (TMLL) free spectral range (FSR).

Stacked WDM/OFDM-PON can also be used to achieve 30.4 dB power budgets to support 1:256 split ratio and 25 km range. In the proposed architecture, tunable band pass filter was used for the selection of downstream and upstream. In OLT, outputs of four DFB lasers are fed into Mach-Zander Modulator (MZM) operated by OFDM signals.

### **XDM/TDM hybrid technologies:**

#### **OCDM/TDM-PON:**

OCDM/TDM-PON is a scalable technology that allows multiplexing time intervals over multiple optical codes over a single channel without losing the original line bit rate. OCDM/TDM-PON is able to increase the system capacity up to N 10 Gbps. However, such a system requires additional equipment including one multiport OCDMA encoder/decoder at the OLT and a Super-Structured Fiber Bragg grating SSFBG at every ONU. However, the main drawback of such a configuration is the difficulty of detecting the upstream burst signals

In a demonstration of OCDM/TDM-PON has been presented focusing on reducing the crosstalk issues neighboring WDM using SSFBG encoder/decoder. This study shows that the crosstalk

crosstalk can be negligible with intervals of 200 and 400 GHz. In a long reach with 65 km 10G OCDM/TDM-PON has been proposed. The architecture is based on implementing a pair of multi-Port encoder and decoder at the OLT and at the RN instead of implementing encoder/decoder at each ONU. The extended reach is achieved by tailoring optical spectrum using narrow band optical band pass filter NBOBPF. The demonstration shows a successful transmission without dispersion compensator.

### **OFDM/TDM-PON:**

OFDM/TDM-PON is another approach that can be considered for NG-PON2. This approach works by dividing each OFDM subcarrier among several services or users for each time slots. In the author proposes a new architecture that is based on OFDM/TDM for EPONs. This architecture eliminates the delay results from bandwidth allocation process (by sending and receiving the control messages) in the centralized scheme. The architecture is decentralized where the OLT will not be responsible for allocating bandwidth rather each ONU run a bandwidth demand determination algorithm. In this algorithm, each ONU reports its queue status to other ONUs through signaling channel. In a short time, each ONU will be aware of the load of the other ONUs. Accordingly, the load will be calculated and the bandwidth will be allocated dynamically for every cycle.

### **Hybrid XDM/TDM/WDM:**

**Hybrid XDM/TDM/WDM** is a possible approach that would enhance NG-PON2 performance. Technologies such as WDM/TDM/ OFDM-PON and WDM/TDM/OCDM-PON have been presented in the literature and the nature of the possible hybrid combinations brings forth several advantages including greater dynamic bandwidth allocation flexibility, high scalability and extending the reach up to 100 km. The main drawback of this technique is its high cost.

In an experimental setup is established which consists of multi-port Encoder/Decoder. The feature of spectral periodicity of this Encoder/Decoder reduces the number of OCs required.

### **NG-PON2 challenges:**

The NG-PON2 is to extend the coverage area, increase the bandwidth, increase the transmission speed, and save cost and energy. Despite the extensive research in developing NG-PON2 technologies, these factors still enforce challenges and remain under questions. In this section, these challenges are addressed and the recent developing progresses are discussed.

### **Increase the capacity:**

One of the most important challenges of NG-PON2 is offering a high bit rate (at least 40 Gbps downstream and 10 Gbps upstream), where each ONU is expected to support a data rate of 1 Gbps Network capacity can be increased using one of the three techniques discussed below.

Increase the number of wavelengths that are transmitted over the same fiber. This technique can be obtained by utilizing WDM and/or OFDM technologies that were discussed in the earlier sections.

Increase the bit rate supported by each wavelength. This option can be achieved by using “larger signal constellations such as Dual Polarization Quadrature Amplitude Modulation (DP MQAM) or Dual Polarization Modulation Quadrature Phase Shift Keying (DP-MQPSK). Utilizing a modulation technique with a low Signal to Noise Ratio (SNR)” improves performance; however, as a result of the nonlinear Shannon’s limit an increase in the data rate is also constrained. Additionally, this technique is considered expensive due to the use of the transponder that increases the cost by a factor of “2 or 2.5 with each fourfold increase in bit rate.

Nonlinearity compensation. The capacity of the fiber is restricted by the nonlinearities. “In the absence of noise, a single channel signal is limited by Self-Phase Modulation (SPM). Whilst, WDM systems are restricted by cross-phase modulation (XPM) as well as Four-Wave Mixing (FWM). The Nonlinear Schrodinger Equation (NLSE) is deterministic; this means that SPM, XPM, and FWM could be compensated with DSP” techniques that might become practical as a result of the capacity improvement; consequently, the system strives to obtain the highest capacity achievable.

The approaches described are discussed in the literature as possible avenues that might lead to an increase in the network capacity. However, all of these approaches utilize advanced modulation formats. Modulation schemes being investigated include Quadrature Amplitude Modulation (QAM), Phase Modulation Quadrature Phase Shift Keying (PM-QPSK), Polarization multiplexing, and OFDM. Among these, PM-QPSK with a coherent receiver is the most popular modulation scheme in the industry.

**Q3. The Advancement in Wireless Communication Technology is considered to be the prominent and the most dominant Innovation of 20th Century. Through these advancements, users can be seamlessly connected to one another through their portable devices supporting different wireless technologies. Make a Comparative Analysis of the Wireless Communication Technology Era’s from 1G to 5G showing how different Wireless Technologies evolved with time.**

### **Evolution of mobile technology:**

#### **FIRST GENERATION (1G):**

1G technology replaced 0G technology, which featured mobile radio telephones and such technologies as Mobile Telephone System (MTS), Advanced Mobile



Telephone System (AMTS), Improved Mobile Telephone Service (IMTS), and Push to Talk (PTT).

1. Developed in 1980s and completed in early 1990's
2. 1G generation of analog cell phones speed up to 2.4kbps
3. Advance mobile phone system (AMPS) was first launched by the US and is a 1G mobile system

### **Second Generation Technology (2G to 2.7G):**

2G is the Second-Generation wireless cellphones, based on digital technologies in the early 1990's. In 1991 2G was launched in Finland. 2G provided services such as text message, picture messages and MMS. 2G has greater security for both sender and receiver. All text messages are digitally encrypted, which allows for

The transfer of data in such a way that only intended receiver can receive and read it. GSM uses TDMA to multiplex up to 8 calls per channel in the 900 and 1800 MHZ bands. GSM can not only deliver voice but also circuit switched data at speed up to 14.4kbps.

### **3G :(THIRD GENERATION)**

3G is the third generation of mobile phone standards and technology. It is based on the International Telecommunication Union (ITU) who formulated a plan to implement a global frequency band in the 2000 MHZ range, which supports a single, ubiquitous wireless communication standard for all countries throughout the world. This plan was called International Mobile Telephone 2000 (IMT-2000), Standard. 3G has the following enhancements over 2.5G and previous networks:

- Enhanced audio and video streaming.
- Several Times higher data speed.
- Video-conferencing support.
- Web and WAP browsing at higher speeds.
- IPTV (TV through the Internet) support.

### **3.5 G — HSDPA (High-Speed Downlink Packet Access):**

High-Speed Downlink Packet Access (HSDPA) is a mobile telephony protocol which provides a smooth evolutionary path for UMTS-based 3G networks allowing for higher data transfer speeds. HSDPA is a packet based data service in W-CDMA downlink with data transmission up to 8–10 Mbit/s (and 20 Mbit/s for MIMO systems) over a 5MHz bandwidth in WCDMA downlink.

### **3.75G — HSUPA (High-Speed Uplink Packet Access):**

HSUPA will enhance advanced person-to-person data applications with higher and symmetric data rates, like mobile e-mail and real-time person-to person gaming. Traditional business applications along with many consumer applications will

benefit from enhanced uplink speed. HSUPA will initially boost the UMTS / WCDMA uplink up to 1.4Mbps and in later releases up to 5.8Mbps.

#### **4G(FOURTH GENERATION):**

4G is the fourth generation of broadband cellular network technology, succeeding 3G. A 4G system must provide capabilities defined by ITU in IMT Advanced. Potential and current applications include amended mobile web access, IP telephony, gaming services, high-definition mobile TV, video conferencing, and 3D television. 4G is a concept of inter-operability between different sorts of networks, which is all about high speed data transfer such as 0–100MBPS of either the server or the data receiver set is moving at a speed of 60 Kmph. If the server and the receiver are stationary, the data transfer would be a minimum of 1GBPS.

#### **5G :(FIFTH GENERATION)**

5G network technology will open a new era in mobile communication technology. The 5G mobile phones will have access to different wireless technologies at the same time and the terminal should be able to combine different flows from different technologies. 5G allows up to 900,000 more devices to be connected per square kilometer than 4G, which supports the connection of at most 100,000 devices per square kilometer. The 5G network will be 100 times more energy efficient than 4G. So even as the number of wireless devices increases, the energy required powering them will decline.

**Q4. Visible Light Communication is considered a promising candidate for future wireless communication because of its feature like non-licensed channel, high bandwidth and low power consumption. For VLC applications, the placement and working principle of transmitter and receiver is very important. Explain the working principle of VLC in terms of its Physical Layer and MAC layer according to the IEEE standards.**

The two integral parts of the VLC system: the transmitter and receiver generally consist of three common layers. They are the physical layer, MAC layer and application layer. Only two layers (such as PHY and MAC) are defined for simplicity.

## MAC layer:

The tasks performed by Medium Access Control (MAC) layer include:

- (1) Mobility support,
- (2) Dimming support,
- (3) Visibility support,
- (4) Security support,
- (5) Schemes for mitigation of flickering,
- (6) Color function support,
- (7) Network beacons generation if the device is a coordinator,
- (8) VPAN disassociation and association support,
- (9) Providing a reliable link between peer MAC entities.

The topologies supported by the MAC layer are peer-to-peer, broadcast and star as illustrated in below (Fig), the communication in the star topology is performed using a single centralized controller. All the nodes communicate with each other through the centralized controller as shown in Fig. below. The role of the coordinator in the peer-to-peer topology is performed by one of the two nodes involved in communication with each other as illustrated in Fig. below.

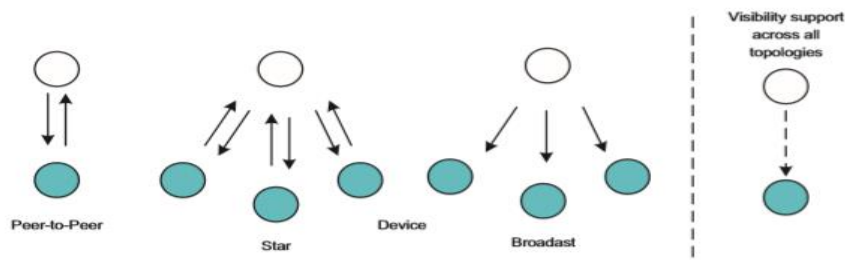


Fig. 10. Supported MAC topologies by IEEE 802.15.7 [25].

## Physical layer:

The Physical layer provides the physical specification of the device and also, the relationship between the device and the medium. Fig. 12 shows the block diagram of the general physical layer implementation of the VLC system. First of all, the input bit stream is passed through the channel encoder (optional). Linear block codes [26], convolutional codes [27] and the state of the art turbo codes [28] can be used to enhance the performance of the VLC system. Then, the channel encoded bit stream is passed through the line encoder to yield the encoded bit stream. After line encoding, modulation (such as ON–OFF keying, PPM and PWM, etc.) is performed and finally, the data is fed to the LED for transmission through the optical channel.

Different implementations of the visible light communication systems are given. In [29], a full-duplex bi-directional VLC system utilizing RGB LEDs and a commercially available phosphor-based LED in downlink and uplink, are proposed respectively. Wavelength Division Multiplexing (WDM) and Subcarrier Multiplexing (SCM) are used to achieve the bi-directional transmission. Furthermore, Orthogonal Frequency Division Multiplexing (OFDM) and Quadrature Amplitude Modulation (QAM) were employed to increase the data rate. The speed of the VLC system in [30] was increased to 3.75vGb/s as compared to that in [29] which was 575Mb/s downlink and 225Mb/s uplink. At the receiver side, the receiver (such as a silicon photo diode and PIN photodiode) received the optical signal. After demodulation and line decoding, the bit stream passed through the channel decoder to yield the output bits.

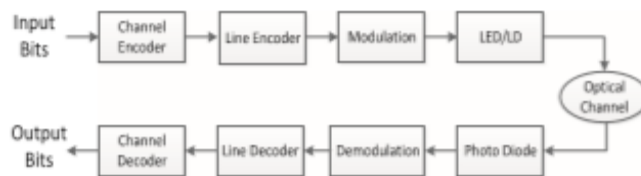


Fig. 12. Typical physical layer system model of VLC.

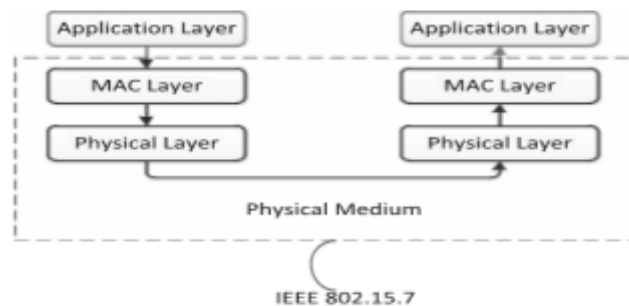


Fig. 11. Layered architecture of VLC.

Three different types of physical implementations of VLC are given in IEEE 802.15.7. The operating range of PHY I, PHY II and PHY III are 11.67–266.6 kbps, 1.25–96 Mbps and 12–96 Mbps, respectively. The different channel coding schemes supported by 802.15.7 are listed in Table 1, Table 2 and Table 3 [25]. Convolutional codes and Reed Solman (RS) codes are used by the PHY I because of its design for outdoor use and PHY II (intended for indoor use) provides support for Run Length Limited (RLL) code to address flicker mitigation and DC balance. The different optical rates and data rates provided by IEEE 802.15.7 are also listed in Table 1, Table 2 and Table 3.

**Table 1**  
PHY I operating mode specifications [25].

Modulation	RLI code	Optical clock rate	FEC		Data rate (kbps)
			Outer code (RS)	Inner code (CC)	
OOK	Manchester	200 kHz	(15,7)	1/4	11.67
			(15,11)	1/3	24.44
			(15,11)	2/3	48.89
			(15,11)	None	73.3
			None	None	100
VPPM	4B6B	400 kHz	(15,2)	None	35.56
			(15,4)	None	71.11
			(15,7)	None	124.4
			None	None	266.6

**Table 2**  
PHY II operating mode specifications [25].

Modulation	RLI code	Optical clock rate (MHz)	FEC	Data rate (Mbps)
VPPM	4B6B	3.75	RS(64,32)	1.25
			RS(160,128)	2
		7.5	RS(64,32)	2.5
			RS(160,128)	4
			None	5
OOK	8B10B	15	RS(64,32)	6
			RS(160,128)	9.6
		30	RS(64,32)	12
			RS(160,128)	19.2
		60	RS(64,32)	24
			RS(160,128)	38.4
		120	RS(64,32)	48
			RS(160,128)	76.8
	None	96		

**Table 3**  
PHY III operating mode specifications [25].

Modulation	Optical clock rate (MHz)	FEC	Data rate (Mbps)
4-CSK	12	RS(64, 32)	12
8-CSK		RS(64, 32)	18
4-CSK	24	RS(64, 32)	24
8-CSK		RS(64, 32)	36
16-CSK		RS(64, 32)	48
8-CSK		None	72
16-CSK		None	96

