Department of Electrical Engineering

Assignment
Date: 23/06/2020

Course Details

Course Title:	Mobile and Broadband Networks	**Module:**	3rd
Instructor:	Pir Meher Ali Shah	**Total Marks:**	50

Student Details

Name:	**Mujtaba Khurshid**	**Student ID:**	**15607**

Q1.	Passive Optical Network is a promising broadband Access Technology that provide 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).	**Marks** **12**
Q.2	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	**Marks** **12**
Q.3	The Advancement in Wireless Communication Technology is considered to be the prominent and the most dominant Innovation of 20^{th} 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.	**Marks** **12**

Q.4	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.	

Ans.1:

The four main PON variations developed by the ITU and IEEE can be categorized into two groups .The first kind of architecture is based on Asynchronous Transfer Mode (ATM) and includes ATMPON (APON), Broadband PON (BPON) and Gigabit PON (GPON) and the second group consists of Ethernet PON (EPON).EPON and GPON are the most popular PON variations found in use today. A conventional PON architecture is presented in Fig. 1.

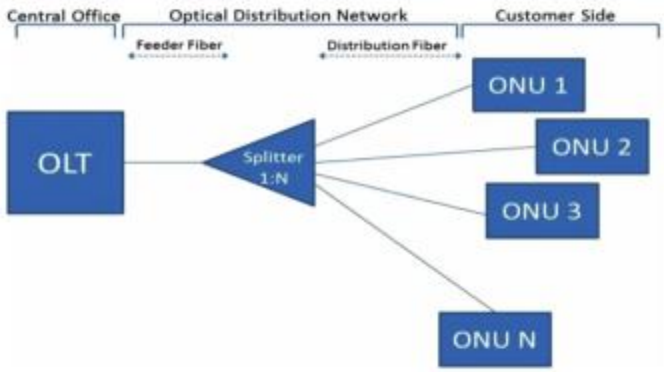


Fig. 1. PON architecture.

In the figure, it can be seen that the PON architecture consists of an Optical Line Terminal (OLT), Optical Distribution Network (ODN), and Optical Network Units (ONU).The OLT is placed at the Central Office (CO) and connected to the splitters by fiber .The optical splitters connect to customer premises making PON appoint to multi-point architecture (P2MP). The EPON and the GPON standards have the same general principle in terms of frame work and applications but their operation is different due to the implementation of the physical and data link layers. EPON is defined by IEEE 802.3 and it is widely deployed in as ia whilst GPON is deployed in a number of other regions. GPON's requirements were defined by the Full Service Access Network(FSAN) group that was ratified as ITU-TG.984 and is implemented in North America, Europe, Middle East, and Australasia .In this paper the advancement of PON technology is classified into three generations :the first generation(deployed PON), next generation stage 1 (NG-PON1),and next generation stage 2 (NG- PON2). The evolution of the PON architectures and their corresponding capacity features are shown in Fig. 2.

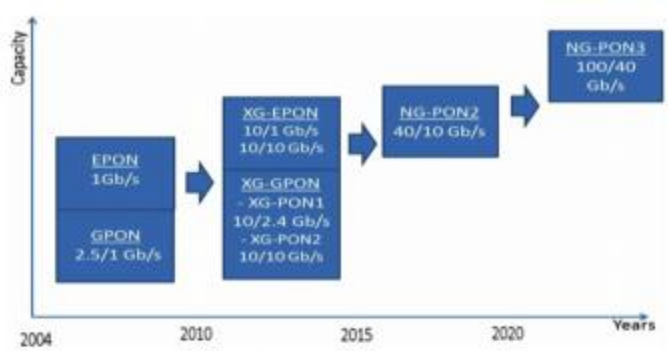


Fig. 2. PON generations.

The first generation of PON Is based on Time Division Multiple Access (TDMA) and provides an EPON downstream rate of 1Gbps and a GPON downstream rate of 2. 4Gbps.The NG-PON1increases the data rate up-to 10Gbps for both standards. There are two main scenarios to achieve an upgrade that are the upgrade from deployed EPON to XG-EPON and from deployed GPON to XG-GPON. An upgrade from deployed GPON to XG-EPON is another potential pathway that can be considered .However, with the rapid increase in high bandwidth applications and Internet services the NG-PON1 would not be able to meet the future demand for band width and Quality of Service(QoS) requirements .To find an acceptable future upgrade pathway ,the research community is investigating the options for NG-PON2 and several technologies that might be used in NG-PON 2 have been studied extensively in order to meet the future requirements of users and network operators. Four multiplexing technologies are being considered for NG- PON2 to provide a downstream transmission of 40Gbps and upstream transmission of 10Gbps.The technologies include high speed Time Division Multiplexing PON(TDM-PON),Wavelength Division Multiplexing PON(WDM-PON),Optical Code Division Multiplexing PON(OCDM-PON),and Orthogonal Frequency Division Multiplexing PON(OFDM-PON).The multiplexing techniques that have been identified to provide a P2MP connection between a single OLT and multiple ONUs .However , each technology has its own pros and cons. To eradicate the multiplexing-specific limitations, hybrid approaches that combine the advantages of multiple technologies have been introduced as a dominant option for the NG-PON2.In the literature, several hybrid technologies have been studied including TDM/WDM-PON,OCDM/WDM-PON,OCDM/TDM- PON, OFDM/WDM-PON ,and OFDM/TDM-PON. Among them, hybrid TDM/WDMPON (TWDM-PON) has been selected as the base element for the NG-PON2 by the FSAN community. The decision was made based on several factors including technology maturity, system performance, power consumption, and cost effectiveness. Despite the efforts to adapt these technologies to meet the requirements of NG-PON2, challenges like increasing the capacity, reducing the cost, extending the reach and power saving still persist and required to be investigated further. Several reviews have been published addressing PONs and its requirements. The possible solutions and prospective technologies for the NG-PONs are also suggested. However, this study reviews the different generations of PONs and focuses on the potential enabling technologies for NG-PON2.

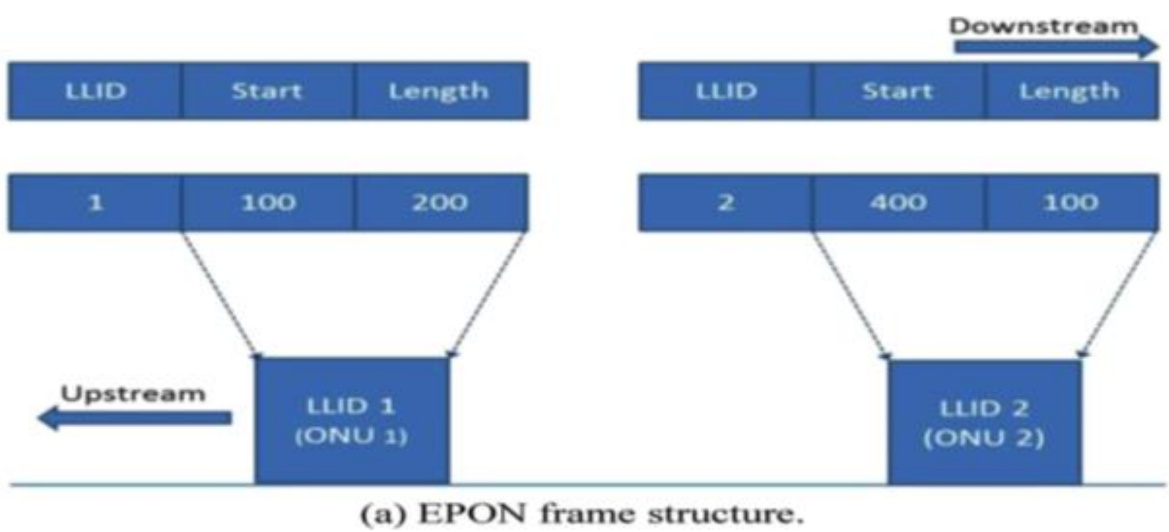
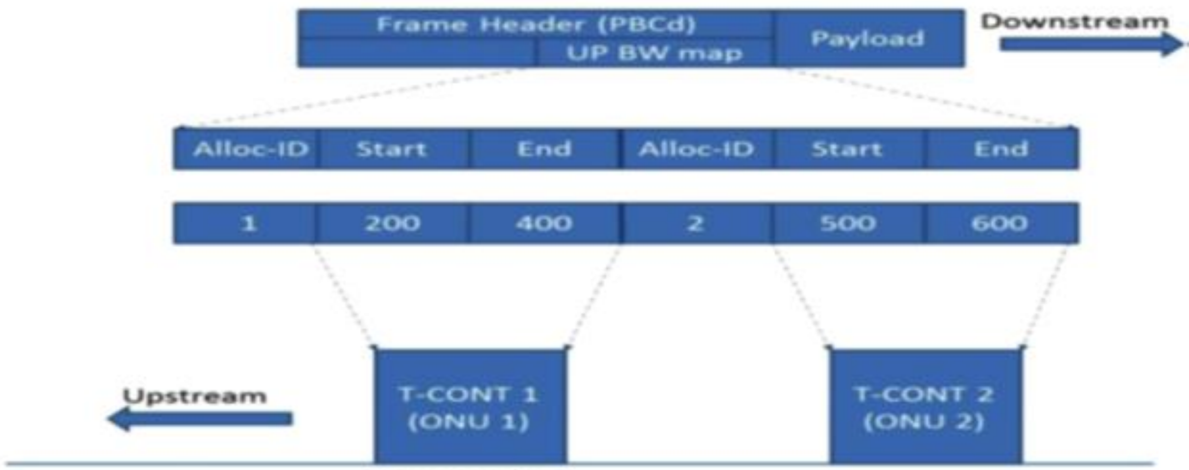


Fig. 3. Frame structure (a) EPON.



(b) GPON frame structure.

Fig. 3. Frame structure (a) EPON, (b) GPON.

Fig. 3(a) presents 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 times lot to every ONU taking into account the distance between each ONU and the OLT. Fig. 3(b) 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 (PCB d) 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 pay- load, 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 (T- CONTs) 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 asto manage fragment transmission.

1) T-CONTtype1 Supports fixed bandwidth that is sensitive to time .The jitter of T-CONTtype-1 is 0 which enhances the suitability it has for Constant Bit Rate (CBR) traffic.
2) T-CONTtype2 This type supports Assured bandwidth where it has a higher delay than T-CONT1. It is used with Committed Information Rate (CIR) traffic.

3) T-CONTtype3 Supports assured and non-assured band widths 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-CONTtype5 This type is mix of all the above T-CONT types. It is appropriate for general traffic flows are located at different distances from the OLT as shown in Fig. 4(a). When each ONU transmits its upstream traffic during the assigned timeslot, there is a possibility that frames from different ONU collide at some point due to the difference in propagation delay. This scenario is illustrated in Fig. 4(b). In order to guarantee that the upstream transmissions do not collide, arranging 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. Fig. 5 shows an ONU in arranging state. While one ONU is active and sending traffic, transmissions from other ONUs must be suspended (Kramer, 1999). Multipoint control protocol (MPCP) has been introduced to facilitate dynamic bandwidth all location process. This is executed at the MAC layer. For EPON, MPCP can be run in one of the two modes.

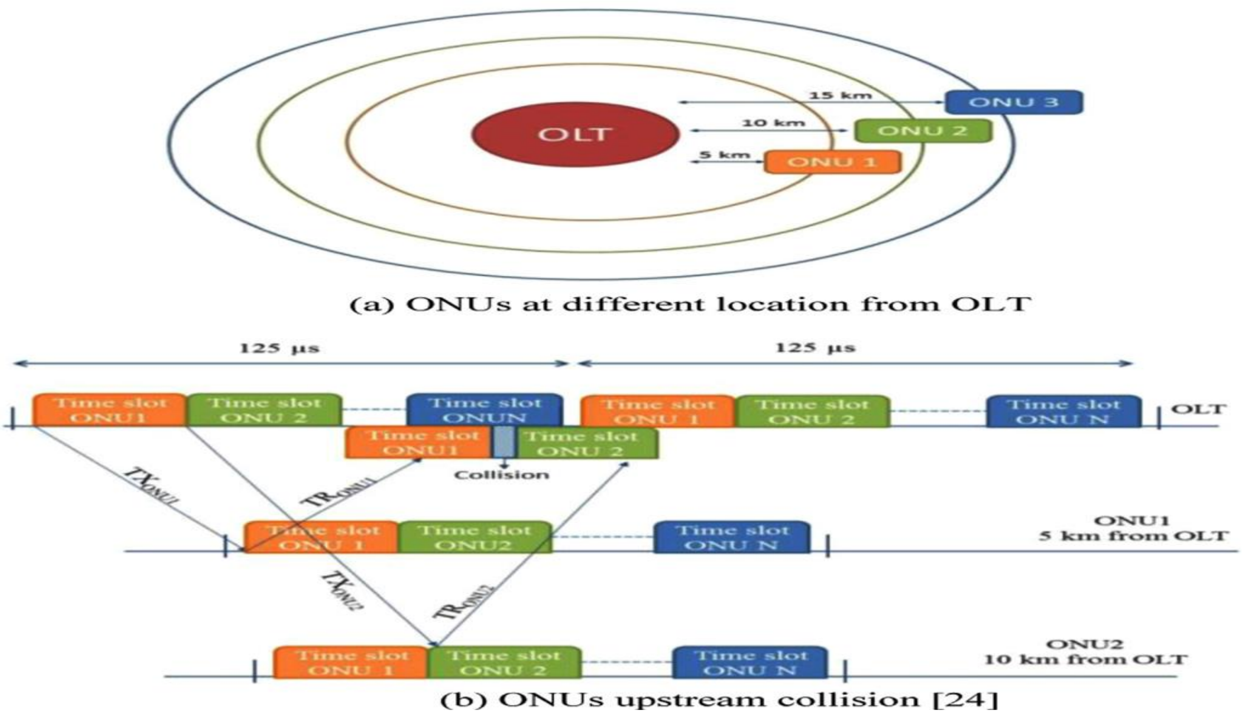


Fig. 4(a) ONUs at different location from OLT. (b) ONU sup stream collision (Kra-mer,1999).

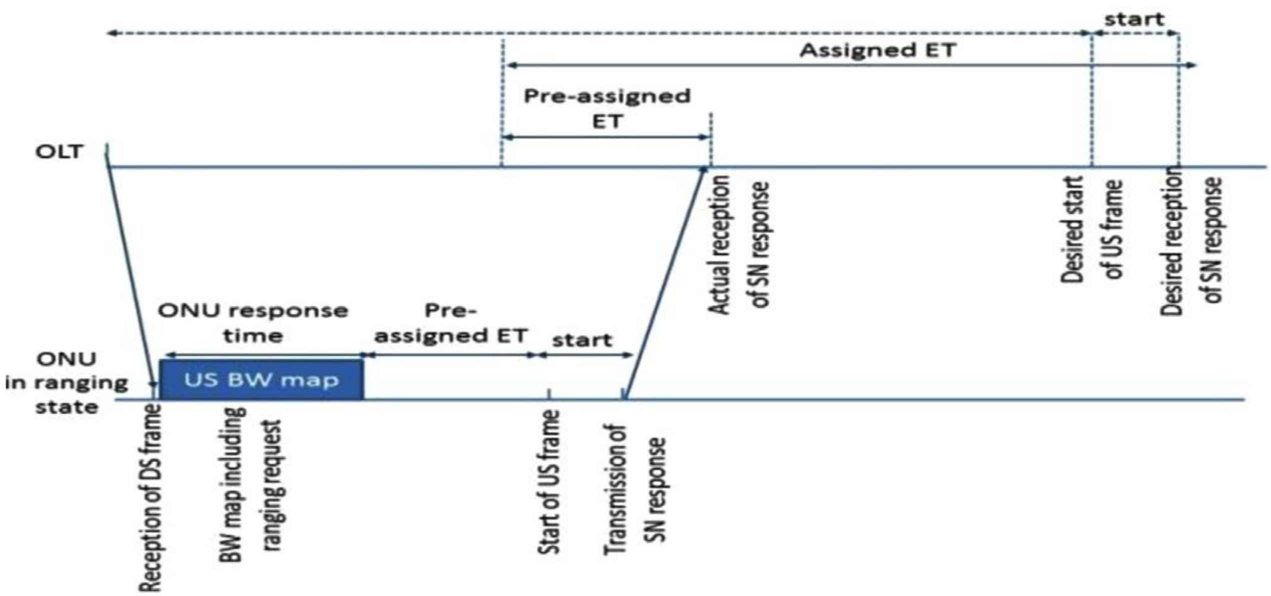


Fig. 5. Ranging state

Firstly, in the normal mode, it makes use of the two control messages to control the allocation of band-width, which are GATE and REPORT messages .In the downstream direction, the GATE messages travel from the OLT to ONUs and carry the allocated bandwidth information. In the upstream direction, the REPORT messages that contain bandwidth request information are sent by ONUs to the OLT.A specific algorithm misused to determine the grant allocation for each of the ONU. These cond mode is the auto-discovery. It is based on three control messages that are REGISTER, REGISTER_ REQUEST, and REGISTER_ ACK. These messages are used to discover and register a new ONU. In addition, it reports in formation about the ONU including MAC address and roundtrip delays. In the GPON scenario, grant messages are sent based on T-CONT. Like EPON, MPCP protocol is implemented to facilitate the dynamic bandwidth allocation in GPON. Two main approaches supported in GPON to deduce the occupancy of the buffer status of each T-CONT which are status 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 band- width use and the amount of defined bandwidth. The header in the downstream frame includes the upstream bandwidth map (BWmap) field that depicts the start and end time for upstream transmission for each ONU.

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ANS.2:

Next generation passive optical networks (NG- PONs) is 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 1OO km 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.

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, TDMPON 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 NGPON2 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 WDMPON 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 link. 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 Wave length 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-Zehnder modulator (DP-MZM)
- Four-wave mixing (FWM).

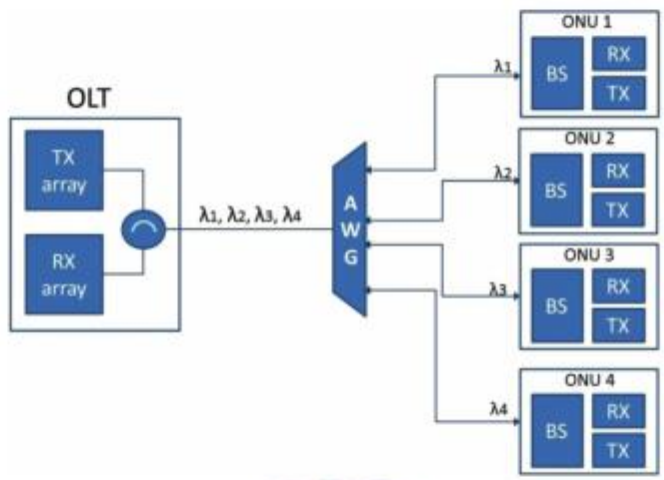

Fig. 9. WDM-PON.

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 (Banerjee et al., 2005).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-use WDM-PON (Nesset, 2015): 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 Returnto-Zero format 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 (Tanaka et al., 2010): 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 non-reliance on phase synchronization detection, incoherent system has emerged as the preferred detection scheme. Fig. 10 shows 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 a duration of Tc¼T/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 are shown in Table 4. In Table 5 a comparison of different OCDM receiver structures is presented.

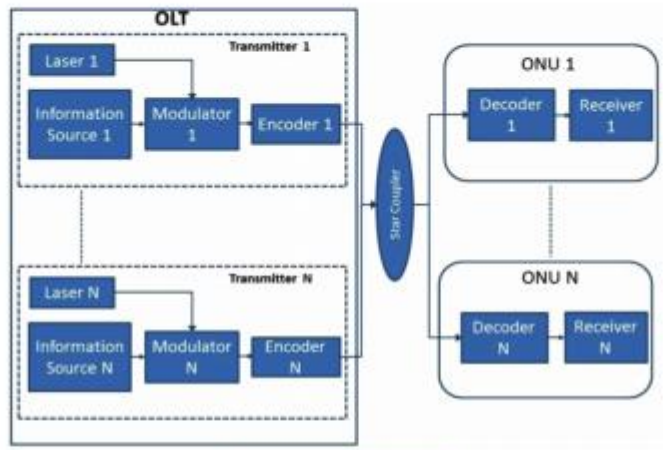

Fig. 10. OCDM architecture.

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 [Online]).

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.

PDM-PON

PDM-PON technology uses orthogonal polarizations at the same wavelength. It is capacity efficient but due to the polarization behavior in the fiber, it would be very hard to separate the signals at the receiving end.

ITU-T NG-PON2 technology

TWDM-PON

In April 2012, hybrid TDM and WDM (TWDM-PON) technology was selected as the multiplexing technique for NG-PON2 by the FSAN community. The decision was made based on several factors including; technology maturity, system performance, power consumption and cost. In July 2013, the selection of TWDM-PON was confirmed by ITU-T "under the G.989 series" and it was named as NG-PON2. TWDM-PON combines the advantages of the high capacity provided by TDM and the large number of wavelengths provided by WDM into one architecture by transmitting TDM frames to several users over several wavelengths.

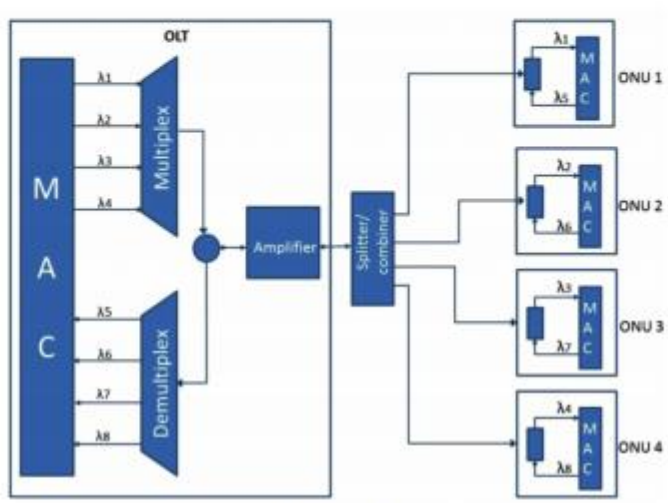

Fig. 11. TWDM-PON.

The basic structure of TWDM-PON consists of four techniques of XG- GPON1s. They are stacked by utilizing four pairs of wavelengths. Fig. 11 shows TWDM-PON and the wavelength pairs that are "{λ1, λ5}, {λ2, λ6}, {λ3, λ7} and {λ4, λ8}" (ITU-T, G.989.1, 2014). Each XG-GPON1 provides 10 Gbps and 2.5Gbps of data rate in downstream and upstream transmissions respectively. Thus, TWDM-PON increases the bit rate up to 40 Gbps for downstream transmission and 10 Gbps for upstream transmission. Implement

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 in PON. Fig. 15 shows the basic architecture of OCDM/WDM-PON, which works by superposing OCDM channels over WDM

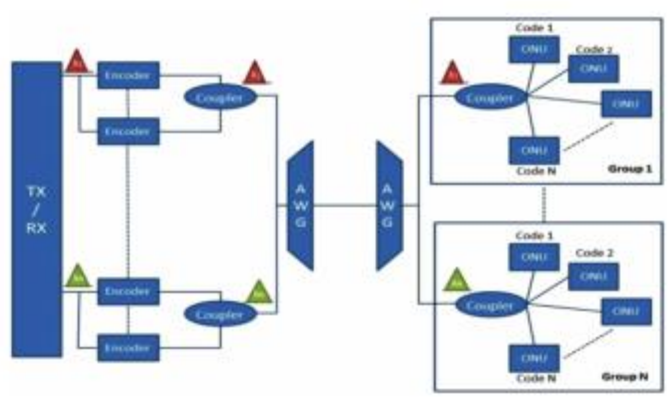

Fig. 15. OCDM/WDM-PON.

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 ONU, 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/WDMPON 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 Tbps 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.

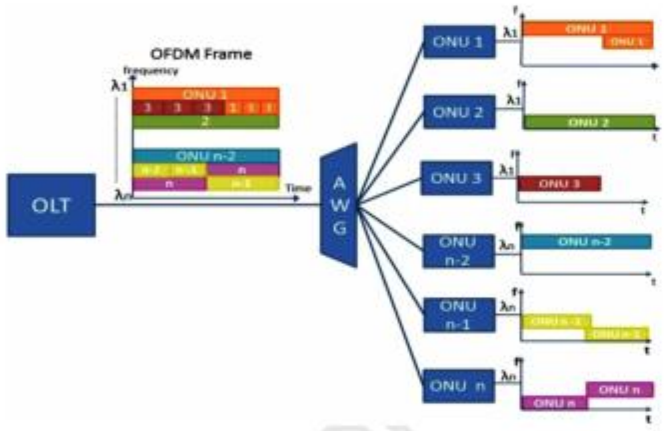

Fig. 16. OFDM/WDM-PON.

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 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, describes the experimental results of compatible single side-band (SSB) based technique by using mode locked combo source. After 50 km, the penalty of o1 dB was obtained at BER of $3x10^{-3}$ .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 budget to support 1:256 split ratio and 25 km range. In the proposed architecture, tuneable band pass filter was used for the selection of downstream and upstream. In OLT, outputs of four DFB lasers are fed into Mach-Zehnder 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.

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 can be negligible with intervals of 200 and 400 GHz. In (Kodama et al., 2013) 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 t 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.

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.

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. The result of this experiment confirms that with the help of RS-FEC, the bit error rate of less than 10^{-3} can be achieved for the receiver sensitivity < -24.1 dbm.

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 (SFM). 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.

ANS.3:

Telecommunication and networking has been and will be one of the core technologies in helping the evolution of mankind and technology itself. If it wasn’t for it for these channels of communications and data transmission, we would probably still be in an era where technology isn’t as advanced as today.

Wireless communication technology inside cell phones and other mobile devices has evolved over several decades. Starting with the then revolutionary 1G (referred to as the earliest form of voice only network) all the way to the 4G of today and the 5G of the near future. But what has really changed? And what is the core driving principles of these wireless communication technology?

First off, the G in “4G” or “5G” stands for generation and the number is just a representation of the evolution of technology. Currently, as you may know, we are using the 4th generation of wireless communication technology. But let’s start from where it all began:

Features	1G	2G	3G	4G	5G
Start/Devlopment	1970/1984	1980/1999	1990/2002	2000/2010	2010/2015
Technology	AMPS, NMT, TACS	GSM	WCDMA	LTE, WiMax	MIMO, mm Waves
Frequency	30 KHz	1.8 Ghz	1.6 - 2 GHz	2 - 8 GHz	3 - 30 Ghz
Bandwidth	2 kbps	14.4 - 64 kbps	2 Mbps	2000 Mbps to 1 Gbps	1 Gbps and higher
AccessSystem	FDMA	TDMA/CDMA	CDMA	CDMA	OFDM/BDMA
Core Network	PSTN	PSTN	Packet Network	Internet	Internet

FIRST GENERATION (1G)

1G is the first generation wireless telephone technology, Cell phones. They were analog cell phones and were introduced in 1980. In 1979, the first cellular system in the world became operational by Nippon Telephone and Telegraph (NTT) in Tokyo, Japan. In Europe two most popular analog systems were Nordic Mobile Telephone (NMT) and (TACS) other analog systems were also introduced in 1980’s across the Europe. All the systems offered handover and roaming capability but the cellular networks were unable to interoperate between countries. This was the main drawback of First Generation mobile networks. 1G has low capacity unreliable handoff, poor voice links and no security since voice calls were played back in radio towers making these calls susceptible to unwanted. In USA AMPS was first 1G standard launched in 1982. AMPS system was allocated a 40 MHZ bandwidth within the 800-900 MHZ frequency range by the federal Communication Commission (FCC). In 1988 additional 10 MHZ bandwidth, called expanded spectrum (ES) was allocated to AMPS.

Italy used a telecommunication system called RTMI. IN UK, YACS was used. France used RadioComm 2000. In West Germany, Portugal and South Africa a telecom standard known as C-450 was used.

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 was old analog system and supported the 1st. 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
4. Allows users to make voice calls in 1 country.

SECOND GENERATION TECHNOLOGY (2G TO 2.7 G)

2G is the Second-Generation wireless cellphones, based on digital technologies and in 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. 2G system uses digital mobile access technology such as TDMA and CDMA. TDMA divides signal in time slots while as CDMA allocates each user a special code to communicate over a multiplex physical channel. Different TDMA technologies are GSM, PDC, iDEN , iS-136. GSM was first 2G System. CDMA technology is IS-95. GSM (Group Special Mobile) has origin from Europe. GSM is most admired standard of all the mobile technologies used in more than 212 countries, in the world. GSM standard makes international roaming very common between mobile phone operators, enabling subscribers to use their phones in many parts of the world. GSM uses TDMA to multiplex upto 8 calls per channel in the 900 and 1800 MHZ bands. GSM can't only deliver voice but also circuit switched data at speed upto 14.4kbps. In US FCC also auctioned a new block of spectrum in the 1900MHZ band. During 20 years, GSM technology has been continuously improved to offer better services in the market. New technologies has been developed based on the original GSM system, leading to some advanced system, known as 2.5 generation (2.5 G) Systems.

2.5G – GPRS (General Packet Radio Service)

GPRS is extension of existing 2G network to have the capacity of launching packet based services while enhancing the data rates supported by these networks. The term "Second and a half generation" is used to describe 2G-Systems that have implemented a packet switched domain in addition to circuit switched domain.

"2.5 G" is an informal term. GPRS provided data rates from 56 Kbps upto 384 Kbps, using database HLR, VLR, EIR, and AuC with HSCSD, GPRS and EDGE technologies. It provides services such as Wireless

Application Protocol (WAP) access, Multimedia Messaging Service (MMS) and for internet communication services such as e-mail and World Wide Wireless Web (WWW) access. GPRS data transfer is typically charged per megabyte of traffic transferred, while data communication via traditional circuit switching is billed per minute of connection time, independent of whether the user actually is utilizing the capacity or is in an idle state. 2.5G networks may support services such as WAP, MMS, SMS mobile games, and search directory and well internet access.

2.75 – EDGE (Enhanced Data rates for GSM Evolution)

GPRS network s evolved to EDGE networks with the introduction of 8PSK encoding. Enhanced Data rates for GSM Evolution, Enhanced GPRS (EGPRS), or IMT Single Carrier (IMT-SC) is a backward-compatible digital mobile phone technology that allows improved data transmission rates, as an extension on top of standard GSM. EDGE was deployed on GSM networks beginning in 2003 initially by Cingular (now AT & T) in the United States. EDGE is standardized by 3GPP as part of the GSM family, and it is an upgrade that provides a potential three-fold increase in capacity of GSM/GPRS networks. The specification achieves higher data –rates (up to 236.8 Kbits/s) by switching to more sophisticated methods of coding (8PSK), within existing GSM timeslots.

EDGE technology is an extended version of GSM. It allows the clear and fast transmission of data and information. It is also termed as IMT-SC or single carrier. EDGE technology was invented and introduced by Cingular, which is now known as AT& T. EDGE is radio technology and is a part of third generation technologies. EDGE technology is preferred over GSM due to its flexibility to carry packet switch data and circuit switch data. EDGE transfers data in fewer seconds if we compare it with GPRS Technology. For example a typical text file of 40KB is transferred in only 2 seconds as compared to the transfer from GPRS technology, which is 6 seconds. The biggest advantage of using EDGE technology is one does not need to install any additional hardware and software in order to make use of EDGE Technology. There are no additional charges for exploiting this technology. If a person is an ex GPRS Technology user he can utilize this technology without paying any additional charges.

Keys: -

1. In between 2G and 3G there is another generation called 2.5G.
2. 2.5G represents handsets with data capabilities over GPRS.
3. But this has not brought out any revolution.

Migration path towards 3G Wireless System Soon, a greater demand to remove the distinction between fixed and mobile networks will become apparent. Access to the Internet and Intranets, Teleworking and the advent of the Virtual office are concepts which will become more commonplace in the near future. For the third generation communication system, the challenge will be the globalization and convergence of office and home applications and services with the help of new communication tools.
However, the situation is not the simple. The variety of communication systems in the market today, as discussed above, across different geographical locations, with their own economic, political, regulatory and social issues, make it difficult to bring all the players together to one single convergence point. There are large investments involved already and it is extremely difficult if not possible to develop standards right from scratch. Keeping this in mind, it has been recognized that a standard should be developed that accommodates the backward-compatibility of existing networks, while at the same time defining a common framework under which these networks can evolve. This will be an evolution from each of the regional second generation systems – wireless and wireline- and will satisfy market demands

for global roaming, service portability and multimedia, allowing for differentiation of services and products.

Third Generation 3G

3G is the third generation of mobile phone standards and technology, superseding 2G, and preceding 4G. It is based on the International Telecommunication Union (ITU) who formulated a plan to implement global frequency band in the 2000 MHZ range, which will support a single, ubiquitous wireless communication standard for all countries throughout the world. This plan is called International Mobile Telephone 2000 (IMT-2000), Standard.

3G evolution for CDMA systems lead to Cdma 2000. Several variants of CDMA 2000 are based on IS-95 and IS95B technologies. 3G evolution for GSM is IS-136 and PDC System lead to wideband CDMA (WCDMA), also called Universal Mobile Telecommunication Service (UMTS) , W-CDMA is based on GSM network. Cdma 2000 and W-CDMA, will remain main 3G technology popular. 3rd. Generation Partnership Project (3GPP) has continued that work by defining a mobile system that fulfills the IMT-2000 standard.

3G technologies enable network operators to offer users a wider range of more advanced services while achieving greater network capacity through improved spectral efficiency. Services include wide area wireless voice telephony, video calls, and broadband wireless data, mobile television, GPS (global positioning system) and video conferencing all in a mobile environment.

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, also called 3.5G (or "3½ G"), 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. HSDPA implementations includes Adaptive Modulation and Coding (AMC), Multiple-Input Multiple Output (MIMO), Hybrid Automatic Request (HARQ), fast cell search, and advanced receiver design.

3.75G – HSUPA (High-Speed Uplink Packet Access)

The 3.75G refer to the technologies beyond the well-defined 3G wireless/mobile technologies. High Speed Uplink Packet Access (HSUPA) is a UMTS / WCDMA uplink evolution technology.

The HSUPA mobile telecommunications technology is directly related to HSDPA and the two are complimentary to one another.

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.

Fourth Generation 4G

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.

4G is the next generation wireless networks that will replace 3G networks sometimes in future. In other context, 4G is simply an initiative by academic, R & D labs to move beyond the limitations and problems of 3G which is having trouble getting deployed and meeting its promised performance and throughput.

These days in 3G we can access the internet through our mobile phone with the help of various technologies, like Wi-Fi, Wi-Max, GPRS, EDGE, WAP and Wi-Bro. But the problem is that if you are accessing the internet through your mobile phone within the help of any of these technologies and you move to place where inter-operability between different networks obtains, you are stuck. If you are using 4G, you can access the net through any of the aforesaid technologies even while moving from one place to another.

Expected issues considered to be resolved in this 4G mobile technology which are as under:-

It is considered to embed IP feature in the set for more security purpose as high data rates are send and receive through the phone using 4G mobile technology.

- 4G mobile technology is going to be able to download at a rate of 100Mbps like mobile access and less mobility of 1GBps for local access of wireless
- Instead of hybrid technology used in 3G with the combination of CDMA and IS-95 a new technology OFDMA is introduced 4G. In OFDMA, the concept is again of division multiple accesses but this is neither time like TDMA nor code divided CDMA rather frequency domain equalization process symbolizes as OFDMA.
- CDMA sends data through one channel but with the division of time in three slots. While CDMA also sends data through one channel identifying the receiver with the help of code. Whereas in 4G mobile technology OFDMA is going to introduce in which data packets sends by dividing the channel into a narrow band for the greater efficiency comprises a prominent feature of 4G mobile technology.
- IEEE 802.16m is processing for the IEE802.16e comprising the 4G brand will define it as WMBA (Wireless Mobile Broadband Access). This is a plain indicator for the internet availability. The implementation is in progress to avoid the call interference in case of data download from a website. It will propose 128 Mbps downlink data rate and 56Mbps uplink data rate which is an extra ordinary step in 4G mobile technology. The service will limit as the availability of hotspot is condition for the internet connectivity.

Parallel with WiMAX, LTE is intended to incorporate in 4G mobiles. It is also a wireless technology for the broadband access. The difference between WiMAX and LTE is that LTE goes for the IP Address. It follows the same TCP / IP concept inherited from networking technology. Restricted for the IP addresses it will provide great security as well as high data transferability, avoid latency, having the ability to adjust the bandwidth. LTE is compatible with CDMA so able to back n forth the data in between both networks.

• 3GPP Organization is going to introduce two major wireless standards; LTE and IEEE802.16m. Former is granted permission for the further process while second is under consideration and that will become a part of 4G mobile technology.

• IPv6 is approved by Version as a 4G standard on June 2009.

FIFTH GENERATION (5G)

5G uses the rarely used radio millimeter bands in the 30 GHz to 300 GHz range. Testing of 5G range in mm Wave has produced results approximately 500 meters from the tower. Using small cells, carriers using millimeter wave for the deployment of 5G can improve overall coverage area. Combined with Beam forming, small cells can deliver extremely fast coverage with low latency.

Low latency is one of 5G's most important features. 5G uses a scalable orthogonal frequency-division multiplexing (OFDM) framework. 5G benefits greatly from this and can have latency as low as one millisecond with realistic estimates to be around 1 – 10 seconds. 5G is estimated to be 60 to 120 times faster than the average 4G latencyWith speeds of up to 10 Gbps, 5G is set to be as much as 10 times faster than 4G.

COMPARISON OF 1G TO 5G TECHNOLOGIES

Technology	1G	2G/2.5G	3G	4G	5G
Deployment	1970/1984	1980/1999	1990/2002	2000/2010	2014/2015
Bandwidth	2kbps	14-64kbps	2mbps	200mbps	>1gbps
Technology	Analog cellular	Digital cellular	Broadbandwidth/ cdma/ip technology	Unified ip & seamless combo of LAN/WAN/WLAN/PAN	4G+WWWW
Service	Mobile telephony	Digital voice,short messaging	Integrated high quality audio, video & data	Dynamic information access, variable devices	Dynamic information access, variable devices with AI capabilities
Multiplexing	FDMA	TDMA/CDMA	CDMA	CDMA	CDMA
Switching	Circuit	Circuit/circuit for access network& air interface	Packet except for air interface	All packet	All packet
Core network	PSTN	PSTN	Packet network	Internet	Internet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal&Vertical	Horizontal&Vertical

Ans.4:

Introduction The limited radio frequency spectrum puts constraints on the increasing demand for ubiquitous connectivity and high capacity. According to CISCO, there will be an 11-fold increase in mobile data traffic in 2018 compared to 2013 as shown in Fig. 1 [1]. The increase in the number of devices accessing the mobile networks is the primary reason for the drastic increase in mobile data traffic. Along with this, the development of online social services (such as Facebook and Twitter) has further increased the mobile data traffic. Apart from the spectrum deficiency issues in RF wireless communication, interference is another problem since most wireless devices are electromagnetic. The RF communication suffers from problems such as the following.

(a) Interference, according to Federal Aviation Administration (FAA) the use of mobile phones on aircraft causes interference with communication and navigational systems. Along with this, mobile phones on aircraft will also cause disruption with ground system towers as argued by the Federal Communication Commission (FCC).

(b) Regardless of the interference, it is clear that in a wireless communication system that needs very low latency requirements (such as in vehicular communication, safety system), the use of radio frequency is not suitable due to its bandwidth limitations.

(c) As RF waves easily penetrate the walls, they suffer from security issues.

(d) The increase in RF waves, transmission power beyond a certain limit results in risks to human health.

(e) RF communication suffers from power inefficiency, because we require a separate setup for communication of the RF waves. To overcome the drawbacks of the RF communication systems, it is imperative to design new communication technologies.

Visible Light Communication (VLC) systems employ visible light for communication that occupy the spectrum from 380 nm to 750 nm corresponding to a frequency spectrum of 430 THz to 790 THz as shown in Fig. 2. The low bandwidth problem in RF communication is resolved in VLC because of the availability of the large bandwidth as illustrated in Fig. 2. The VLC receiver only receives signals if they reside in the same room as the transmitter, therefore the receivers outside the room of the VLC source will not be able to receive the signals and thus, it has the immunity to security issues that occurs in the RF communication systems. As a visible light source can be used both for illumination and communication, therefore, it saves the extra power that is required in RF communication. Keeping in view the above advantages, VLC is one of the promising candidates because of its features of non-licensed channels, high bandwidth and low power consumption.

Architecture of VLC
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

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. The communication in the star topology is performed using a single centralized controller. All the nodes communicate with each other through the centralized controller. 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.

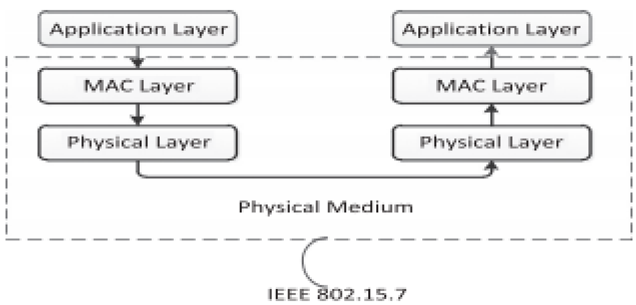

Fig. 11. Layered architecture of VLC.

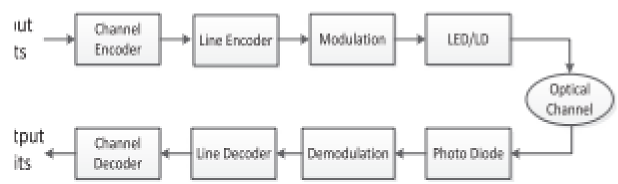

Fig. 12. Typical physical layer system model of VLC.

Physical layer
The Physical layer provides the physical specification of the device and also, the relationship between the device and the medium. First of all, the input bit stream is passed through the channel encoder (optional). Linear block codes, convolutional codes and the state of the art turbo codes 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. In different implementations of the visible light communication systems are given. In 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 was increased to 3.75vGb/s as compared to that in 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.

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. 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.

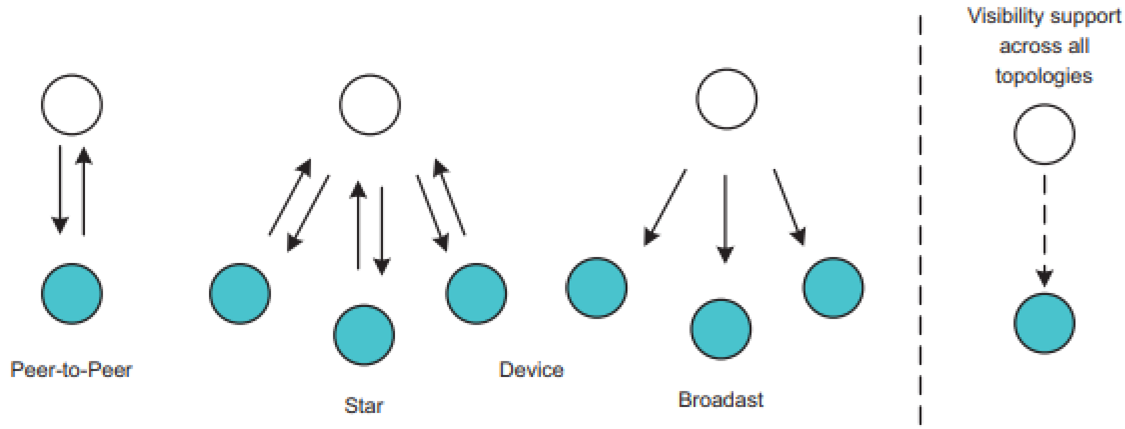

Fig. 10. Supported MAC topologies by IEEE 802.15.7 [25].

Transmitter

The development of LEDs has made the solid state lighting an emerging field. LEDs have surpassed the incandescent light sources in terms of reliability, power requirements and luminous efficiency. The efficiency of LEDs is 20 lm/W greater than the incandescent lamps efficiency. LEDs and Lasers are used as transmission sources for VLC. The LED should be used when both communication and illumination have to be performed using a single device. The white light based on LEDs and wavelength converters is one of the attractive candidates for being used as the VLC source. There are different possible spectra in which white light is produced by the LEDs. The Tetra-chromatic, dichromatic and tri-chromatic modes used for generation of white light are shown in Fig. 13. The most commonly used methods for generation of white light using LEDs is trichromatic (such as red, green and blue). The advantage of using an RGB LED for white light generation is the high bandwidth and thus, high data rates. The downside of the RGB LED is their high associated complexity and difficulties in modulation. Comparison of the phosphor based LEDs and RGB LEDs are shown in Table 4. In different methods have been adopted for characterization of the optical wireless channel. The appropriate LED is selected based on the channel model.

Receiver

The typical VLC receiver consists of an amplification circuit, optical filter and optical concentrators as shown in Fig. 14. The beam divergence that occurs in LEDs due to illuminating large areas results in attenuation so the optical concentrator is the device that is used to compensate this type of attenuation. In the VLC receiver, the light is detected using a photodiode and then converted to photo current. The parameter specification of the VLC will be different from that of the infrared communication because of the different wavelengths. The silicon photodiode, PIN diode and avalanche photodiode are used for VLC. The avalanche photodiode has a higher gain than a PIN photodiode but at the expense of the high cost. The VLC is vulnerable to interference from other sources such as sunlight and other illumination; therefore, optical filters should be designed to mitigate the DC noise components present in the received signal. In a VLC receiver, the photodiode is generally used for reception of the VLC signals. It is better to use a photodiode in the case of a stationary receiver; however, the imaging sensor is employed instead of a photodiode because of the larger FOV in the case of mobility. Operating imaging sensors is energy expensive and slow. Therefore, a trade-off should be made between the cost, speed and complexity while considering photodiode and imaging sensors.

VLC standardization

VLC is one of the promising candidates for communication because of the rapid development of the solid state lighting. However, certain challenges that exist and must be addressed are listed as follows: a. Integration of the VLC with the already existing communication standards such as Wi-Fi etc. b. The issue of interference with ambient light sources. c. The mobility issues such as handover should be properly considered in VLC. d. To improve the communication system performance by specifying Forward Error Correction schemes. e. Interference between the different devices using VLC is expected in the future because of an increase in the number of VLC devices. To tackle the above problems, a standardization of VLC is imperative. The standardization of VLC has been performed by the Visible Light Communication Consortium (VLCC) in Japan and IEEE. The Japan Electronics and Information Technology Industries Association (JEITA) CP-1221, JEITA Cp-1222 and JEITA Cp-1223 are published by the VLCC. The 802.15.7 is the standard completed by the IEEE for physical and MAC layers. This standard is aimed at:

(1) Providing access to several hundred THz bands.
(2) Providing immunity against the electromagnetic interference.
(3) Communication that complements extra services to the existing visible light infrastructure.
(4) Specifying the FEC schemes, modulation techniques and data rates for VLC communication.
(5) The channel access mechanisms such as Contention Access Period (CAP), Contention-Free Period (CFP) and visibility support when channel access are also described.
(6) The PHY layer specifications, such as optical mapping, TX-RX turnaround time, RX-TX turnaround time and flicker and dimming mitigation, are also explained.

The IEEE 802.15.7 provides a minimum benchmark for the development of new products. The three different classes of devices considered for VLC are vehicle, mobile and infrastructure as indicated in Table 5 [48]. The JEITA CP-1221 standard is aimed at presenting necessary requirements and the indication level that is required to avoid the interference between different VLC devices. The wavelength range for VLC assumed by JEITA CP-1221 is 380–750 nm. JEITA uses the frequency range 1 for implementing visible light ID system as shown in Fig. 15. The inverter fluorescent lamp radiates in the frequency range 2, therefore this range is not suited for VLC communication. The frequency range 3 is used for high speed communication. In JEITA CP-1222, the subcarrier frequency 28.8 kHz with a transmission rate of 4.8 kbps is used. For error correction, cyclic redundancy check was employed.