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RESEARCH ARTICLE

A survey/ Development of Passive Optical Access Networks Technologies

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Manuscript Info ***Abstract***

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The bandwidth requirements of the telecommunication network users increased rapidly during the last decades. Optical access technologies must provide the bandwidth demand for each user.The passive optical access networks (PONs) support a maximum data rate of 100 Gbps by using the Orthogonal Frequency Division Multiplexing (OFDM) technique in the optical access network. In this paper, the optical broadband access networks with many techniques from Time Division Multiplexing Passive Optical Networks (TDM PON) to Orthogonal Frequency Division Multiplex Passive Optical Networks (OFDM PON) are presented. The architectures, advantages, disadvantages, and main parameters of these optical access networks are discussed and reportedwhich have many advantages to become next-generation broadband access networks.

Introduction

The appearance of new Internet services such as video conference, high performance gaming, video telephony, high definition television and E-learning have changed the broadband environment. Access technologies have been evolving from wire based subscribers to optical fiber networks. As the installed digital subscriber line (DSL) has turned out to be insufficient for providing the bandwidth required for triple-play services (data, voice, video), and it has become essential to extend the optical networks toward end users. Figure (1) shows forecast of the evolution of the global consumer internet traffic from 2011 to 2016 [1]. Among the several available technologies, passive optical network (PON) has been considered as a promising option due to its large throughput and quality of service (QoS) [2].

In [3] migration from classical PON to new generation PON (NG PON) is discussed. The classical PONs can offer sufficient bandwidth, but in the long term (five or more years), this bandwidth can be the bottleneck.
NG PON can solve this problem (bottleneck) because NG PON has four times more bandwidth. Ling in [4] have concentrated on identifying why 10GPON should be standardized and how WDM PON would be able to solve the ever-increasing bandwidth requirements. In [5], the authors propose a next-generation hybrid WDM/TDM optical access network architecture called Stanford University a CCESS or SUCCESS.

This architecture provides practical migration steps from current-generation time-division multiplexing (TDM)-passive optical network (PONs) to future WDM optical access networks.Biswas et al in [6] mentioned that OFDM technology that is well-suited for future PON Systems. But it requires advanced Digital Signal Processing (DSP), providing an analysis of primary cost factors in a practical DSP-based OFDMA-PON implementation and survey the most recent achievements in this domain. The rest of this paper is organized as follow section 2 will illustrate PON architecture, section 3 explain TDMA PON technology, section 4 illustrate hybrid TDMA/WDM PON, then WDM PON discuss in section 5, section 6 will explain OFDM PON and conclusion will be in section 7.

PON Architecture

All transmissions in a PON are performed between Optical Line Terminal (OLT) in the Central Office (CO) side and Optical Network Units (ONU) at the user side through passive optical splitter as shown in Figure (2). In the downstream direction (transmission from OLT to ONUs), PON is a point-to-multipoint network, and in the upstream direction (transmission from ONUs to OLT) it is a multipoint-to-point network [7].

In its most general form, an optical network will contain both active and passive optical elements. Active components can be located at the central office, within termination points at the customer’s premises, and in the repeaters, switches, and other equipment located in the transmission path between the central office and the customer.

They are used for functions such as coupling light from one fiber to another, redirecting the light signal to another transmission path, splitting the signal into two or more branches, amplifying the optical signal power, and processing information contained in the signal [5]. If active devices are used in the transmission path, they require electrical power to perform their functions.Some type of dynamic status monitoring mechanism is needed to verify that the active devices are working properly.

If the status information indicates a pending or actual malfunction, a network operator needs to take action and dispatch a maintenance person to the fielded unit to correct the fault. These factors add cost and complexity to the system operation compared to the case in which no active devices are used between network endpoints. In contrast to conventional networks, a PON has no active components between the central office and the customer’s premises. Instead, only completely passive optical components are placed in the network transmission path to guide the traffic signals contained within specific optical wavelengths.

Replacing active devices with passive components provides a significant cost savings in maintenance by eliminating the need to power and manage active components in the outside cable plant [8].

There are several PON protocols and standards defined by the ITU organization with varying levels of maturity. The three main ones are BPON, EPON and GPON. Table 1 below illustrates their main features.

TDMAPON

Two key network functions of an OLT are to control user traffic and to assign bandwidth dynamically to the ONT modules. Since up to 32 ONTs use the same wavelength and share a common optical fiber transmission line, some type of transmission synchronization must be used to avoid collisions between traffic coming from different ONTs. The simplest method is to use *Time-Division Multiple Access* (TDMA), wherein each user transmits information within a specific assigned time slot at a prearranged data rate as shown in Figure (3). The multiplexed downstream signal is broadcast to all the ONTs. Each ONT discards or accepts the incoming information packets, depending on the packet header addressing. Sending traffic in the upstream direction is more complicated, since all users have to time share the same wavelength. To avoid collisions between the transmissions of different users, the system uses a TDMA protocol.

However, this does not make efficient use of the bandwidth available since many time slots will be empty when several network users do not have information to be sent back to the central office. A more efficient process is *Dynamic Bandwidth Allocation* (DBA), wherein time slots of an idle or low-utilization user are assigned to a more active customer.

The exact DBA scheme implemented through an OLT in a particular network depends on factors such as user priorities, the quality of service guaranteed to specific customers, the desired response time for bandwidth allocation, and the amount of bandwidth requested by a customer [9].

The OLT controls and coordinates the traffic from each ONT by sending permissions to them to transmit during a specific time slot. The time slots are synchronized so that transmission bursts from different users do not collide. Since each end terminal is located at different distances from the central office, the OLT uses a ranging technique to measure the logical distance between the users and the OLT. This enables each ONT to adjust its transmission timing properly to avoid traffic collisions.

WDM PON

TDM-PONs cannot cope with the requirements of future network evolution with respect to aggregated bandwidth and the allowable power budget [10]. These problems can be mitigated with WDM-PONs, in which ONUs are assigned individual wavelengths such that the bandwidth of fiber is utilized more effectively to further increase the transmission speed.

A major point to keep in mind when implementing a Wavelength Division Multiplexing (WDM) system is that the wavelengths in WDM must be spaced properly to avoid interference between adjacent channels. A basic PON design accommodates this through the selection of wavelengths at 1310 in upstream direction, 1490 in downstream direction for data and voice, and 1550 nm for video.

WDM-PON provides the dedicated bandwidth of a P2P network with the fiber sharing inherent in PON access networks. The straightforward approach to build a WDM-PON is to employ a separate wavelength channel from the OLT to each ONU, as shown in Figure (4).

In the downstream direction, the wavelength channels are routed to the corresponding ONUs using a passive Arrayed Waveguide Grating (AWG) as a WDM demultiplexer**.** The AWG replaces the passive powersplitter used in a TDM-PON. The AWG is a passive optical device with the special property of periodicity, the cyclic nature by which multiple wavelength channels are routed to the same output port from an input port. This enables spatial reuse of the wavelength channels. The insertion loss does not scale with the number of users and is considerably smaller than a passive splitter and (for example a 1x32 splitter introduces loss of 18 dB while the loss of AWG is typically in the range of 3-5 dB, independently of the number of routed channels).

For the upstream direction of the WDM-PON, the same AWG performs as a WDM multiplexer to combine all the upstream wavelength channels together. At the OLT, another AWG is employed along with a receiver array to detect the upstream signals. In such WDM-PON architecture, each subscriber gets a dedicated Point to Point (P2P) optical channel to the OLT, although they are sharing a common Point to Multi Point (P2MP) physical architecture like the TDM-PON.

Because of the virtual P2P architecture of WDM-PON, it has many advantages over the TDM-PON [11]:

- Huge bandwidth: each ONU is assigned an individual wavelength (each user can operate at a rate up to the full bit rate of a wavelength channel).
- The usage of the AWG router removes the splitting loss problem increasing the reach and scalability.
- Good security and protocol transparency: no sharing information between users.
- Less complexity and easier implementation: no need for any sophisticated media access controller algorithms to manage the timing of the ONU transmissions.

Also there are several issues need to be developed in WDM-PON they are:

- AWGs usually require thermal control to keep their wavelength channels locked to the ITU grid. Technology advances have allowed the recent commercialization of a thermal AWGs.
- Each wavelength-specific sources requires thermo-electric coolers to stabilize their wavelengths. Wavelength stabilized lasers are usually expensive.
- The scheme of WDM-PON require a different or “colored” transceiver for each user, resulting in high costs for installation, management and maintenance.

Hybrid TDMA/WDM PON

Hybrid WDM–TDM PON that applies wavelength-independent or colorless ONU technologies will further reduce implementation and maintenance expenses.

The “wavelength-reuse” colorless ONU technology imposes a physical constraint in the hybrid WDM–TDM PON that the same wavelength is used for both upstream and downstream traffic transmission of an ONU.An integration of WDM and TDM techniques applied in the PON results in a WDM–TDM PON, in which a number of wavelengths are deployed and eachwavelength is shared through TDM among several ONUs rather than being dedicated to a single ONU. AWDM–TDM PON therefore presents an economical upgrade step from TDM PON to WDM PON by offering both high-bandwidth and resource utilization efficiency [12].

The design and deployment of the hybrid WDM–TDM PON face many challenges. Its architecture should allow wavelengths to be assigned to different ONUs dynamically, and traffic scheduling algorithms should be able to dynamically allocate not only wavelengths but also timeslots to the ONUs based on traffic conditions and available resources, that is, perform dynamic wavelength andbandwidth allocation (DWBA).A wavelength-reuse” colorless ONU technology is used to achieve higher cost-effective deployment by using a Reflective Semiconductor Optical Amplifier (RSOA) instead of a tunable wavelength transmitter in the ONU.

In a hybrid WDM–TDM PON architecture that applies colorless/wavelength-reuse ONU technologies, only an array of transmitters (Tx’s) is deployed in the CO, and each ONU is equipped with a Tunable Optical Filter (TOF), a Receiver (Rx), and perhaps a RSOA as shown in Figure (5).

In this architecture, a splitter is deployed to allow all wavelengths to reach every ONU, so that an ONU can join other ONUs by selecting the same wavelength. The TOF is deployed in the ONU to select the downstream wavelength.More than one ONU can select the same wavelength, and this enables the wavelength and timeslot resources to be dynamically shared among the ONUs in the network [5].

In hybrid WDM/TDM PONs, the optical laser used for generating optical signals with multiple wavelengths. Depending on the wavelength generation capability, there are three major classes of lasers: multi wavelength lasers, wavelength-specified lasers, and wavelength-tunable lasers [13].

Multi wavelength lasers are used at OLT to generate downstream traffic or seed optical network units (ONUs) with optical signals for their upstream data transmission. Instead of generating multiple wavelengths, a wavelength-specified laser can only emit one specific wavelength.

Wavelength-tunable lasers are able to generate multiple wavelengths, but only one wavelength at a time. Comparing with wavelength-fixed lasers, tunable lasers possess advantages in two major aspects. First, from the perspective of network operators, tunable lasers enable the color-free property of ONUs, which further facilitates the simplified inventory management, reduced sparing cost, and automated wavelength provisioning. Second, from the perspective of the MAC layer, the wavelength tunability of tunable lasers facilitates the statistical multiplexing of traffic from all ONUs, thus potentially yielding better system performance. Owing to these advantages, wavelength-tunable lasers are promising light source generators for hybrid WDM/TDM PONs.

OFDM PON

Orthogonal Frequency Division Multiplexing (OFDM) technology utilizes several low bit rate sub-carriers of the link to carry different QAM symbols simultaneously. When the scheme is employed to allow for Multiple Access (OFDMA), different users are assigned to different OFDM sub-carriers. Recently OFDM has also been making its way into the optics world, both in core [14], and access networks.

Basic principles of OFDM

OFDM is a multi-carrier transmission technique, which divides the available spectrum into many carriers, each one being modulated by a low rate data stream. OFDM is similar to FDMA in that the multiple user access is achieved by subdividing the available bandwidth into multiple channels that are then allocated to users. However, OFDM uses the 10 spectrum much more efficiently by spacing the channels much closer together. This is achieved by making all the carriers orthogonal to one another, preventing interference between the closely spaced carriers [15].The reason why OFDM boasts a spectral efficiency advantage over conventional FDM is precisely that it eliminates the spectral guard bands by invoking the principle of orthogonality.

OFDM based PON

In OFDM, a high-speed data stream is converted to aparallel of multiple low-speed data streams. The low-speed data streams are converted from frequency domain to time domain through inverted fast Fourier transform (IFFT), and then combined for signal transmission. Because of the nature of Fourier transform, the sub-carriers carrying the low speed datastreams are orthogonal to each other. At the receiver side, the received signal is converted back from time domain to frequency domain via fast Fourier transform (FFT). The signal distortions can be compensated through the signal equalization in the frequency domain.

The practical OFDM-PON implementation uses the orthogonal sub-carriers transmission realized by IFFT and FFT is shown in Figure (7). Advanced DSP enables practical, cost efficient and multiuser implementation.

OFDM sub-carriers can be dynamically assigned to services in different time slots. By properly designing the sub-carrier allocations, transparent pipes can be reserved within the overall OFDM signal bandwidth, which can be used to transmit different services independently.Figure (8) shows an example of OFDM-PON with thetransparent pipes for multiple services. Sub-carriers are reserved as two transparent pipes for the legacy TOM(Tl /EI) services of the business area and the RF radio signal from the mobile base station.

The number of sub-carriers of each transparent pipe depends on the bandwidth required by the service. The remaining sub-carriers are allocated to packet basedIP traffic, shared between the ONU-1 and ONU-3 both infrequency and time domain. The sub-carriers and time slots allocation are controlled by the optical line terminal (OLT) and sent to the ONUs over non-reserved sub-carriers in the preconfigured time slots.

To complete downstream transmission, the OFDM frame and any other analog signals are mixed by an electrical coupler to drive the optical modulator. At the ONU side each ONU selects its own data or signal from its pre-assigned subcarrier(s) and/or time slots, as communicated by the OLT scheduler. To transmit upstream traffic, each

ONU maps its data and/or signal to its assigned OFDM subcarrier(s), nulls all remaining subcarriers, and performs OFDM modulation to generate a complete frame. For upstream transmission, each ONU maps its data and/or signal to its assigned OFDM subcarrier(s), nulls all remaining subcarriers, and performs OFDM modulation to generate a complete frame. In Figure (8), for example, ONU-3 would assign zeros to the subcarriers carrying the traffic of both ONU-1 and ONU-2, and use its pre-assigned OFDM subcarriers for upstream Ethernet packet transmission. It is also noted that ONUs with a variety of services and data rates can all be supported in a heterogeneous OFDMA-PON, which can help achieve a high degree of network flexibility and effectively manage cost.

There are multiple variants of optical OFDMA [16] can be illustrated in Figure (9). The simplest form, shown in Figure(9-a), consists of assigning different subcarriers from the same OFDM band to different users.

Adaptive bandwidth provisioning is thus performed by changing the number of subcarriers allocated to a given user/service depending on the real-time traffic demand.

The result is a dynamic bandwidth allocation scheme can be implemented in DSP via MAC layer algorithms [17]. To achieve higher granularity and flexibility, each OFDM subcarrier bandwidth resource can be further subdivided in time, by combining one subcarrier OFDMA with classic TDMA, as shown in Figure 9(b). In this scheme (OFDM+TDMA), multiple users can access the same OFDM subcarrier in different time slots. As in OFDMA, the OFDM+TDMA approach can be implemented in DSP via MAC layer protocols. Finally, by implementing the DSP-based OFDMA+TDMA bandwidth scheduling of Figure 9(b) on each of possible WDM wavelengths, a (WDM+OFDM+TDM) scheme can be achieved as in Figure 9(c). In this case, the first step of wavelength assignment can be static, as is the case in conventional point-to-point WDM systems, or dynamic, if tunable optical devices are available at the ONU receivers. In either case, colorless (wavelength agnostic) ONU-side optics are a key requirement.

Key Benefits of OFDM PON Transmission

OFDM PON regarded as a very promising solution for future PON-based access due to its benefits those can be summarized as below:

- **Speed and distance**
  - Up to 100Gb/s/λ downstream transmission.
  - Up to 100Gb/s/λ upstream transmission.
  - Up to 100Km reach for PON, 1000km for metro.
- **Cost efficiency**
  - Colorless architecture.
  - Stable, accurate DSP- based operation.
  - Non-disruptive to legacy ODN.
- **Flexibility**
  - Adaptive modulation and FCE on subscriber basis.
  - Dynamic band width allocation in time and frequency.
  - Transparency to arbitrary services.
  - Optically-transparent ONUs.

Conclusion

As an ultimate broadband access solution for future Internet, the passive optical network (PON) brings many advantages such as cost effectiveness, energy savings, service transparency, and signal security over other last-/first-mile technologies. Over the past several years, we have witnessed significant development and deployment of time-division multiple access (TDMA) PONs such as IEEE 802.3ah Ethernet PONs (EPONs) and ITUT G.984 Gigabit PONs (GPONs) to provide high-quality triple-play services for residential users. However, future Internet applications, apart from triple-play service (e.g., peer-to-peer [P2P] social networking, online video sharing, grid computing, and mobile Internet), along with their unique traffic characteristics and huge bandwidth requirements, pose big challenges for current PON design and migration, which in turn are driving legacy TDMA PONs toward ultra-high-speed flexible next-generation PONs such as wavelength-division multiplexed (WDM) PONs and optical orthogonal frequency-division multiplexed (OFDM) PONs, and/or a hybrid WDM/OFDM/ TDM PON.

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Figure 1. Forecast of the global consumer internet traffic (2011-2016)

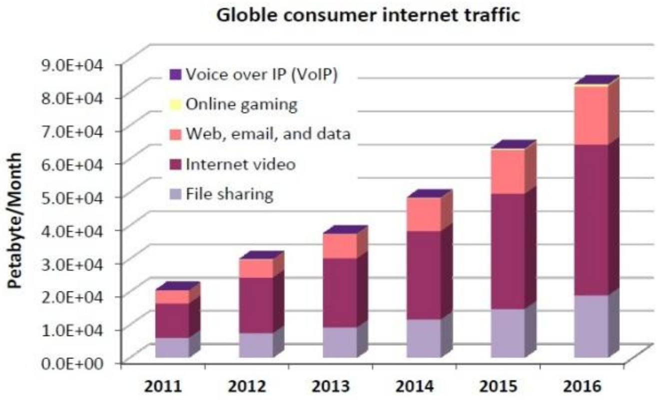


Figure 2. PON Architecture

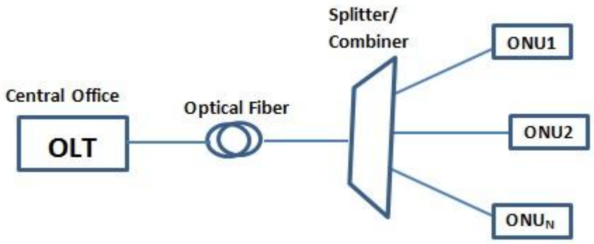


Table (1) PON Access Protocols

	BPON	EPON	GPON
Standard	ITU-T-.983	IEEE 802.3ah	ITU-T G.984
Upstream λ	1310 nm	1310 nm	1310 nm
Downstream λ	1490 &1550 nm	1550 nm	1490 &1550nm
Protocol	ATM	Ethernet	ATM, Ethernet, TDM, GEM
Bandwidth	Down ≤1.24 Gbps Up 622 Mbps	Down ≤1.25 Gbps Up ≤1.25 Gbps	Down ≤2.4 Gbps Up ≤2.4 Gbps
Max Distance	20 Km	10 or 20Km	40 or 60 Km

Figure 3. TDM PON Architecture

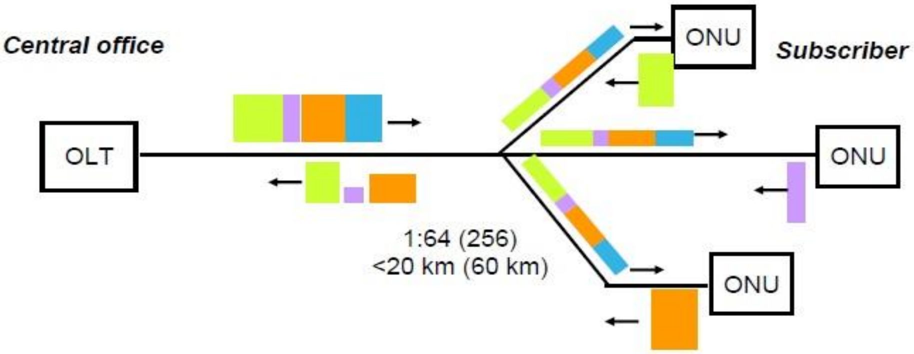


Figure 4. WDM PON Architecture

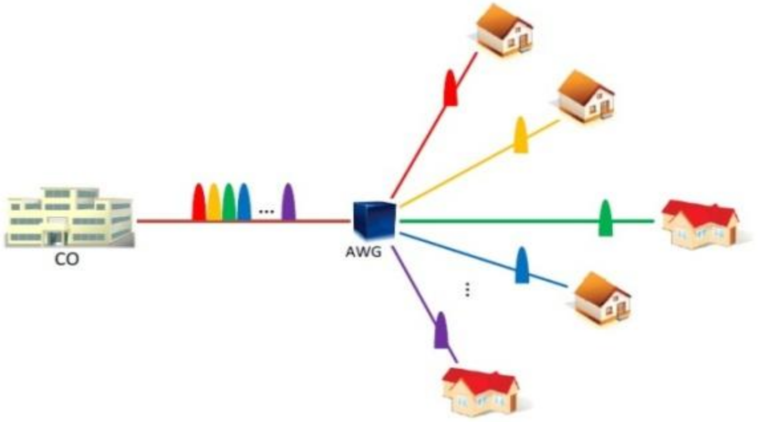


Figure 5. Hybrid TDMA/WDM PON Architecture

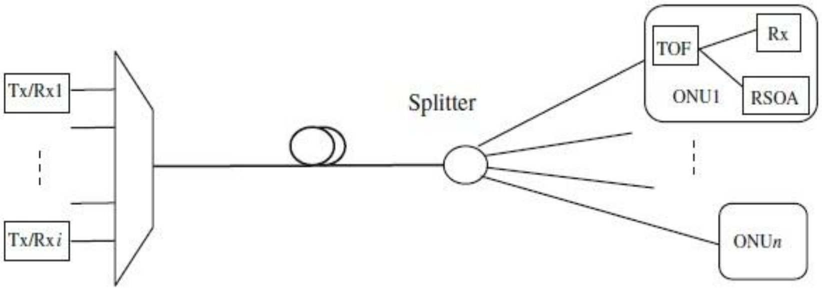


Figure (7) Practical OFDM Implementation

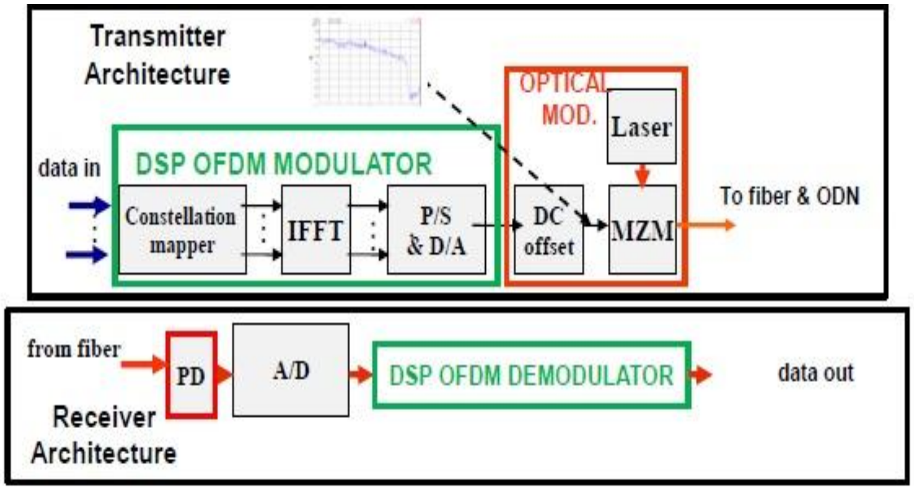


Figure 8.OFDMA PON architecture for delivery of heterogeneous services

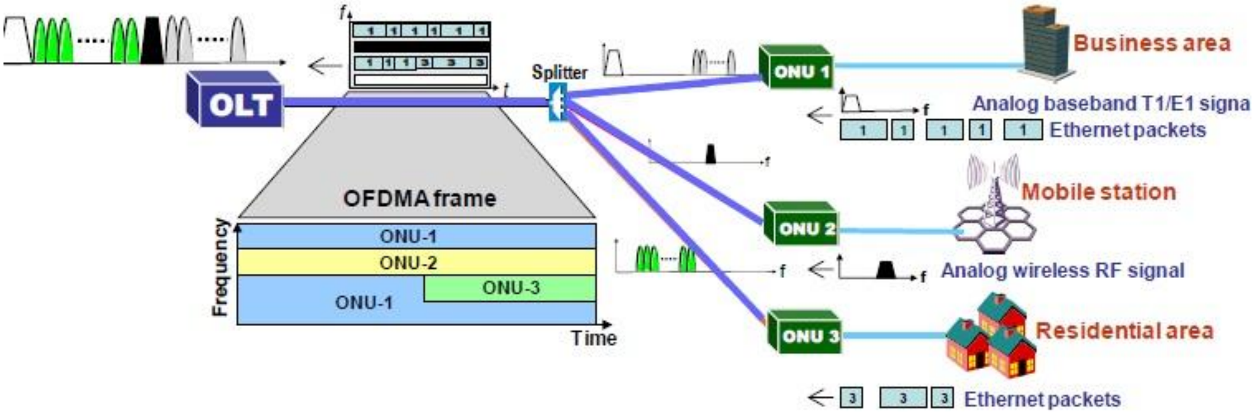
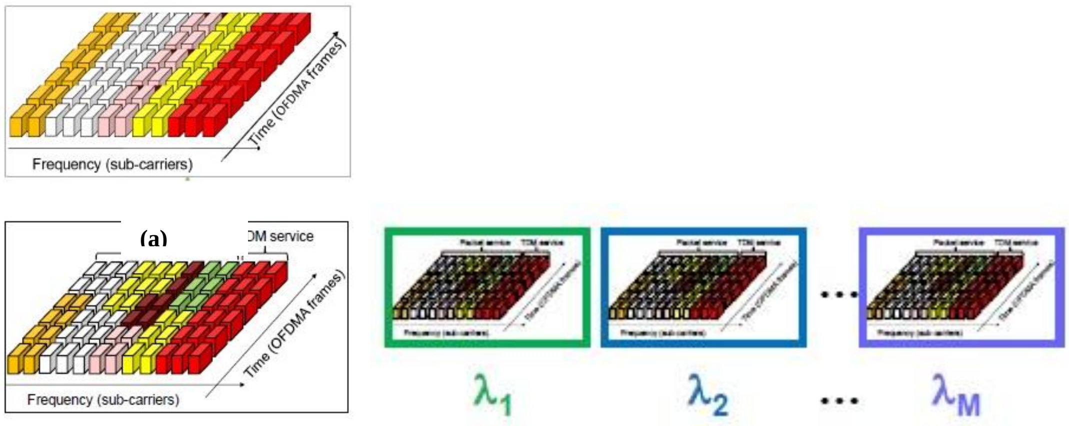


Figure (9).a-OFDM b- OFDM+TDMAc-WDM+OFDM+TDM



(a)

(b) (c)