International Journal of Electrical and Computer Engineering (IJECE)
Vol. 13, No. 4, August 2023, pp. 4152~4158
ISSN: 2088-8708, DOI: 10.11591/ijece.v13i4.pp4152-4158

Design of time division multiplexing/wavelength division multiplexing passive optical network system for high-capacity network

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Article Info

Article history:

Received Jun 17, 2022
Revised Sep 28, 2022
Accepted Oct 1, 2022

Keywords:

High capacity
Passive optical network
Simulation
Time division multiplexing
Wavelength division multiplexing

ABSTRACT

This paper presents the design of time division multiplexing-wavelength division multiplexing-passive optical network (TDM-WDM PON). In this design, the current TDM PON is incorporated with the proposed WDM-PON in order to design a high-capacity network with lower loss requirements. The design has been simulated using OptiSystem software. The upstream wavelength for WDM is between 1,530.334 to 1,542.142 nm while for TDM is 1,310 nm. The downstream wavelength for WDM is from 1,569.865 to 1,581.973 nm, while for TDM is 1,490 nm. Based on the result, it is found that the proposed network is capable to support up to 64 customers with a bit rate of 2.5 Gbps.

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1. INTRODUCTION

It is acknowledged that wavelength division multiplexing–passive optical network (WDM–PON) is one of the most promising technology. This technology is suitable for broadband access network deployment due to its flexibility and capability of the optical network to carry high bandwidth. Recently, transmission in the wavelength domain has been applied for ethernet or gigabit-PON (E/G-PON) technology. Urban *et al.* [1] conducted the combination or hybridization of these technologies for a more cost-effective implementation. Figure 1 shows the WDM-PON technology implementation in E/G PON. The basic components available are such as the optical line terminal (OLT), the PON network, and the optical network unit (ONU). A passive multiplexer and demultiplexer module are applied in the network to accommodate multiple wavelengths transmitted between the OLT and the ONU. Thus, more advantages will be added to the system such as enhancing security with the ability to allocate a desired wavelength to each user, economical implementation since a similar optical network could be utilized, and scalability in distance, speed, and dimension [2].

A C-band WDM–PON prototype [3] is demonstrated to provide 20 Gb/s downstream and 20 Gb/s upstream bandwidth. This prototype system has a minimum loss budget of 21.3 dB and supports a connection distance of 40 km with a split ratio of 1:8. Performance analysis of time division multiplexing (TDM) and WDM–PON has been conducted [4] using OptiSystem software for multiple access networks. Basically, TDM–PON provides a high number of channels with moderate bandwidth using a single wavelength. On the other hand, WDM-PON uses multiple wavelengths to enhance the capacity without increasing the data rate in a single fiber.

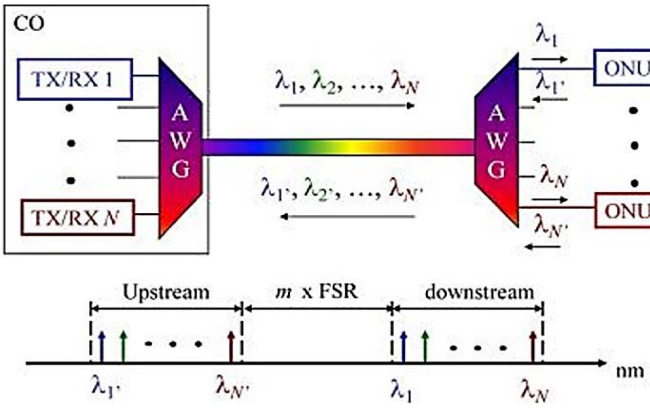

Figure 1. Generic WDM–PON architecture [1]

Li *et al.* [5] proposed a hybrid TDM/WDM-PON architecture compatible with the traditional TDM-PON configuration using a power splitter in the remote node. To select the downstream wavelength of each optical network unit, they use a tunable optical filter (TOF). Meanwhile, by seeding a reflective semiconductor optical amplifier (RSOA) to build a tunable fiber ring, the TOF plays a second role as a colorless upstream source. For the upstream laser source tuned from 1,535 to 1,565 nm, a good output is defined with a modulation data rate of 1.25 Gbps. The upstream wavelength has a 0.1 nm offset with the TOF's central wavelength when the RSOA is skewed in its saturation area, minimizing the Rayleigh backscattering and the reflective back crosstalk in single-fiber bidirectional PON systems.

Manaf *et al*. [6] proposed the upstream characteristics of tunable WDM-PON system. They decided to use a tunable ONU transceivers and tunable OLT as both transmitter and receiver of the system. As for the existing PON structure, they decided to add WDM infrastructure in one design to form a WDM-PON system. A 16-channel wavelength plan is applied in their architecture. They also introduce the usage of arrayed waveguide grating (AWG) in their system. The results show that distance can affect the power received and the laser signal performance at the ONU. Bit error rate (BER) shows that the further the distance, the higher the BER. BER is the ratio of the number of erroneous bits received to the total transmitted bits [7]. In other words, high BER means that the receiver is receiving a high number of error bits as compared to the low BER. This can be an indicator of the condition of the transmission link or system.

Implementing an economic broadband access network is genuinely flexible in scope that will require substantial technological changes. Operating basically passive fiber connections from the client to central offices, which could be between 100 and 150 km away, could lead to significant cost and energy savings [8]. The simplest structure for each connection is precisely point-to-point, with a physical fiber. This selection was chosen for a range of fiber-to-the-home (FTTH) deployments, for example in Sweden and the Netherlands [9], [10]. Such a solution is competitive where there is no unreasonable cost of fiber deployment and where the accumulation point is relatively close to the user. More typically, a 'virtual point-to-point' system is preferable in the case of 'long-reach' access systems. WDM is the key to reducing the required hardware, hence the existence of a WDM-PON [11], either by combining WDM with TDM, these systems can provide the desired economically advantageous long-range service [12] or by allocating each user a full wavelength channel [13]. In order to be economically viable, it is crucial that terminals are all identical in a WDM network, i.e., 'colorless' – inventory management and deployment problems will otherwise dominate installation costs. Many solutions have been proposed to this problem, including injection-locked laser systems on the user site [14] and on reflective modulation [15]. Such systems, which are indeed successful, present major challenges that restrict the efficiency and cost-effectiveness of the overall system. Generally speaking, there has been an observation in the industry that solutions focused on tunable laser technology will be expensive for widespread implementation in home terminals.

It is acknowledged that the most widely used multiplexing techniques are TDM and WDM [16]. NG-PON1 may suffer bandwidth restrictions in the future as the network capacity is decreasing very rapidly [17]. TDM PON has its limitations whereas a single wavelength is allocated for the upstream and downstream, thus this will limit the average bandwidth per user and the bandwidth of a single fiber. A high splitting ratio in TDM PON will also limit the fiber reach for up to around 20 km for a 32 split and a 28 dB link budget. Therefore, by combining TDM and WDM-PON can overcome this problem. CWDM technology is deployed upstream and DWDM is deployed downstream [18]. In [19], hybrid TDM–WDM PON and stacked TDM-PON are designed and analyzed to support NG-PON2. The performance of TDM-WDM PON is mainly dependent on the architecture [20]. Kumar and Randhawa [21] improved TDM-WDM PON has been designed with various modulation techniques at the WDM transmitter to improve the performance. Several WDM-PONs performances including hybrid TDM-WDM PON have also been analyzed in [22]. In [23], the hybrid TDM/WDM PON has been designed and analyzed with a bidirectional semiconductor optical amplifier (SOA). Basically, the main objectives of NG-PON are to increase the data rate for the customer and to extend the fiber reach to the customer for cost efficiency [24].

The idea comes as the number of users is increasing. The current TDM-PON design does not support much bandwidth. This supports very powerful user-shared bandwidth, but it requires each ONT to run at a full line speed of 40 Gbps, a rate that far exceeds individual users' needs. The current TDM-PON system design requires a high cost. Full-service access network (FSAN) has discontinued TDM-PON due to high costs and uncertainty associated with certain challenges, such as solving the problem of chromatic dispersion at very high line rates. Hence, WDM-PON will be added to the system design, with tunable 16-channel OLT, where it can handle a greater bandwidth and a high-capacity network.

Thus, this paper is proposed to support a larger bandwidth and handle a great number of users in one system design at a lower loss. It is proven that WDM can increase the capacity of the existing FTTH network, thus it will be added alongside TDM. Moreover, this paper will introduce a design with a higher capability to handle high traffic. Both TDM and WDM designs will be combined to form an economic network with high capacity. It is simulated using OptiSystem software which is well-known for its capability to simulate almost all types of optical links [25].

2. METHOD

This TDM WDM-PON is designed and simulated using OptiSystem software. The current wavelength for the current FTTH technology, which employs TDM-PON, is 1,490 nm for downstream and 1,310 nm upstream. For the WDM-PON system, a new wavelength plan is proposed. The selected wavelength is based on the C and L band's 100 GHz spacing. The C-band is used for upstream signals between 1,530.334 and 1,542.142 nm, while the L-band is used for downstream signals between 1,569.865 and 1,581.973 nm. That value was selected because the current 10G/G/EPON network does not conflict with it.

The proposed design of TDM WDM-PON is shown in Figure 2. The WDM-PON system is integrated into this concept and its components are represented by the orange-colored blocks in Figure 2. Next, the WDM multiplexer and demultiplexer are applied based on the wavelength plan. The function of the WDM multiplexer and demultiplexer is to multiplex and route the downstream wavelengths from the OLT, and to demultiplex the designated subscribers. Meanwhile, for upstream signals, another multiplexer and demultiplexer will multiplex the signals from the ONUs and route them back to the OLT. In this case, each port is defined with wavelengths for downstream and upstream signals, respectively. It is decided that the transmitter will be set at 5 dBm for both upstream and downstream fiber laser at both OLT and ONU.

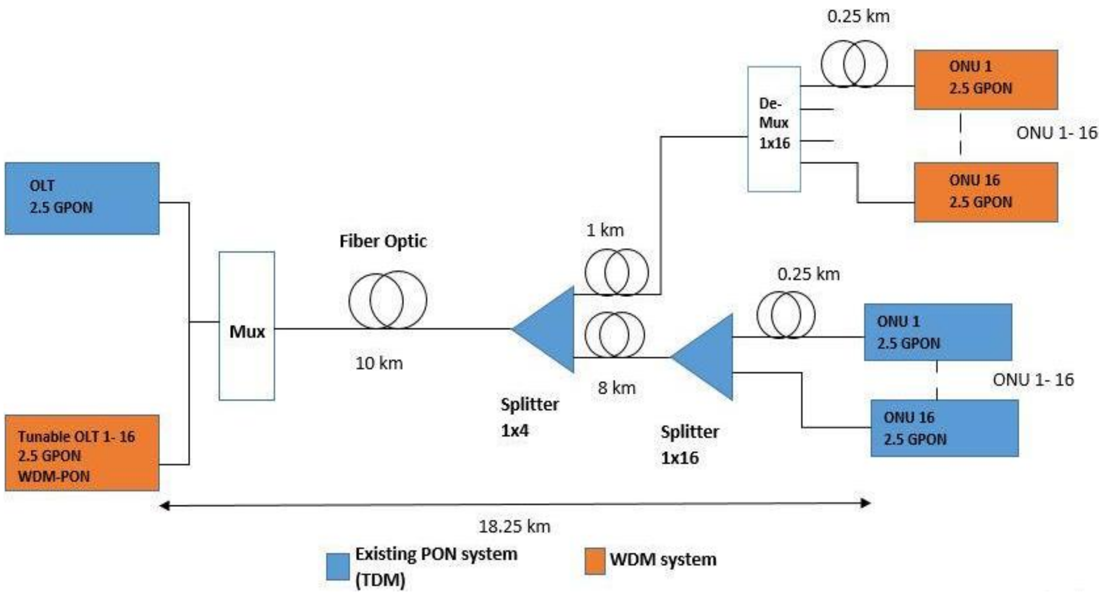

Figure 2. Proposed sharing concept with existing PON infrastructure

Next, the proposed design is modeled using the OptiSystem simulation for verification. Figure 2 shows the proposed sharing concept of TDM WDM-PON. In this design, the existing TDM-PON is combined with WDM-PON. At the central office, the existing OLT is integrated with TDM and WDM standards. The TDM downstream signal of 1,490 nm is multiplexed with WDM downstream signals ranging from 1,569.865 to 1,581.973 nm. The downstream signals will pass through the feeder fiber with a fiber length of 10 km. For TDM PON, a 1×4 power splitter will split the downstream signal to a 1×16 splitter before it reaches the ONU. In the existing network, a 1×8 or 1×16 is used for TDM-PON. By employing the WDM concept in this network, a demultiplexer of 1×8 or 1×16 will be used to replace the use of a power splitter. Employing a demultiplexer in the network will reduce the total loss as a demultiplexer has lower insertion loss as compared to a power splitter. The maximum length for this network is fixed at 20 km.

3. RESULTS AND DISCUSSION

In this part, a detailed analysis of the simulated design is conducted. For 32 users, it can be seen in Figure 3 that the laser signals are received and traveled through a multiplexer, splitter, and demultiplexer. The signal successfully arrived at the OLT. The same goes for a downstream architecture where the laser signals successfully reach ONU as in Figure 4.

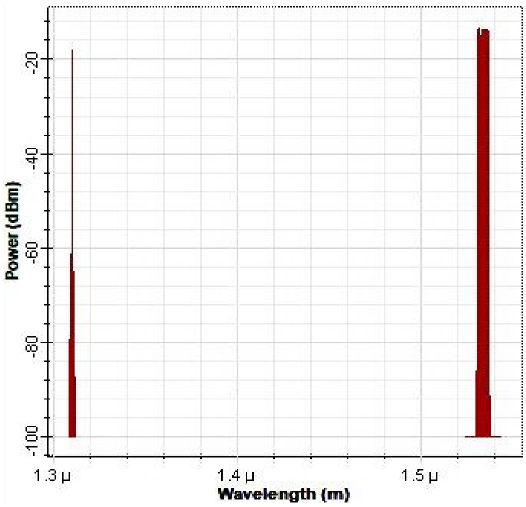

Figure 3. Upstream signal at OLT with 1,310 nm for TDM and 1,530.334 to 1,536.088 nm for WDM

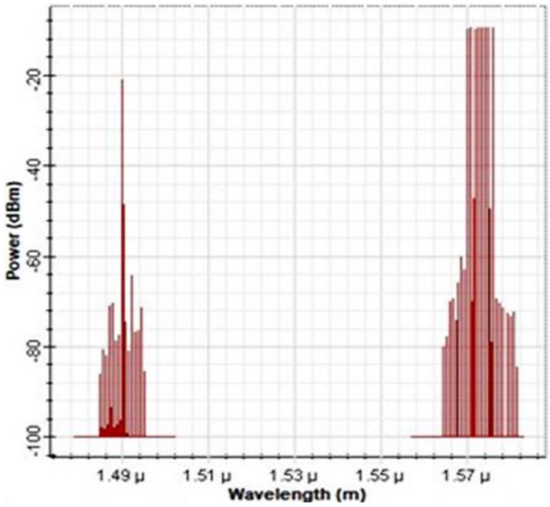

Figure 4. Downstream signal at ONU with 1,490 nm for TDM and 1,569.865 to 1,575.619 nm for WDM

As displayed in Figure 5, for 8 wavelength channels, the power received at ONU for both WDM and TDM are -4.3700277 dBm and -18.862161 dBm, respectively. Meanwhile, for OLT, both WDM and TDM received a power of -8.0446148 dBm and -18.643456 dBm. As for 16 wavelength channels, the power received at ONU for both WDM and TDM is -4.3700318 dBm and -22.249513 dBm. Meanwhile, for OLT, both WDM and TDM received a power of -8.0446148 dBm and -21.653756 dBm. As the number of channels increased, the received power at each OLT and ONU terminals decreased due to higher losses mostly produced by the splitter, especially for TDM PON.

As depicted in Figure 5, the received power for downstream signals decreases as the number of ONUs increases. The splitter causes the loss as it splits into more channels to deliver the signal. Theoretically, the higher the splitting ratio of the splitter, the higher the insertion loss. Basically, this network is able to support up to 64 ONUs and the power received is -27.2 dBm which is higher than the ONU sensitivity which is -28 dBm for TDM PON. For WDM-PON, it is found that the power received at the ONU is almost constant as it uses a mux/demultiplexer to replace the optical splitter. Thus, by incorporating WDM-PON into TDM PON, the constraints due to optical losses are not the issue.

Figure 6 shows the power received from upstream signals for TDM and WDM-PON. Again, the power received for TDM PON is decreased due to the losses mainly from the optical splitter. However, for WDM-PON, a very slight loss is suffered only due to the optical fiber loss which is 0.2 dB/km. The OLT sensitivity for TDM PON is -28 dBm. Thus, this network is capable to be used for up to 64 ONUs as the power received for 64 ONUs is only -24.8 dBm.

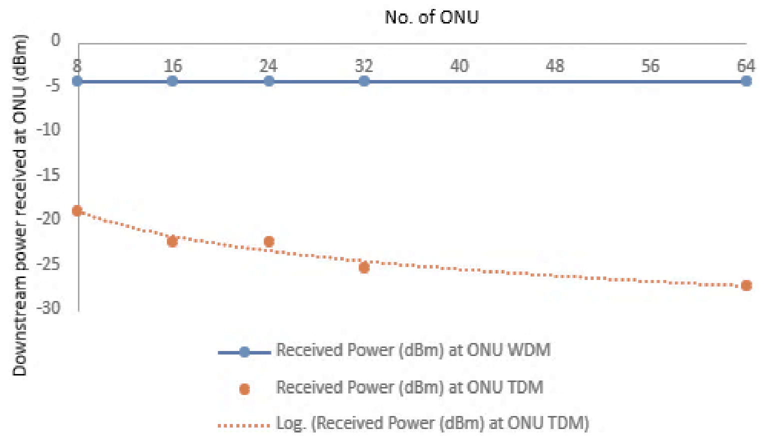

Figure 5. Graph of downstream received power at ONU versus number of ONU

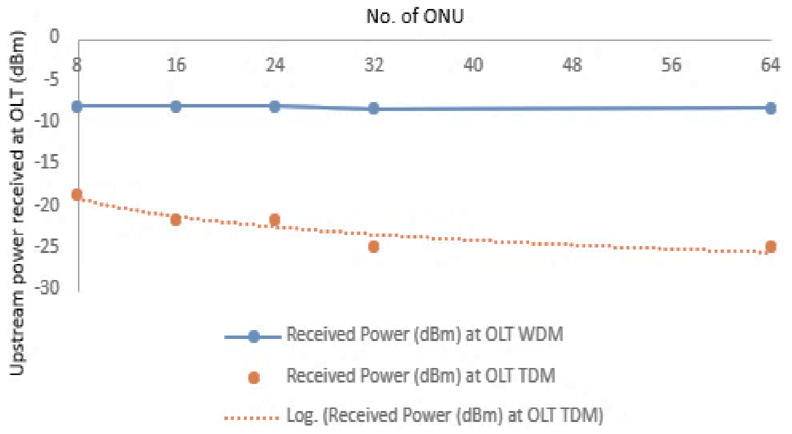

Figure 6. Graph of upstream received power at OLT

Figure 7 shows the power received from the downstream and upstream signals for various numbers of ONUs. It can be clearly perceived that the power decrease is very low at WDM-PON as it uses a mux/demultiplexer which will produce a very low loss. In contrast to TDM-PON, it uses an optical splitter which will produce higher losses as compared to mux/demultiplexer.

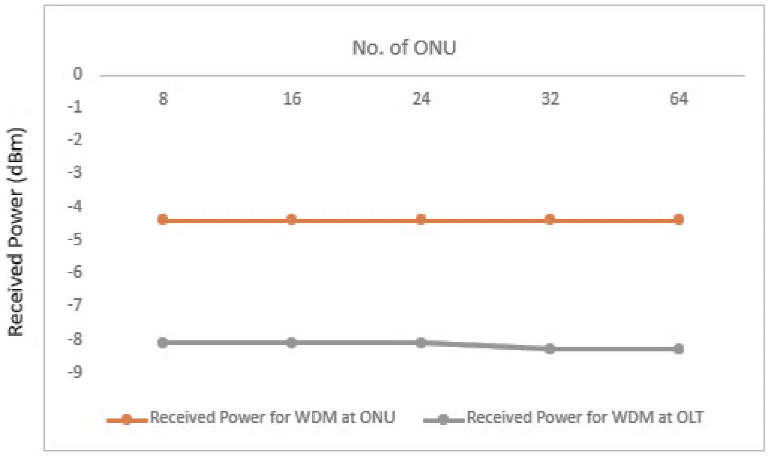

Figure 7. Graph of downstream and upstream received power for WDM-PON at ONU and OLT

4. CONCLUSION

In conclusion, this project has successfully demonstrated the design of TDM WDM-PON which can be implemented for the current use of PONs. The design has been simulated using OptiSystem software and the result has been analyzed. It is found that the integration of TDM and WDM-PON can support up to 64 customers with a bit rate of 2.5 Gbps.

ACKNOWLEDGMENT

The author wishes to thank Universiti Teknologi MARA (UiTM) under internal research grant 600- RMC/GPK 5/3 (101/2020) for supporting this project.

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