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RESEARCH ARTICLE

Analysis on multiple optical line terminal passive optical network based open access network

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Abstract Passive optical networks (PONs) offer sufficient bandwidth to transfer huge amount having different packet sizes and data rates being generated by fusion of various networks. Additionally, multiple optical line terminals (OLTs) PONs reduce the computational complexity of data processing for nonuniform traffic. However, in order to improve the bandwidth allocation efficiency of a mixture of service providers, dynamic bandwidth algorithm (DBA) is needed for uplink communication. In this paper, a PON based open access network (OAN) is analyzed for bi-directional communication at various data rates. Multiple wavelengths are used to modulate the data of various service providers to evade the complicated DBA for uplink data broadcasting. The performance of the network is reported in terms of bandwidth exploitation, uplink effectiveness, overhead-to-data ratio and time cycle duration. The network is analyzed at various data rates to reveal the data accommodation capacity.

Keywords passive optical network (PON), open access network (OAN), optical line terminal (OLT), hybrid network

1 Introduction

A fusion of networks where various service donors can use the network simultaneously is known as an open access network (OAN). The OAN unfasten the every service supplier locally or remotely and offer various services to the consumers. The service suppliers offer diverse services and the consumers can pick the required service [1,2]. As the numbers of service providers will rise soon, there is an utmost need of a backhaul network with huge bandwidth. Also in hybrid networks a central office grants self-regulating connection to the various networks and service suppliers. Usually, an OAN offers a self-regulating connection between a central office and various service suppliers. Although, an ordinary access network and every service supplier can unite to the access network by a single access terminal [3]. The passive optical network (PON) is the accepted access network technology for OAN, due to higher bandwidth availability [4] at lower cost [5]. In PON-OAN, the OLTs of PON serve as a central office and optical network units (ONUs) act as access terminals of OAN to share all the service suppliers. PONs have high bandwidth which make them capable to support the present and future demands of recently deployed multiple operators in densely populated cities. To a connect number of service suppliers, single-OLT PON is not an efficient method due to heavy traffic burden. Further, such systems reduce the data processing computational complexity for non-uniform data traffic. Therefore, multiple-OLT PON is a good contender to overcome the problems of single-OLT PON-based OAN. In conventional multiple-OLT PON based hybrid networks [6,7], every ONU connected to the single service supplier under-utilizes optical network bandwidth. Therefore, a dynamic bandwidth allocation scheme is required for uplink communication to enhance the bandwidth utilization efficiency. Hence, some modifications are needed in conventional multiple-OLT PON based hybrid network to effectively utilization the on hand bandwidth. In this manuscript, an analysis is done for multiple-OLT multiple-wavelength PON based OAN. A dedicated wavelength is provided to individual service supplier to avoid the requirement of complex dynamic bandwidth algorithm (DBA) in uplink broadcasting of multiple service suppliers, such as HDTV, femto-networks, WSN and FTTH. In this scheme, each OLT separately handles the incoming data of every service

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supplier and uplink data of every service supplier is modulated with dedicated wavelength. The analysis for this scheme is performed in terms of uplink efficiency, time cycle duration, bandwidth exploitation and overhead-to-data ratio for non-uniform traffic.

The remaining manuscript is organized in four sections. The related work is presented in Section 2, followed by architecture of multiple-OLT multiple-wavelength PON based OAN in Section 3. The investigations for the network are carried out in Section 4. Finally, the manuscript is concluded in Section 5.

2 Related work

In literature sundry algorithms have been interpreted by numerous researchers such as interleaved-poling algorithm [8], multi-threaded scheduling algorithm [9], wavelength-scheduling-polling algorithm in the finish time with void filling (EFT-VF) [10], single tread scheduling algorithm for grant sizing [11], elementary grant sizing scheme [12], online-interleaved-polling and offline multi-thread polling algorithms [13] of long reach passive optical networks (LR-PONs), modified-latency sync (LS)-bandwidth allotment scheme for multi-OLTs [14]. The multi-threaded scheduling algorithm is appropriate for fusion of hybrid wavelength divison multiplexed – time divison multiplexed – passive optical network (WDM-TDM-PON) where multiple wavelengths are used to transfer multiple signals at the same instance. The system reduces the transmission delay by interleaved polling algorithm. Further, the EFT-VF reduces the packet transmission time with less complexity as compared to the wavelength scheduling technique. The analysis for single thread scheduling algorithm with grant sizing has been presented in Ref. [11], where bandwidth demand is determined by OLT without discriminating the diverse service suppliers. Further, an analytical analysis published in Ref. [13] shows a comparison for multi-thread offline algorithm and online interleaved polling scheme. The results reveal that multi-thread polling scheme is better than the online interleaved polling in terms of communication delay and throughput for LR-PON. Further, an analytical model for interleaved polling with adaptive cycle time (IPACT) is demonstrated in Ref. [15] for fixed packet length with Poisson distribution which makes it a further sophisticated system.

The uplink communication using modified-LS-bandwidth allocation approach has been introduced in Ref. [14] for multiple OLT system. This bandwidth scheme reduces the bandwidth usage of every OLT for real-time traffic. In this modified scheme, unutilized bandwidth is shared between OLTs when a specific service supplier suffers from heavy traffic load. In case of OLT failure, shared bandwidth approach can be a good alternative [16]. The analysis for multi-OLT-PON based hybrid network reported by Refs. [6,7] incorporates new DBA for single wavelength and each ONU is connected to a dedicated service provider. Further, a correlation of multi-OLT multi-wavelength system with single-OLT single-wavelength system with online interleaved polling scheme discussed in Ref. [17]. This scheme is useful to reduce the information processing complexity in resemblance to the conventional OLT based PON incorporating different maximum transmission windows for each service supplier. Earlier, the authors of Ref. [18] have thrown light on a new ethernet passive optical network (EPON) grant scheduling technique known as shortest propagation delay (SPD). The analytical results revealed that the proposed technique minimizes the grant cycle length while elevating the channel utilization. The finding of this research indicates significant improvement in channel utilaztion when EPON contains some ONUs near to OLT as well asfar away to OLT.

In this paper, an analysis for multi-OLT multi-wavelength PON based OAN [17] has been done for diverse service rates. The system is analyzed in terms of bandwidth exploitation, overhead-to-data ratio, uplink efficiency and timing cycle durations. In this system, M-number of service providers are connected with single ONU. The information from each service provider modulated with different wavelengths for granting instantaneous uplink transmission. Every service supplier uses different wavelengths and transmission windows, thus expelling the requirement of wavelength scheduling. The evaluation of different data rates has been carried out for non-uniform traffic and inconsistent cycle time span.

3 System architecture

The architecture for convergence of multi-OLT multi-wavelength PON with OAN is shown in Fig. 1. The number of OLTs depends on the number of service supplier used established OANs. In this arrangement, four OLTs have been used to connect four service providers such as WSN, FTTH, HDTV and femto networks that are part of OAN. The OLT1 is associated with WSN, OLT2 for FTTH, OLT3 for HDTV, and OLT4 is dedicated to femto network as per Ref. [17].

As a dedicated OLT is allocated to a specific service supplier, so it does not take care of the data packets arriving from other supplier. Therefore, during uplink transmission each ONU is representating a different service supplier as shown in Fig. 1. Figure 1 is drawn for two OLTs and two service suppliers for simplicity; but, in actual system four OLT and four wavelengths for four service suppliers are considered for evaluation purpose. However, the number of OLTs and uplink wavelengths may alter according to number of service providers. This multi-OLT multi-wavelength approach reduces the data handling complexity. To offer synchronization among

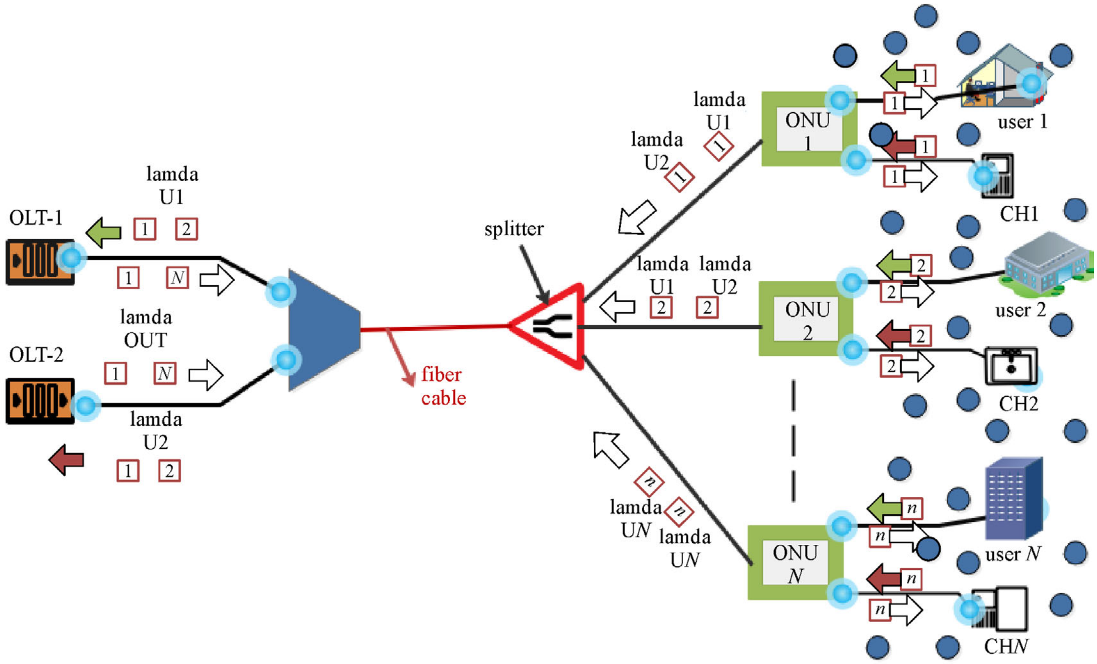

Fig. 1 Architecture for multi-OLT multi-wavelength PON based OAN

multi-OLT, shared polling table has been utilized in this work and to enlarge the range of PON, an array waveguide grating (AWG) is used. The power splitter and AWG is used to disburse the data packets of specific service supplier to its associated OLT. In downstream transmission, multi-point control protocol is used to transmit the OLTs data to ONUs. As multi-point control protocol is a dynamic bandwidth allocation scheme, it provides the multiple transmission windows to several ONUs. This protocol provides time based synchronization and is supportive to estimate the round trip time (RTT). The RTT depends on the fiber length used to connect the OLT and ONU. The maximum cycle time is uniformly shared to ONUs, therefore maximum window size $W_{\max} = T_{\text{cycle}}/N$, where T_{cycle} is time cycle, N is number of ONUs [17].

Figure 1 illustrates the uplink modulation process of data packets from service provider. Each service provider modulated with different wavelengths and transmitted at individual time slots as each service supplier produce data packet of different size. The complexity scale of such converged systems depend upon number of service providers and number of OLTs. This model has been designed by using mathematical formulation cited by Ref. [17] and based on few assumptions. However, this model has reduced the complexity of PON based OAN converged system as reported in Ref. [17]. The complexity of such system increases with increase in number of ONUs which depends on number of service providers. Further, more number of ONUs will also vary the transmission window, bandwith utilization, overhead-to-data ratio, uplink efficiency and increase chances for inaccurate data detection. As these types of networks are generally deployed for cities, it is essential to analyze the performance of system with varied length of fiber cable which is considered as a few kilometers in this paper. The system response is based on six trials for all the performance parameters. However, number of trails can be increased depending upon complexity of system. The timing diagram for uplink and downlink transmission is illustrated in Fig. 2.

The $W_{\max}$ is prone to incoming data traffic of individual service supplier modulated with different wavelengths. In this scheme, each service supplier data includes same ethernet overhead but different report messages. For uplink broadcasting, the four service providers such as WSN, FTTH, HDTV, and femtonetwork are pigeonholed as Group-I and Group-II on the basis of packet length. The Group-I include WSN and HDTV whereas Group-II contains FTTH and femto network. As the transmission window depends upon the number of ONUs and data packet length, the maximum transmission window for Group-II is lager than Group-I [17]. Hence, the maximum granted window can be described as

$$W_{i,j}^{\text{grantmax}} = \begin{cases} W^{\max 1}, \\ W^{\max 2}, \end{cases}$$

$W^{\max 1}$ and $W^{\max 2}$ serve as the transmission window for Group-I and Group-II respectively whereas $W_{i,j}^{\text{grantmax}}$ is the maximum allocated transmission window for ONU$_i$ in time slot j for specific group of services. As the granted transmission windows of ONUs have variations due to dynamic bandwidth allocation, T_{cycle} varies at every

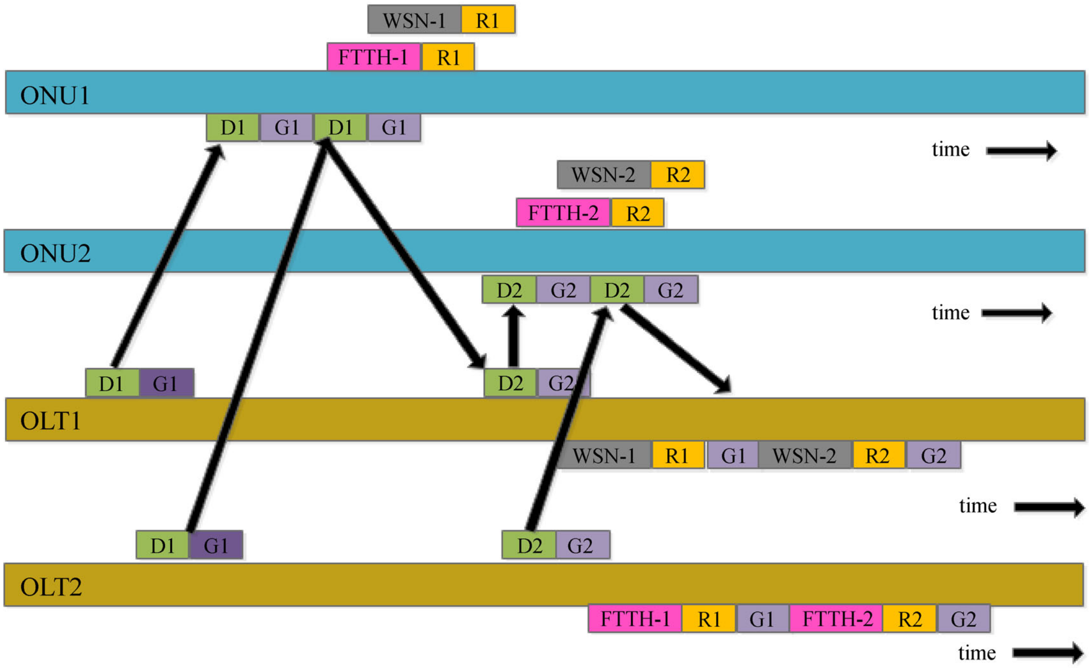

Fig. 2 Timing diagram for multi-OLT multi-wavelength PON based OAN

instance. Therefore, T_{cycle} calculations are crucial to define the cycle duration in dynamic bandwidth allocation scheme. The relationship for T_{cycle} for time cycle j is given as [17]

$$T_{\text{cycle},j} = \sum_{x}^{N} W_{x,j}^{\text{grant}},$$

where x is an integer varied from 1, 2, 3,…,N.

4 Performance evaluations

In this section, computer-based simulation results for multiple-OLT with multiple-wavelength PON-OAN as shown in Fig. 1 are presented. To evolve the system, the behavior for bandwidth exploitation, time cycle duration, efficiency for uplink and overhead-to-data ratio is reported.

The performance of multi-OLT multi-wavelength PON-OAN converged network has been reported for different service supplier. These service supplier are randomly connected with ONUs and have dynamic behaivour. In this manuscript, the service supplier are categorized in two groups, FTTH and WSN are placed in Group-I having packet size of 1024 bytes whereas 1500 bytes packet size is allocated to Group-II composed of HDTV and femtonetwork [17]. During uplink transmission, individual service provider need a different transmission window for successful data broadcasting as the size of transmission window depends upon data packet length and number of service providers. As the data packet length and number of ONUs increases, transmission window increases. In this setup, distance between OLT and ONUs is considered as 10–20 km whereas the number of ONUs varied from 3 to 18. The analysis of the proposed system is reported at various time cycle (varied from 0.5 – 3 μs) at a constant interval. During computer based simulative analysis of the proposed system, it is assumed that all data packets generated by various service provider (WSN, HDTV, FTTH and femto network) have same priority. In this analysis, first cum first severed (FCFS) scheme has been adopted for simplicity. In near future, other schemes such as the packet with different priorities last in first out and round robin can be analyzed for monitoring the performance of proposed system. The various symbol and parameters used in this manuscript are tabulated in Table 1. The data processing time depends on the number of ONUs and service suppliers. The time cycle varied at a constant interval as it depends upon the ethernet overhead, the data transfer speed, report message length, processing time and guard time.

Figure 3 shows deviation in time cycle at various data packet rates. It has been analyzed from the outcomes that time cycle increases as data rate elevated due to augmentation of data in such converged PON based OANs. It has also been examined that as the ONUs are increased the time cycle duration is almost same at different data rate. Therefore, time cycle for more number of ONUs becomes almost constant even at higher data rates.

The bandwidth exploitation has been examined on the

Table 1 Symbol and parameters

symbol	parameter	value
N_{OLT}	number of OLT	4
n	number of ONUs	3 – 8
T_{cycle}	time cycle (μs)	variable
PL_k (Group-I and II)	packet length (bytes)	1500 and 1024
B	data transmission speed (Gpbs)	0.25, 0.5, 1
W_k^{grant}	maximum transmission window	variable
fiber length		10 – 20 km

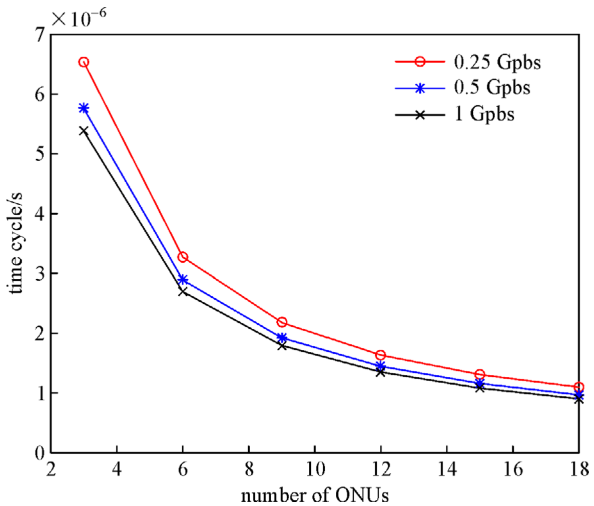

Fig. 3 Time cycle variation with number of ONUs

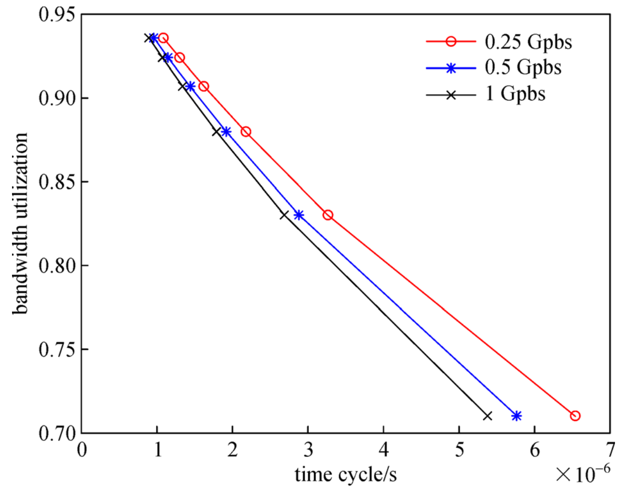

Fig. 4 Bandwidth exploitation at various data transmission speed

basis of equation given below by incorporating bandwidth sharing scheme as reported in Ref. [17]:

$$\mathrm{BU} = \frac{n\sum_{k=1}^{m} W_k^{\mathrm{grant}}}{n\sum_{k=1}^{m} W_k^{\mathrm{grant}} + T_{\mathrm{cycle}}}.$$

The bandwidth utilization (BU) is reported at data rate of 0.25, 0.5 and 1 Gbps as shown in Fig. 4. It is observed that the bandwidth utilization of such converged network decreases as time cycle duration increases. It has been reported on the basis of simulation results that time cycle increasing for lower data rate. It is due to the fact that at lower data transmission speed such converged system may underutilize the bandwidth of optical fiber cable as bandwidth utilization almost remain same at higher data rate.

Here, it is necessary to introduce uplink efficiency (UE) of proposed converged system as data traffic depends on number of ONUs and service providers. The uplink efficiency is the ratio of successful data transmission to total traffic produced by OAN. The expression for uplink efficiency for multi-OLT and multi-wavelength is given as [17]

$$\mathrm{UE} = \frac{n\sum_{k=1}^{m} W_k^{\mathrm{grant}}}{n\sum_{k=1}^{m} \mathrm{PL}_k B + nT_{\mathrm{cycle}}}.$$

Figure 5 illustrates the uplink efficiency at 0.25, 0.5 and 1 Gbps data rate vs. time cycle. It has been examined that the data processing speed of such converged sytem reduced at higher data rate.

The uplink efficiency are quite similar to bandwidth utilization as maximum channel bandwidth is exposed during uplink data transmission. This shows the scope of more data accommodation at lesser time cycle for proposed converged PON based OAN.

Another, important parameter to analyze the behavior of such a network is overhead-to-data ratio as it provides information regarding quality of services (QoS). It has been reported ealier that a converged PON based OAN has good QoS at the lower value of overhead-to-data ratio. The overhead-to-data ratio (ODR) is calculated as [17]

$$\mathrm{ODR} = \frac{nT_{\mathrm{cycle}}}{n\sum_{k=1}^{m} \mathrm{PL}_k B}.$$

The outcomes shown in Fig. 6 divulge that as the data

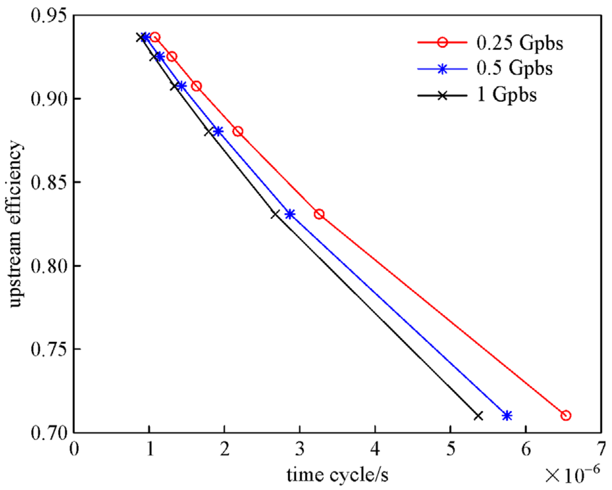

Fig. 5 Uplink efficiency at various data transmission speed

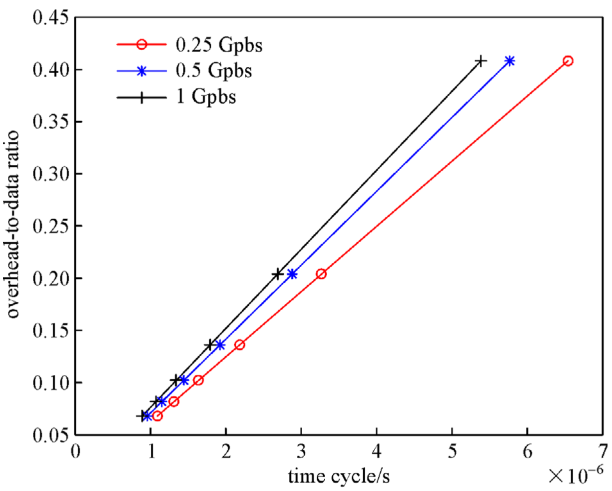

Fig. 6 Overhead-to-data ratio at different data rates

rate increases the overhead-to-data ratio of the scheme increases as time cycle increases, which shows that PON based OAN system has better QoS for shorter time cycle duration.

It has also been revealed from computer-based simulation that of such type of system are more effective at higher data rates as overhead-to-data ratio is bit lower at higher data rate as compared to lesser data rate. Hence, it supposed that this system can handle a massive amount of data and adjust more number of service providers with good QoS at higher data rates.

5 Conclusion

In this paper, the performance analysis for multiple-OLT multiple-wavelength PON based OAN has been performed. The system performance is evaluated in terms of time cycle variation with number of ONUs, bandwidth exploitation, uplink efficiency, and overhead-to-data ratio at various data transmission rates for 18 ONUs in the network. The results reveal that at higher data transmission rate more service providers can be accommodated by PON based OAN. The overhead-to-data ratio sets the guideline to ensure the quality of service offered by such networks. Further, an analysis reported for non-uniform traffic with variable time cycle durations. Lastly, it is observed that the multiple-OLT multiple-wavelength PON based OAN can efficiently share the bandwidth of different optical networks for a number of service suppliers with reduced computational complexity and minimal data processing.

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