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# Bidirectional Transmission in TWDM Optical Access Network with Tunable Wavelength ONU

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In this paper, a novel configuration for bidirectional hybrid time and wavelength division multiplexing (TWDM) optical access network is presented that fulfills the growing broadband requirements of next generation 5G customers. A purely passive system module is suggested for 512 subscribers that can communicate at a line rate of 240 Gbps in downlink and 160 Gbps in uplink over the common fiber cable. Shared network infrastructure helps in amortization of the installation and recurring operational expenses. Subscriber optical network unit (ONU) consists of tunable wavelength transmitter that can adjust uplink channel on the instructions of the medium access control layer (MAC). Improved Bandwidth Optimization Hybrid Scheduling Algorithm (BOHSA1) is implemented in the network to reduce the wastage of time slots per channel that helps in improving the channel utilization. The demonstrated architecture is extensively investigated to know the impact of diverse encoding scheme; photo-detector and electric filter have on the network performance.

**Keywords:** Bandwidth Allocation, BOHSA, Channel Utilization, Scheduling

## Introduction

Recently, data carrying ability of the internet and associated services has noticed a exponential growth owing to the innovation in optical fiber technology. Modernization of infrastructural required for such services started from backbone networks till the metropolitan area networks. On the other hand, access network which interconnects end user with the backbone network has not seen the same level of progression in channel bandwidth. This is because of the cost dynamics as backbone network carries information signals of large number of users but access networks provides services to few hundred of customers.[1]

Optical access systems can be configured either with Active optical networks (AONs) or Passive optical networks (PONs). AONs operate using active elements such as power driven Ethernet switches while PON works through passive components like power splitters. Passive components has negligible power requirement making the networks employing them economical and energy efficient. Thus in terms of revenue dynamics PON is more cost effective than AON.

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In PON systems, the user is connected in a multipoint to point topology in uplink and point to multipoint configuration in downlink direction. In the downlink, the information frames are communicated from the optical line terminal (OLT) positioned in the central office (CO) of service provider to various associated optical network units (ONUs).

Shared transmission medium with passive components reduces the installation cost and recurring expenses.[2] In uplink direction, common transmission channel is shared by the entire ONUs with the help of power splitter/combiner. Upstream traffic is quite bursty because of which required slots on the transmission channel generally vary. Static allocation of bandwidth resources is not effective, so dynamic bandwidth allocation algorithm plays a crucial role in improving the access system performance.[3,4]

PONs are initially designed using the technique of Time Division Multiplexing (TDM) referred as TDM-PONs that broadcasts message frames on a common channel in a prescribed time period. Another alternate to TDM-PONs are based on Wavelength Division Multiplexing WDM-PONs and Hybrid TDM-WDM (TWDM) technique.[5,6] With ever increasing multimedia information exchange, TWDM-PON is considered to be the best solution for future 5G access systems. Next generation access systems (NGANs) requires designing novel network architectures that can achieve a cumulative line rate of 128 Gbps to 500 Gbps, covers a minimum distance of 40 Km for providing services to more than 1024 connected nodes.[6–10]

In literature, next generation passive optical network (XGPON) architectures are suggested with components in varying configuration employing bandwidth allocation schemes, finding optimum network model is a challenge. Researchers[2] proposed next-generation passive optical system for a network data rate of 10 Gbps using Return to Zero (RZ) and Non-Return to Zero (NRZ) modulation formats. In the study by Kaur *et al*.[4] the authors employed Electro absorption modulator (EAM) as external modulator for transferring information signals on four channels at a line rate of 10 Gbps in an optical access network. Optical access network architecture for different system filters namely Butterworth filter, Chebyshev filter & Bessel filter was analyzed.[8] Authors[5], proposed an effective technique Bandwidth Optimization Hybrid Scheduling Algorithm (BOHSA) mechanism for hybrid WDM/TDM passive optical network which grants time slots on uplink channel with shortest span that increases the quality of the communication network for 100 users.

Till now, it is observed that different network parameters and choice of system components of influence the performance of optical access network. TWDM based optical access networks were designed and tested separately at the transmitter end either for diverse modulation formats, use of external modulator and choice of electric filter. Bandwidth allocation mechanism plays an important role in improving the performance of the access networks. It is noticed that the system architectures were investigated in terms of any one component/parameter but an all-inclusive study taking into account each component is still required to be done. Also, it is observed that demonstrated network models are limited in terms of network span, line rate, connected number of subscriber ONUs for an optical access network with bidirectional communication through the use of single laser with fixed wavelength.

In this paper, the work presented in literature is expanded by demonstrating a novel bidirectional TWDM optical access network model which is tested in various system configurations to meet the objectives of next generation optical access networks. In the proposed system architecture, subscriber ONUs employs single light source that can adjust their transmission wavelength on the directions of OLT. The system model employs an improved BOHSA (IBOHSA) scheduling mechanism. The presented architecture is investigated in various configurations to suggest an optimum configuration for optical access network which can satisfy the requirements of NGANs. The optimum configuration so concluded in this paper offers higher line rate with increased network span and services to maximum number of subscriber ONUs than what is conveyed in the literature.

The remaining paper is arranged as follows. In section II, novel architecture and the bandwidth allocation scheme is presented. Section III covers the simulation results with their description. In section IV, conclusions are made.

## Architecture

In the proposed TWDM Optical access network 512 far-end subscribers can access information through OLTs stacked in a single Central office (CO) chasis. The presented access system carries information over sixteen downlink wavelength channels using technology of coarse wavelength division multiplexing (CWDM). It operates at a line rate of 15 Gbps in downlink direction and at 10 Gbps in uplink direction per channel over a fiber channel. In the uplink direction, user information signals are transferred on eight channels by employing transmitters with dense wavelength division multiplexing (DWDM) mechanism. ONUs can alter their uplink wavelength on the instructions of OLT through the use of single tunable ONU transmitter, so as to give flexibility in bandwidth allocation. Both the uplink and downlink signals are communicated on the single optical cable. Circulator with an insertion loss of 3 dB is employed with a Bidirectional optical channel. Every transmitter, a Pseudo-Random Data Generator (PRDG) is utilized for generation of data bits which are grouped into frames. Two analog signal generators (ASG), a summer and a laser is used to generate video component and produced optical signal is passed onto the other input of the multiplexer. The encoded frames are represented as electrical pulses using either Non return to zero (NRZ)/ Return to zero (RZ)/ Manchester modulation formats which are implemented in ASG section. At the receiver side, optical signal is recovered with the help of Avalanche optical detector and sent to electrical filter. The recovered information signal is evaluated using BER spectrum analyzers to perceive on diverse performance parameters like Q factor, Eye diagram.

Architecture of TWDM optical access network with tunable wavelength ONU is shown in Fig. 1. The architecture is evaluated for obtaining the optimum configuration including for modulation formats (NRZ/RZ/Manchester and electrical filter (Bessel filter/Butterworth filter/Gaussian filter/Chebyshev filter) employed at ONU. The demonstrated architecture can transfer data with acceptable quality within a network span of 120 Km.

This architecture employs dynamic bandwidth allocation techniques to share the common fiber channel and is implemented in the Medium Access Control layer (MAC). The presented passive optical system uses improved Bandwidth Optimization Hybrid Scheduling Algorithm (BOHSA1) defined in Singhal *et al*.[5] which calculates the bandwidth for every user and schedules them accordingly.

In improved BOHSA, optical line terminal gets real time communication from connected client optical network unit about their uplink transmission bandwidth requirements ($r_i$) for each scheduling cycle. For grant of available transmission resources, OLT first calculates the minimum secured transmission capacity on a given wavelength ($\lambda_{1,2\ldots n}$) as per following expression[5]

$$T_{min} = \frac{(R - B_{Guard})}{O} \quad \ldots (1)$$

Where R is the rate of communicated frames in Gbps, O (1, 2…N) the number of subscriber ONUs and $B_{Guard}$ is the time gap between two consecutive slots. If the requested timeslots on a particular channel are less than or equal to the $T_{min}$, OLT grants the time slots on a given channel otherwise ONU tunes its wavelength and remaining left over slots are granted on the next available wavelength.

## Results and Discussion

In this section, the results of the proposed system model in diverse configurations are demonstrated. The presented architecture is comprehensively tested in diverse with various encoding schemes, external modulator, Photo-detector and electrical filter. For investigation, Quality factor (Q) and channel utilization is the most regularly used parameter. Q-factor is a preferred parameter instead of Bit Error rate (BER) because for large values of Q-factor above 40 the value of BER is zero.

In Fig 2 (a)–(b), Q Factor vs. Distance plot, measured for the proposed system architecture in different arrangements are displayed. The illustration considers a network span of 70 Km to 120 Km for the analysis. It is observed that with the increase in distance, the Q factor decreases. A comparative

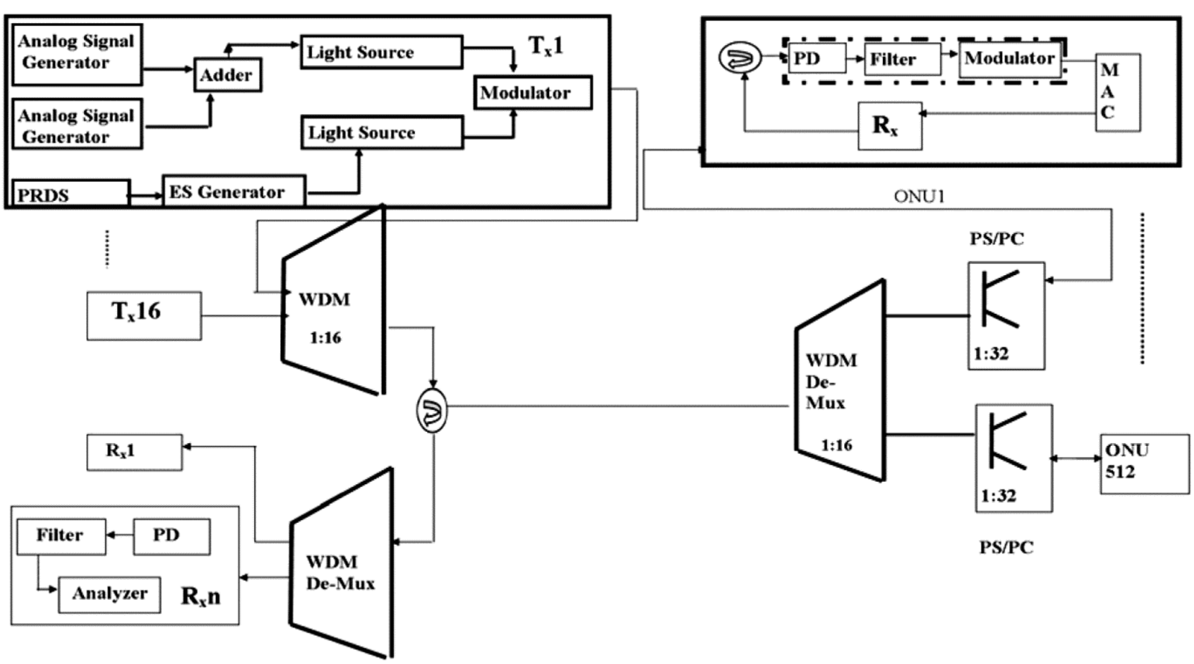


Fig 1 — Architecture of TWDM optical access network with tunable wavelength ONU

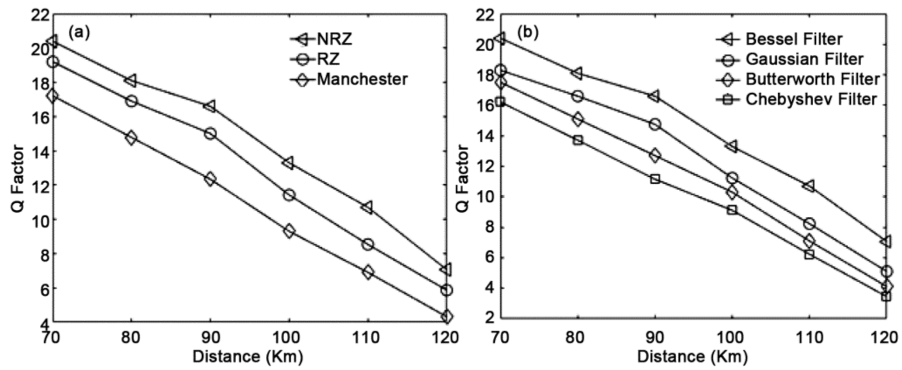


Fig 2 — Q factor plots vs. distance in (a) encoding schemes, (b) electrical filter

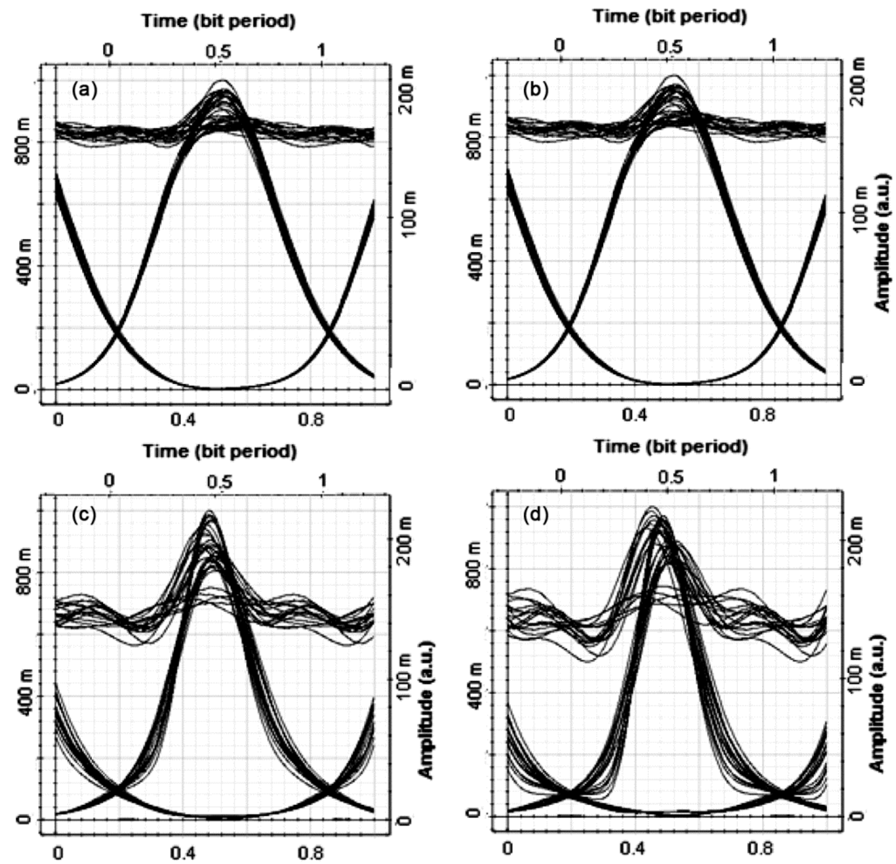


Fig. 3 — Eye diagram of the proposed system architecture at (a) 30 Km, (b) 60 Km, (c) 90 Km, (d) 120 Km

analysis of encoding scheme, NRZ, RZ and Manchester Modulation format are shown Fig. 2 (a). It is noticed that NRZ encoding gives higher Q factor than others.

Four electrical filters namely Gaussian Filter, Chebyshev Filter, Bessel Filter and Butterworth Filter are evaluated for transmission of multimedia streams in Fig 2. From the Fig. 2(b) it is noted that the Bessel Filter outperforms all other electrical filters and gives the best results. It is evident that Bidirectional system model with tunable receiver at ONU works well when at transmitter side NRZ modulation format. Also, Bessel electric filter at the receiver circuit, the system performs to the optimum level.

Eye diagram of the proposed system architecture at (a) 30 Km (b) 60 Km (c) 90 Km, (d) 120 Km are given in Fig. 3. The eye diagram of the proposed optical access network model measured at a distance of 30 Km, 60 Km, 90 Km and 120 Km respectively are depicted in Fig. 3 (a)–(d). It is evident that the

Table 1 — Channel Utilization vs. No. of Users

| No. of Users | Channel Utilization (BOSCH) | Channel Utilization (IBOSCH) |
|---|---|---|
| 50 | 0.99151 | 0.99273 |
| 60 | 0.99193 | 0.99317 |
| 70 | 0.99245 | 0.99362 |
| 80 | 0.99318 | 0.99407 |
| 90 | 0.99343 | 0.99472 |
| 100 | 0.99396 | 0.99498 |

information is received with an acceptable level up-to 120 Km and beyond this the system performance degrades. The demonstrated system architecture give optimum output when configured with NRZ as an encoding scheme and Bessel filter at the receiver module.

The comparative analysis of the improved bandwidth allocation and scheduling mechanism implemented in the proposed model (BOHSA1) with BOHSA are shown in Table 1. Channe l Utilization (CU) is used for analysis which can be termed as utilization of available transmission resources in percentage. It is witnessed that BOHSA1 achieves better channel utilization because overlapping time slots is avoided in various transmission channels in the improved scheduling scheme utilized in the present system model.

## Conclusions

In this paper, a novel architecture of bidirectional TWDM passive optical network with tunable ONU is presented which can communicate for subscribers stationed at a distance of 120 Km from the transmitter. The bandwidth sharing is optimized using IBOHSA which allocates time slots per wavelength for every customer. It helps in improving channel utilization of the access system by avoiding the wastage of time slots. It is observed that the information signal is recovered with an acceptable quality when optical access network is configured with NRZ encoding scheme. Further, Bessel filter is the best choice for photo-detector and electrical filter respectively for configuring improved line rate with reach extended access system. The achieved result is a valid indicator for enhanced performance and an optimal choice that converges with the features of next generation access networks and 5G communication networks.

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