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Investigation of bandwidth optimization hybrid scheduling algorithm for hybrid WDM/TDM passive optical system

Ankur Singhal[a], Amit Gupta[a]*, Charanjeet Singh[b] & R S Kaler[c]

[a]Electronics & Communication Engineering Department, I K G Punjab Technical University, Jalandhar 144 603, India

[b]School of Electronics & Electrical Engineering, Lovely Professional University, Jalandhar 144 411, India

[c]Electronics & Communication Engineering Department, Thapar University, Patiala 147 001, India

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Hybrid WDM/TDM optical access network has evolved as a cost-effective solution to the higher requirements of bandwidth in the access network. Bandwidth allocation and scheduling mechanism have become critical issues in the optical access networks. In this paper, a novel upstream bandwidth optimization hybrid scheduling algorithm has been proposed in which optical network units can employ tunable wavelength for upstream transmission with a single optical source. Resources allocations have been done utilizing multi point control protocol and for wavelength scheduling the shortest length of channels have been computed. Investigation of the proposed algorithm for providing improved channel utilization has been performed and a comparative analysis has been done for validation.

Keywords: Bandwidth allocation, Channel scheduling, Channel utilization, Hybrid WDM/TDM optical system, Optical access network

1 Introduction

Passive optical access networks (PON) are considered to be the best solution for optical access networks because of their longer lifespan, economic infrastructure, and enormous data transmission capability[1]. All communication in PON system is carried out between optical line terminal (OLT) and optical network units (ONU) through a shared fiber and power splitter. Usually, OLT is installed in telecom service provider central office (CO) and links subscribers through ONUs to the backbone networks. In the downstream direction, data frames are communicated to various ONUs from OLT. In upstream multiple ONUs competes among them to transfer information packets over the common channel to OLT, so contention resolution is required to avoid collision of packets. To prevent the collision, data signals are combined either using time division multiplexing (TDM) or wavelength division multiplexing (WDM) technique. In TDM based PON, subscribers are assigned unique slots over a single channel by OLT through multi point control protocol (MPCP). MPCP was designed for registration of newer ONUs along with dynamic bandwidth allocation (DBA). Fixed bandwidth assignment techniques do not allocate the available capacity in an efficient manner as the data transmission in the access network is often bursty. Due to this, transmission capacity demands from various subscribers fluctuate with time. So DBA provides an efficient and fair allocation of the available resources among various ONUs in the upstream direction[2].

In WDM system data packets are communicated over a distinct wavelength in upstream direction[2-7]. But if the diverse wavelength channels are shared among subscribers using TDM, such multiplexed network is referred to as hybrid WDM/TDM PON. Hybrid WDM/TDM multiplexing is considered to be the technique for next-generation PON based access networks.

In literature, various algorithms for DBA and scheduling were described. Mcgarry *et al.*[2] had explained the concept of MPCP protocol for bandwidth allocation in TDM PON where numerous ONUs are connected through a common channel to OLT and so contention resolution is required to avoid collision of data transmission from multiple ONUs. The protocol defines two branches of DBA; grant sizing and grant scheduling. Grant sizing decides the size of transmission window and the number of time slots allocated to every ONU while grant scheduling decides in which order ONUs will transmit the data

*Corresponding author (E-mail: amitguptacgc@gmail.com)

over the upstream channel. Grant sizing is further divided into three major classes in which the first type is Gated grant sizing in which grant size is equal to the requested bandwidth by the ONU. This technique improves average packet delay but does not provide the fair allocation to different subscribers. The second type is termed as limited grant sizing in which grant size is decided on the basis of the minimum of either the reported bandwidth requirement or the maximum grant size. In this scheme, every user is provided minimum guaranteed bandwidth. So, this technique helps in providing fair access to users by limiting the grant size and reduces chances of monopolizing the channel by one particular ONU/subscriber. But there are always chances that some users have requirements more or less than the fixed minimum guaranteed bandwidth. The third category of grant sizing is called as limited with access distribution where the unused bandwidth of subscribers is distributed among users whose requirements are more than the allocated bandwidth. Zheng[8] presented an efficient dynamic bandwidth allocation (*n*-DBA) algorithm for TDM PON which allocates excess bandwidth to ONUs having higher capacity demands.

DBA algorithms for WDM PON structures were introduced by Mcgarry*et al.*[9], where multiple wavelength channels are available between ONUs and OLT but every ONU is believed to transmit over fixed wavelength. This mechanism offers low channel utilization which can be improved by transmission over tunable wavelengths instead of fixed channels. Dalamagkas *et al.*[10] presented a novel mechanism for bandwidth allocation based on the concept of game theory. Through this technique capacity of multiple wavelength channels is used to meet the bandwidth demands for carrying a large amount of user data traffic. Singhal *et al.*[11] proposed a novel heavy load optimized dynamic bandwidth allocation algorithm (HLO-DBA) is proposed for WDM/TDM Virtual PONs (VPONs). MPCP protocol of Ethernet passive optical network (EPON) is implemented for WDM/TDM VPONs subscribers transmitting on a fixed wavelength. In this technique, ONUs informs their bandwidth requirements using a separate wavelength to OLT. The excess bandwidth of lightly loaded subscribers is distributed among heavily loaded users through an efficient mechanism. In this type of VPONs statistical multiplexing and sharing between various channels become tough.

Wang *et al.*[12] investigated scheduling schemes in hybrid WDM/TDM VPON having tunable wavelength with an aim of reducing the scheduled length and accommodating all bandwidth demands of customers. The authors proposed a lightweight optimal wavelength sharing (LOWS) scheduling algorithm for the optimum channel utilization. Subscribers can inform their bandwidth requirements using a separate channel. LOWS algorithm computes scheduled length of the channel on the basis of user demands and the grant size is equal to the subscriber bandwidth requirements. If the transmission slots are not available on the assigned wavelength, the ONU can adjust its wavelength as per the instruction of the OLT. This scheme improves the channel utilization but doesn't provide fair access to every subscriber.

In the literature[8], bandwidth allocation scheme is designed for TDM PON, but these types of networks suffer from the problem of latency which can severely degrade the system performance particularly when the information consists of audio and video data. In previous study[9], multiple channels are available for uplink transmission but everysubscriber is assigned a fixed wavelength that leads to decreased channel utilization. HLODBA bandwidth allocation scheme is designed for the WDM/TDM subscribers where MPCP protocol is employed for bandwidth allocation but subscribers are tuned to fixed wavelength[11]. This concept does not provide optimum utilization of the resources. Also, the subscribers inform their bandwidth requirements using a separate channel which can be avoided if the bandwidth requirements can be embedded with the upstream transmission. WDM/TDM users are having tunable wavelength and every user demand is assigned a transmission slot that may lead to the monopoly of the channel and does not guaranty fair access to all the subscribers[12].

To resolve the above problems, a hybrid approach combining MPCP protocol for tunable wavelength users with piggybacking bandwidth demands is presented. A novel bandwidth optimization hybrid scheduling algorithm (BOHSA) algorithm for upstream contention resolution and scheduling of ONUs in a hybrid WDM/TDM access network is proposed. The novel scheme uses MPCP protocol for bandwidth assignment in a network having a single transmitter with tunable wavelength, a case which has not been used comprehensively till now. For grant sizing, the concept of limited with excess distribution is employed where every user has assured minimum bandwidth, also the excess bandwidth slots can be assigned on a separate channel. This improves the chances of fair allocation to every ONU. Here, ONUs are scheduled and granted time slots on a channel having shortest span. Also, the ONUs informs their upstream data requirements using piggybacking by embedding the demands in uplink information transfer that decreases the overhead required for the bandwidth requests[13]. An investigation is performed for periodic scheduling, where every scheduling cycle contains multiple time slots on every channel that may be allocated to various users. For every cycle, a number of slots assigned over every wavelength may be different, because of which algorithm need to compute maximum time slots per wavelength. The objective is to analyze and improve the performance of upstream transmission in the hybrid passive access networks.

2 System Architecture

The system model employed in the investigation of BOHSA is presented in Fig. 1. Here optical network units can place their information signals on different wavelength channels by employing a tunable laser for upstream communication to OLT. Albeit every ONU has tunable channels for transmission but it can't place its data on more than one wavelength at the same time concurrently as ONU has only one optical source. Tunability gives ONU the possibility to transmit on different wavelengths with the condition that there should not be any overlapping between time slots allocated on various wavelength channels. In the system model, 100 subscribers are connected to OLT and multiple wavelengths are available for transmission. OLT on the basis of received REPORT messages containing the instantaneous bandwidth requirements and computes the size of the transmission window. OLT notifies the ONU by sending a GRANT message carrying the start time and the number of time slots along with local clock information for synchronization. At the designated time ONU starts placing its data on the allocated channel time slots. In this model, sixteen wavelength channels are employed for transmission to 100 users. Wavelengths are spaced with a band gap of 0.8 nm as defined by ITU-T.

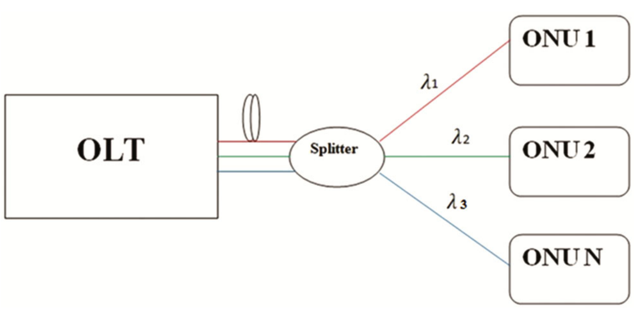


Fig. 1 — Hybrid WDM/TDM PON architecture.

3 Proposed Bandwidth Optimization Hybrid Scheduling Algorithm

In this section, the proposed BOHSA algorithm is presented. In this algorithm for every scheduling cycle, ONUs reports their instantaneous queue sizes (q_i) to the optical line terminal. OLT on the basis of requests received from every ONU allocates the resources through an allocation mechanism and informs the ONU of granted transmission window and the transmission wavelength. The first step in bandwidth allocation is the calculation of minimum assured bandwidth for every user, computed according to Eq. (1).

$$G_{min} = \frac{(\mathrm{T}- L_{Guard})}{N} \quad \ldots (1)$$

where N $(1,2\ldots k)$ is the number of ONUs connected with OLT,T is the total available bandwidth of a particular upstream channel and further bandwidth is divided between various slots say $t(k)$ which are separated by a guard band L_{Guard}. Both the guard band and the slots are part of the bandwidth and have the same unit of nm.

If the demand from the ONU is more than the available bandwidth then the OLT allocates minimum guaranteed bandwidth ($G_{\min}$).

The transmission window will be granted (G_{Grant}(k) to each ONU according to the following relation:

(i) If ONUk requirements are $G_{min} > r(k)$, allocate time slots as demanded by ONUk, $i.e., G_{Grant}$(k)= $r(k)$, where $r(k)$the total is requested bandwidth slots.
(ii) Otherwise, assign minimum guaranteed bandwidth G_{Grant}(k)=G_{min}(k), leftover demands are buffered and can be placed on a different wavelength with the instruction of OLT.

After receiving the information about granted transmission window ONUs transmits data frames as per the allocated channel and time. The scheduling of granted bandwidth on multiple wavelength channels in the upstream direction is performed in which every scheduling cycle comprises a sequence of time slots ($t(k)$) for every channel that is allotted to various ONUs. The available time slots within a channel per scheduling cycle may vary. Every scheduling cycle comprises of different time slots ($t(k)$) allocated from each wavelength/channel. The channel length is denoted as $S_{\text{ch}}(k) = t(k)$,each upstream channel consists of various slots say $t(k)$, so the length of the channel $S_{\text{ch}}(k)$ is equal to no. of time slots per channel. Further, each scheduling cycle consists of available time slots from every available channel.

In this paper, the maximum length of the channel (S) per scheduling cycle is given by Eq. (2).

$$S = max[S_{ch}(\text{k})] = max(\text{t(k)}) \quad \dots (2)$$

The maximum scheduled length has a bearing on the channel utilization which is a very important quality of service (QoS) metric and computed as per Eq. (3).

$$CU = \frac{Q}{F} \quad \dots (3)$$

where Q is the total allocated time slots and F is the total quantity of data slots used, that is the product of the maximum length of the channel (S) and the number of channels (C). So, smaller the length of the channel better is the channel utility.

In the proposed system, ONUs can adjust their wavelength but within the onetime slot, they can transmit only through one channel. Further, ONU can transmit information through other wavelengths if there are no time slots available in a given channel but with a condition that there should be no overlapping of timeslots on multiple wavelengths for the same **o**ptical network unit. The smaller scheduled length ($S_{shortest}$) gives the best channel utilization and it can be obtained by considering two cases:

(i) The first case is if $S < S_{shortest} = \max_{k\epsilon\beta} G_{Grant}(\text{k})$ means if the scheduled length of a channel is less than the optimal scheduled length there will be some overlapping timeslots placed on a different channel for same ONU.

(ii) In the second case, if $S < S_{shortest} = \left\lceil \frac{\sum_{k\epsilon\beta} G_{Grant}(\text{k})}{C} \right\rceil$, total available time slots don't satisfy the granted transmission bandwidth.

where $\sum_{k\epsilon\beta} G_{Grant}(\text{k})$ the total time slots allotted, C is total wavelength channels available, β is set of ONUs.

BOHSA algorithm assigns not more than $S_{shortest}$ time slots on every available wavelength to every ONU. After computing $S_{shortest}$ the best possible schedule length the algorithm starts scheduling ONUs in the sequence where every channel needs to assign maximum of $S_{shortest}$ time slots. Whenever allocated time slots are assigned to ONU, it is required to find the unfilled slots on a particular channel say I. If the required time slots are available on wavelength I, then ONUk transmits through the channel I otherwise algorithm makes sure that the allocated time slots are placed on two channels say I and I+1 and in the process channel I reaches the optimal scheduled length. The results of scheduling are stored in a variable say μ with information about channel id, allocated time slot and this information is communicated to every ONU before the start of upstream transmission from ONU to OLT. The proposed algorithm works according to the steps given in Fig. 2.

(i) **ONU sends REPORTS messages to OLT, informing about their bandwidth requirements.**

(ii) **OLT computes G_{min} and decides transmission window on the basis of**
- **If ONUk requirements are $G_{min} > r(k)$, allocate time slots as demanded by ONUk $i.e.$ $G_{Grant}(\text{k}) = r(k)$**
- **Otherwise assign minimum guaranteed bandwidth $G_{Grant}(\text{k}) = G_{min}(\text{k})$, left over demands are buffered.**

(iii) **For scheduling of time slots on various available upstream channels, Compute optimal scheduled length**

$$S_{shortest} = \max\left(\max_{k\epsilon\beta} G_{Grant}(\text{k}) \,,\, \left\lceil \frac{\sum_{k\epsilon\beta} G_{Grant}(\text{k})}{C} \right\rceil\right)$$

(iv) **Schedule channels to ONU sequentially, with maximum time slots in a channel to be $S_{shortest.}$ if unfilled slots in channel say C(k) is less than required time slots, then allot the unfilled slots and remaining required slots be placed on next channel C(k+1) with non overlapping slots.**

(v) **Scheduled info to be notified to ONU with information of allocated channel Id, Start and end time of allocated slots.**

(vi) **ONU transmits at allocated time and upstream wavelength.**

(vii) **If in current scheduled cycle, channels have some free slots, then assign them to ONUs whose demands are more than $G_{min}(\text{k})$ sequentially.**

Fig. 2 — BOHSA algorithm.

The subscriber informs OLT its instantaneous bandwidth requirements for the next scheduling cycle by piggybacking it in the current cycle[13]. It increases the efficiency of the system by improving bandwidth allocation.

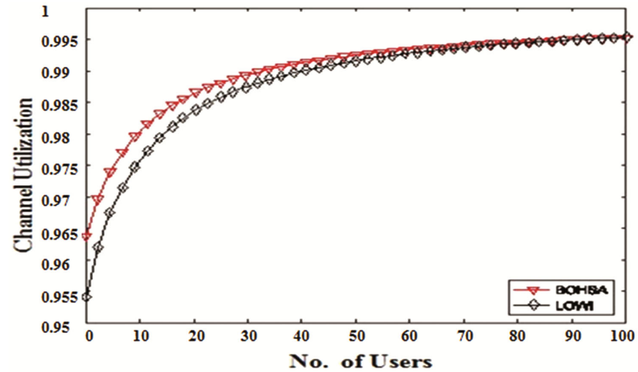
4 Results and Discussion

The numbers of users for simulation is taken to be hundred, requirements of time slots reported by ONUs varied from r_{min}= 5 (minimum requirement) to higher demands r_{max}= 10. Three different cases are considered with three varied requirements of 10, 20 and 30. The minimum demand is fixed at 5 and in the first case upper limit is set to 10. In the second case, the upper limit of requirements has been increased from 10 to 20 (r_{max} 20) and in the third case the maximum demand is considered to be 30 (r_{max} 30) and their effect on channel utilization is observed and are compared with LOWS scheme presented in the literature. The number of users used for analysis has been increased to 100 and with the increase in time slots requirements; the disparity between ONU demands also increases.

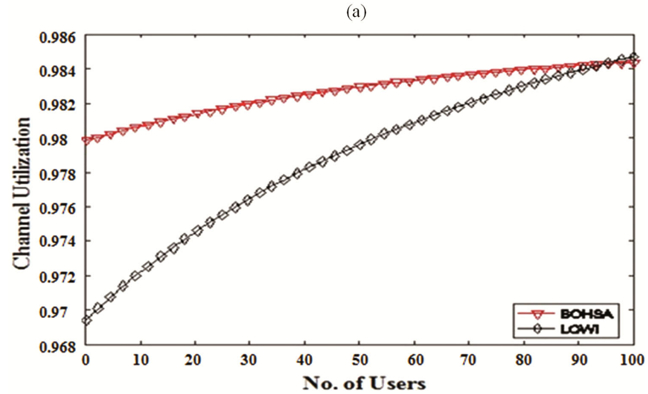
The objective is to examine the effect of this discrepancy and number of ONUs on the overall utilization of channel.

From the Fig. 3 (a-c), it is observed that with increase in number of clients and discrepancy in user requirements, the proposed algorithm performs better in terms of channel utilization if compared with various schemes given in literature like round robin in which every ONU is granted bandwidth by turn, LOWS where the channel is scheduled on the basis of its length. BOHSA allots bandwidth on the basis of demands of users sequentially by avoiding overlapping of time slots in various channels.

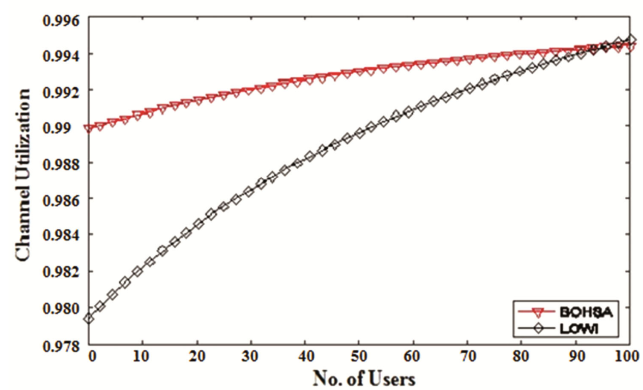
From the simulation results, it is evident that with the increase in user demands the channel utilization performs better. The higher the value of r_{max}, greater is the discrepancy between the subscriber requirements. With the increase in the number of subscribers, the channel utilization also increases. This is because of the fact that with the increase in a number of subscribers the demand disparity among various ONUs will decrease. This makes every channel with the almost same length which helps in improving the utilization of the channel.



(a)



(b)



(c)

Fig. 3 — (a-c) Channel Utilization versus number of users for r_{max} 10, 20 and 30, respectively.

5 Conclusions

This paper presents a novel bandwidth allocation and scheduling scheme for the hybrid WDM/TDM optical access system having tunable ONUs with a single transmitter. Multiple operational upgrades into the previous schemes are presented and evaluated. Through extensive simulations, it has been observed that under high user requirements the proposed mechanism significantly improves the system performance with maximum channel utilization.

BOHSA computes the optimal channel length so as to achieve the maximal usage of the available resources. It is concluded that BOHSA provides optimized bandwidth with improved channel utilization for upstream communication.

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