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# A New Architecture and MAC Protocol for Fully Flexible Hybrid WDM/TDM PON

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**Abstract** In this paper we propose a novel architecture and MAC protocol for a scalable, cost effective WDM / TDM PON providing fully flexible dynamic bandwidth allocation for upstream and downstream data transmission.

## Introduction

Passive optical networks (PONs) are considered as an attractive access network solution thanks to their low operational costs and huge bandwidth. Today, TDM PONs are widely deployed, but these single channel systems are unable to provide sufficient bandwidth for emerging services like video-conferencing, interactive gaming or video on demand. Hybrid WDM/TDM PON has been considered in the literature as a promising alternative and will enable a scalable and smooth transition from today's access network to future high capacity access networks.

In this paper we propose an architecture and MAC protocol for a hybrid WDM/TDM PON that facilitates a fully flexible dynamic bandwidth allocation (DBA) in both upstream and downstream direction.

## PON Architecture

Fig.1 shows the architecture for the proposed PON. To achieve fully flexible wavelength routing (packet by packet) we have modified the structure of the flexible  $\lambda$ -router proposed in<sup>1</sup>. Two separate TDM PONs are shown, each using two sets of downstream/upstream wavelength combinations. The fully flexible DBA scheme enables each of the TDM PONs to utilize the spare bandwidth available on the other wavelengths. The architecture shown in Fig. 1 uses  $\lambda_1$  and  $\lambda_2$  for downstream data and  $\lambda_3$  and  $\lambda_4$  for upstream data transmission. The flexible  $\lambda$ -router at the remote node routes the wavelengths to the appropriate ONUs.

In our proposed scheme each of the downstream packets has the format shown in Fig. 2(a). The control header contains the information about which ONU or ONUs (in case of multicasting) the packet is intended for along with the length of the packet. The control

header processing unit of the flexible  $\lambda$ -router reconfigures the SOA gates to correctly route the wavelengths as done in<sup>2,3</sup>. A WDM splitter separates modulated upstream data from the SOA gate array.

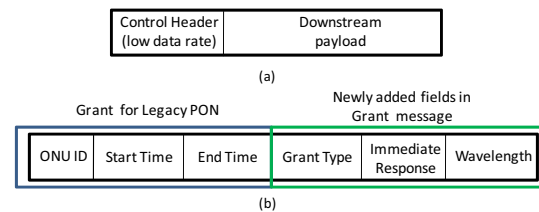


Fig. 2: (a) Downstream data format (b) New Grant message

At the ONU side a WDM splitter separates the up- and downstream wavelengths. The downstream data is received through two separate photo detectors (PDs), one fixed and one tuneable. For every passive splitter there exists a dedicated wavelength assigned to it ( $\lambda_1$  for ONU 1 in Fig. 1). Most of the downstream data packets are transmitted through this wavelength. However, when the download demand increases, a second wavelength from another passive splitter (e.g.  $\lambda_2$  from passive splitter 2) can be assigned to it. This particular downstream data is received using a tuneable PD. Besides, the MAC protocol should have provision for one additional Grant packet for the downstream data, as shown in Fig. 2(b). A Grant Type field has been added to distinguish between two different Grant messages (up- and downstream). Both Grant messages are transmitted by the OLT using the dedicated downstream wavelength for a particular passive splitter. The Grant for downstream informs the tuneable PD to which wavelength it has to tune to and the start / end time for the required transmission.

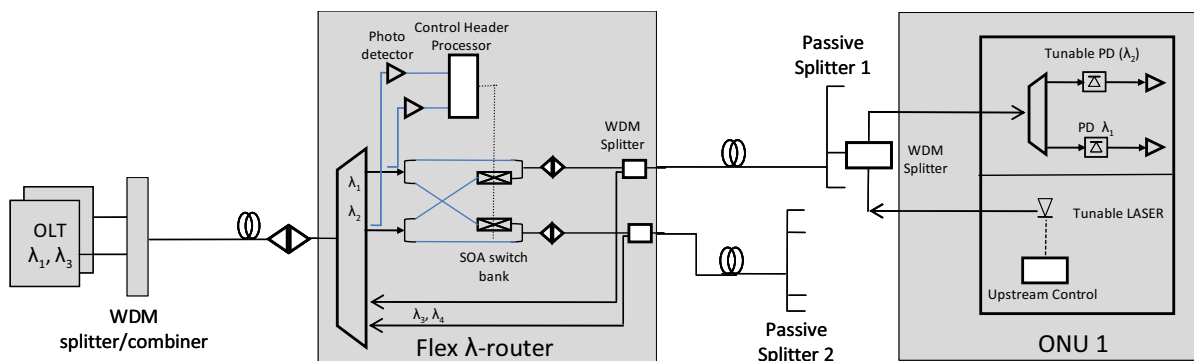
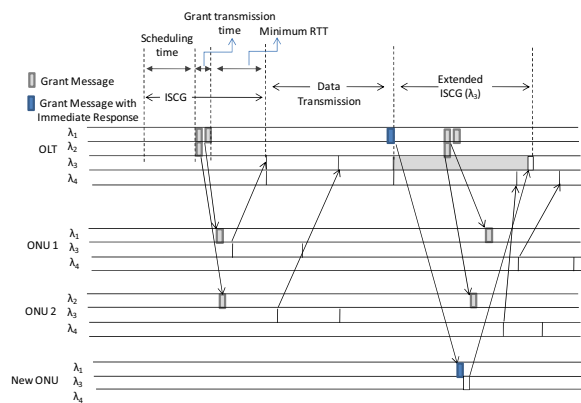


Fig. 1: Architecture for the proposed hybrid WDM/TDM PON

For upstream data transmission a tuneable LASER source is added. The usual Grant message for upstream data has been modified according to Fig. 2(b) to include the wavelength specification for any upstream transmission. The upstream control uses this information to choose the appropriate wavelength for the tuneable LASER.

**MAC Protocol**

We adopt a similar MAC protocol as the one described in<sup>4</sup>. We consider offline scheduling for the DBA scheme in the upstream wavelengths, which means that all the demands are available to the scheduler<sup>4</sup>. Fig. 3 gives an illustration of the MAC protocol with two upstream and two downstream wavelengths shared among multiple ONUs (two [ONU 1 and New ONU] with passive splitter 1 and one [ONU 2] with passive splitter 2).



**Fig. 3:** Timing diagram for the proposed MAC

ONU 1 and New ONU use the dedicated downstream wavelength  $\lambda_1$  for splitter 1 whereas ONU 2 uses the dedicated downstream wavelength  $\lambda_2$  for splitter 2. The timing diagram has two separate phases, (a) data transmission (b) inter-scheduling cycle gap (ISCG). The scheduler located at the OLT gathers information through request messages from each of the ONUs in the previous data transmission cycle. The scheduler then runs the scheduling algorithm to efficiently allocate bandwidth to all users according to their traffic demand and transmits Grant messages to each ONU. The ISCG consists of three components: (a) the time the scheduler takes to allocate bandwidth, (b) the transmission time for all Grant messages and (c) the minimum round trip time required before the transmission of the actual data from each ONU resumes (Fig. 3). The offline scheduling has the opportunity to allocate bandwidth in the best possible way, with the trade-off of a waste of time for a duration of ISCG in every cycle.

We now describe the features added to the MAC protocol making it more robust, efficient and scalable.

- MAC alteration for downstream DBA:

MAC alteration for downstream traffic has already

been discussed in the architecture section.

- MAC alteration for switched-off ONUs:

In case an ONU is switched-off, the OLT does not receive any data in the allocated slot. It continues polling the ONU for the next few cycles with zero byte allocation to test if the node is still alive. If no responses are received anymore it deletes the ONU from the scheduler's polling list and adds it to the list of reported switched-off ONUs.

- MAC alteration for new and turned-on ONUs:

In case a new ONU is added to the network, the ONU number is added to the list of switched-off ONUs. The OLT keeps polling the switched-off ONUs after a regular interval of a few seconds (2-4 sec) to test if an ONU is turned on. For such testing, a special Grant message, allocating zero bytes, is transmitted to the switched-off ONUs immediately before the end of a data transmission session (Fig. 3). As the OLT cannot know the round trip time (RTT) for a new ONU and cannot assume the old RTT for a switched-off ONU (as it may be relocated), it has to range the ONU first. Hence in the Grant message, shown in Fig. 2(b), the OLT sets the bit for "immediate transmission" to mention the ONU to transmit a minimum length data immediately after receiving this Grant, which helps the OLT to range the ONU. Due to this, the OLT requires to extend the ISCG for that particular cycle to the maximum possible RTT (shown in Fig. 3 for  $\lambda_3$ ). This process not only ensures the inclusion of a new node in the network but gives provision to add and drop nodes at will from the network as per requirement. The latter even gives opportunity to individual ONUs to operate in sleep or power saving mode whenever it has no data to transmit or receive. This process also keeps provision for long reach PON as the ranging for long reach ONUs is allowed.

**Conclusions**

In this paper we have provided a new architecture for hybrid WDM/TDM PON that cost-effectively ensure fully flexible dynamic bandwidth allocation in both upstream and downstream. We can utilize any of the wavelengths for the downstream reception by using only two photo detectors and line cards. Additionally our proposed MAC enhances the existing MAC for such a PON to allow ONUs to operate in sleep mode.

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