A Novel Hybrid WDM/TDM GPON Topology with Central Bandwidth Allocation and QoS Support

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Abstract—**A novel hybrid WDM/TDM GPON topology with reflected-based ONUs is proposed. The OLT takes control of the bandwidth allocation for WDMA and TDMA ONUs. Differentiated QoS services are employed to support multiple different traffic patterns.**

I. Introduction

Gigabit Passive Optical Networks (GPONs) [1] have been viewed as a promising technology for fiber-to-the-home (FTTH) optical systems because they can deliver multi-services (e.g. TDM, Ethernet) with the required Quality of Service (QoS). These services include multi-pattern triple-play services (voice, video, and data) that are bandwidth intensive. Consequently, bandwidth management with effective and fair QoS support becomes a challenge in GPON network designs. A GPON consists of an Optical Line Terminal (OLT) at the Central Office (CO) and Optical Network Units (ONU) for the local users of the network. The conventional Time Division Multiplexing (TDM) GPON standard specified by the ITU-T requires OLT broadcasting all downstream traffic to ONUs while ONUs time share upstream bandwidth. Hence, long queue delays emerge because different QoS requirements must be met using the upstream bandwidth. This can lead to congestion that quickly occurs when the traffic load is high.

This paper introduces a novel 1.25 Gbps Hybrid Time Division Multiplexing (TDM) / Wavelength Division Multiplexing (WDM) GPON topology. Its performance is compared to a conventional TDM GPON topology. Reflective Semiconductor Optical Amplifiers (RSOAs) are adopted in the reflective-based ONUs [2]. Additionally, a modified MAC protocol is proposed enabling an overall control by the OLT using a Centralized Dynamic Bandwidth Allocation (CDBA) algorithm. The proposed topology exhibits better performance for two reasons. Firstly, the hybrid TDM/WDM GPON provides shorter queuing delay for each ONU buffer queue compared to the pure TDM GPON case. Secondly, differentiated QoS support performs better for three types of traffic: TDM traffic, real-time traffic and best-effort traffic. Hence, the hybrid WDM/TDM GPON offers effective bandwidth management and flexible QoS support towards a cost-effective architecture for next-generation optical access networks.

II. Network Topology and Protocol

The 1.25 Gbps bidirectional WDM/TDM hybrid GPON topology consists of eight ONUs (Fig. 1). They are separated into two WDM groups sharing two wavelengths in a WDM mode. Within each group, four ONUs share one wavelength in a TDM mode. A Tunable Laser Source (TLS) is used as the transmitter while a broadband receiver (RX) is used to receive signals at the OLT in the Central Office (CO). In the Remote Node (RN), Array Waveguide Gratings (AWGs) are employed as wavelength routers for wavelength multiplexing and de-multiplexing. Two wavelengths (λ1, λ2) are separated by the AWG and input traffic streams are redirected using an optical splitter to the appropriate output within one of the two ONU groups. The fiber length between the CO and the RN is 15 km, and 5 km between the RN and the ONU. The propagation delay is 100 us from the CO to the ONU. At the ONU, a cost-effective RSOA is used instead of a transmitter. The RSOA fulfills two functions: (1) it modulates the downstream carrier back, (2) acts as a receiver. The OLT carries out global bandwidth allocation for all ONUs through the modified MAC controller using CDBA algorithm. Hence, the RSOAs are only active when empty downstream carriers are transmitted to the ONUs by the OLT.

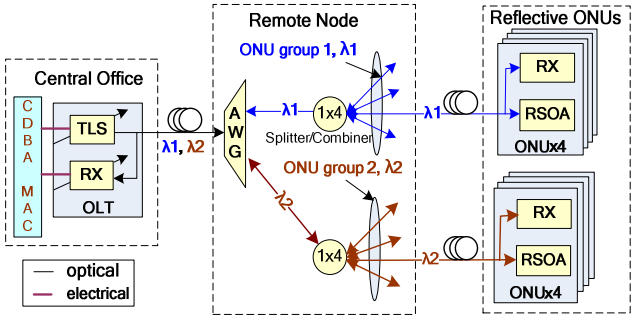

Figure 1. Hybrid WDM/TDM GPON Topology.

Using the ITU-T GPON specification, a novel GPON MAC protocol is proposed with a polling-based Request-Grant signaling method [3]. Incoming upstream multi-pattern traffic is buffered in 10 Mbps Virtual Output Queues (VOQs) within each ONU. As Fig. 2 shows, different traffic is encapsulated into General Encapsulated Method (GEM) frames and sent with additional control frames. The OLT checks its ONU request table for the bandwidth (BW) request condition of all ONUs and then schedules BW allocation using CDBA algorithm. After the scheduling is done, the OLT sends a "BW Grant" frame (BWmap) and downstream data (GEM) frames to the appropriate ONU. Upon receiving the BWmap frame, the ONU sends upstream GEM data no larger than the granted BW, along with the "BW request" frame (DBRu) for the next round of BW requests to the OLT. Compared to pure TDM PON, the hybrid PON has two separate WDM ONU groups with independent BW allocation and polling cycles. The CDBA algorithm defines a strict bandwidth allocation policy for each QoS level. Using this approach the protocol enables

the OLT to take full control of the allocated bandwidth to each ONU while offering efficient and flexible QoS support.

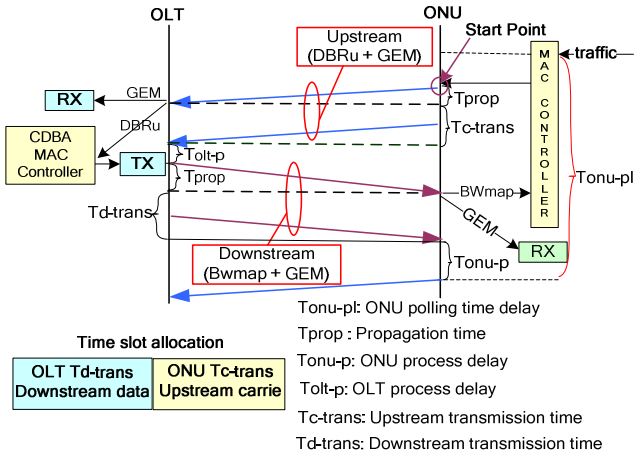

Figure 2. Developed GPON MAC signaling procedure.

III. Simulation Results

For each ONU, three QoS levels are provided. QoS_1 stands for a TDM leased line traffic requiring guaranteed bandwidth allocation. QoS_2 stands for bursty and delay sensitive services (e.g. video or voice) needing guaranteed access time. QoS_3 is for best effort service without a need for a guaranteed bandwidth allocation or a guaranteed access time. In Fig. 3, we compare the delay performances of the hybrid GPON proposed (Fig. 1) with a traditional TDM GPON of eight ONUs. Our results indicate that the queuing delay of the TDM GPON becomes much larger than WDM GPON for the two higher QoS levels (QoS_1 and QoS_2) needing guarantee. The reason for the performance difference is that the hybrid GPON has eight ONUs grouped into two WDM groups sharing two wavelengths, while the TDM PON has eight ONUs sharing a single wavelength. As the polling frequency increases, the hybrid GPON offers much shorter polling cycle causing less VOQ queuing delay.

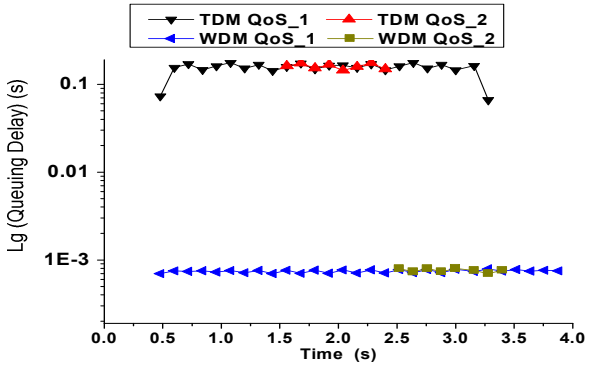

Figure 3. Performance comparison for TDM and Hybrid PON.

To examine the QoS performance, the hybrid GPON is tested using traffic at different aggregated rates and traffic patterns. All traffic loads have been set to be 1.54 Mbps TDM-T1 traffic for QoS_1, 10 Mbps real-time traffic with bursty Poisson arrival rate for QoS_2, and 10 Mbps best effort traffic for QoS_3. As Fig. 4 shows, the buffer queue size and queuing delay stays constant for Qos_1 as traffic load varies due to the guaranteed fixed bandwidth. QoS_2 is served with approximately 400 us queuing delay while the queue size varies by only 1000 bits. For QoS_3, the queuing delay varies within a larger range from 0 to 1 ms while the queue size reaches more than 1 Mbit since there is no service guarantee. The bottom figure shows the congestion of the queue size for QoS_3. The congestion becomes more severe as the load increases but does not influence the performance of the other queues. As a result, QoS_1 and QoS_2 which have higher priority will be served first with their respective guaranteed service. Congestion occurs for QoS_3 when the offered load is high due to its lower priority. As demonstrated, the proposed hybrid topology with a centralized control at the OLT can successfully accommodate different QoS classifications.

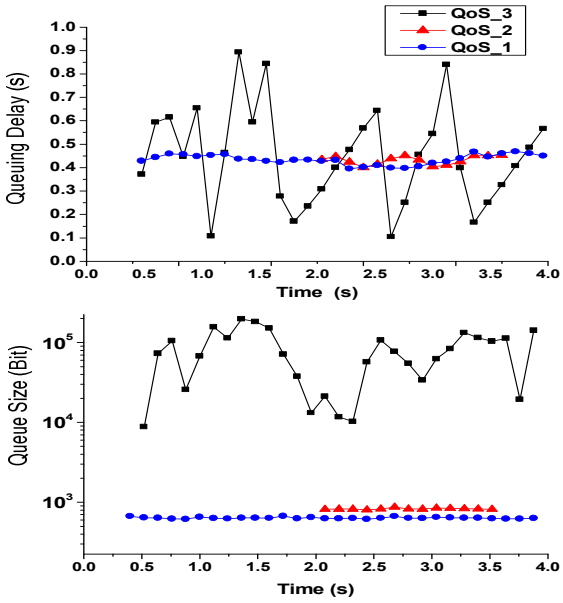

Figure 4. QoS queuing Delay time (top) and size (bottom).

IV. Conclusion

In this paper, we proposed a WDM/TDM hybrid GPON topology with eight reflective ONUs in two independent WDM groups. A novel MAC protocol is realized with Centralized Dynamic Bandwidth Allocation algorithm. Simulation results confirm that the hybrid GPON offers better performance than a conventional TDM PON. QoS support was realized using a novel algorithm for three types of differentiated traffics.

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