QoS aware MAC Protocol for OFDMA-PON

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ABSTRACT
A quality of service (QoS) aware medium access control (MAC) protocol is presented for next generation OFDMA-PONs. The end-to-end delay and network throughput are investigated in the presence of class-of-service and service-level differentiation. In addition, this paper proposes a new dynamic subcarrier allocation (DSA) algorithm. The monitoring window time technique is used where OLT measures the state of the ONU's queue instead of exchanging traditional report messages. As a result, the end-to-end packet delay of high and middle SLAs is less than 0.7 ms even if the ONU offered load is 1.0. The packet delay of the high priority traffic class regardless of SLA levels is however less than 0.6 ms. The total network throughput is 97 % of total capacity.
Keywords: dynamic subcarrier allocation (DSA), orthogonal frequency division multiple access (OFDMA), medium access control (MAC) protocol, quality of service (QoS).

1. INTRODUCTION

The increasing demand of modern applications such as HDTV, 3DTV and ultra-high speed browsing lately lead the research towards increased-capacity optical access solutions [1]. To that extent, a few studies, with relevance to access networks, have recently been presented which prove that orthogonal frequency division multiplexing (OFDM) can provide high capacity, long reach and cost-effective operation for passive optical networks (PONs) [2]. Therefore, an efficient bandwidth utilization mechanism must be provided adhering to service level agreements (SLAs) and the appropriate class of service (CoS) indicators in order to achieve the QoS aware MAC protocol. Therefore, individual performance measures, including the time-sensitiveness and buffer queues, should be individually applied. For instance, the transmission of high priority packets such as VoD should always be guaranteed low packet delay and loss rate, however the performance of middle and low priority packets could be temporarily degraded.

2. CLASS OF SERVICE DIFFERENTIATION WITH REFERENCE TO G/EPON

The DSA algorithm proposed in this paper is based on the adoption of existing definitions in the view of G/EPON standards. To that extent, for the GPON standard [3], in order to demonstrate transparent propagation, the full service access network (FSAN) group has defined five types of CoS, each delivered in a transmission container (T-CONT). Different T-CONTs exist based on CoS parameters [4]. The T-CONT 1 traffic represents fixed data rate services, while T-CONT 4 is assigned for the best effort traffic (T-CONT 5 is a class reserved for system providers).

For the purpose of adapting FSAN functionality in the proposed DSA algorithm, OFDMA subcarriers are dynamically assigned to satisfy the basic service requirements corresponding to T-CONT 2 and part of T-CONT 3 traffic. Since the value of each polling cycle is calculated dynamically according to the overall network capacity and ONUs' service levels, system providers could directly add and remove services to a subscriber without affecting other network users. Furthermore, as all subscribers are not expected to fully utilize their allocated subcarriers in each cycle, the unutilized resources can be allocated by means of an extra assigned subcarrier to T-CONT 4 traffic.

When ONUs receive their upstream bandwidth maps, the strict priority queue method could allow sequential delivery of T-CONT2, T-CONT3, and finally, T-CONT 4 traffic by means of high-priority queuing packets. As a result, all traffic types are expected to benefit from sufficient transmission bandwidths under low network load while experience additional buffering when the overall traffic exceeds the maximum network capacity (assuming QoS as a reference measure). To that extent, longer packet delay is expected for T-CONT 4 at high network load allowing for bandwidth to be effectively allocated to higher priority traffic classes. Similarly, T-CONT 3 traffic will start experiencing longer packet delays for further load increase.

In the EPON standard [5], bandwidth management for different traffic classes plays an important role in supporting QoS in the emerging PON based Diffserv capable access network with CoS field [6]. CoS refer to three bits in L2 (layer 2) header at Ethernet frame. QoS is the mechanism that incorporates a number of bandwidth control strategies which help deliver network traffic in an ordered manner and thereby reducing the impact of frame delay under the congestion situation. To support QoS, Ethernet networks must be able to classify traffic by CoS and provide differentiated treatment to each class. SLAs are defined as a contract between the service provider and customer that specifies the QoS level that can be expected [7-8]. As far as QoS standards are concerned, EPON supports three CoSs, expedited forwarding (EF), assured forwarding (AF) and best effort (BE). Packets are first segregated and classified according to the packet classification based on the CoS field of each L2 packet encapsulated in the Ethernet tag frame and then placed into the different priority queues at the ingress stage [5]. Finally, Table 1 below outlines the QoS parameters objectives, accounting for all processes associated with the flow of data at both the ONU and OLT, distinguishing between individual CoS behaviour and GPON.

Table 1: QoS parameters for various priority classes for GPON and EPON.

	High priority	Medium priority	Low priority
GPON	T-CONT 2	T-CONT 3	T-CONT 4
EPON	Expedited forwarding (EF)	Assured forwarding (AF)	Best effort (BE)

3. DYNAMIC SUBCARRIER ALLOCATION ALGORITHM

The protocol allows for the bandwidth allocation process to be performed in a reporting or non-reporting manner. Since communicating grant/report packets between the network ONUs and OLT increases the ONU queuing delay, the protocol utilizes a non-reporting, constant traffic monitoring to evaluate each SC's usage by dividing the transmission time into monitoring windows. The flowchart of the DSA algorithm described above is displayed in **Error! Reference source not found.**, and consists of the following steps:

<u>*STEP 1*</u>: By the end of each window, the OLT calculates the average subcarriers used per ONU during the preceded monitoring window time.

<u>*STEP 2*</u>: As a result ONUs are partitioned into two groups; the *overperforming* and *underperforming* ONUs:

- *overperforming* group: *Pre_SC* = *Used_SC*.
- *underperforming* group: *Pre_SC* < *Used_SC*.

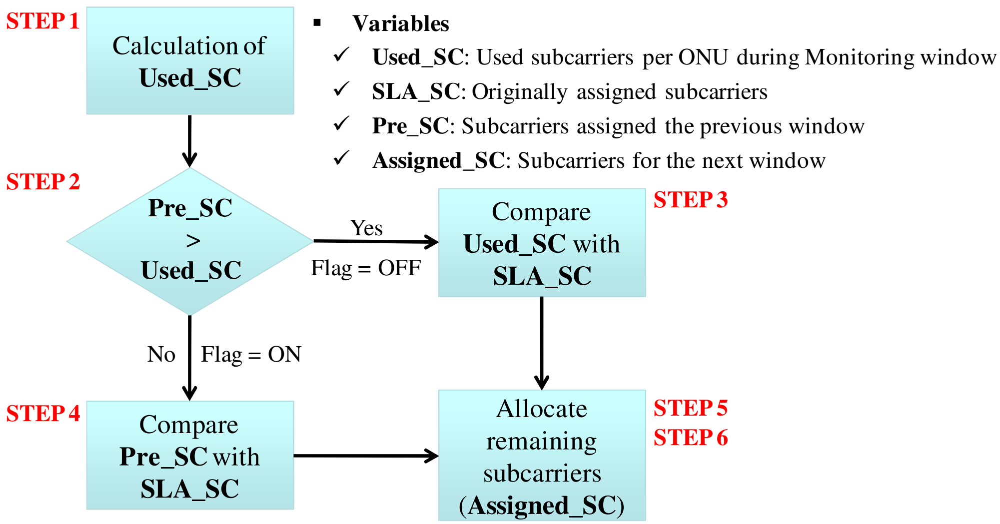

Figure 1. Flowchart of dynamic subcarrier allocation algorithm.

<u>*STEP 3*</u> (*for underperforming* group from *STEP 2*): The OLT compares *Used_SC* with *SLA_SC* using different reference subcarriers to distinguish SLA grades. The following cases are considered:

- If *Used_SC* is smaller than or equal to *SLA_SC*, then the OLT defines *Assigned_SC* based on the *Used_SC*, subtracts *Used_SC* from *SLA_SC* and assigns the difference to the group of "remaining subcarriers".
- If *Used_SC* is greater than *SLA_SC*, then the OLT defines *Assigned_SC* equal to *SLA_SC* because it is not aware at this stage if there are "remaining subcarriers".

<u>*STEP 4*</u> (*overperforming* group from STEP 2): The OLT compares *Pre_SC* with *SLA_SC* without considering the *Used_SC* since it has already determined in STEP2 that ONUs require more subcarriers. The additional subcarrier allocation is performed as follows:

- If *Pre_SC* is smaller than *SLA_SC*, then the OLT increments *Pre_SC* by 1 (*Pre_SC* + 1) and allocates it to *Assigned_SC*. Then it subtracts *Assigned_SC* from *SLA_SC* and assigns this difference to the "remaining subcarriers".

If *Pre_SC* is greater than or equal to *SLA_SC*, then the OLT defines *Assigned_SC* equal to *SLA_SC* because it is unaware at this stage if "remaining subcarriers" are available.

STEP 5: After completing STEPs 2, 3 and 4 the OLT gathers the "remaining subcarriers" from the first case of STEP 3 and STEP 4 and distributes them to requesting ONUs based on their SLA priority.
STEP 6: Following STEP 5 if there are "remaining subcarriers" the OLT assigns them to ONUs based on SLA priority.

4. SIMULATION RESULTS

To evaluate the proposed algorithm in terms of the network throughput and end-to-end packet delay, an event-driven packet-based simulation model is developed using the industrial standard OPNET. The simulation model exhibits an OFDMA-PON composed of one OLT and 32 ONUs. The distance between the OLT and each ONU is 40 km. Three SLAs, SLA_t, t=0, 1, 2, from high to low priority have been considered. The number of ONUs in each service level is set to 2, 10 and 20 with the buffer size of each ONU limited to 10 MBytes. The total upstream data capacity is 10 Gbps, arranged in 64 subcarriers of 156.25 Mbps each. In addition, the guaranteed bandwidth of the high SLA to low SLA is set to 468.75 Mbps, 312.5 Mbps and 156.25 Mbps respectively. Grant processing and propagation delays are considered as 0.5 µs and 0.5 µs/km respectively. The traffic profile is as follows: 20% of the total generated traffic is considered for high priority (CoS_0) and the remaining 80% is equally distributed between medium priority (CoS_1) and low priority (CoS_2) traffic. The network traffic is implemented by a Pareto self-similar traffic model with a typical Hurst parameter of 0.8 to simulate practical network patterns. The packet size is uniformly generated between 64-1518 Bytes.

Figure 2 (a) confirms that the end-to-end packet delay of high and middle priority SLAs is less than 0.7 ms even if the ONU offered load is 1.0. This is because the guaranteed bandwidths of the high and middle SLAs are greater than or equal to the ONU offered load of 1.0 corresponding to 312.5 Mbps. In addition, the DSA algorithm allocates the remaining subcarriers according to the SLA priority. As expected, the end-to-end pack delay of low priority SLAs dramatically increases at an ONU offered load of 0.7 since a DSA algorithm cannot support

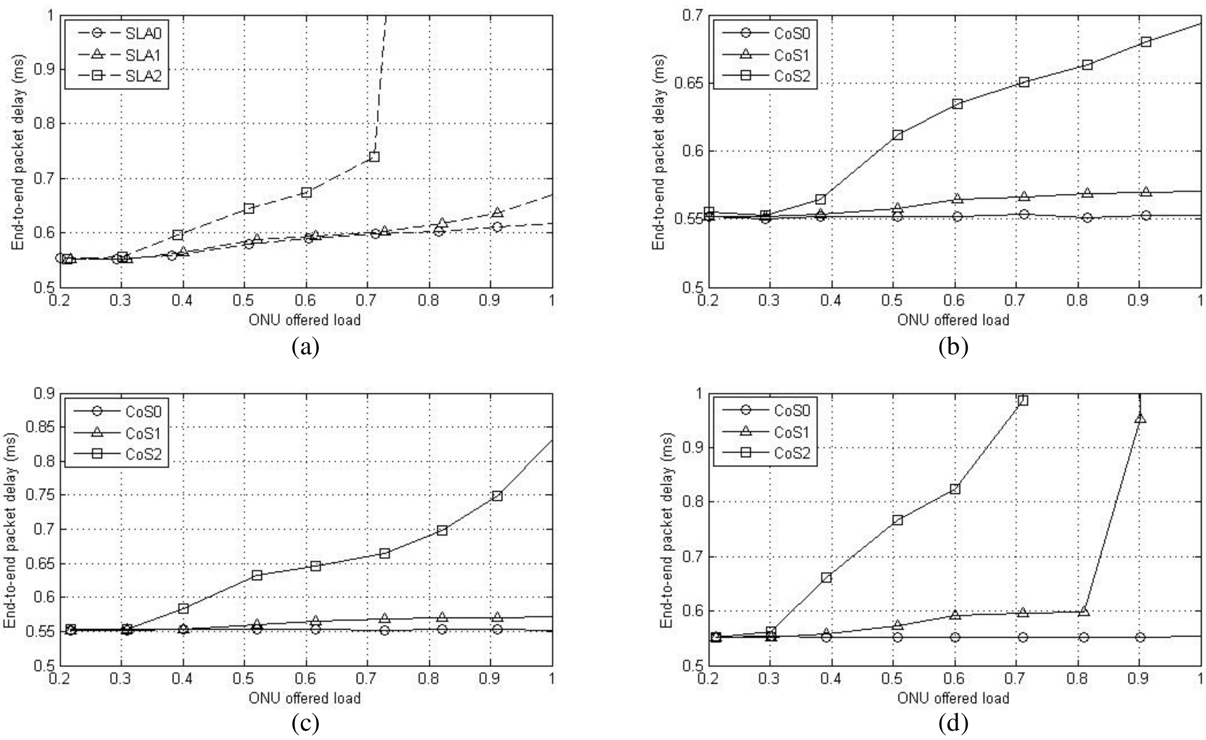

Figure 2. End-to-end delay according to (a) three SLA levels (b) three CoS grades under SLA_0, (c) three CoS grades under SLA_1 and (d) three CoS grades under SLA_2.

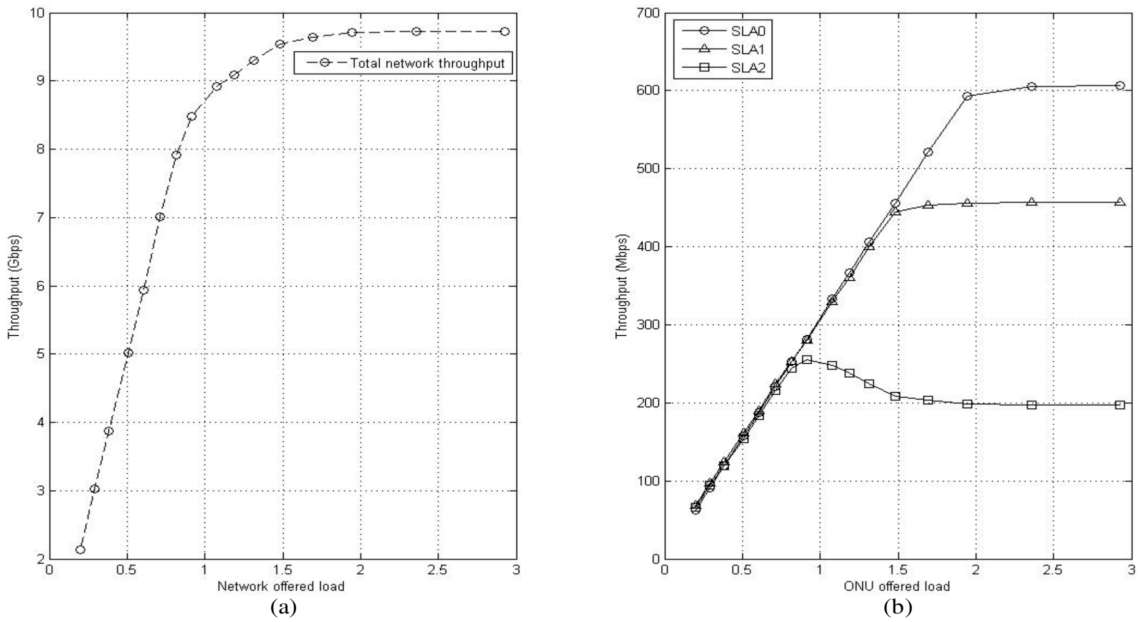

Figure 3. (a) Total network throughput and (b) network throughput according to three SLA levels.

granularity and subcarrier sharing among low bandwidth ONUs. Figure 2 (b), (c) and (d) represent the end-to-end packet delay according to three CoSs under each SLA. The packet delay of the high priority (CoS_0) traffic regardless of SLA levels is less than 0.6 ms because CoS_0 traffics are first transmitted from each ONU's queue. Figure 3 (a) shows the total network throughput as a function of the network load (load 1.0 represents 10 Gbps). Figure 3 (b) displays the network throughput according for all three SLAs as a function of the ONU offered load instead of the network load. A load of 1.0 corresponds to a data rate of 312.5 Mbps (10 Gbps divided by 32 ONUs). The saturated throughput is 600 Mbps, 460 Mbps and 200 Mbps corresponding to high to low SLAs respectively.

5. CONCLUSIONS

In order to provide QoS aware MAC protocol for next generation OFDMA-PONs, this paper demonstrated a novel dynamic subcarrier allocation (DSA) algorithm. The performance in the distinction of three SLA levels and CoS grades for a 40 km reach, 32-split OFDMA-PON has been evaluated. In particular, the OLT automatically monitors each ONU's queue status instead of using traditional report messaging resulting in simple MAC processing and reduced packet delays while maintaining satisfactory network throughput. The obtained end-to-end packet delay of the high priority traffic class is less than 0.6 ms regardless of SLAs at the heavy traffic load of 1.0 because of the sequential transmission from high priority packets. The total network throughput is 97% of total capacity.

ACKNOWLEDGEMENTS

This work was supported by the ACCORDANCE project, through the 7th ICT Framework Programme.

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