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LTE Scheduler for LTE/TDM-EPON Integrated Networks

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***Abstract*—This paper introduces a novel LTE uplink scheduler called *Hybrid Z-Based QoS Scheduler* (HZBQoS), a fully standard-compliant LTE scheduler designed to operate in ONU-eNB devices of integrated LTE/TDM-EPON networks. The HZBQoS scheduler provides delay bound and guaranteed rate even when the backhaul and mobile network are heavily loaded. We evaluated the proposed scheduler under heterogeneous traffic and compared its performance to that of another LTE uplink scheduler, called *Z-Based QoS Scheduler* (ZBQoS), which does not take into account the variability of the backhaul link capacity. Simulation results show that HZBQoS is able to provide QoS requirements in the integrated network and outperforms the ZBQoS scheduler.**

Keywords*—Long Term Evolution, Passive Optical Network, Mobile backhaul, Quality of service, Resource management, Scheduling algorithm.

I. INTRODUCTION

The increasing demand for mobile broadband has motivated operators to deploy the Fourth Generation vision of the International Mobile Telecommunications Advanced based on Long Term Evolution (LTE) technology. This demand will increase dramatically the number of base stations. For instance, the Docomo's network in 2020 will grow far beyond the 80.000 base stations of today [1]. Moreover, an LTE base station, also known as evolved NodeB (eNB), will offer peak rates of 100 Mbps in the downlink and 50 Mbps in the uplink, injecting a large amount of traffic into the mobile network backhaul (MBH). The cost of the future MBH can be reduced by using already deployed network infrastructures, e.g., Fiber to the Home (FTTH) systems based on Passive Optical Network (PON) [2]. In this converged network scenario, an eNB is connected to an Optical Network Unit (ONU) and can be integrated in a device known as ONU-eNB.

FTTH based on PONs is already a reality in many countries [3]. In addition, Time Domain Multiplexing PON (TDM-PON) is the most widely deployed architecture by operators and it will dominate the near-future deployments [4]. As of June 2011, there were more than 112.6 million FTTx subscribers around the world, and the global FTTx market continued to grow [5]. Ethernet Passive Optical Network (EPON) is the most used FTTH technology, specially in Asia, where the world leader countries in terms of FTTH subscribers come from [5]. Thus, in this paper, we use EPON as a TDM-PON technology in the MBH. Moreover, it is expected that the use of PON technology for mobile backhaul will generate a market opportunity on the scale of $1 billion [5].

Currently, more and more network operators are planning their FTTx networks around mixed services, including FTTH, Fiber to the Enterprises, and mobile backhaul. However, while FTTH connects to single subscribers, a base station provides services to hundreds of mobile users. Thus, QoS provisioning in the integrated networks is quite important and when a TDM-EPON network is used as a backhaul of the mobile network, the variability of the backhaul channel capacity can significantly impact the QoS provisioning to mobile users.

This paper introduces a novel uplink scheduler for LTE/TDM-EPON integrated networks, called *Hybrid Z-Based QoS Scheduler* (HZBQoS). HZBQoS resides at the ONU-eNB and it has the great advantage of being independent of the scheduler and the QoS scheme adopted in the TDM-PON side. This facilitates the rapid deployment of LTE/TDM-PON integrated networks since no change in the already deployed PONs is required. The HZBQoS scheduler is based on the *Z-Based QoS Scheduler* (ZBQoS) [6], a standard-compliant LTE uplink scheduler which employs a relaxed z-shaped function to deal with the dynamic prioritization of uplink users requests. Unlike ZBQoS, HZBQoS scheduler is designed to work in an LTE/TDM-PON integrated network, taking into account the backhaul capacity variations. The proposed solution provides delay bound and guaranteed rate according to the LTE specification. To the best of our knowledge this is the first standard-compliant uplink scheduler for LTE/TDM-PON integrated networks which is able to support both delay bound and guaranteed rate requirements even under heavy load mobile network conditions and backhaul capacity variations. This paper differs from our previous work [6] in that the scheduler presented here considers not only the mobile network condition but also the backhaul status at the moment of making scheduling decisions.

This paper is organized as follows. Section II briefly reviews LTE and EPON technologies and their integration. Section III discusses related work. Section IV introduces the proposed standard-compliant uplink scheduler for LTE/TDM-PON integrated networks. Section V details the simulation model, the scenarios used and describes the results derived via simulations. Finally, Section VI concludes the paper.

II. LTE-EPON INTEGRATED NETWORKS

The LTE Radio Resource Management (RRM) block located at the base station, performs two major tasks: Radio Admission Control (RAC), to decide about the admission of new connections, and Packet Scheduling (PS), to distribute radio resources among user equipments (UEs). LTE PS comprises time-domain (TD) and frequency-domain (FD) scheduling algorithms. The TD scheduler selects a group of UEs requests to be scheduled in the following transmission time interval (TTI) based on their QoS requirements. The selected group is passed to the FD scheduler which determines the Physical Resource Blocks (PRBs) that should be assigned to them based on the channel quality.

In order to support the QoS requirements of multimedia applications, flows are mapped onto dedicated bearers and a QoS Class Identifier (QCI) assigned to each bearer. The assigned QCI value determines how the bearer should be served considering the following parameters: bearer type, priority and Packet Delay Budget (PDB). There are two types of bearers: Guaranteed Bit Rate (GBR) and non-GBR (nGBR). GBR receives guaranteed data rate, while non-GBR does not. The PDB provides a delay bound with confidence level of 98%. The priority level indicates the bearer priority. In addition to the QCI, each bearer can be characterized by other QoS attributes as the Guaranteed Bit Rate (GBR) which refers to the minimum bit rate that should be sustained to the GBR bearers.

UEs use a signaling message called Buffer Status Report (BSR) to request resources to the eNB for uplink transmissions. The BSR allows UE to inform the eNB about the amount of buffered data to be sent and their priority. Based on the QoS requirements of each bearer and on the BSRs received by the eNB, the TD uplink scheduler performs a prioritization of the currently active UEs to be scheduled for the upcoming TTI.

1G TDM-EPON was specified in the IEEE 802.3ah standard [7]. An EPON network is composed of an Optical Line Terminal (OLT), splitters and ONUs. The uplink channel is shared among ONUs and a Dynamic Bandwidth Allocation (DBA) algorithm is needed for arbitrating upstream ONU transmissions. The IEEE 802.3ah also defines the Multipoint Control Protocol (MPCP) which is proposed to be used by DBA mechanisms as a signaling protocol for bandwidth request and granting. MPCP defines the report and grant messages. The former is used by ONUs to inform the OLT the amount of bytes in their queues. The latter is sent by the OLT to ONUs to inform the granted bytes for the next cycle and the time to start the transmission.

However, IEEE 802.3ah did not define any DBA algorithm but left them to the vendors to implement. Interleaved Pooling with Adaptive Cycle Time (IPACT) [8] is the most widely used DBA algorithm. In IPACT, the OLT polls ONUs and grants time slots to each ONU in a round-robin fashion. At every round of the bandwidth granting cycle, the OLT decides the amount of bandwidth each ONU will receive. IPACT defines some scheduling policies but the most common is the limited one. This scheduling policy grants the maximum between the reported bytes and the maximum granted bytes per cycle that depends on the number of ONUs and their Service Level Agreements.

Figure 1 shows the considered LTE-EPON integrated network. The eNB and the ONU are integrated both in hardware and software in a device called ONU-eNB. The eNB is a client of the EPON network through the ONU module of the ONU-eNB device. In this architecture, the bandwidth granted to the ONU-eNB must be distributed among the UE

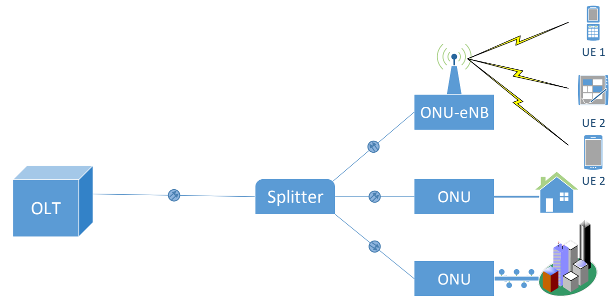

Figure 1. LTE/TDM-PON Integrated Network Architecture

bearers. In this integrated network, the bandwidth received by the ONU-eNB can change at every round of the EPON bandwidth granting cycle. Taking advantage of the integrated architecture, the LTE uplink scheduler located at the ONU-eNB should take into account this variability when providing transmission opportunities to its users in order to maintain their QoS requirements.

III. Related Work

There are few QoS schemes for the integration of LTE and PON architectures.

Chung *et al.* [9] proposed one of the first schemes that employed PONs for the backhaul of wireless networks. The architecture used by the authors was a two-upstream-wavelength PON (2W-PON) in which the ONUs are classified into two groups and each group has a different upstream transmission wavelength. The scheme prioritizes real-time packets and control packets by transmitting them on one wavelength while the low priority traffic is sent on another wavelength. This architecture is not common in real network operators, so the mechanism is not very useful at all.

Ranaweera *et al.* [10] analyzed the effect of EPON cycle-length on the QoS performance of an EPON-LTE converged network with different scheduling mechanisms. They showed that scheduling schemes are affected with the variation of the maximum cycle length and they state that it needs to be selected properly in order to achieve the optimum QoS performance.

Lim *et al.* [11] proposed two QoS mapping mechanisms for LTE backhauling over OFDMA-PONs. The first one is 1:1 mapping between LTE QCIs and DiffServ queues. Under this scheme, every ONU and OLT need to be directly configured with the mapping between a QCI value and its corresponding DSCP value. In situations which the number of LTE bearers is greater than the number of DiffServ queues, the second scheme, called Group Mapping is used. Under this scheme, bearers are mapped onto 3 groups and put into the DiffServ queues. They use a non-mapping scheme as baseline, where the LTE bearers are mapped onto the low priority queue in the DiffServ domain. The author did not specify the mapping for the QCI 4. The problem with this approach is that the traffic in the EPON network can impact the QoS provisioning of mobile users.

IV. Time-Domain Packet Scheduler for QoS Provisioning in LTE-EPON Integrated Networks

This section introduces a novel standard-compliant time-domain uplink scheduler for LTE-EPON integrated networks, called *Hybrid Z-Based QoS Scheduler* (HZBQoS). It follows the LTE specification and employs QoS-related metrics to prioritize users for scheduling.

The HZBQoS scheduler is based on the ZBQoS scheduler [6] which provides delay bound and rate guarantees even under heavy load network conditions and increases the aggregated throughput of the network by dynamically prioritizing bearers. Prioritizing GBR over nGBR bearers may lead to unnecessary loss of nGBR requests, decreasing the total throughput of the system [6]. To cope with the dynamic prioritization of GBR from nGBR bearers without sacrificing throughput, ZBQoS uses a z-shaped function into its QoS scheduling metric. However, ZBQoS, as many other LTE schedulers, was designed for an LTE network without taking into account backhaul constraints. In order to deal with the capacity variation of the backhaul channel of a TDM-PON network, HZBQoS uses a compensation factor in a way that when requests made by an ONU-eNB device to the OLT are not completely provided in a given EPON cycle, GBR bearers are prioritized in the following TTIs by the LTE scheduler. By following this behavior, the ONU-eNB can reduce its uplink packet buffer occupancy and prioritizes real-time over non real-time traffic in backhaul congestion situations.

First, HZBQoS scheduler calculates the metric value for each UE with pending transmissions to define the UE request priority. Then UEs requests are sorted in a decreasing priority order and the algorithm selects a group of them to be sent to the frequency-domain scheduler. Priority is given to requests with delay close to the user's Packet Delay Budget or with deficit in their guaranteed bit rate, depending on the class of traffic. The value of the QoS scheduling metric for GBR bearers is the minimum between the value of a delay-related metric and a rate-related metric. Non-GBR bearers use only a delay-related metric which is specific to the type of traffic served by this class and a compensation factor is used inside this metric to decrease the priority of this kind of flows under short-term and long-term backhaul congestion situations.

The priority value associated to the request of the UE u at time interval n for the bearer i is denoted by $M_{u_i}(n)$ and defined as:

$$M_{u_i}(n) = \begin{cases} \min(D^{GBR}_{u_i}(n), R_{u_i}(n)), & \text{for GBR} \\ D^{nGBR}_{u_i}(n), & \text{for nGBR} \end{cases} \tag{1}$$

where $D^{GBR}_{u_i}(n)$ and $D^{nGBR}_{u_i}(n)$ are the delay-related metrics for user u at the time interval n for bearer i, of the type GBR and non-GBR, respectively. $R_{u_i}(n)$ is the rate-related metric for UE u at time interval n for bearer i.

The relaxed z-shaped function can be defined as:

$$f_z(x;a,b) = \begin{cases} 1, & \text{if } x \le a \\ 1 - 2\left(\frac{x-a}{b-a}\right)^2, & \text{if } a < x \le \frac{a+b}{2} \\ 2\left(\frac{x-b}{b-a}\right)^2, & \text{if } \frac{a+b}{2} < x \le b \\ 0, & \text{if } x > b \end{cases} \tag{2}$$

where x is the function input and the parameters a and b delimitate the range of x values corresponding to the slope portion of function. Readers are referred to [6] for further details about the z-shaped function and its utilization in the scheduling metric.

In order to employ the relaxed z-shaped function to the delay-related metric, the ratio x was defined to measure how close a packet delay is to the packet delay budget.

$$x = \frac{HoL^i_u(n)}{PDB^i} \tag{3}$$

where $HoL^i_u(n)$ is the head of the line packet delay for bearer i of UE u at time interval n. PDB^i is the Packet Delay Budget of bearer i and its value depends on the QCI assigned to bearer i. When x is close to 1, the bearer has high priority since its HoL packet delay is close to the Packet Delay Budget.

The delay-related metric for non-GBR bearers is defined as:

$$D^{nGBR}_{u_i}(n) = 2 - x + C_j(k) \cdot (f_z(x; 0.7, 0.85) - f_z(x; 0.85, 1)) \tag{4}$$

$C_j(k)$ is a compensation factor for the ONU-eNB j in the EPON cycle k. $C_j(k)$ is defined as:

$$C_j(k) = \frac{Gate_j(k)}{Report_j(k-1)} \tag{5}$$

where $Gate_j(k)$ is the number of bytes granted to the ONU-eNB j by the OLT in the EPON cycle k and $Report_j(k-1)$ is the number of bytes requested by the ONU-eNB j in the EPON cycle $k-1$. Note that, $Gate_j(k)$ is the response from the OLT to the $Report_j(k-1)$ sent by the ONU-eNB j in the EPON cycle $k-1$. $C_j(k)$ is introduced to track the optical channel variations. When $C_j(k)$ is close to zero, the backhaul link is congested and then, the priority value of non-GBR bearer is decreased proportionally to this "deficit" (i.e. the sloped portion of the non-GBR metric value in Fig. 2 is reduced proportionally with $C_j(k)$) until the situation changes. When $C_j(k)$ is equal to 1, the backhaul link is not congested and the behavior of the HZBQoS scheduler is equal to that of the ZBQoS one. $C_j(k)$ has to be updated periodically, and the updating period will be analized later in the next section.

The delay-related metric for GBR bearers is defined as:

$$D^{GBR}_{u_i}(n) = 1 - x \tag{6}$$

Figure 2 shows the delay-related metric value for GBR and nGBR bearers as a function of the parameter x in an *underloaded* backhaul. It is interesting to note that $D^{nGBR}_{u_i}(n)$ value is always higher than $D^{GBR}_{u_i}(n)$ for the same value of x (the higher the metric value, the lower the priority). The nGBR bearers with metric values between 2 and 1 have always lower priority than any GBR bearer. Aditionally, for x greater than 0.75, when the metric value for nGBR bearers is below 1, a nGBR bearer can receive higher priority than a GBR bearer with low x value associated to it. The above two metrics give absolute priority to GBR bearers with x values greater than 0.85, i.e., higher priority over any nGBR bearers.

The rate-related metric for GBR bearers is defined as:

$$R_{u_i}(n) = \frac{R_{sch_{u_i}}(n)}{GBR^i_u} \tag{7}$$

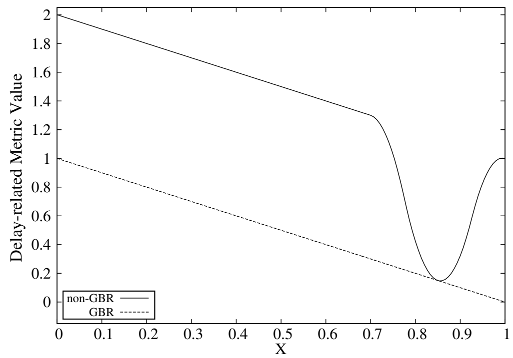

Figure 2. Delay-related metric value for GBR and nGBR bearers as a function of the ratio x

where GBR_u^i is the minimum guaranteed bit rate for bearer i of UE u and $R_{sch_{u_i}}(n)$ is the weighted average rate given to bearer i of UE u at time interval n defined as:

$$R_{sch_{u_i}}(n) = \left(1 - \frac{1}{T_{PF}}\right) R_{sch_{u_i}}(n-1) + \frac{1}{T_{PF}} \hat{r}_{sch_u}(n) \quad (8)$$

where T_{PF} is the duration of a window used for measuring the obtained rate. $\hat{r}_{sch_u}(n)$ is the instantaneous achievable rate in case UE u is scheduled at the time interval n. This metric is close to 0 when no transmission opportunity has been given to the bearer and close to 1 when the minimum bit rate for that bearer is provided.

V. Performance Evaluation

In this section, we evaluate the performance of the proposed scheduler using an integrated LTE-EPON simulation. The LTE module was implemented in the LTE-Sim simulator version 4.0 [12]. LTE-Sim is an event-driven packet level simulator developed in C++, widely used for simulating MAC functions of E-UTRAN. We implemented the proposed uplink packet scheduler and improved the implementation of the uplink part of the LTE-Sim simulator. We introduced the support to QoS for uplink transmissions and divided the uplink scheduling in time and frequency domains. The EPON module was developed in Java and implements the IPACT DBA algorithm, together with the scheduling disciplines introduced by Kramer *et. al* [8]. In order to simulate an integrated network, we also developed an interface for communicating the LTE and EPON modules and implemented the GTP-U protocol [13] in the S1 interface between the ONU-eNB and the OLT.

The implemented QoS mapping scheme in the integrated device is as follows. When a packet sent by an UE arrives at the ONU-eNB device, the LTE module encapsulates the packet in a GTP tunnel. The packet is sent to the ONU module. On receiving at the ONU module, the packet is queued in a FIFO queue in the EPON module (this scheme uses only one queue).

The performance of the time-domain uplink scheduler proposed in section IV was compared to the performance of another uplink scheduler, called ZBQoS [6], which does not take into account the capacity variation in the mobile backhaul network. In order to do a fair comparison, the QoS mapping scheme described above and the frequency-domain uplink scheduler used in [6] was employed with both time-domain schedulers.

Table I. Traffic Model and QoS Requirements (LTE Part)

Service	VoIP	Video	CBR
Description	G.729 ON/OFF Model	H.264 Trace-based[a]	1000 Bytes every 8 ms
Bit Rate	8.4 Kbps	242 Kbps	1 Mbps
QCI	1	2	8
PDB	100 ms	150 ms	300 ms
GBR	8.4 Kbps	242 Kbps	N/A
Proportion	2 (40%)	2 (40%)	1 (20%)

[a] We use the trace of the video Foreman; it is available in LTE-Sim [12].

The simulated scenario in the EPON part is made up of 1 OLT, 31 ONUs and 1 ONU-eNB. The tree topology is used in the EPON network and the optical channel capacity is 1 Gbps. The ONUs traffic was simulated using aggregation of ON-OFF pareto sources with inter-burst generation time exponentially distributed and packet lengths between 64 and 1518 bytes long. The LTE network part is composed of a single cell (served by the ONU-eNB device) and several users (varying from 10 to 180, with increments of 10). Users are uniformly distributed and for every two users transmitting VoIP traffic and two users transmitting video traffic there is one user transmitting CBR traffic. The UEs follow the Random Walk mobility model with a speed of 3 Km/h. VoIP and video traffic are transmitted using GBR bearers and CBR traffic (best effort traffic) uses non-GBR bearers. When the delay of a packet is higher than the PDB, the packet is dropped. This process is performed every TTI by the UE in the beginning of the uplink transmission. Information about the delay of the HoL packet of each radio bearer is considered to be available at every TTI at the ONU-eNB. To avoid intra-user scheduling interferences, each UE is assumed to have only one bearer with a single traffic class. $C_j(k)$ is updated every EPON cycle. Table I contains the traffic models employed in the LTE simulation and their QoS requirements. Table II summarizes the main configuration parameters used in the simulation.

The figures presented in this section show mean values with confidence intervals with 95% confidence level derived using the independent replication method. The duration of each execution was 100s. Packet loss ratio (PLR), average delay and average throughput per UE are used for comparison. All of these metrics are presented as a function of the number of user in the cell (i.e., traffic load in the LTE network).

We evaluated the performance of both schedulers under two different EPON cycle length, namely 5 ms and 10 ms. The scheduler behavior was also analyzed under two distinct loads in the backhaul, 0.6 and 0.95. The former is a *lightly loaded* backhaul scenario with an ONU traffic load of 19 Mbps and the latter is a *heavily loaded* backhaul scenario with an ONU traffic load of 30 Mbps.

The aim of this experiments was to assess the ability of HZBQoS scheduler to support QoS requirements of the LTE users under variable traffic conditions in both the backhaul and the LTE network. This experiments also aim to define the updating period for the $C_j(k)$ factor.

Figure 3 shows the PLR for video users. HZBQoS is able to provide low packet loss ratio to video traffic under all traffic conditions in both the backhaul and the LTE network, which

Table II. SIMULATION PARAMETERS

Parameter	Value
System Type	Single Cell
Cell Radius	0.5 Km
Channel Model	Macro-Cell Urban Model
Numbers of UEs in the Cell	10-180
Mobility Model	Random Walk (Speed of 3 km/h)
System Bandwidth	15 MHz
Number of Resource Blocks	75 (BW per RB: 180 KHz)
Carrier Frequency	2 GHz
Frame Structure	FDD
TTI Duration	1 ms
UL Schedulers	TD: ZBQoS FD: PF-FME TD: HZBQoS FD: PF-FME
Max. UEs passed to the FDPS	15
Max. Schedulable UEs per TTI	15
T_{PF}^{TD} and T_{PF}^{FD}	100 ms and 300 ms
Number of ONUs	31
Number of ONU-eNB	1
Optical Speed	1 Gbps
ONU Load	19 Mbps and 30 Mbps
Propagation Delay in Fiber	5 μs/km
Distance between OLT and ONU/ONU-eNB	[10,20] Km
OLT-ONU/ONU-eNB RTT	[100,200] μs
ONU/ONU-eNB Buffer Size	10 MB
Maximum Cycle Time	5 and 10 ms
OLT Scheduler	IPACT (Limited Policy)
Guard Band	1 μs

does not happen with the service provided by the ZBQoS scheduler. Moreover, the packet loss ratio produced by ZBQoS surpasses 1% and increases with the traffic load, reaching 5% under heavy load. Actually, the maximum acceptable PLR for video traffic without affecting the users' quality of experience is 1% [14]. Moreover, both schedulers produced no loss service to VoIP traffic as a consequence of its low bandwidth demand and high priority.

Figure 4 shows the aggregated throughput of CBR users. This graphic shows the decrease of CBR traffic to support the QoS requirement of real-time traffic in overloaded scenarios. Saturation under the ZBQoS scheduler is achieved with 90 UEs while under the HZBQoS scheduler it is achieved with

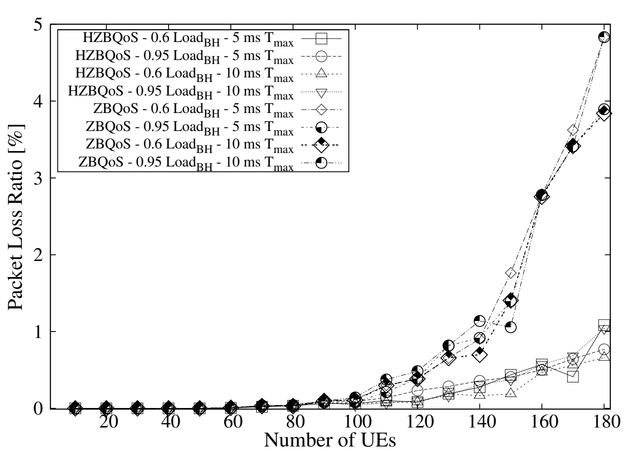

Figure 3. Packet Loss Ratio for Video Traffic

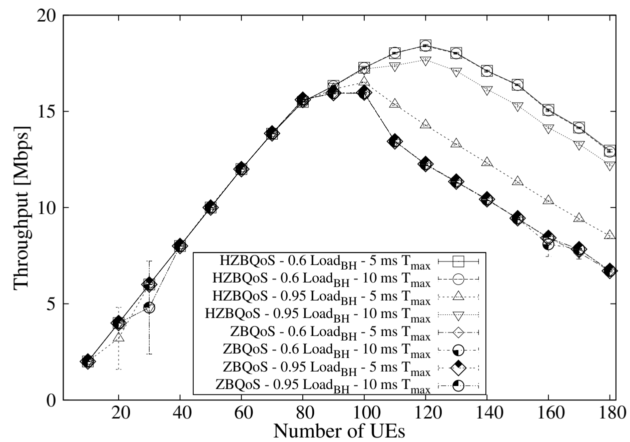

Figure 4. Aggregated Throughput for CBR Traffic

100 UEs and 120 UEs, for cycle lengths of 5 ms and 10 ms, respectively. This fact shows the lack of capacity of the ZBQoS to deal with capacity variation of the backhaul link. Moreover, the throughput achieved by ZBQoS remains constant, independently of the cycle length and backhaul load condition. This fact leads to a better utilization of the network by the HZBQoS scheduler in overloaded scenarios. HZBQoS provides throughput 40% higher than that given by the ZBQoS scheduler. The throughput achieved by the HZBQoS scheduler in *heavily loaded* backhaul networks increase with the cycle length. The reason for this behavior will be explained later, when delay is considered. In *lightly loaded* backhaul, the throughput does not change with the cycle length and it is higher than that of the *heavily loaded* scenarios because more CBR traffic can be transmitted giving the effect of $C_j(k)$.

Figures 5, 6 and 7 show the average delay for CBR, video and VoIP traffic, respectively. As expected, the delay is higher when the backhaul is *overloaded*. For a cycle length of 5 ms the delay given by the HZBQoS scheduler start to increase sharply with 120 UEs since the period to update the $C_j(k)$ factor and maintain the reaction to changes in the backhaul is very short. This behavior does not happen for a cycle length of 10 ms.

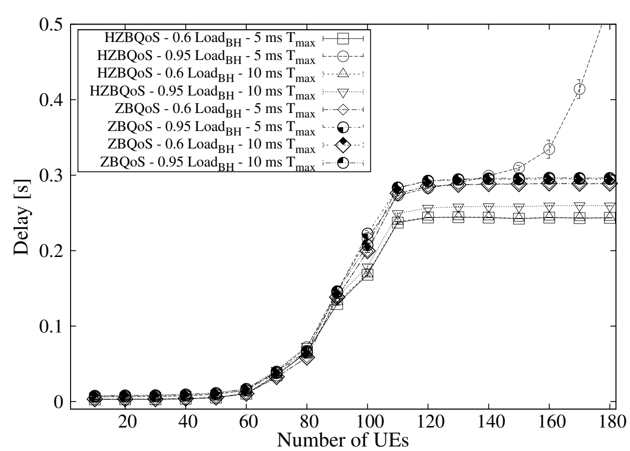

Figure 5. Average Packet Delay for CBR Traffic

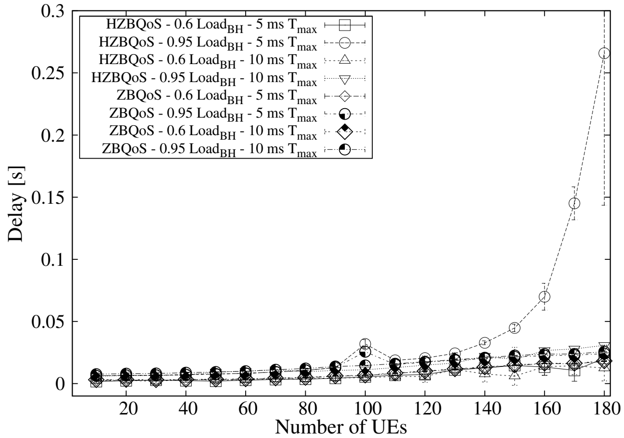

Figure 6. Average Packet Delay for Video Traffic

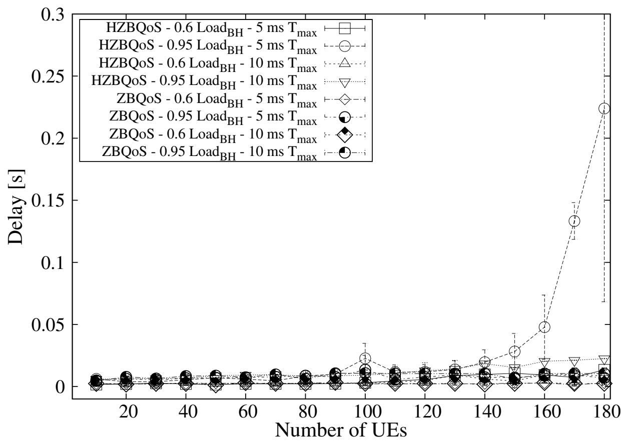

Figure 7. Average Packet Delay for VoIP Traffic

Fig. 8 shows the backhaul delay for video traffic. The shape of the delay given by HZBQoS scheduler for a cycle length of 5 ms is very similar to that of the total delay (Fig. 6), indicating that most of the delay is due to the delay in the backhaul link. This suggests that $C_j(k)$ should be updated approximately every 10 ms regardless of the cycle length. If $C_j(k)$ is not updated properly it produces congestion in the backhaul link. Moreover, it explains the lower throughput achieved by HZBQoS with a cycle length of 5 ms in an *overloaded* network.

VI. Conclusion

This paper introduced a novel uplink scheduler for dynamic packet scheduling in LTE-EPON integrated networks called HZBQoS which is standard-compliant and guarantees QoS. The performance of the HZBQoS scheduler proposal was compared to that of the ZBQoS scheduler, which does not take into account the backhaul conditions at the moment of making scheduling decision. Simulation results show that the proposed scheduler provides lower packet loss ratio than does the ZBQoS scheduler. Moreover, the ZBQoS scheduler produces PLR greater than the maximum acceptable rate under high traffic load in the backhaul network. Additionally, HZBQoS improves the aggregated throughput of CBR traffic up to 40%,

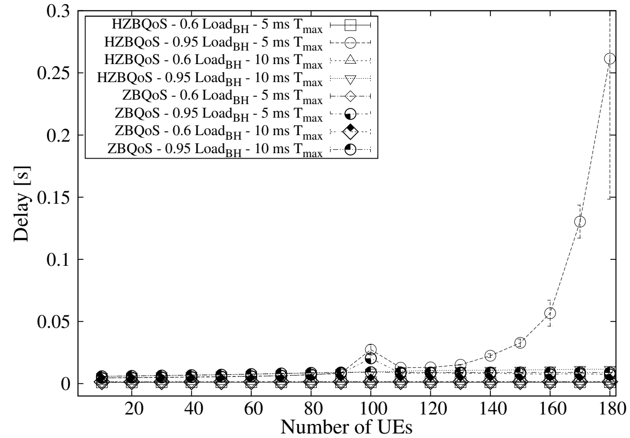

Figure 8. Average Packet Delay in the Backhaul for Video Traffic

when compared to the throughput given by ZBQoS under overloaded scenarios.

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