Synchronous Interleaved DBA for Upstream Transmission over GPON-LTE Converged Network

I-Shyan Hwang, Tzu-Jui Yeh, MohammadAmin Lotfolahi, Bor-Jiunn Hwang and AliAkbar Nikoukar

Abstract— **Gigabit-Capable Passive Optical Network (GPON) and Long Term Evolution (LTE) are two promising broadband access technologies with high-capacity and QoS services for wired access networks and wireless access networks, respectively. A convergence of GPON and LTE networks is proposed to take the bandwidth advantage of optical networks and the mobility feature of wireless communications in this paper. First, GPON-LTE Converged Network Architecture (GLCNA) is presented and especially the concept of Optical Network Unit-evolved NodeB (ONU-eNB). Second, the QoS mapping strategy is defined for GPON-LTE converged networks. Third, a Synchronous Interleaved Dynamic Bandwidth Assignment (SIDBA) scheme is proposed to alleviate the asynchrony problem in upstream bandwidth allocation due to the cycle time of GPON (usually is between 1*ms* and 2*ms*) and the frame size of LTE (usually is 5*ms* or 10*ms*) are mismatched. The simulation results show that the proposed SIDBA scheme can effectively enhance the system performance for different polling cycle time/frame size pairs in terms of network throughput and packet delay, especially the polling cycle time/frame size pair is 2*ms*/5*ms* performs the best.**

Index Terms —**GLCNA, QoS mapping strategy, SIDBA, Asynchrony problem.**

I. Introduction

In recent years, the network equipment companies and carriers have widely utilized the medium of communication for the deployment of fiber-optic network to provide the ultimate broadband service capability. Point to Multipoint technology erected Passive Optical Networks (PONs) which might be viewed as the final frontier of optical fiber to the Home/Curb/Building (FTTx) networks.

With 10Gbps Ethernet Passive Optical Network (EPON) standard - IEEE 802.3av as well as Gigabit-Capable Passive Optical Network (GPON) standard - ITU-T G.984.3 announced, these are one of the best solutions for the construction of broadband transmission network architecture with the advantages of low-cost, high bandwidth and high transmission rates [1]. GPON provides various QoS requirements, such as multi-rate, comprehensive services, and the advantages of high efficiency and has a concept to adapt to the variety of transmission tools.

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However, for the current demand for ubiquitous network, the PON might not be an appropriate solution where mobility is an important concern, or might not be a cost-effective solution depending on geographical restrictions. On the contrary, the wireless broadband access technologies have no terrain limits and have low cost such that remote areas users are easy to reach accessing broadband Internet network. The WiMAX uses the OFDMA in both downlink transmission and uplink transmission, and the LTE also uses the OFDMA in downlink transmission. Whereas in uplink transmission, the LTE takes advantage of Single Carrier Frequency Division Multiple Access (SC-FDMA) which can reduce a lower Peak to Average Power Ratio (PAPR) by about 5*dB*. The performance can be protruding one to three times the performance of Mobile WiMAX by applying Time Division Duplex (TDD) or Frequency Division Duplex (FDD) operation. Overall, the LTE provides higher throughput and QoS optimizations in lower-quality channel conditions compared to the WiMAX. Moreover, the LTE is a smooth upgrade path for GSM/UMTS network operators.

With the Fixed Mobile Convergence (FMC) [2] and next generation optical-wireless converged networks [3] development of new types of services, their derivatives cause significant changes in telecommunication structures.

The dominant optical-access network is the PON where the head of each PON is driven by an OLT, and the tail end of each PON segment has a number of PUNs to serve end-users. The wireless BSs are directed to ONUs and the wireless portion of the WOBAN may employ standard technologies such as Wi-Fi or WiMAX. Optical wireless integration (OWI) aims at integrating PONs with WiMAX to reduce the cost and complexity, and elaborate on the operational and structural considerations of these architectures which support a future and emerging broadband services and applications on the same infrastructure.

Four broadband access architectures to integrate EPON and WiMAX is proposed in [2], and the hybrid architecture is an enhanced integration, in which an ONU and a WiMAX BS are embedded in a single system box, in terms of cost reduction and better system throughput and service QoS. Two challenging issues in the integration of EPON with WiMAX are to efficiently allocate bandwidth to users, and QoS mapping mechanism is required between EPON priority queues in a DiffServ mode and WiMAX service connections in an IntServ

ISBN: 978-988-19253-9-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

mode [2].

To cope with the bandwidth- and quality of service (QoS)-intensive applications, the next generation hybrid fiber-wireless networks need to leverage these emerging access technologies [2]. This paper investigates the GPON-LTE converged network by taking advantage of LTE can provide broadband wireless bandwidth and support QoS services for both GPON and LTE. LTE can support up to 100Mb/s of data rate, also it uses the evolution of existing Universal Mobile Telecommunications Systems (UMTS) infrastructure, currently being used by mobile service providers worldwide. With the advantages of LTE wireless transmission is to reduce implementation costs of fiber-optic lines and increase network coverage; thus achieving complementary and seamlessly of the high-speed transmission bandwidth of GPON and the mobile coverage of LTE.

Developing a resource allocation protocol for the converged network complies with both the Multipoint Control Protocol (MPCP)-based PON Dynamic Bandwidth Allocation (DBA) and an effective mapping mechanism between GPON priority queues and LTE service connections to support high bandwidth and QoS-intensive applications is one of key challenges. It aims at smoothing the stock of resources which reducing both excess inventories and shortages, and meets different user's requirements using the corresponding different priorities to guarantee QoS. However, the asynchrony problem in upstream bandwidth allocation will occur due to the cycle time of GPON (usually is between 1ms and 2ms) and the frame size of LTE (usually is 5ms or 10ms) are mismatched. This paper builds on the QoS mapping strategy and proposes a Synchronous Interleaved Dynamic Bandwidth Assignment (SIDBA) scheme based on the Interleaved Dynamic Bandwidth Allocation in [4] to alleviate the asynchrony problem in the proposed GPON-LTE Converged Network Architecture (GLCNA).

The rest of this paper is organized as follows. The GLCNA is proposed, and the Interoperation of Function Modules for GLCNA, SIDBA and the QoS mapping strategy are introduced in Section II. Performance evaluation is conducted by simulation in terms of the throughput and packet delay in Section III. Conclusions are given in Section IV.

II. Proposed GPON-LTE Converged Network Architecture

We propose an integration of GPON-LTE Converged Network Architecture (GLCNA) which includes Optical Line Terminal (OLT), Passive Splitter (PS), hybrid Optical Network Unit–Evolved Node B (ONU-eNB) and End Users (EUs) which is User Terminal (UT) or User Equipment (UE). The ONU-eNB has one Control Plane which is responsible for collecting requests from GPONs and LTEs, making a report to OLT and receiving a grant from OLT, and broadcasting the grant to EUs after the bandwidth allocation is made; the other is Operation Plane which is responsible for one to one traffic mapping for GPON and LTE which is scheduled for the transmission in next polling cycle. The proposed GLCNA is to reduce capital expenditures and operating expenditures by embedding all functional modules of the ONU, the eNB and Join Controller (JC) into a Printed Circuit Boards (PCB) in the ONU-eNB. In which, the ONU-eNB processes two protocol features including GPON protocol (Packet Classifier, Packet Scheduler and Priority Queues) and LTE protocol (Packet Reconstruct Upstream Scheduler)that shown in **Figure 1**.

A. Interoperations of Function Modules for GLCNA

The interoperations of function modules between End Users (EUs) and OLT in GLCNA are described as follows:

Step 1： Connection requests originating from a variety of applications in UTs/UEs arriving at the GPON/LTE request aggregator through bandwidth request messages in which requests connecting the ONU-eNB are aggregated and classified from T-CONT 1 to T-CONT 4 or QCI 1 to QCI 9.

Step 2： The service classes requirement from GPON/LTE requests will be transferred and mapped to the GPON priority queue; and then waiting for the upcoming polling cycle, the GPON REPORT message with those aggregated requests behind previously granted data.

Step 3： When the OLT receives the REPORT message, the bandwidth allocation module of the OLT assigns bandwidth to the ONU-eNB and sends the GRANT message including the actual values of the allocated bandwidth.

Step 4：After a certain time interval, the GRANT massage with granted bandwidth to service classes of GPON arrives at the GPON grant processor where a specific service class of GPON is mapped to one of LTE QoS. While the corresponding grant information is passed to the GPON upstream/LTE uplink scheduler. When the request bandwidth is assigned to the ONU-eNB, the GPON upstream/LTE uplink scheduler reallocates the bandwidth to UEs with reference to the requested bandwidth. The LTE Grant Generator UEs passes the required bandwidth and the transmission time of the message transmitted through the air link.

Step 5： For this moment, bandwidth reservation and transmission scheduling of the proposed mechanism are executed in the control plane. With the bandwidth allocated for the UE, the UE scheduler decides to provide bandwidth for the service classes to transmit traffics. During the transmission of EU, all traffic flows of the LTE were entrained traffic flow of GPON and bursts are allocated into the air link.

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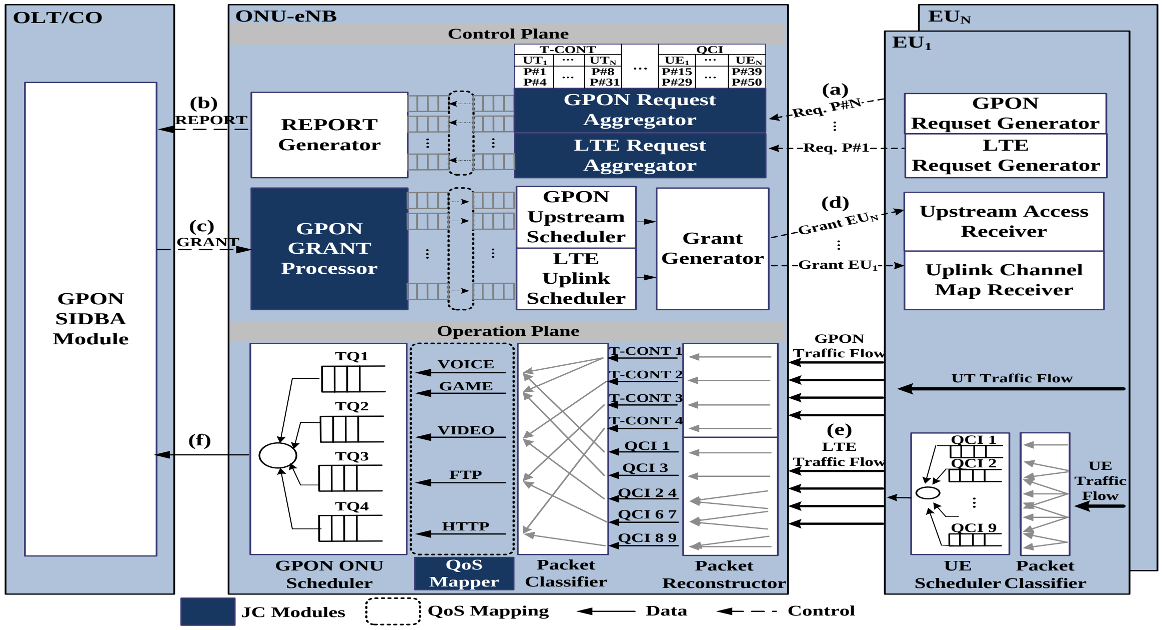

Figure 1. Interoperations of Function Modules for GLCNA.

Step 6： Data bursts ranged from T-CONT 1 to T-CONT 4 or QCI 1 to QCI 9 are scheduled and transferred into the ONU-eNB. Through the packet reconstructor and classifier, the connections of GPON/LTE data return to application flows and are multiplexed to priority queues by the QoS mapper. The scheduler of GPON ONU will transfer the data including the REPORT message at a predetermined time to the OLT. Finally, data bursts coming from the EU will be transmitted with minimal delay through the OLT passing through ONU-eNB.

B. Synchronous Interleaved Dynamic Bandwidth Assignment

Dynamic Bandwidth Assignment (DBA) provides an effective bandwidth management to maximize the utilization of network with Service Levels Agreements (SLA) based QoS requirements includes packet classification, traffic analysis, the transmitting sequence of packets, bandwidth guarantee and transmission delay limit. The difference between the polling cycle time of GPON and the frame size of LTE will cause asynchrony problem in the upstream bandwidth assignment, shown in **Figure 2(a)** for the polling cycle time is 2*ms* and the frame size is 5*ms***.** However, the polling cycle time can be between 1*ms* and 2*ms*, and the frame size can be 5*ms* or 10*ms*.

The transmission data in Cycle Time (k) from GPON and LTE are scheduled as follows: the transmission data from GPON is scheduled in DBA at the end of Cycle Time (k-1); the transmission data from GPON is scheduled in DBA at the end of Cycle Time (k-3). At the same time, after executing the DBA at the end of Cycle Time (k-3), the LTE data will be transmitted at the Cycle Time (k+3) and the Cycle Time (k+4), respectively.

The transmission data in Cycle Time (k+1) from GPON and are scheduled as follows: the transmission data from GPON is scheduled in DBA at the end of Cycle Time (k); the transmission data from GPON is scheduled in DBA at the end of Cycle Time (k-3).

The transmission data in Cycle Time (k+2) from GPON and LTE are scheduled as follows: the transmission data from GPON is scheduled in DBA at the end of Cycle Time (k+1); the transmission data from GPON is scheduled in DBA at the end of Cycle Time (k-3). Due to the Asynchrony problem, the LTE Request Message must be waited to the end of Cycle Time (k+2) to execute the DBA, and the LTE data will be transmitted at the Cycle Time (k+5), Cycle Time (k+6) and Cycle Time (k+7), respectively.

In our previous work [4,5], we proposed a QoS-Aware Interleaved Dynamic Bandwidth Allocation (QA-IDBA) which divides all of the OUN-eNBs into two groups in a round robin cycle and transmits data alternately. This method can solve idle period problem of the traditional DBA mechanism, meet the high priority traffic of low delay, low delay variation, and guarantee QoS services for different traffic characteristics. In the GLCNA, We have inherited the idea of QA-IDBA to design the *Synchronous Interleaved Dynamic Bandwidth Allocation* (*SIDBA*) shown in **Figure 2(b)**.

Due to the polling cycle time is defined as 1*ms*~2*ms* in GPON and the frame size is defined as 5*ms* or 10*ms* in LTE. The following simulations we will compare the performance for various cycle time/frame size pairs in terms of 1*ms*/5*ms*, 1*ms*/10*ms*, 2*ms*/5*ms* and 2*ms*/10*ms*.

C. Quality of Service Mapping

After the SIDBA is executed, different users or different data streams use the corresponding different priorities in heterogeneous networks to guarantee the performance of the stream reaches a certain level. In terms of the number of QoS queues, the GPON defines five different priority queues (T-CONTs), while the LTE defines nine standardized QCIs. In addition, the packet scheduler at ONU-eNBs and the OLT must use the same packet forwarding method for both GPON and LTE upstream/downstream traffic for each and every

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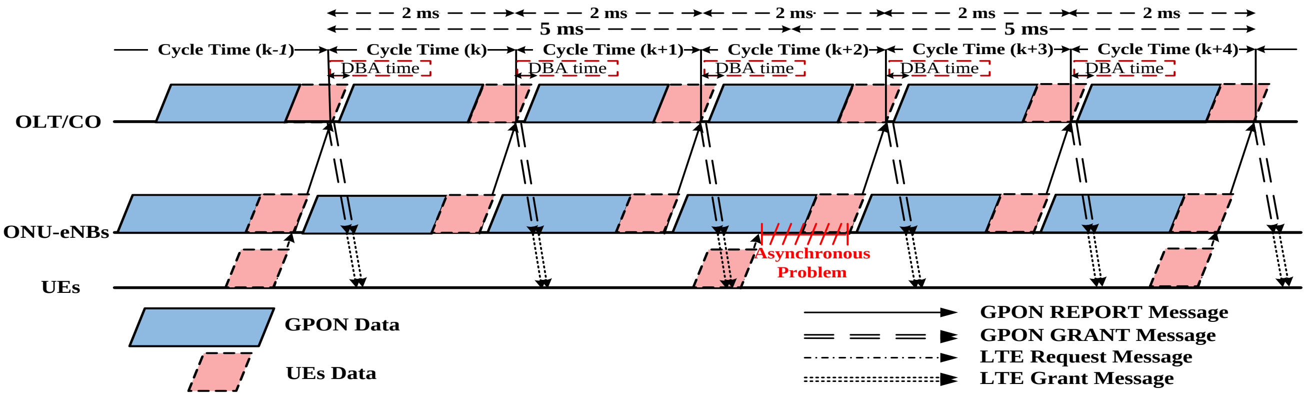

Figure 2(a). Asynchrony Problems in Integrated GPON-LTE Network.

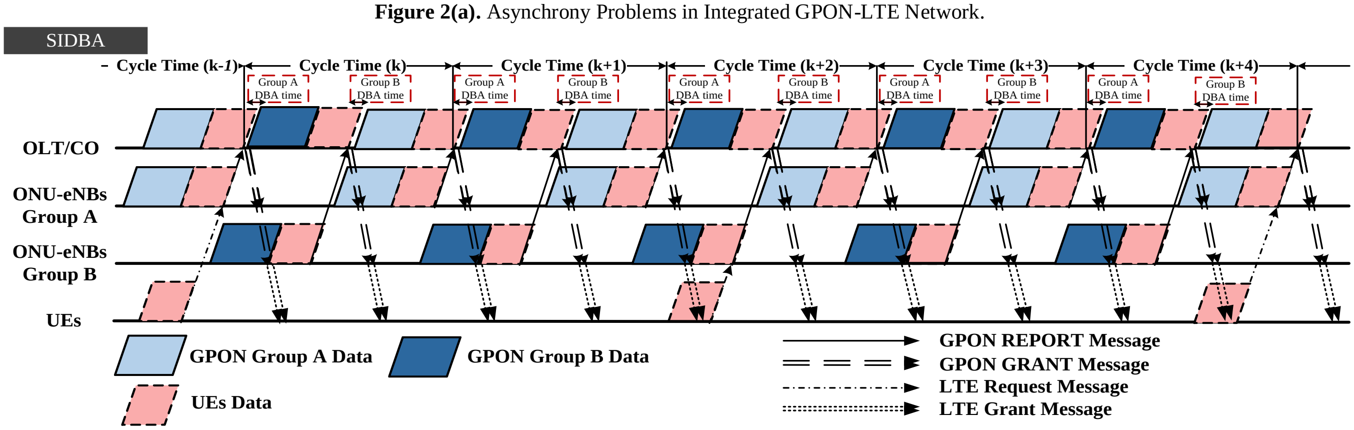

Figure 2(b). Synchronous Interleaved Dynamic Bandwidth Assignment.

configured QCI/DSCP value associated with a given IP flow.

Group mapping adopted in this paper, which provides a full-service integration by more complex mapping schedule, is based on [6].

III. Performance Evaluation

In this section, the system performance of the proposed SIDBA mechanism is evaluated and compared with the IPACT [7] in terms of the throughput and packet delay for different polling cycle time/frame size pairs: 1*ms*/5*ms*, 1*ms*/10*ms*, 2*ms*/5*ms* and 2*ms*/10*ms*. OPNET is used to simulate the proposed scheme, the upstream/downstream link capacity is 1Gbps, the OLT-ONU distance is 10-20km, the buffer size is 10MB, and the guard time is 0.5μs as shown in Table I. The Cisco forecasts optical/wireless traffic ratio that was 55%/45% in 2011, and 39%/61% in 2016 [8]. The service policy follows the first-in first-out (FIFO) principle. For the traffic model, an extensive study has shown that most network traffic can be characterized by self-similarity and long-range dependence (LRD) [9]. In GPON, the packet size generated each time for T-CONT 1, T-CONT 2, T-CONT 3 or T-CONT 4 traffic is 560 bytes, 560 bytes, 64-1518 bytes (exponential) and 64-1518 bytes (exponential) with probability of 10%, 50%, 25% and 15%, respectively [8]. In LTE, the packet size generated each time for VOICE, VIDEO, HTTP, FTP or GAMING traffic is 180/280 bytes (uniform), 200-500 bytes (uniform), 1300 bytes, 1300 bytes and 100/240 bytes (uniform) with probability of 5%, 50%, 25%, 15% and 5%, respectively [10]. In GPON-LTE, we sets TQ1-TQ4 corresponds T-CONT 1, QCI 1 and QCI 3; T-CONT 2, QCI 2 and QCI 4; T-CONT 3, QCI 6 and QCI 7; T-CONT 4, QCI 8 and QCI 9, respectively. In order to simulate the effect of high-priority traffic, the proportion of the traffic profile is analyzed by simulating the different cycle time/frame size pairs. The simulation scenario is summarized in **Table I**.

Table I.
Simulation Scenario

Global

Number of ONUs	32
Upstream/downstream link	1 Gb/s
OLT-ONU distance (uniform)	20 km
Buffer size	10 MB
GPON/LTE traffic load ratio [18]	55%/45% (2011 years) 39%/61% (2016 years)
Guard time	5 μs

GPON

QoS	Distribution	Packet size	Traffic type ratio
T-CONT 1	CBR	560 bytes	10 %
T-CONT 2	CBR	560 bytes	50 %
T-CONT 3	VBR	64-1518 bytes (exponential)	25 %
T-CONT 4	VBR	64-1518 bytes (exponential)	15 %

LTE

QoS	Distribution	Packet size	Traffic type ratio
QCI 1	CBR	180, 280 bytes (uniform)	5 %
QCI 2, QCI 4	VBR	200-500 bytes(uniform)	50 %
QCI 6, QCI 7	CBR	1300 bytes	25 %
QCI 8, QCI 9	CBR	1300 bytes	15 %
QCI 3	CBR	100, 240 bytes (uniform)	5 %

A. Throughput

Figure 4 shows the throughput of IPACT and SIDBA for different polling cycle time/frame size pairs in terms of 1*ms*/5*ms*, 1*ms*/10*ms*, 2*ms*/5*ms* and 2*ms*/10*ms* with GPON/LTE traffic loads of 55%/45% and 39%/61%. For studying different cases of polling cycle time/frame size pairs, the 2*ms*/5*ms* has the highest throughput, the second is 2*ms*/10*ms*, followed by 1*ms*/5*ms*, 1*ms*/10*m*s. For different GPON/LTE traffic load pairs, the throughput in case of 39%/61% is higher than 55%/45% due to the traffic priority of LTE is higher than GPON. For the TQ2 throughput, as shown in **Figure 4**(a), the proposed SIDBA with 2*ms*/5*m*s (55%/45%) scenario outperforms the other scenarios because the idle time problem is overcame. The performance of others are similar to case of total throughput, shown in **Figure 4**(a), except IPACT_2*m*s5*m*s (39%/61%) because the IPACT cannot satisfy the requirement when the traffic load of LTE is high. Furthermore, for the TQ3 and TQ4 throughputs, as shown in **Figure 4**(b) and **Figure 4**(c), the SIDBA_2*m*s5*m*s has the highest throughput. The reason is that even without a higher priority, the packet can be quickly transmitted by SIDBA. The TQ3 throughput of SIDBA_1*m*s10*m*s begins to decrease when the traffic load exceeds 60%, whereas the TQ4 throughput of SIDBA_1 ms10ms begins to decrease when the traffic load exceeding 40%. The reason is that the SIDBA cannot support the greater ratio between cycle time and frame size.

B. Packet delay

Figure 5 shows the packet delay of IPACT and SIDBA for different cycle time/frame size pairs in terms of 1*ms*/5*m*s, 1*ms*/10*m*s, 2*ms*/5*ms* and 2*ms*/10*m*s with GPON/LTE traffic load of 55%/45% and 39%/61%. In **Figure 5**(a), the simulation results show that both the SIDBA_1*m*s10*m*s and the SIDBA_2*m*s10*m*s cases have higher packet delay when the traffic load exceeds 60%. The SIDBA_2*m*s5*m*s has the best performance in packet delay when the ratio of TQ2 traffic increases. The reason is that the SIDBA mechanism can satisfy the required bandwidth of TQ2 first followed by the required bandwidth of TQ3 and TQ4. Based on **Figure 5**(b), The SIDBA_2*m*s5*m*s has the best performance of packet delay in TQ3 delay. The reason is that the SIDBA can quickly transmit the packet when packets arrived. The TQ3 performance of packet delay of SIDBA_1*m*s5*m*s (55%/45%) begins to decrease with the traffic load exceeding 60%, whereas the TQ4 performance of packet delay of the SIDBA_1 *m*s10*ms* begins to decrease when the traffic load exceeds 40%. One possible reason is that the wireless frame cannot fill the free time slots when the polling cycle time is quite short.

IV. CONCLUTION

This paper has addressed the issue on the convergence of GPON and LTE broadband access networks. The GPON-LTE Converged Network Architecture (GLCNA) is proposed and the control and operation of this architecture is discussed. The GLCNA scheme takes into account the specific features of the converged network to enable a smooth data transmission across optical and wireless networks. The QoS mapping strategy is defined for GPON-LTE converged networks to make efficient conversions between GPON in DiffServ and LTE in IntServ services for supporting different services. Finally, the Synchronous Interleaved Dynamic Bandwidth Assignment (SIDBA) scheme is proposed that is specifically tailored to the unique features and resolve the idle period and asynchronous problem in upstream bandwidth assignment between the heterogeneous networks. Moreover, the different period of times between polling cycle time and frame size are evaluated in this paper. The simulation results show that the throughput, packet delay can be improved, specially, in the case of 2*ms*/5*ms*. Our work in this paper only presents some preliminary study in this area with a particular focus on bandwidth assignment. Some other topics such as admission control and effect of handover on network performance can be investigated in the future.

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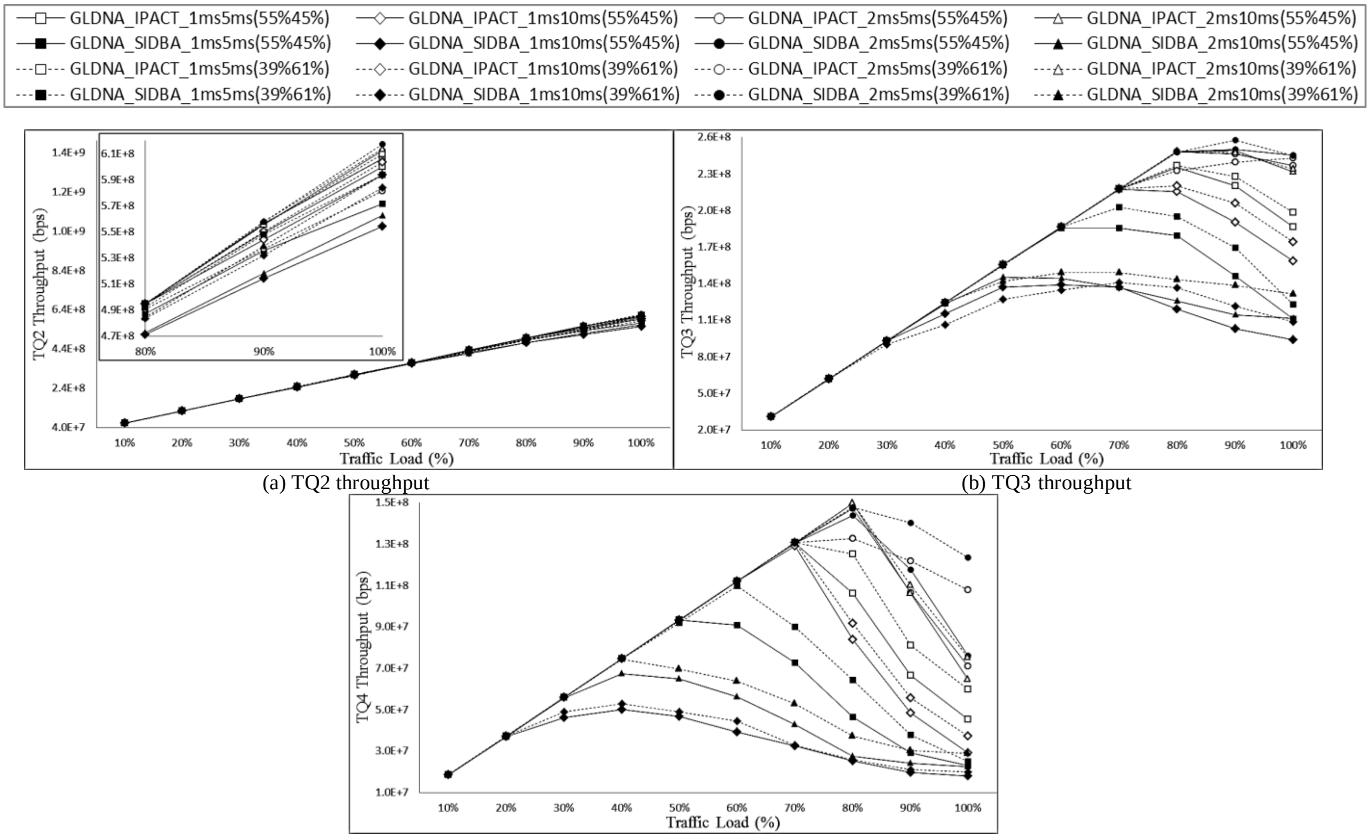
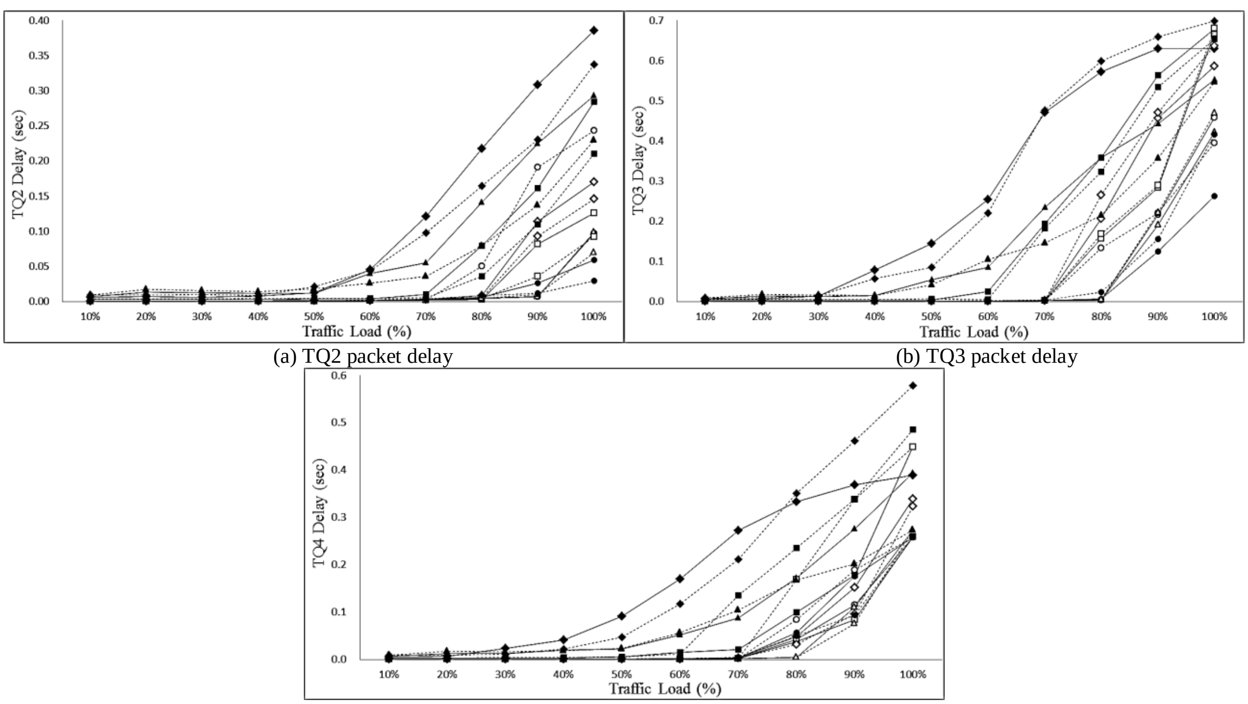
ISBN: 978-988-19253-9-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)



(a) TQ2 throughput (b) TQ3 throughput

(c) TQ4 throughput

Figure 4. TQ 2, TQ 3, TQ 4 Throughput versus different traffic load comparisons with the IPACT scheme and SIDBA scheme for 1ms/5ms, 1ms/10ms, 2ms/5ms and 2ms/10ms of cycle time/frame size ratio.



(a) TQ2 packet delay (b) TQ3 packet delay

(c) TQ4 packet delay

Figure 5. TQ 2, TQ 3, TQ 4 Packet delay versus different traffic load comparisons with the IPACT scheme and SIDBA scheme for 1 ms/5 ms, 1 ms/10 ms, 2 ms/5 ms and 2 ms/ 10 ms of cycle time/frame size ratio.

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