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Extended WiMAX QoS-aware Scheduling for Integrated CWDM-PON and WiMAX Network

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Abstract: Worldwide Interoperability for Microwave Access (WiMAX) has emerged as one of key technologies for wireless broadband access network while Coarse Wavelength Division Multiplexing-Passive Optical Network (CWDM-PON) is one of the potential solutions for future high speed broadband access network. Integrating both networks could enhance the whole network performance by allowing cost-effectiveness, higher capacity, wider coverage, better network flexibility and higher reliability. In this study, scheduling algorithm is proposed as means to maintain the Quality of Service (QoS) requirements of two different media whilst allocating the bandwidth to the subscribers. The NS-2 simulation results demonstrate how network performances of the integrated CWDM-PON and WiMAX networks are improved in terms of delay and throughput.

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1. Introduction

Coarse Wavelength Division Multiplexing-Passive Optical Network (CWDM-PON) is among the latest broadband access network technologies which are still in the research and development stage. Some experiments set up have shown the ability of the system to be deployed in Fiber-to-the-Home (FTTH) environment where high bandwidth requirement is one of the critical factors demanded from the subscribers (Khairi *et al.*, 2009). In general, FTTH is responsible in carrying triple play services comprises voice, video and data services. Following the QoS traffic classes of similar PON system by Yang *et al.* in 2009, CWDM-PON QoS traffic classes can be divided into Expedited Forwarding (EF), Assured Forwarding (AF) and Best Effort (BE).

Meanwhile, Worldwide Interoperability for Microwave Access (WiMAX) has shown its potential for the next-generation wireless networks technology as it provides high mobility and bandwidth. IEEE802.16 standard of WiMAX consists of five QoS classes, which are Unsolicited Grant Service (UGS), real-time Polling Service (rtPS), extended real-time Polling Service (ertPS), non-real-time Polling Service (nrtPS) and Best Effort (BE) (Yang *et al.* 2009, Hwang *et al.* 2009 and Ranaweera *et al.* 2011).

Currently, the integration of optical and wireless technologies to create a single access network has been one of the hot topics among researchers because of the advantages in the mobility and flexibility of the network compared to the fixed network infrastructure such as PON alone. With proven reliability of optical networks at the back end and flexible wireless network at the front end, the integrated network is believed to provide better service to the subscribers.

In 2009, Lee *et al.* had come up with hybrid network of Ethernet PON (EPON), WiMAX and Wireless Local Area Network (WLAN). The proposed network included QoS mapping but lack of detailed technical solutions for QoS support. Hwang *et al.* have also studied integrated network of EPON and WiMAX in the same year, with introduction of two-step scheduling without leaving out the QoS mapping, but the work only focused on dynamic bandwidth allocation at downlink transmission. The work of Hwang *et al.* (2009) is then enhanced by Yang *et al.* (2009), by introducing virtual Optical Network Unit-Base Station (ONU-BS). Yang *et al.* (2009) focused on bandwidth allocation only; neither scheduling scheme nor admission control is mentioned. In 2011, Shaddad *et al.* have proposed another integrated network which combined TDM/WDM-PON with WiMAX, but this network only focused on physical layer analysis without any scheduling scheme. So far, it can be seen that a vast majority of previous works on integrated optical wireless have not addressed the issue of both fairness and Quality of Service (QoS) during bandwidth allocation. On the other hand, Freitag and da Fonseca (2007 and 2008) have proposed a scheduling algorithm used to allocate bandwidth to the subscriber's stations (SSs) based on the QoS requirements of the connections for uplink WiMAX network. The proposed scheme is able to support QoS guarantees as well as to allocate bandwidth fairly among flows of the same service type.

Currently, no work has been done to integrate the CWDM-PON and WiMAX in order to provide the applications and services for network subscribers while maintaining the QoS over different network channel. Thus, such architecture is proposed to face the increasing demand from the subscribers in the future. This study extends the WiMAX scheduling algorithm by Freitag and da Fonseca (2007) for the converged network of CWDM-PON and WiMAX, exploiting the existing QoS parameters of the WiMAX network that will be mapped to the three QoS traffic classes of CWDM-PON (Yang *et al.* 2009, Hwang *et al.* 2009 and Ranaweera *et al.* 2011).

2. Network Topology

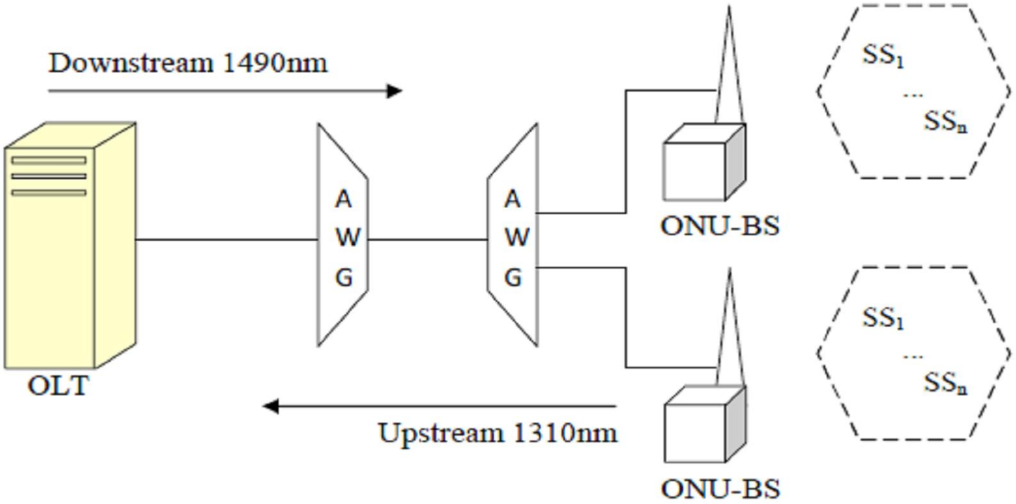

Figure 1: Proposed integrated CWDM-PON and WiMAX network.

Typically, an integrated CWDM-PON and WiMAX network utilizes the tree topology at the optical backend while Point-to-Multipoint (PMP) topology is applied at the wireless front end. An Optical Line Terminal (OLT) from CWDM-PON is connected to the integrated Optical Network Unit-Base Station (ONU-BS) by two Arrayed Waveguide Gratings (AWGs), adopted from previous CWDM-PON system of Khairi *et al* in 2009. The OLT is responsible for scheduling the up-link traffic among all the ONU-BSs since they share the up-link resources from the AWGs to the OLT, as shown in Figure 1. The ONU-BS is then connected to subscribers station (SS) wirelessly.

3. QoS Mapping and Scheduling Mechanism

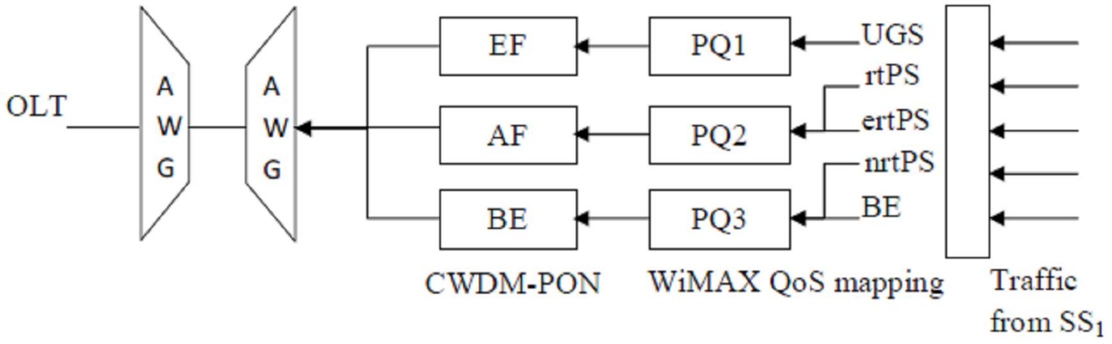

Figure 2: Proposed QoS mapping of integrated CWDM-PON and WiMAX network.

As the nrtPS service in WiMAX is quite similar to BE of the network, these two service types are combined as Priority Queue 2 (PQ3) and then mapped to BE classes of CWDM-PON in this work. rtPS and ertPS are combined as Priority Queue 2 (PQ2) and are mapped to CWDM-PON AF, while UGS at Priority Queue 1 (PQ1) is mapped to CWDM-PON EF class to be sent to the OLT. Three types of traffic are considered: voice, video, and data, which are associated to PQ1, PQ2, and PQ3 services, respectively.

Three queues are used in this proposed scheduler, referred as low priority queue, intermediate queue and high priority queue (Freitag and da Fonseca, 2007 and 2008). The requests are served in a strict priority order from the high priority queue to the low priority queue. The bandwidth requests of the PQ3 service flows are stored in the low priority queue while the bandwidth requests sent by PQ2 connections are held by the intermediate queue. The high priority queue stores the bandwidth request of PQ1 service flows. The proposed discipline is presented as follow:

```
ALGORITHM Scheduling
Insert the periodic data grants in high priority queue, and unicast request opportunities that must be scheduled in the next frame;
CheckDeadline;
CheckMinimumBandwidth;
Schedule the requests in the high priority queue starting from the head of the queue;
If intermediate queue is empty and available_slots > 0, schedule the requests in the low priority queue starting from the head of the queue;

CheckDeadline:
for each request i in the intermediate queue do
  if service[CID] == PQ2 then
    frame[i] = $\left\lfloor \frac{(\text{deadline}[i]-\text{current\_time})}{\text{frame duration}} \right\rfloor$;
    if frame[i] == 1 then
      if available_bytes ≥ BR[i]
        migrate request i to high priority queue;
        granted_BW[CID] = granted_BW[CID]  + BR[i];
        backlogged[CID] = backlogged[CID] – BR[i];
        available_bytes = available_bytes – BR[i];

CheckMinimumBandwidth
for each connection CID of type PQ2 do
  backlogged_tmp[CID] = backlogged[CID];
  granted_BW_tmp[CID] = granted_BW[CID];
for each request i in the intermediate queue do
  if BWmin[CID] ≤ granted_BW_tmp[CID] then
    priority[i] = 0;
  else
    priority[i] = backlogged_tmp[CID] – (granted_BW_tmp[CID] – BWmin[CID];
    granted_BW_tmp[CID] = granted_BW_tmp[CID] + BR[i];
    backlogged_tmp[CID] = backlogged_tmp[CID] – BR[i];
sort the intermediate queue;
for each request i in the intermediate queue do
  if available_bytes ≥ BR[i] then
    migrate request to the high priority queue;
    granted_BW[CID] = granted_BW[CID] + BR[i];
    backlogged[CID] = backlogged[CID] – BR[i];
    available_bytes = available_bytes – BR[i];
```

The data grants are periodically inserted into the high priority queue to guarantee the bandwidth to PQ1 flows. After inserting it, the scheduler checks whether the request in the intermediate queue should be scheduled in the following frame or not based on the deadline and the minimum bandwidth required. If the high priority queue is empty, the scheduler would migrate the request from the intermediate queue to the high priority queue. This also applied to the low priority queue when the intermediate queue is empty and there are available slots in the uplink frame.

4. Simulation Setup

The simulation experiment is done in NS-2 to measure the throughput and the delay of the network. PQ1 traffic generator is an "on/off" one with duration of periods exponentially distributed with a mean of 1.2 s and 1.8 s for the "on" and "off" periods, respectively. A new packet for one PQ1 connection is generated every 20 ms with packet size of 66 bytes (IEEE Standard, 2004). According to Alsolami (2008), most of the Internet traffic is generated by http, VBR, and FTP. Thus, PQ2 traffic consumes most of the network bandwidth compared to the PQ1 traffic. PQ2 traffic is generated by real MPEG traces (Seeling *et al.,* 2004), with delay requirement of 100 ms. Each connection has its own minimum bandwidth requirement which varies according to the mean rate of the transmitted video. PQ3 traffic is not sensitive to delay as PQ1 and PQ2; however it is subject to a minimum bandwidth requirement.

For all simulated scenarios, it is assumed that each SS has only one traffic flow to prevent interference between packet scheduling in the SSs and the evaluation of the scheduling mechanism at the BS. The performance of the network is evaluated considering ideal channel condition of CWDM-PON system following the experimental analysis on physical layer. The duplex link was used for both downlink and uplink transmission. The optical characteristics in NS-2 simulation were defined for the link bandwidth and time delay properties. As for CWDM-PON, the channel link capacity is assigned 2.5 Gbps with 2 ms delay. This link is created between the wired CWDM-PON network segment and BS nodes of WiMAX network.

The delay of CWDM-PON link is mainly contributed by fiber propagation, processing and transmission delays. Our preliminary analysis using Optisystem proves that the received SNR at maximum length 100 km is 15.11 dB (input SNR=27 dB), which is within the allowable SNR limit at 2.5 Gbps i.e. 10.4 dB (Ali and Pennickx, 2004). As light velocity inside fiber is at 2.0×10^{-8} m/s, the light propagation delay is 0.5 ms. Therefore, for network layer analysis of the proposed integrated network, contribution from other delays including device rise/fall time, device processing time, transmission delay is assumed to be three times the fiber propagation delay or 1.5 ms.

For each scenario, one ONU-BS is connected to multiple SSs. In this work, the number of BS and SSs are based on the work of Freitag and da Fonseca in 2007. The number of PQ1, PQ2 and PQ3 connections is varied according to the offered traffic load. In this paper, the simulation is done in three parts, detailed as follows:

A. Effects of Increasing Voice Traffic Load to other Service Classes

This simulation aims to investigate whether or not the increase of the PQ1 traffic load degrades the QoS level of services with lower priority. The scenario for this experiment consists of one BS and 61 SSs. There are 6 PQ2 connections, 20 PQ3 connections, and the number of active PQ1 connections varies from 15 to 35.

B. Effects of Increasing Video Traffic Load to other Service Classes

The impact of the load increase of the video service on the performance of other service classes is also verified. The PQ2 service carries video traffic which is quite bursty, and the peak loads must be handled by the scheduler without giving so much effect to the QoS level of the other service classes. Because of the bursty traffic, the variation of the number of PQ2 connections has stronger impact on the offered load and on the traffic dynamics than the variation. For this scenario, one BS and 42 SSs are involved. There are 15 PQ1 connections, 20 PQ3 connections and the number of active PQ2 connections is varied from 1 to 7.

C. Effects of Increasing Data Traffic Load to other Service Classes

In this experiment, the traffic load of data service is varied to understand how it influences the QoS level of services at higher priority. The active PQ3 connections which hold data service is varied from 10 to 35 connections. There is one BS connected to 15 PQ1 connections and 5 PQ2 connections, which compute 55 SSs in total.

5. Results Analysis

Results of the three simulation scenarios are compared to the simulation results of Freitag *et al.* in 2007. Figure 3 to 8 compare the delay performances of our proposed algorithm, which is named as C-QWi algorithm, with the already published algorithm of Freitag *et al.* (2007), which is labeled as QWi algorithm.

From Figure 3 to 8, the delay of PQ1 connections are not affected by the increasing connection numbers for the whole connection range. This proves that the scheduler is able to provide data grants at fixed intervals as required by the service. The delay of PQ2 connections show little oscillation as the number of connections increased for all three simulation scenarios because the scheduler have to fulfill the demands of high priority PQ1 traffic class before offering the bandwidth to lower priority PQ2 traffic class.

When comparing both Figure 3 and 4, it can be seen that the service performance is quite similar, except that in between 15 to 30 connections of PQ1, the delay of video service for C-QWi scheduler is much better than the delay of video service for QWi scheduler. Comparing both Figure 5 and 6, video service in Figure 6 suffers higher delay than Figure 5 as the number of video service connections increases. In spite of the increment in video connections, the delay values are considerably lower than the required one, according to WiMAX standard as mentioned in Section 4.0, which is 100 ms.

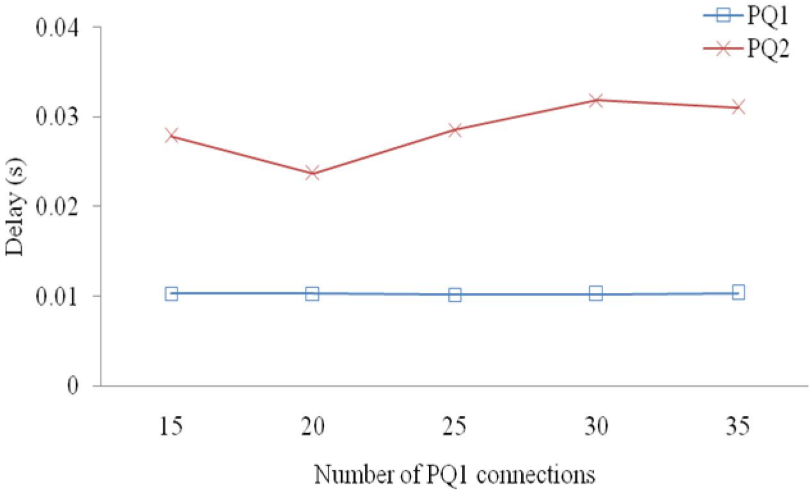

Figure 3: The delay of high priority classes over increasing PQ1 connections for the proposed C-QWi scheduler.

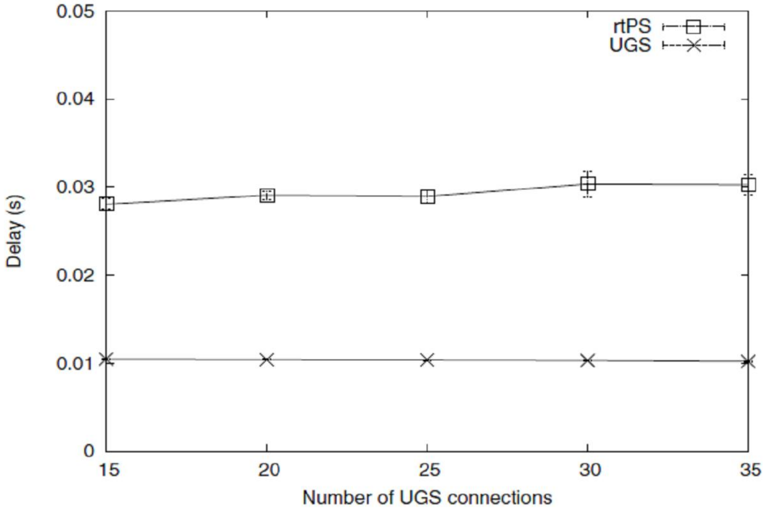

Figure 4: The delay of high priority classes over increasing UGS connections using QWi scheduler (Freitag *et al.*, 2007).

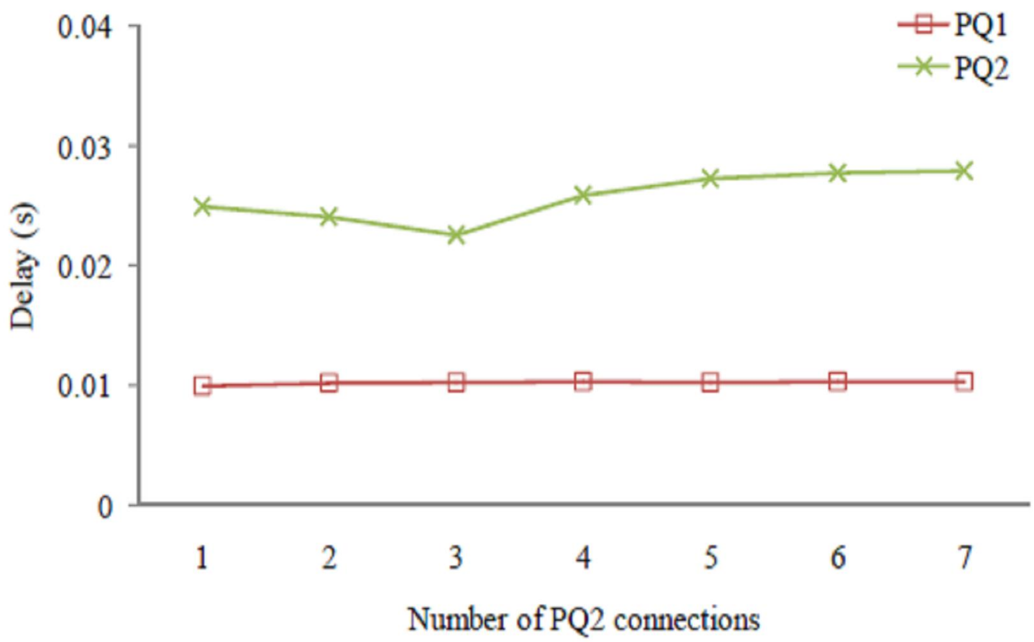

Figure 5: The delay of high priority classes over increasing PQ2 connections for the proposed C-QWi scheduler.

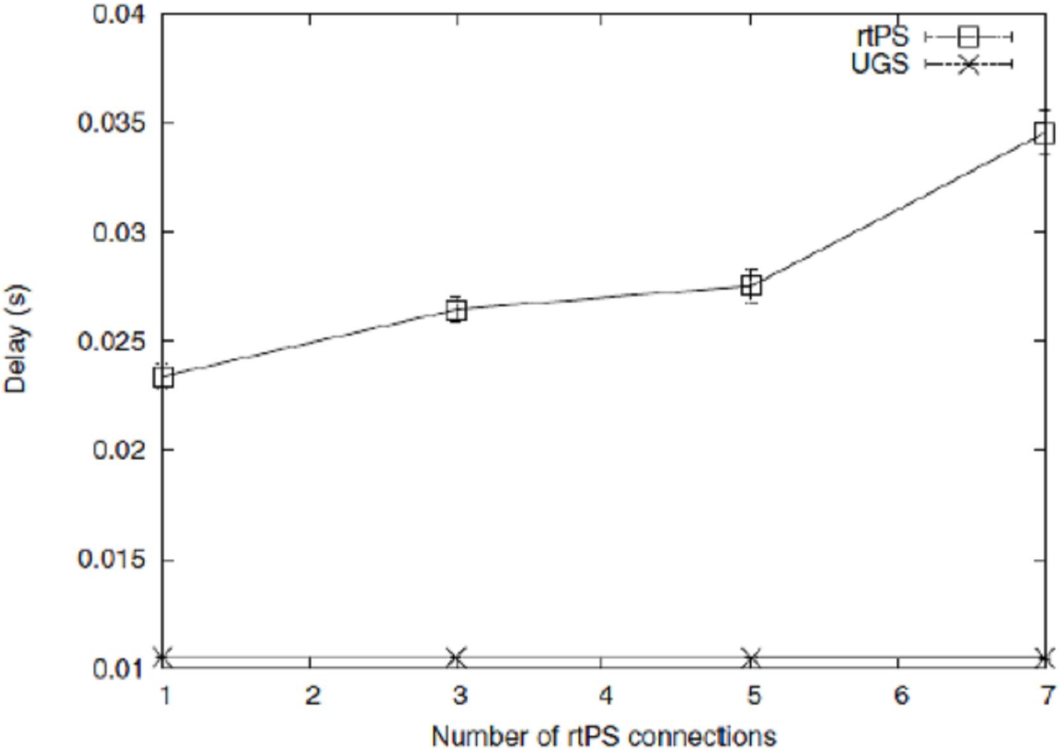

Figure 6: The delay of high priority classes over increasing rtPS connections using QWi scheduler (Freitag *et al.*, 2007).

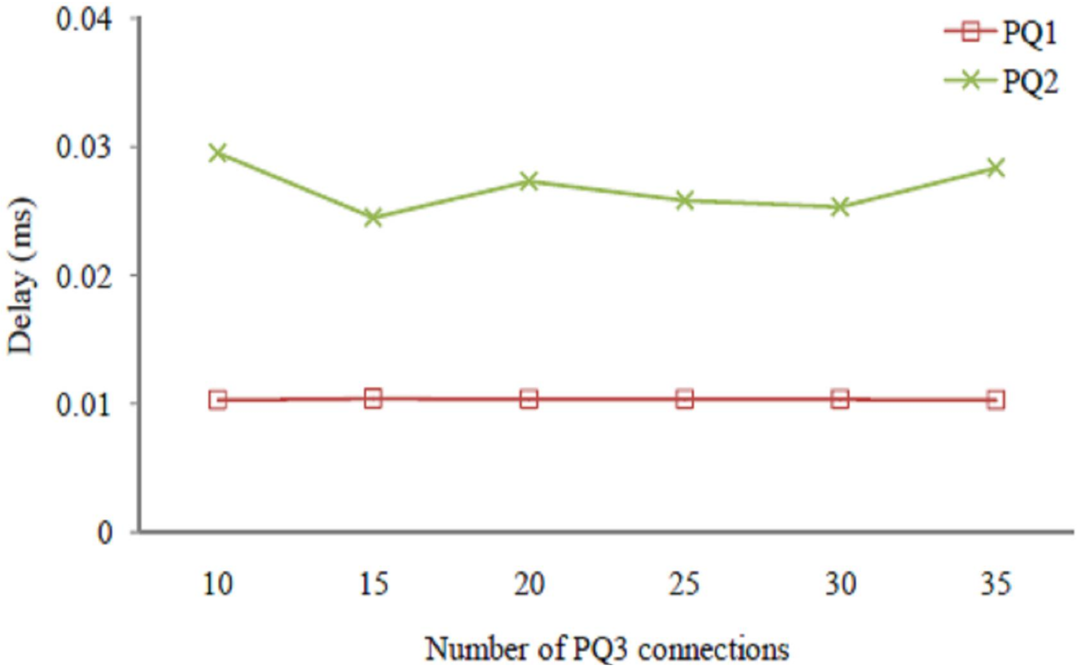

Figure 7: The delay of high priority classes over increasing PQ3 connections for the proposed C-QWi scheduler.

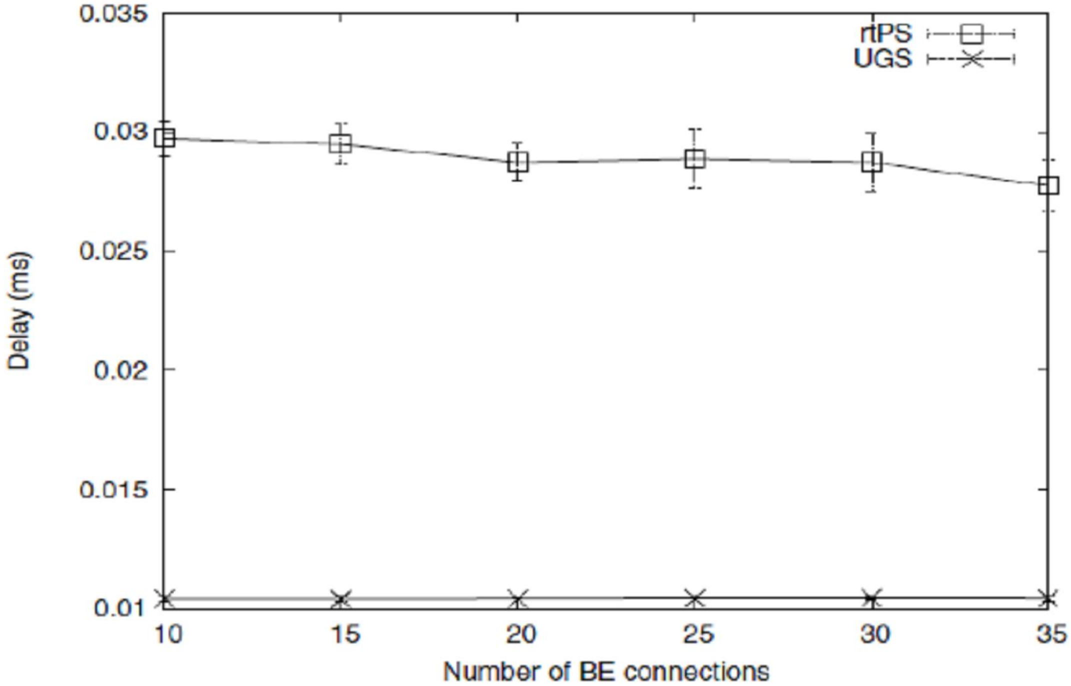

Figure 8: The delay of high priority classes over increasing BE connections using QWi scheduler (Freitag *et al.*, 2007).

As for Figure 7, PQ1 connections experienced constant delays for all simulated loads and the delay of the PQ2 connections show little oscillation as the number of PQ3 connections increased for C-QWi scheduler. In spite of oscillated delay performance of PQ2 connections, the delay performances of both higher priority classes were still satisfying the network traffic demands. This result is quite similar with the delay of high priority traffic classes over the number of BE connections for QWi scheduler in Figure 8.

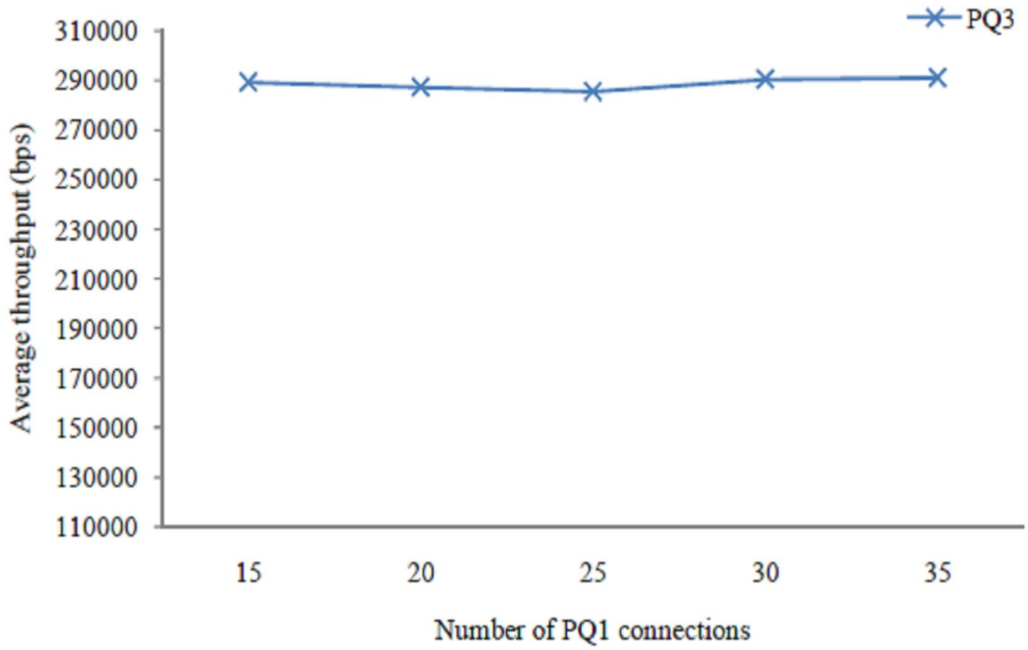

Figure 9: Average throughput of PQ3 connections over the number of PQ1 connections for the proposed C-QWi scheduler.

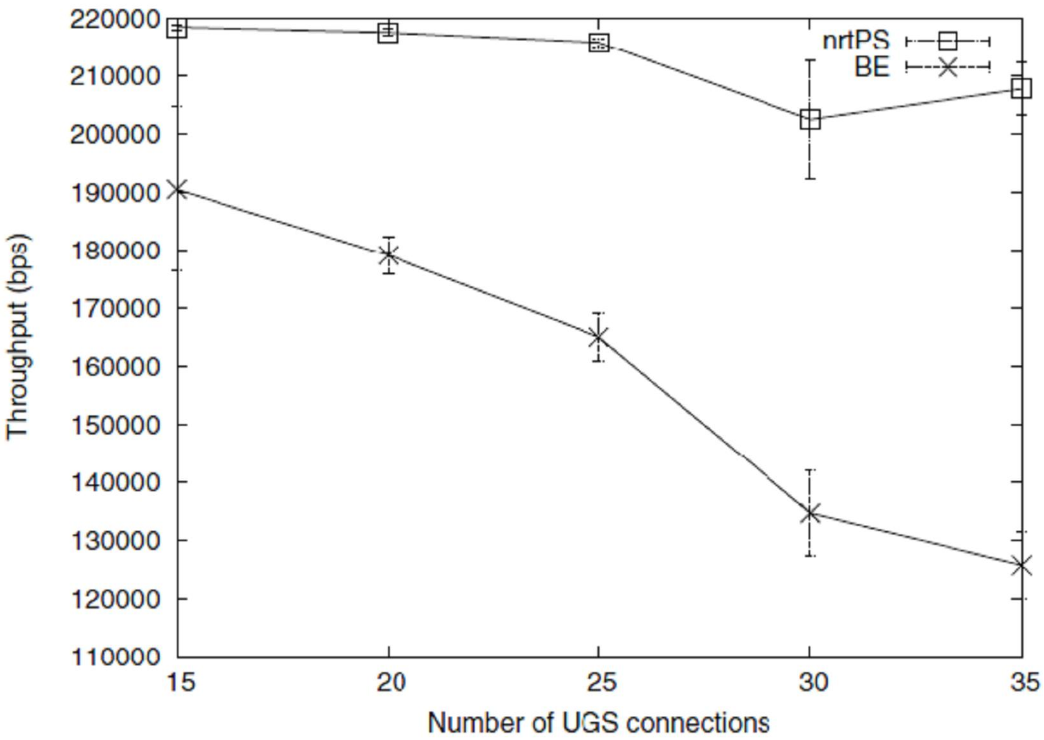

Figure 10: Throughput of nrtPS and BE connections over the number of UGS connections using QWi scheduler (Freitag *et al*., 2007).

For throughput performance, the throughput of the lower priority class, PQ3 almost maintains at high bit rate with an increasing number of PQ1 connections (Figure 9). This shows that the C-QWi scheduler can allocate bandwidth to the lower priority classes even the voice load increases. Large optical link capacity of CWDM-PON at the back end is able to use the excess bandwidth from the higher priority classes to serve the lower priority classes.

The presence of 2.5 Gbps CWDM-PON link at the optical back end of the integrated network is able to help the network to maintain the throughput of the lower priority class, compared to the 40 Mbps WiMAX network alone while using QWi scheduler. This surpasses the throughput performance of nrtPS and BE connections over the number of BE connections for the QWi scheduler, as shown in Figure 10.

6. Conclusion

In this study, the QoS-aware scheduling algorithm of integrated CWDM-PON and WiMAX network is concerned. The addition of CWDM-PON to the WiMAX network enables the use of higher optical link capacity and variation of offered loads. Based on the simulation work, the proposed C-QWi scheme could satisfy the delay requirement for real time traffic, specifically video service, PQ2. The delay of all classes of services were not much affected when the offered load is varied, showing that the optical link delay is negligible, thus would not degrade the performance of the proposed integrated network. The findings show the feasibility of the proposed integrated CWDM-PON and WiMAX network, also throughput improvement compared to the WiMAX network alone.

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