Best Effort Traffic Uplink Transmission Performance Evaluation of an Integrated EPON/IPACT and WiMAX (OFDMA) Architecture

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Abstract. A performance analysis has been undertaken for best effort uplink traffic within an integrated EPON and WiMAX OFDMA architecture. Although studies into this type of integration have been reported, a rigorous analysis has not been carried out in integrating EPON with WiMAX with mobility. The paper describes the last mile problem, EPON and WiMAX. Also an integration approach will be presented and analysed in the paper in the form of average delay, throughput and packet loss.

Keywords: Ethernet Passive Optical Network, WiMax, OFDMA, MAC, Dynamic Bandwidth Allocation.

1 Introduction

The last mile has been the focus of much development. Bandwidth intensive services such as VoIP, VoD, IPTV and Video teleconferencing are becoming increasingly popular with end users; however the current infrastructure exhibits limited evolution in terms of provisioning a rich mix of real-time services to a growing number of users.

One future proof approach centres on the deployment of optical fibre to end user's premises as it provides a virtually unbounded bandwidth capability. However this type of deployment represents a significant cost to the service providers [1]. Therefore to lower the cost of provisioning services an alternative strategy is to extend the reach – the 'last drop' - of the optical fibre through the use of appropriate wireless broadband technologies.

A route to implementing this strategy is to integrate Ethernet Passive Optical Networks (EPON) and technologies defined by the Worldwide Interoperability for Microwave Access (WiMAX) standards into a single architecture. Although a number of possible integration approaches have been reported [1][2], this paper highlights the issues and undertakes an initial performance evaluation of the integration in the WiMAX OFDMA mode for mobile users. Before detailing the potential integration option and its analysis, in order to provide a foundation to bring clarity to the results, a brief overview of EPON and WiMAX are presented.

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2 Technologies Review

2.1 EPON Overview

Ethernet Passive Optical Network (EPON) is a passive optical technology which consists of three components, the OLT, the ONU and the passive splitter [3] [4]. OLT (Optical line termination) is the interface between the service providers and the users and resides at the central office. The passive splitter/combiner is a device that requires no electrical supply and therefore lowers the cost of deployment. The functionality of the passive splitter/combiner is to split the signal to every user in the network and to combine signals from the user to the OLT. The ONU (Optical Network Unit) resides near the end user. The ONU can be either located near the end user or be an interface between the optical network and a copper or wireless network. The ONU receives packets from the users and stores them in the appropriate queue according to their type. The data rate between the ONU and OLT is 1GB\s symmetric. The topology of the network that the paper is focused on is the tree topology as shown below:

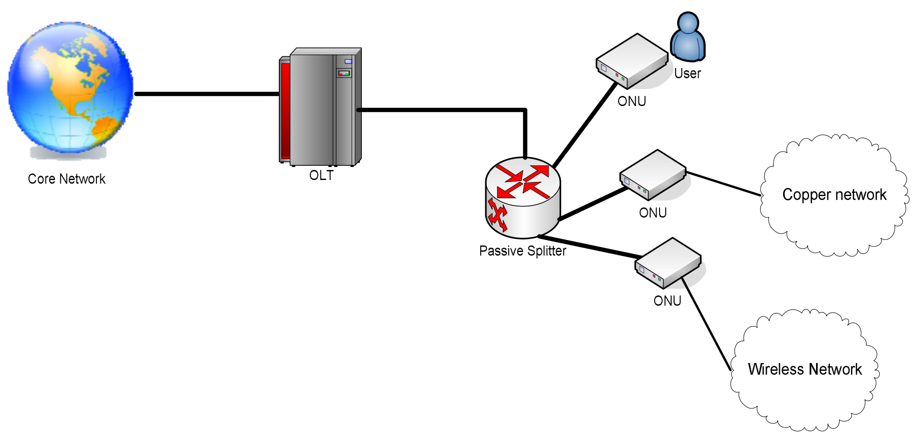

Fig. 1. The above network shows the topology of an EPON network. The network consists of an OLT which is connected to the core network, a passive splitter which is located between the OLT and ONUs and an ONU which is located near the end user or connected to another network.

At the packet level, in the downlink (OLT to ONU), packets are broadcast to all ONUs (at a wavelength of 1550nm) via the passive splitter [3]. Once each ONU receives the packets, it filters out the data designated for it and discards the rest. In the uplink, packets are transmitted (at a wavelength of 1330nm) again via the passive splitter; however since the fibre is a shared medium, time slots are normally allocated to each ONU so that they can transmit data without collisions. Time slots are allocated by the OLT and the amount granted is dependent on a bandwidth allocation process. Once the ONU receives a grant, scheduling is performed to allow queues inside the ONU to send data and requests.

2.2 WiMAX Overview

WiMAX (Worldwide Interoperability for Microwave Access) is a mobile broadband wireless access technology which operates between the bandwidth of 1.25MHz and 20 MHz [5][6]. The WiMAX network consists of two components the Base station (BS) and the Subscriber station (SS). In a WiMAX deployed network the BS like the OLT is the interface between the service providers and the users and resides at the central office. The SS resides at the user's home and collects packets from the user and stores them into appropriates queues. The transmit rate is dependent on the frame size, the DL to UL ratio, the modulation and coding rate assigned to the SS and the number of sub channels and slots assigned to the SS. A high level schematic of a typical deployment topology is shown in Fig. 2.

The BS functionality is similar to that of the OLT, receiving packets from the core network and broadcasting them to all SSs. When the SS receives the packets it filters out the intended data using a connection ID and discards the rest. For the uplink, the medium is again shared and therefore the BS needs to allocate resources to the SS. The resources allocated in the OFDMA mode are both in time and frequency and are referred to as slots. Once the SS receives a grant, scheduling is performed to allow queues or connections to send data and requests. Each connection has its own request mechanism [5] [6].

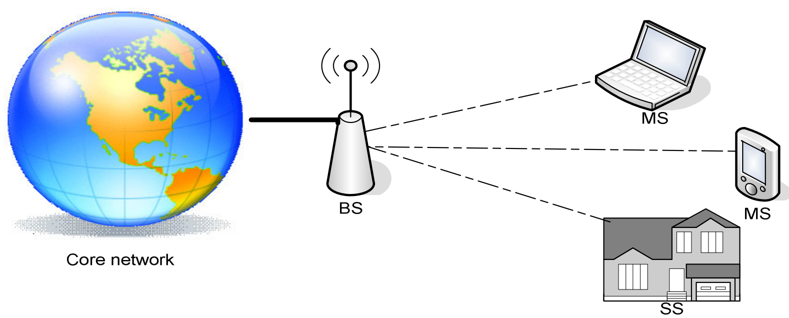

Fig. 2. The above network shows the topology of a WiMax network. The network consists of a BS which is connected to the core network, and an SS/MS which is located near the end user or connected to another network.

WiMAX supports five types of connections [5, 6]:

- Unsolicited Grant Service (UGS). It is used for services such as T1/E1 traffic and VOIP without silence suppression. WiMAX supports this service by allocating it fixed size grants on a real time periodic basis
- Extended Real Time Polling Service (ERTPS)**;** used for VOIP with silent suppression. The BS supports this service by allocating grants to the SS on a periodic basis which the SS can use to send data or requests.
- Real Time Polling Service. (RTPS); used for video (MPEG) services. The BS supports this service by sending unicast polls to the SS at periodic intervals

- Non Real Time Polling Service (NRTPS). It is commonly used for FTP and other best effort traffic. The BS supports this service by either sending unicast polls at less frequent intervals than the RTPS service or by allowing the SS to send a bandwidth request in the collision region of the uplink frame
- Best Effort Service (BE); used for traffic such as http. This service is supported in the same way as the NRTPS service, however polling would occur at less frequent intervals.

3 Benefits of Integration

The integration of EPON and WiMAX will look similar to Figure 3, where EPON is used as a backhaul to WiMAX. The technologies are combined at the ONUs and the Base Stations to create the ONU-BSs.

The first benefit is that the extension of the reach of the broadband connectivity can be achieved without the deployment of optical fibre to end-user's premises which lowers the cost of the network deployment.

Secondly, WiMAX at close range can provide the user with high bandwidth connections; however when the user is relatively far, the connection bandwidth available will lower in proportion to the signal degradation. With EPON as a backhaul, many more BSs can be established closer to end premises resulting in an increase of end users enjoying enhanced quality mobile broadband connections.

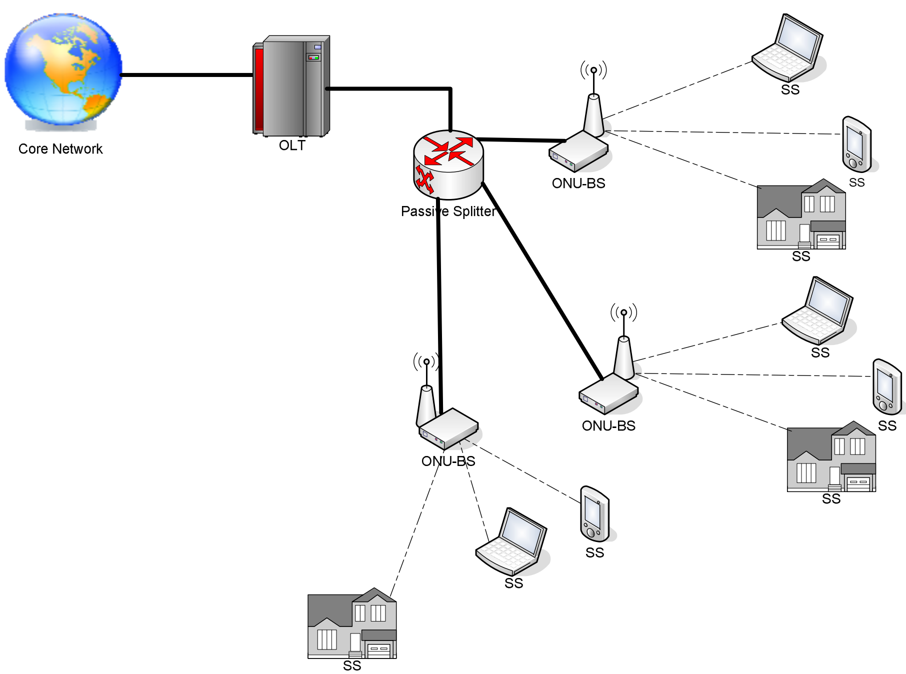

Fig. 3. The above diagram shows the schematic of the proposed integration where the EPON network is used as a backhaul to the WiMAX network. The two networks will integrate at the ONU and the BS to create the ONU-BS

The third benefit is that OFDMA distributes subcarriers among users; thus all users can transmit at the same time. Sub-channels can be matched to user needs taking into account location and propagation characteristics, in doing so provisioning optimum connection quality.

Previous studies [1] have proposed the integration of EPON and WiMAX OFDM and have shown that when the OLT is given the responsibility to allocate resource to the SS, the performance is better than alternatives. However none have explored the integration in the OFDMA domain for mobility.

4 Integration Approach

There are two options for integration. Either the systems bandwidth allocation can be fully controlled by the OLT or jointly controlled by the OLT and the BS. The paper will focus on the jointly controlled scheme, which is called the hybrid scheme.

The hybrid scheme was introduced in the paper [1] which we have adapted to the OFDMA domain. This scheme is jointly controlled by the OLT and BS, where the EPON and WiMAX run their own bandwidth allocation process. The following processes occur starting from the arrival of the packet to the SS:

1. Packets arrive from the user to the SS.
2. The SS waits for a grant to be received from the BS. Assuming it is a RTPS connection, when the grant arrives at the SS a bandwidth request will be sent to the BS.
3. The BS will receive the request and use it as an input for the bandwidth allocation algorithm. The grant will be sent out at the next frame.
4. When the SS receives the uplink grant, it waits till the next uplink section of the frame to use the grant.
5. When the SS applies the grant, it will divide the bandwidth among the various connections using a scheduling algorithm. Once the packet is selected it is sent to the BS.
6. Once the BS receives the message it will forward it to the ONU.
7. The ONU will store the packet into the appropriate queue and wait for a grant from the OLT.
8. Once a grant is received from the OLT the ONU will send a request to the OLT.
9. The OLT will receive the request and use it as an input for resource allocation in the next cycle. The OLT will send the grant to the ONU.
10. Once receiving the grant, the ONU will apply a scheduling algorithm and assign the bandwidth to the different queues.
11. The data will be sent from the ONU to the OLT.

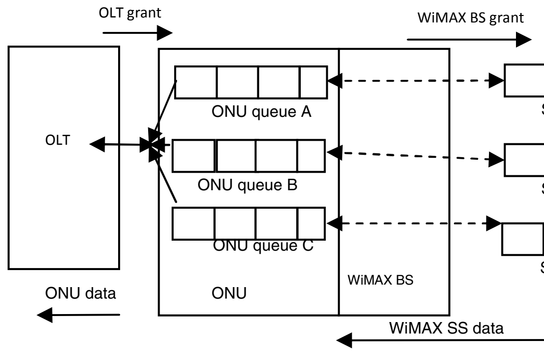

Fig. 4. The above diagram shows the resource allocation strategy of the hybrid scheme

5 Simulations

The parameters under which the hybrid integration scheme has been analysed are summarised in the following sections.

5.1 WiMAX MAC Parameters

- 8 http request applications per SS (362 bits/s each) [8]
- 3 email applications per SS (62123 bits/s each) [9].
- 2 ftp applications per SS (2920 bits/s each) [10].
- 1 http page application per SS (19511 bits/s each) [11].
- 214616 bit / s / SS.
- Email and HTTP pages inserted into BE connection
- FTP and HTTP requests inserted in NTRPS connection
- BE connection uses bandwidth stealing and collision area to send requests
- NRTPS uses polling opportunities and collision area to send requests
- 10 collision request opportunities per frame
- Polling interval 0.5s
- Frame size 5ms
- Sequential Bandwidth allocation and priority scheduling (NRTPS, BE)
- Max NRTPS and BE delay, 5s and 8s respectively.

5.2 WiMAX PHY Parameters [5][6]

- 92.4e-6s per symbol
- 70 uplink sub-channels per column
- Minimum uplink allocation slot is 3 symbols and 1 sub-channel
- Each uplink allocation slot contains 48 data carriers
- Modulation and coding scheme 64 ¾ QAM fixed. Therefore 216 bits per slot.
- 5ms frame (51 symbols + guard)

- Downlink to Uplink ratio 1:1. Uplink section begins at 27th symbol.
- Therefore there are 24 symbols (51 – 27) symbols available in the uplink.
- Per sub-channel there are 8 slots available (24 / 3 symbols)
- Therefore there are ((8 * 70) – 10 contention slots) slots available
- Therefore 118800 bits / frame (550 * 216 bits) which translates into 23.76 Mb/s (118800 bits * (1 / 0.05s))

5.3 EPON Parameters

- 1 Gb/s uplink capacity
- Priority scheduling in the ONU same as SS where NRTPS data is given priority over BE data.
- OLT uses the Limited IPACT bandwidth allocation process [3] with max requests 120000 bits and guard 5e-6.

6 Results

Fig. 5, Fig. 6 and Fig. 7 show the hybrid simulation's throughput, percentage packet loss and average packet delay with respect to increasing SS and increasing ONUs respectively.

From the throughput behaviour (Fig. 5), as the number of SS increase, so does the number of bits received at the OLT per second. The result is expected because the greater the number of SS inserted into the network the greater the incoming number of bits per second. Therefore the throughput increases. However there is no saturation of the throughput regardless of the increase in SS or ONU. This means that in the hybrid scheme the packet loss of 5 and 8 seconds does not have a major impact in the system as the number of SS increase or as the number of ONU increase**.**

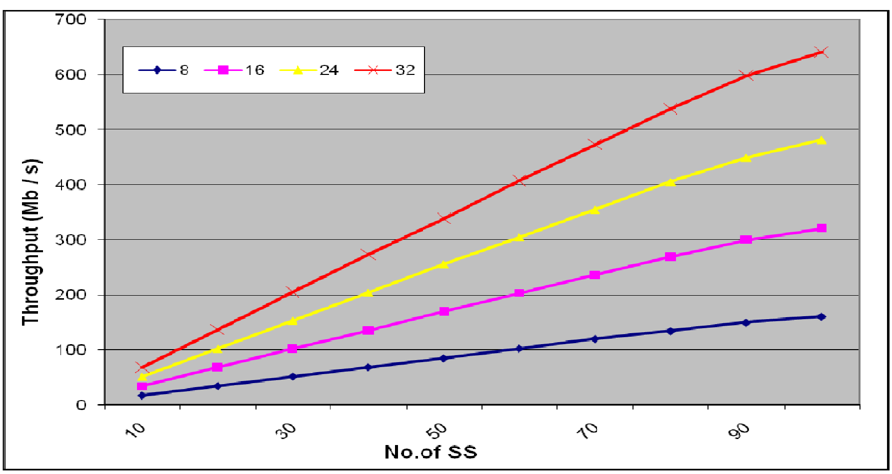

Fig. 5. The above graph shows the throughput of the hybrid scheme with respect to increasing SS and increasing ONU

From the packet loss graph below (Fig. 6), you can see why the throughput consistently increases as the number of SS increase. The average delay of 5s and 8s does not cause a significant impact on the packets at the SS until the 80 to 100 SS mark and at that mark the network has a packet loss of 6%. Therefore as the numbers of SS increase so does the throughput. The reason for such a low packet loss even at 100 SS is because even at this level the number of incoming bits per second does not exceed the number of bits WiMAX can support in a 5ms frame. Also from the graph below, the increase in the number of ONUs does not affect the packet loss. The same reasoning can be applied and is discussed later in the paper.

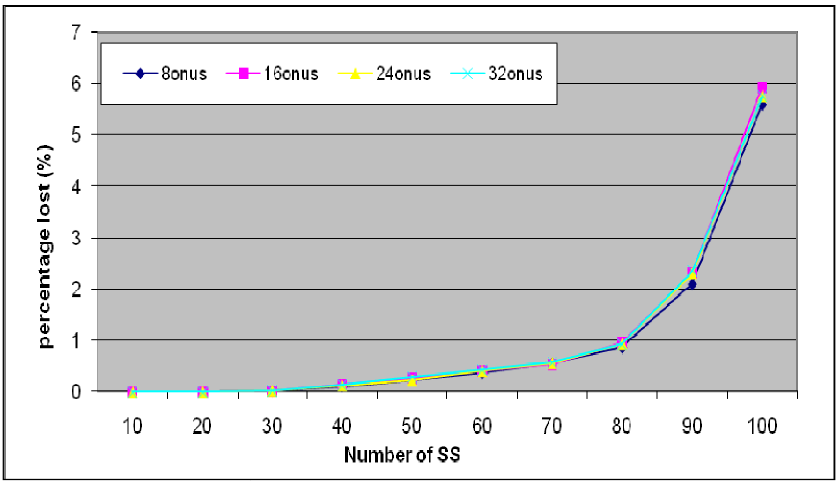

Fig. 6. Percentage packet loss as a function of increasing SSs and ONUs for the hybrid integration approach

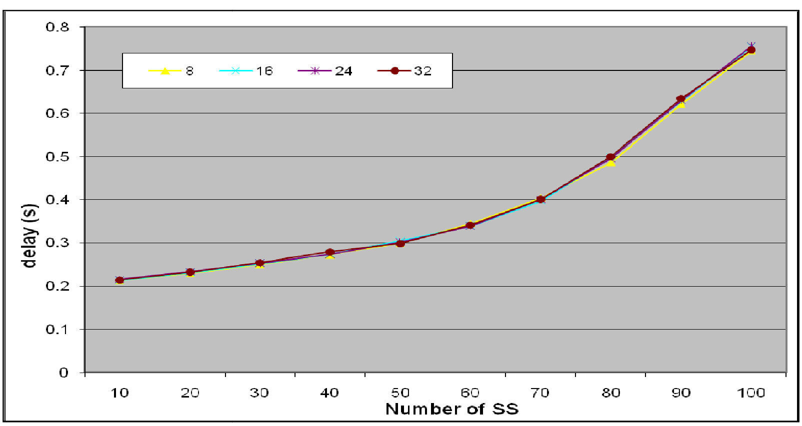

Fig. 7. Average packet delay as a function of increasing SSs and ONUs for the hybrid integration approach

The average packet delay increases as the number of SS per ONUBS increases. This is as expected because as more SS are introduced into an ONUBS network, an increasing number of SSs will have to wait longer to be allocated bandwidth as it is allocated sequentially. Therefore the packets will have to wait longer.

Also an increase in the number of ONUs does not affect the average delay. The reason for this is as follows. The limited schemes worst case cycle time for the ONUs is calculated using the following:

$$CT = \left(\left(\frac{(MD + R)}{DR}\right) + GT\right) * TO \tag{1}$$

Where,

CT = Cycle time
MD = Max Data sent = 119968 bits
R = Request size = 32 bits
GT = Guard Time = 5e-6s
TO = total onus = 8 – 32.

The number of bits sent by the WiMAX frame can be calculated using the following method. Firstly a calculation of how many time slots are available within the polling cycle time has to be made.

$$Timeslots = Rounddown\left(\frac{CT}{(92.4e^{-6} * 3)}\right) \tag{2}$$

The amount of bits transferred in that time can now be calculated by using the following:

$$UBS = Timeslots * BPS * 70 \tag{3}$$

Where,

UBS = Uplinks bits sent
Time slots = the amount of slots that will be received in the cycle time.
Round down = Round down number
BPS = Bits per slot = 216

Table 1 shows the cycle time of the ONUs in the worst case scenario and the number of bits that can be sent in that time.

Table 1. Worst case cycle time for the ONUs in the limited scheme

ONUs	Polling time	WiMAX bits received
8	0.001	45360
16	0.002	105840
24	0.003	118800
32	0.004	118800

The values for 24 and 32 ONUs are the same since the polling cycle intervals leak into the next frame's downlink section where no data is transmitted in the uplink.

The maximum amount of bits that can be transferred from the ONU to the OLT in one cycle is 120000 bits. The bits received from the WiMAX station are less than that maximum, consequently all the data can be sent in one cycle. That is why there is a slight but not noticeable difference in the packet delay for the different number of ONUs. The throughput increases as extra ONUs are added, as expected since additional ONUs means more SSs which results in more bits incoming per second and since the delay is not affected significantly as the number of ONUs increase, no extra packets are lost. Therefore the throughput rises.

7 Summary and Conclusions

The paper has introduced and evaluated the performance of a jointly controlled EPON and WiMAX OFDMA integration approach as a potential solution to the last mile problem; referred to as the Hybrid scheme. The performance of the scheme has been analysed as a function of the number of SSs and ONUs for best effort traffic and the results analysed in the form of throughput, packet loss and average packet delay..

In conclusion the results show that the Hybrid scheme, which relies on a joint OLT and BS control strategy, can be a viable solution to the last mile problem. In the Hybrid scheme, the BS can poll the SSs irrespective of the state of EPON resources, which translates into more frequent polling of the SS and therefore low delay and loss and high throughput. Also the hybrid scheme allows for the network to be flexible as from 8 to 32 ONUs, the increase in ONUs does not have an effect on the average delay or packet loss.

In practical network scenarios, channel conditions vary from SS to SS and the bandwidth allocation scheme is smarter in that it takes into account channel conditions, QoS conditions of a SS and ONU and the request made. In addition, any scheduling scheme at the SS and ONU would take into account packet delays and fairness as well as the end user accessing different services. Therefore the analysis of the Hybrid scheme will need to be executed for different traffic scenarios.

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