A Novel Framework for Distributed Dynamic Bandwidth Allocation in EPON-WiMAX Networks

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***Abstract*—In Ethernet Passive Optical Networks (EPON), allocation of bandwidth to the Optical Network Units (ONU) is a critical issue in determining the performance of the network. The resource allocation process in EPON is carried out by the Dynamic Bandwidth Allocation (DBA) algorithm. The onus of resource allocation or DBA estimation is bore solely by Optical Line Terminal (OLT) which results in more idle time at the OLT, thereby resulting in wastage of bandwidth and increased delay in data transmission. In this paper, a new framework for EPON is proposed, wherein, the DBA estimation is shared by the OLT and ONU, thereby reducing the idle time in OLT and improving the bandwidth utilization. The proposed framework is evaluated under heavy load conditions with the help of OPNET simulations and it has been demonstrated that the proposed framework outperforms the conventional scheme in terms of throughput, percentage of utilization and other QoS services.**

Keyword-Dynamic Bandwidth Allocation, EPON, OLT, ONU, QoS, WiMAX

I. INTRODUCTION

With growing demand of network utilization for high-speed video, voice, data and mobility services by users, service providers face a tremendous challenge to increase the available bandwidth for users. Broadband Wireless Access networks like WiMAX [1] provide a solution to the existing scenario with high-capacity bandwidth links supporting bandwidth intensive applications. Among the different network access solutions available, PON [2] emerges as the most assuring, cost-effective (overlapping of low-cost Ethernet equipment and low-cost fiber infrastructure and void of maintenance cost) and high-performance solution. A merger of the two is essential in the evolution of a new generation wired-wireless access, which would see the integration of the latest advances in optics and electronics.

One major challenge associated with the integration process is the proper selection of a DBA algorithm since DBA is solely responsible for effective allocation of resources in the system. There are two broad classes of DBA algorithms, namely, centralized and decentralized DBA algorithms.

There are many complex and diverse centralized DBA algorithms proposed by the research community and it is difficult to select the best one that supports multiple services and their requirements. Of all the available DBA algorithms, Interleaved Polling with Adaptive Cycle Time (IPACT) [3] is considered to be one of the most efficient. In IPACT, all ONUs are polled in a round-robin fashion and $(i+1)^{th}$ ONU is sent grant information when i^{th} ONU is transmitting. The major disadvantage of the IPACT algorithm is that there is no provision to support reservation or prioritization of bandwidth allocation to ensure QoS assurances or service differentiation. Another distinct disadvantage is that even though the OLT has more bandwidth to support a particular ONU, it limits the grants to the maximum configured size thus resulting in unused bandwidth in every cycle. The packets arriving during the waiting time are also not considered in [3]. Reference [4] addresses the issue by estimating the early arrival of packets in a polling cycle and the estimation is included in the requested bandwidth there-by reducing the waiting delay. Another improvement of [3] is attempted in [5] by arranging all pending ONU requests in ascending order according to their queue length and ONUs with smallest queue length are favored with grants. The algorithm proposed in [6] also arranges the ONUs according to the queue length but in descending order. This scheme would perform better under low and medium load, but makes no difference at high load as the number of heavily loaded ONUs increase. Authors in [7] propose a linear prediction algorithm to include the early arriving packets in the requested bandwidth. The ratio of the ONU waiting time to the entire polling cycle time is used in the prediction. The algorithm would definitely improve the packet delay of the traffic but would perform badly under non-uniform load. Another prediction based scheme is proposed in [8] and it can be seen as an improvement of [7] but the algorithm requires an optimal number of REPORT messages for good estimation. The algorithm attempts to have more accurate prediction by delaying REPORT messages of most unstable ONUs in an attempt to have more information during the waiting time for these ONUs.

Most of the proposed DBA algorithms discussed so far are centralized [9] wherein the OLT takes the sole responsibility of estimating and allocating the bandwidth to ONUs based on their queue length. To the best of our knowledge, the work proposed by Marilet De Andrade et al. [10] is the only decentralized approach, where the estimation and allocation of bandwidth is done at the ONUs and not at OLT. The algorithm proposed by [10] is as follows: Each ONU on registration is assigned a weight based on Service-Level Agreement (SLA). The OLT also sends each ONU the list of weight values of all currently active ONUs. The unused fields (Pad / Reserved) in the REPORT and GATE messages are used for the purpose. Each ONU will send its weight value in the REPORT message and the OLT on receiving the message adds / updates the value in its list which it sends back to ONU along with GATE message. The ONUs estimate its upstream window size for the next grant based on values in this list. Unfortunately, the authors of [10] have failed to address the fact that the ONU's bandwidth request for the current cycle is solely based on the previous cycle's data and any new add / delete / modify of the bandwidth request by the rest of the ONUs for the current cycle doesn't get reflected in a ONU's estimation.

There are two major advantages in migrating to decentralized DBA algorithm. First, it reduces the DBA processing overhead in the OLT thereby improving the system efficiency. Second, although EPON protocol permits large split ratios (up to 32,768), in practice most PONs deploy a split ratio of 1:32 or smaller. 1G EPON supports 1:16 splitter ratio without FEC and 1:32 splitter ratio with FEC. With 10G EPON and new power budget classes, split ratios of 1:256 or more could be easily supported. When N increases in the 1:N optical splitter used, the overhead due to DBA operation in the OLT would increase since N describes the number of ONUs supported by a single OLT. Hence decentralization of DBA calculation from OLT to ONUs proves to be the best direction in the effort to improve the system for future.

The research community has however put maximum effort in proposing and improving centralized DBA algorithms with different viewpoints and the one in [10], which attempts to do it in de-centralized way, has multiple drawbacks as stated earlier. Hence an attempt is made in this research work to fine tune the de-centralized DBA process in a different perspective to maximize bandwidth utilization and minimize packet delay, which are the objectives of a good DBA algorithm.

II. DISTRIBUTED DBA ALGORITHM FOR EPON-WIMAX INTEGRATION

The proposed distributed framework is described in this section. The ONUs estimate the required bandwidth for the current cycle and informs OLT of its requirement via the REPORT message. The details of the requested bandwidth exceeding the SLA agreement are also included in the REPORT message. The existing MPCP protocol suite which is responsible for exchange of frames between endpoints does not have any provision to do this. However, the 802.3ah architecture [11] being a non-proprietary protocol provides the flexibility to modify the protocols to suite the customer requirement. Hence the format of the REPORT message is modified to suit the algorithm as illustrated in Fig. 1.

Destination Address (6)	Source Address (6)	Length/Type = 88-08 (2)	Opcode = 00-03 (2)					
Timestamp (4)	Number of QS (1)	Report Bitmap (0/1)	Queue #0 Report (0/2)	Queue #1 Report (0/2)	Queue #2 Report (0/2)	Queue #3 Report (0/2)	Queue #4 Report (0/2)	
Queue #5 Report (0/2)	Queue #6 Report (0/2)	Queue #7 Report (0/2)	Status bitmap (1)	SLA #0 Report (0/2)	SLA #1 Report (0/2)	SLA #2 Report (0/2)	SLA #3 Report (0/2)	SLA #4 Report (0/2)
SLA #4 Report (0/2)	SLA #5 Report (0/2)	SLA #6 Report (0/2)	SLA #7 Report (0/2)	Pad / Reserved (0 – 5)	FCS (4)			

Fig. 1. Modified REPORT message differs from the standard version in: (1) Number of QS set to 1, (2) newly added text highlight items and (3) only ONE occurrence of color background items.

The following changes are carried out to accomplish the intended purpose of the proposed algorithm:

1. Number of Queue Set (QS) is restricted to ONE whereas the standard format supports 1 to 13 QS. The standard REPORT message reports bandwidth request of each service flow to the OLT. Whereas, in the proposed algorithm the aggregate bandwidth request value of all the service flows belonging to the same priority is reported.
2. A 1 byte status bitmap is included to specify the heavily loaded priority queues. It is important to inform the OLT about the service classes that have exceeded the SLA agreement in order to provide the flexibility for the ONUs to support them. It also provides an option for the OLT to service heavily loaded ONUs. The status bitmap field is depicted in Fig. 2. A '0' in bit 'n' indicates Queue #'n' is lightly loaded (requirement is within SLA) and a '1'in bit 'n' indicates Queue #'n' is heavily

loaded (requirement is more than SLA) and the SLA value is available in ‘SLA #n Report’ field.

Bit	7	6	5	4	3	2	1	0
Value	0 / 1	0 / 1	0 / 1	0 / 1	0 / 1	0 / 1	0 / 1	0 / 1
Priority	7	6	5	4	3	2	1	0

Fig. 2. Status bitmap field

3. A set of ‘SLA #n Report’ field each of 2-bytes is available to specify the SLA value of each heavily-loaded ONU and this field is present only when the corresponding flag in the Status bitmap is set.

On receiving the REPORT message from a ONU, OLT with the details in ‘Status Bitmap’ byte grants either the SLA BW or the requested bandwidth to the ONU immediately via GATE message. After all requesting ONUs are serviced, OLT estimates the remaining bandwidth in the current cycle and splits it between the heavily-loaded ONUs, serving all the high-priority requests prior to the low-priority ones. The ONUs in the heavily-loaded ONUs list are served sequentially and the last served ONU is served first in the next cycle to maintain fairness.

The sequence for the algorithm is as follows:

Step 1) ONU estimates the bandwidth requirement for the next cycle.

Step 2) ONU checks if the required bandwidth is less than (lightly-loaded) or greater than (heavily-loaded) its SLA value. If lightly-loaded, the ONU generates REPORT message type 2 (relevant fields illustrated in Fig. 3a, Fig. 3b, Fig. 3c) and sends the request message to OLT. If heavily-loaded, the ONU generates REPORT message type 1 (relevant fields illustrated in Fig. 4a, Fig. 4b, Fig. 4c) and sends the request message to OLT.

Step 3) OLT on receiving the REPORT message from the ONU, extracts the Status bitmap field from the REPORT message and determines if the ONU is lightly or heavily loaded. For lightly-loaded ONUs, the OLT grants the requested bandwidth and sets the ‘Force Report’ flag in the GATE message. Whereas, for heavily-loaded ONUs the OLT grants only the bandwidth as specified during the SLA and the ‘Force Report’ flag is reset to inform the ONU that a REPORT message need not be generated for this GATE message.

Step 4) Step 3 is repeated for all active ONUs. Now, OLT does the second round of allocation for all heavily-loaded ONUs with the remaining bandwidth in the cycle in a round-robin fashion and the ‘Force Report’ flag is set in these grant messages since a REPORT message is expected in response from the ONU.

A. ONU Estimation

The bandwidth estimated by ONU for the current cycle is given in (1).

$$BW_p^{Req,N} = Q_p + Pre \qquad (1)$$

where ’p’ is the requirement’s priority value (0-7), $BW_p^{Req,N}$ is the aggregate bandwidth requirement of ONU ‘N’ for its ‘p’ level priority services, Q_p is the queue length of the data to be transmitted in the ONU of priority ‘p’, Pre is the predictive value of the arriving data in the waiting time.

Total bandwidth requested by the ONU for servicing all its requests for the current cycle represented by $BW^{Tot\_req,N}$ is given by (2). ONU determines whether it is lightly-loaded or heavily-loaded based on whether its bandwidth requirement for the current cycle is within or exceeded the SLA.

$$BW^{Tot\_req,N} = \sum_{p=1}^{8} BW_p^{Req,N} \qquad (2)$$

B. ONU to OLT Status Update

ONU may send two types of REPORT messages to the OLT. If the ONU is lightly-loaded, the ONU generates a REPORT message with the Queue #n Report field, Status bitmap field and SLA #n Report field as in Fig. 3a, Fig. 3b and Fig. 3c respectively. Queue #n Report field reports the bandwidth requirement, the Status bitmap byte and the SLA #n Report field are reset to inform the OLT that the requested bandwidth is within its SLA value.

Heavy-loaded ONUs have the BW_p^{Req} value exceeding the SLA_p value and the Status bitmap and SLA #n Report fields in REPORT message are set to reflect the same. Queue #n Report field in this case reflects either the actual bandwidth requirement (if within SLA) or bandwidth requirement value excess of the SLA value (if exceeded SLA). As an example, consider the case where the priority 1 and 3 requirements are heavily-loaded. Fig. 4a, Fig. 4b and Fig. 4c depict the Queue #n Report, Status bitmap and SLA #n Report field values for the same.

Queue #0 Report	7	6	5	4	3	2	1	0
Req BW	BW_7^*	BW_6^*	BW_5^*	BW_4^*	BW_3^*	BW_2^*	BW_1^*	BW_0^*

(a) Queue report field where * means "Req,N"

Bit	7	6	5	4	3	2	1	0
Value	0	0	0	0	0	0	0	0

(b) Status bitmap field

SLA #n Report	7	6	5	4	3	2	1	0
SLA BW	-NA-	-NA-	-NA-	-NA-	-NA-	-NA-	-NA-	-NA-
Field Length (bytes)	0	0	0	0	0	0	0	0

(c) SLA report field

Fig. 3. Lightly-loaded ONU (NA – Not Applicable).

Queue #0 Report	7	6	5	4	3	2	1	0
Req BW	BW_7^*	BW_6^*	BW_5^*	BW_4^*	BW_3^* - SLA_3^N	BW_2^*	BW_1^* - SLA_1^N	BW_0^*

(a) Queue report field where * means "Req,N"

Bit	7	6	5	4	3	2	1	0
Value	0	0	0	0	1	0	1	0

(b) Status bitmap field

SLA #n Report	7	6	5	4	3	2	1	0
SLA BW	-NA-	-NA-	-NA-	-NA-	SLA_3^N	-NA-	SLA_1^N	-NA-
Field Length (bytes)	0	0	0	0	2	0	2	0

(c) SLA report field

Fig. 4. Priority 1 and 3 Heavily-loaded ONU.

C. *OLT Processing*

On receiving a request from the ONU, the OLT usually processes the request message and calculates the bandwidth requested by the ONU using the Report bitmap and Queue #n Report fields. The OLT then allocates certain bandwidth to the ONU based on the bandwidth allocation algorithm it follows.

However, in the proposed algorithm, the OLT looks into the Status-bitmap field of the REPORT message and determines whether the respective ONU is lightly or heavily loaded.

For lightly-loaded ONUs, OLT grants the required bandwidth specified in Queue Report field and issues it immediately to the ONU without waiting for REPORT messages from rest of the ONUs. However, for heavily-loaded ONUs, the OLT serves the SLA bandwidth for the ONU and processes the additional details before serving the excess request bandwidth exceeding the SLA and also maintains a list of heavily-loaded ONUs. The OLT sends two GATE messages for each heavily-loaded ONU. In the first GATE message, OLT grants the bandwidth specified by its SLA immediately and informs the ONU not to respond with a REPORT message for this GATE message by resetting the 'Force Report' flag. The second GATE message is sent after request from all the ONUs are processed.

Bandwidth granted by the OLT to ONU 'N' for priority 'p' services and represented by $BW_p^{Granted,N}$ is determined as in (3) where SLA_p^N is the SLA value of ONU 'N' for priority 'p'.

$$BW_p^{Granted,N} = \min(BW_p^{Req,N}, SLA_p^N) \qquad (3)$$

Total bandwidth granted to ONU 'N' for its request is given in (4).

$$BW^{Granted,N} = \sum_{p=1}^{8} BW_p^{Granted,N} \qquad (4)$$

Total bandwidth granted by OLT to all ONUs after servicing all ONUs once (bandwidth granted with less than or equal to SLA) in a cycle is represented in (5) where 'k' is the list of all active ONUs which generated a request.

$$BW^{Tot\_granted} = \sum_{k=1}^{N} BW^{Granted,k} \qquad (5)$$

Once all the registered ONUs are granted bandwidth, the OLT estimates the unused bandwidth in the current cycle as in (6) and if available, sends another GATE message to each heavily-loaded ONU granting its excess SLA requirement parsing through the heavily-loaded ONUs list in a round robin fashion.

$$BW^{Remaining} = BW^{Tot\_available} - BW^{Tot\_granted} \qquad (6)$$

High priority requirements of the heavily-loaded ONUs are served before processing any of the low priority requirements. Thus all heavy-loaded ONUs are provided an opportunity to get their additional bandwidth requirement if available. The last served ONU is remembered and in the next cycle the round-robin process starts from the next ONU. The second GATE message to heavily-loaded ONUs unlike the first informs it to respond back with a REPORT message to continue with the transmission process for the next cycle.

The second round of bandwidth allocation is illustrated in Fig. 5 where $BW_p^{Granted2,i}$ is the bandwidth granted to a heavily-loaded ONU 'i' during the second round and '*' details if 'z' is the last served ONU in the previous cycle, then 1 = z+1. Even if no bandwidth is left for the second round of allocation, a GATE message with zero bandwidth is sent to each heavily-loaded ONU for it to respond with a REPORT message in order to continue with the transmission process for the next cycle, since the first round of GATE messages wouldn't have generated REPORT messages. Employing the proposed algorithm, we expect reduction in OLT idle time thereby resulting in gain of the upstream bandwidth utilization. This is better represented by the timing diagram in Fig. 6a and Fig. 6b where 'T_p' is the OLT processing time.

for (p = 7 to 0) // service the higher order priority before lower order
{
    for (i = 1* to H) // H – list of heavily-loaded ONUs
    {
        if($BW^{Remaining}$) // if more bandwidth available
        {
            if($BW^{Remaining} > BW_p^{Req,i}$)
            {
                $BW_p^{Granted2,i} = BW_p^{Req,i}$
                $BW^{Remaining} = BW^{Remaining} - BW_p^{Granted2,i}$
            }
        }
    }

}

Fig. 5. Second round of bandwidth allocation by OLT.

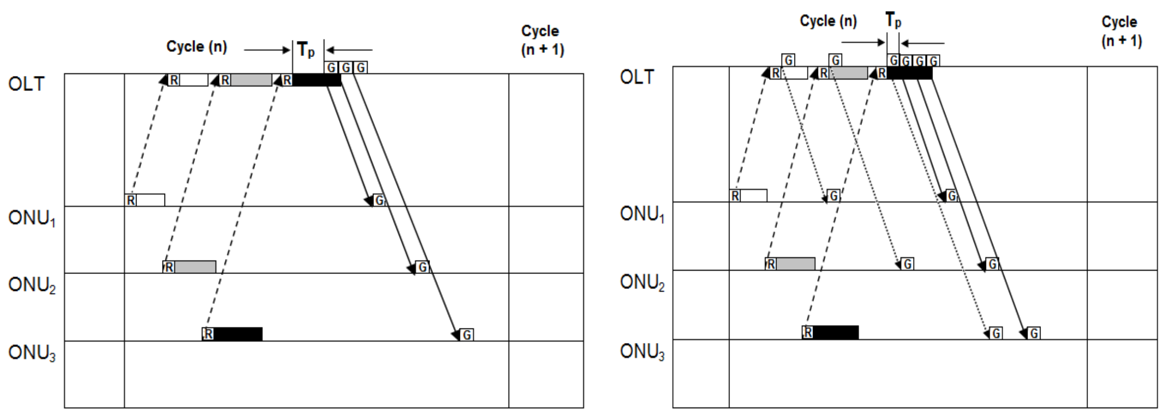


Fig. 6. Comparision of timing diagram for GATE and REPORT messages exchanged within a cycle in the standard version and proposed version.

III. Mapping WiMAX QoS Classes to EPON 802.1p Priority

The algorithm is further improved to guarantee QoS in the integrated network by implementing a mapping mechanism between EPON 802.1p priority queues and the WiMAX connections, for which an efficient QoS guarantor is designed.

EPON supports QoS in DiffServ mode and WiMAX in IntServ mode and hence to support QoS in EPON-WiMAX integrated system a conversion between DiffServ and IntServ mode is to be done and is facilitated by the fact that both have similar QoS support. EPON supports eight priority levels with the bandwidth request packet including QoS for the service represented by the numbered priority queue in the 802.1P nomenclature.

TABLE I
EPON - WiMAX QoS mapping mechanism

Priority	EPON traffic types	WiMAX services
0	Background	
1	Best Effort	Best Effort (BE)
2	Excellent Effort	non-real-time Polling Service (nrtPS)
3	Critical applications	
4	Video	real-time Polling Service (rtPS)
5	Voice	Unsolicited Grant Service (UGS), extended-real-time Polling Service (ertPS)
6	Internetwork Control	
7	Network Control	

WiMAX supports five QoS levels and an effective mapping mechanism is required between EPON priority queues and WiMAX different levels of QoS. WiMAX flow packets are stored in appropriate EPON priority queues such that the mapping provides equivalent QoS levels at both ends as detailed in Table 1.

Since IntServ mode and DiffServ field are to be realized by the router's configuration which is service-provider specific, it is difficult to predict end-to-end behavior. Hence a good solution is to use a combined strategy – per-flow reservation in edge network and aggregate flow reservation in core network. Hence the proposed algorithm reports only the aggregate bandwidth requirement for each priority to the OLT instead of sending different thresholds of the same priority.

IV. Simulation Model

The proposed framework is implemented and evaluated in a WiMAX EPON integrated architecture using OPNET. A 1:16 splitter between the OLT and the ONU is employed. A 1 Gbps EPON network is chosen as the backbone network to support WiMAX network. The WiMAX network is loaded with all type of service requests; however, the system is loaded with UGS call requests as they are more sensitive to delay. It is always important to evaluate a system for time critical applications. Although the proposed framework supports both uplink and downlink directions, the simulation model is evaluated for the uplink part, which is the most critical; hence, all connections are in the uplink direction, originating from each Mobile Station. The physical layer interface in the WiMAX is OFDMA

V. Results and Discussions

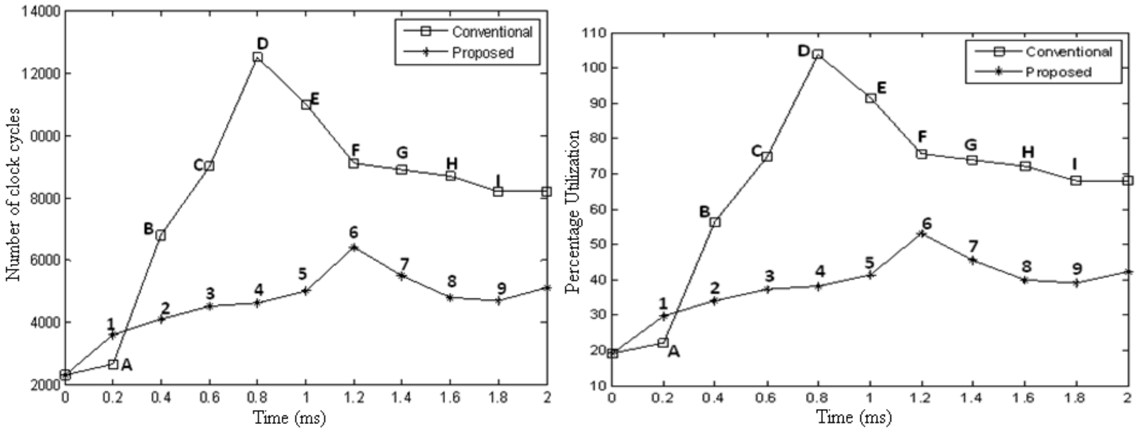
The proposed DBA algorithm aims to achieve low latency, high bandwidth utilization and improved fairness by:

1. Reducing the idle time in OLT: The Upstream channel bandwidth that goes idle while the OLT processes the DBA algorithm is reduced.
2. Reducing latency: OLT issues on-the-fly grants to the ONUs.
3. Employing fairness: All ONUs are assigned equal weights, though higher priority is given to real time services and are served in a round-robin fashion.
4. Achieving QoS by mapping WiMAX's service flow to EPON's priority queues.
5. Improving QoS by providing aggregate bandwidth requirement and favoring high-priority requirements.

A. System Performance

The proposed algorithm is implemented in IXP2400 network processor in which microengines 0 to 3 form functional pipeline of the four major modules. The network processor is configured to work as a EPON network switch. The performance of the whole system critically depends upon the performance of Prioritization code handler since it is this micro block which embeds the active code, thereby enabling a prioritized label switching. The system has been designed in a way such that the highest priority is assigned to voice and video packets to support QoS for the service flows.

Fig. 7a indicates the number of clock cycles required for the microengine in executing the conventional and proposed algorithm in the OLT. The observation from the clock cycles indicates that the processor requires more cycles to run the conventional algorithm since OLT does the entire processing of bandwidth calculation and assignment for all ONUs in the network. Whereas, in the proposed algorithm ONU helps in reducing the OLT's processing for bandwidth calculation and assignment and hence the overall processing generally reduces in the OLT. As can be seen in the conventional algorithm, REQUEST from all ONUs are collected through A, B, C, D and at D - the peak where REQUESTs from all ONUs are received, the clock cycles are at the maximum



(a) Number of clock cycles to execute the algorithm (b) Processor percentage utilization for the algorithm

Fig. 7. Proposed algorithm performance.

indicating the full buffered REQUESTs and the OLT now starts processing them and assigns grants to the ONUs there after marked by the decline in the cycles used indicated by E,F,….

In the proposed algorithm, the ONUs are granted bandwidth as and then their REQUESTs are received represented by the cycles used through 1,2,3,4,5,6 and at 6 – the second round of bandwidth allocation to the ONUs (after REQUEST from all ONUS are received) starts and hence more cycles are used at this stage and there after the cycles used declines. It could be inferred that there is a general reduction in machine clock cycles used and that the OLT is not overloaded and hence provides provisions for increasing the number of ONUs. Thus the same processor can accommodate more ONUs using the proposed algorithm than the conventional means.

Fig. 7b plots the percentage of processor utilization against time. This graph reinforces the above said facts about the clock cycles used. For instance, at the peak load marked by ‘D’ the percentage of processor utilization is also at its peak. At this point, the micro engine is fully loaded and the buffer starts filling up. Here further requests will be delayed even more thereby increasing the latency and reducing the throughput of the network. And this in turn increases the jitter and degrades the other QoS parameters, whereas in the proposed algorithm this doesn’t happen so, thus helping the QoS of the entire system. As can be seen from the plot, the percentage of processor utilization has reduced by about 50% in the proposed algorithm, thereby paving way to double the number of ONUs deployed in the system. This framework, for the specified hardware supports the deployment of 1:32 splitter for ONUs in place of 1:16 splitter thereby helping to broaden the network.

In this section we evaluate the performance of Wi-MAX with respect to the throughput of all its service classes namely UGS, ertPS , rtPS, nrtPS and BE. Moreover, we measure the average delay in comparison to the maximum latency, and we assess the maximum delay of UGS to ensure that no packet is delayed more than its allotted limit. Finally, the network utilization is measured to indicate the extent to which network resources are used efficiently.

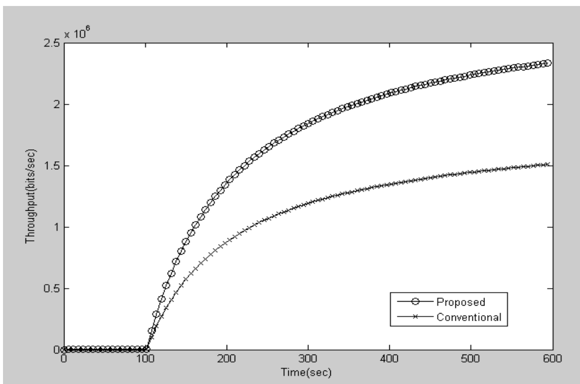
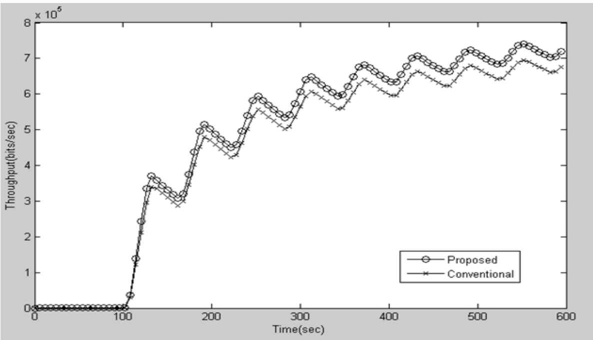


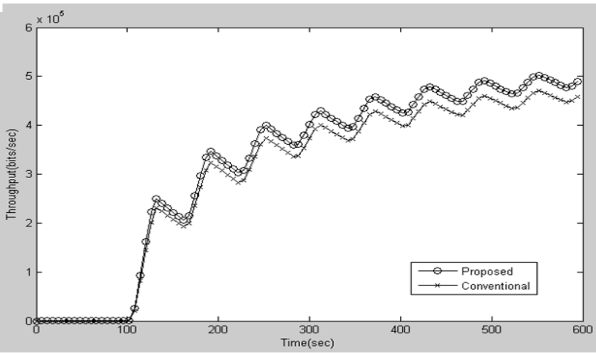
Fig. 8. UGS throughput.

Fixed-size data packets at CBR are supported by UGS. Real time applications such as VoIP with silent suppression and streaming applications are also supported by the UGS scheme and hence in the simulation the EPON-WiMAX system is loaded with UGS call requests. Fig. 8 clearly illustrates that the throughput of the UGS service class has improved by implementing the proposed algorithm because the proposed algorithm does not wait for all ONUs to send the request and the grants are assigned as soon as a REQUEST reaches the OLT. Since a ONU is granted bandwidth immediately after the REQUEST reaches the OLT, the upstream bandwidth utilization is much effective than the standard version thereby reducing latency and improving the efficiency of the entire transmission system.

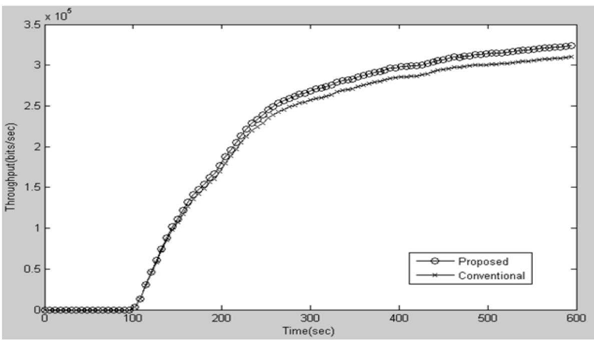
In the simulation scenario it may be noted that the switch is loaded with a large number of UGS calls. The UGS scheme requires real time processing and hence it would be better to demonstrate the performance of the algorithm with respect to UGS services as UGS plays a critical role in defining the QoS of WiMAX system. ertPS is defined to support variable rate real-time services such as VoIP with silence suppression. This service requires guaranteed data rate and delay. For VoIP applications, it causes lower overhead than UGS. A variable bit rate real-time service such as MPEG video is supported by rtPS, which generates the variable size data packets periodically. Minimum reserved traffic rate, maximum sustained traffic rate, maximum latency, and request/transmission policy are the mandatory service flow parameters that are defined in rtPS. Delay-tolerant applications such as FTP are designed to be supported by nrtPS service flow. Data streams, such as Web browsing, that do not require a minimum service-level guarantee are designed to be supported by Best Effort service. It may be noted that the proposed algorithm perform well than the conventional algorithm in maintaining the throughput of all the above mentioned service flows. The simulation is carried out in such a way that the system is loaded with UGS requests while maintaining an optimum request value for other service flows and it may be noted that the throughput of the UGS scheme has improved considerably. It may also be noted from Fig. 9a, Fig. 9b, Fig. 9c and Fig. 9d that the improvement in throughput of the UGS scheme is not achieved at the cost of reducing the throughput of the other service schemes and hence it is an appreciable improvement.



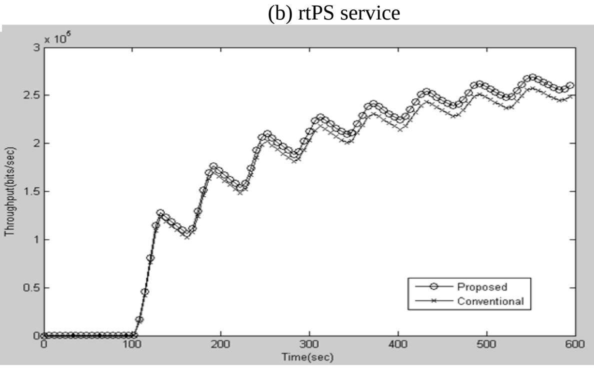
(a) ertPS service



(b) rtPS service



(c) nrtPS service

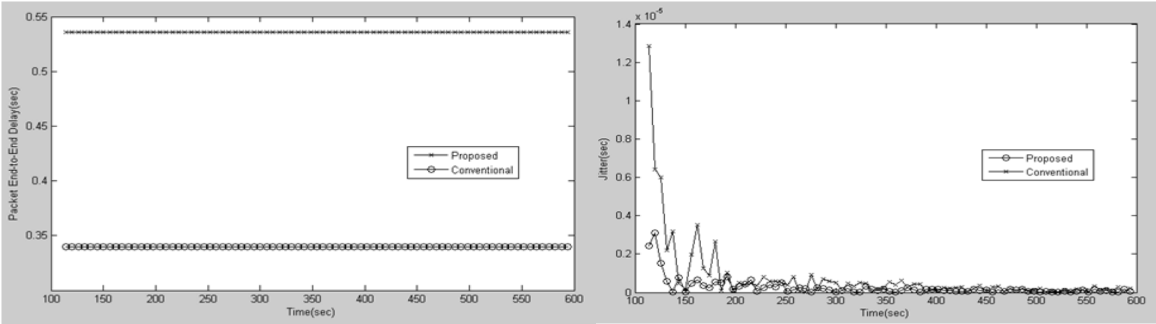


(d) BE service

Fig. 9. Comparison of throughput for different service classes in the conventional and proposed algorithms.

B. Observation on Voice Scenario

Throughput is an important performance metric in evaluating the performance of any WiMAX system. However, it is not the only metric and the improvement in throughput cannot be achieved at the cost of compromising other QoS parameters. It may be noted that the improvement in UGS throughput directly reflects the increase in throughput of voice calls and hence it is important to verify if the throughput improvement is achieved at the cost of the other performance metrics of voice, namely Delay and Jitter. Fig. 10a and Fig. 10b illustrate that the proposed algorithm has reduced the end to end packet delay of voice significantly as the latency is reduced considerably in the proposed schema and also maintains the jitter of voice.

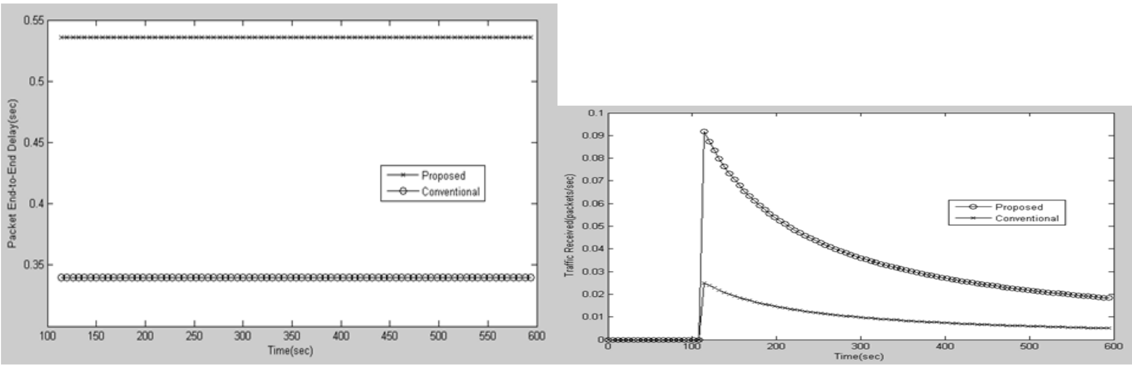


(a) End-to-end delay (b) Jitter

Fig. 10. Comparison of end-to-end delay and jitter for voice packets in the conventional and proposed algorithms.

C. Observation on Video Scenario

Similar to voice scenario it is important to verify if the throughput enhancement in UGS is achieved at the cost of other video performance metrics. However, Fig. 11a illustrates that the packet end to end delay for the proposed algorithm has come down significantly for the video packets because idle time in the OLT is reduced considerably supporting immediate bandwidth grants thereby reducing latency. Fig. 11b illustrates that the traffic received for the video packets has improved for the proposed algorithm and this is a direct reflection of the ertPS service throughput.



(a) End-to-end delay (b) Traffic received

Fig. 11. Comparison of end-to-end delay and traffic received for video packets in the conventional and proposed algorithms.

VI. CONCLUSION

An efficient framework for WiMAX EPON integration is proposed in this paper. The framework reduces the load on the OLT by sharing the work of DBA estimation between the OLT and ONU thereby reducing the delay and improving the bandwidth utilization of the integrated architecture. Since the percentage of utilization has almost halved, for the same set of hardware we can double the number of ONUs supported by a OLT. However, it would be even more interesting to evaluate the proposed framework in a real time Switch.

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