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Performance Evaluation of a Scheduler for the ONU-BS of Integrated EPON-WiMAX Networks

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Performance Evaluation of a Scheduler for the ONU-BS of Integrated EPON-WiMAX Networks

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Abstract

The integration of WiMAX networks with EPON networks combine the large bandwidth availability in optical access networks with the mobility provided by wireless technologies. In this integration, a WiMAX bandwidth scheduler that takes into account the variability of the channel capacity provided by the EPON scheduler is quite important, since the granted bandwidth must be sufficient to support the QoS of WiMAX connections. This paper evaluates the performance of a standard-compliant WiMAX uplink scheduler designed to the ONU-BS. The evaluation is conducted using integrated simulators for the WiMAX and for the EPON components. Simulation results show that the proposed scheduler is able to provide QoS to the subscriber stations

1 Introduction

There has been consideration for the integration of wireless Worldwide Interoperability for Microwave Access (WiMAX) and optical Ethernet Passive Optical Network (EPON) [1] [2] technologies for the enlargement of coverage areas. WiMAX [3] is a broadband wireless access network that provides Quality of Service (QoS), wide coverage, low cost infrastructure and high speed access while EPON provides much higher bandwidth.

In both EPON and WiMAX, the controlling station either, Optical Line Terminal (OLT) or Base Station (BS), polls the controlled stations, Optical Network Units (ONU) or Subscriber Stations (SS), for bandwidth requests. Furthermore, the controlling station in each network allocates bandwidth. Both EPON and WiMAX employ a request/grant mechanism, known as the report/gate in EPON, for bandwidth allocation.

Different architectures for this integration have been proposed [4]. In the hybrid architecture, the WiMAX base station is a client of the EPON network and it is connected to an ONU of the EPON. In the EPON network, the OLT distributes the available bandwidth

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among the ONUs in a cyclical way; at every round of bandwidth granting, the EPON protocol decides the amount of bandwidth each ONU will receive. In addition, the bandwidth granted to the ONU-BS must be distributed among the SS.

In such integrated network, the bandwidth received by the BS changes at every round of the EPON bandwidth granting cycle. Therefore, the WiMAX scheduler located at the ONUBS should take into account this variability when providing transmission opportunities to its SSs. It is possible that the BS receives less bandwidth than the necessary one to support the QoS requirements of its connections. Therefore, special WiMAX scheduler needs to be defined for dealing with such variabilities to maintain the QoS support.

Previous work [5] introduced a WiMAX standard-compliant uplink scheduler for the integrated EPON-WiMAX networks. Most of existing work [6][7][8][9][10][11] proposes changes or even new bandwidth granting protocols for the EPON part of the integrated network. Conversely, the scheduler proposed here is for the ONU-BS and it has the great advantage of being independent of the EPON protocol adopted. This facilitates the deployment of EPON-WiMAX networks and increases its benefits. The performance evaluation of the proposed scheduler was conducted using a random generator of bandwidth grants. In this paper, we evaluated the performance of the proposed scheduler by using a WiMAX NS-3 module integrated with a developed EPON simulator. The Interleaved Polling with Adaptive Cycle Time (IPACT) [12] is used in the EPON network. In IPACT, the OLT polls ONUs and grants time slots to each ONU in a round-robin fashion. The length of the allocated time slot is determined by the request message sent by ONUs.

This paper is organized as follows. Section 2 shows related work. Section 3 describes the integrated EPON-WiMAX network designed. Section 4 describes how quality of service is provided in WiMAX networks. Section 5 presents the DBQUS scheduling mechanism. Section 6 gives details on how the simulation experiments were conducted. Section 7 shows the analysis of the results obtained. Section 8 draws some conclusion.

2 Related Work

Several scheduling mechanisms have been proposed to integrated EPON-WiMAX networks.

In [6], the authors proposed the QoS-based Dynamic Bandwidth Allocation (QDBA) together with the Prediction-based Fair Excessive Bandwidth Allocation (PFEBA) scheme to enhance the system performance in EPONs. In QDBA, each ONU handles three queues with different priorities and it also classifies WiMAX traffics into three priority levels mapping them into ONU queues.

The dynamic bandwidth allocation scheme in [7], considered an integrated network to enable data transmission across optical and wireless networks, and an end-to-end differentiated service for diverse QoS requirements. This QoS-aware scheme supports bandwidth fairness at the ONU-BS level and classof-service fairness at the WiMAX subscriber station level.

A QoS-aware scheduling mechanism for the integrated EPON-WiMAX network is proposed in [10] but it does not consider the size of the ONU queues.

In [11], a two-level scheduling scheme for the integrated EPON-WiMAX network was proposed which takes into consideration the queue length and head-of-line (HoL) delay. In this scheme, it is used proportional fairness for the transmissions from SSs over the WiMAX channels and a centralized mechanism at OLT for EPON uplink transmission that connects to multiple WiMAX-ONUs.

None of these bandwidth allocation mechanisms support all service flows defined in the WiMAX standards. The scheduler proposed here is for the ONU-BS and it has the great advantage of being independent of the EPON protocol adopted. This facilitates the deployment of EPON-WiMAX networks and increases its benefits.

3 EPON-WiMAX Integrated Network

In the EPON-WiMAX Integrated Network [4], the BS of the WiMAX network is a client of the EPON network and it is connected to an ONU of the EPON (Figure 1). In the EPON network, the OLT distributes the available bandwidth among the ONUs in a cyclical way using the IPACT [12] protocol. At every round of bandwidth granting, the EPON protocol decides the amount of bandwidth each ONU will receive. In addition, the bandwidth granted to the ONU-BS must be distributed among the SS. In such integrated network, the bandwidth received by the BS changes at every round of the EPON bandwidth granting cycle. Therefore, the WiMAX scheduler located at the ONU-BS should take into account this variability when providing transmission opportunities to its SS. It is possible that the BS receives less bandwidth than the necessary to support the QoS requirement of its connections. Therefore, a WiMAX scheduler, known as DBQUS was proposed in this paper to deal with such variabilities.

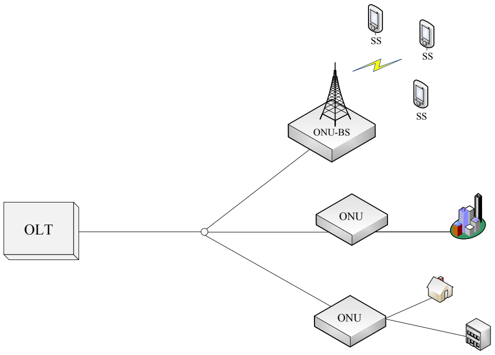

Figure 1: Integrated architecture of EPON and WiMAX Networks

The IEEE 802.ah standard specifies that the Multipoint Control Protocol (MPCP) [1] should be used for bandwidth request and granting between the OLT and the ONUs. In the MPCP, the ONUs send report messages to the OLT to solicite the bandwidth needed to transmit their backlog. The OLT sends gate messages to the ONUs to inform their bandwidth grant at every round of bandwidth granting cycle.

The IPACT algorithm distributes the OLT bandwidth to the ONUs in a round robin fashion being the ONUs slots proportional to their backlog. The IPACT sends control messages piggybacked to Ethernet frames, reducing the control overhead when compared to MPCP.

In the IEEE 802.16 standard, a signaling mechanism for information exchange between the BS and SSs was defined. This signaling mechanism allows the SSs to request bandwidth to the BS. Bandwidth allocation is provided on demand. When an SS has backlogged data, it sends a bandwidth request to the BS. The BS controls the bandwidth allocation for SSs using the poll/request/grant scheme allocating time slots to the SS based on both the bandwidth request and the QoS requirements of the requesting connection.

In this paper, both the EPON cycle and the WiMAX frame last for 5 ms. Thus, there is no synchronization mismatch and waste of bandwidth for that.

4 QoS in WiMAX Networks

Quality of service (QoS) provisioning in WiMAX networks is facilitated by the use of connections and service flows. Each connection in the uplink channel of a subscriber station (SS) to a base station (BS) is mapped to a service flow. The five services flows are: UGS (Unsolicited Grant Service), ertPS (extended real-time Polling Service), rtPS (real-time Polling Service), nrtPS (non-real-time Polling Service) and BE (Best Effort). The UGS is used for real-time services with fixed packet sizes. The ertPS is used for services with variable packet sizes with silence suppression. The rtPS is designed for real-time services. This service allows variable bit rate transmissions and offers minimum rate and delay bound. The nrtPS service flow is similar to the rtPS service flow except that no delay bound is guaranteed. The BE shares contention bandwidth request opportunities with nrtPS and no guarantee is given to this class.

Each service flow has associated to it a set of QoS parameters [13]. The maximum latency specifies the maximum latency between the reception of a packet by the SS at its network interface and the forwarding of the packet to its RF interface. The minimum reserved traffic rate specifies the minimum rate for ertPS, rtPS, and nrtPS service flows. The uplink scheduler must be able to satisfy the bandwidth requests for a service flow at least to its minimum reserved traffic rate. The maximum sustained traffic rate defines the peak information rate of UGS, ertPS, and rtPS service flows. The service shall be policed to conform to this parameter. The maximum traffic burst defines the maximum burst size that shall be accommodated for the service. The unsolicited grant interval specifies the nominal interval between successive data grant opportunities for UGS and ertPS service flows.

To ensure that the quality of service requirements are met, efficient scheduling mechanisms must be implemented. However the IEEE 802.16 standard does not define any specific mechanism for that.

5 DBQUS Scheduler

This section introduces a WiMAX uplink scheduler for EPON-WiMAX networks. The mechanism called, Deficitbased QoS Uplink Scheduler (DBQUS), is based on the Migrationbased Scheduler for QoS Provisioning (MBQoS) proposed in [14][15], which does not take into account the variability of channel capacity.

The DBQUS scheduler keeps track of the amount of bandwidth that was not supplied to each connection (*deficitMinimum*). Such amount occurs when the bandwidth given to a connection is below the minimum required one. In DBQUS, the deficit is compensated by furnishing additional bandwidth as soon as possible so that the minimum bandwidth requirement is supported. Such compensation is provided to the connections according to a decreasing order of priority.

The proposed scheduler uses three queues, each with a different priority level: low, intermediate and high priority queues. The scheduler serves the queues according to their level of priority. The low priority queue stores BE bandwidth requests. The intermediate queue stores bandwidth requests sent by both rtPS and nrtPS connections. These requests can migrate to the high priority queue to guarantee that their QoS requirements are met. In addition to the requests migrating from the intermediate queue, the high priority queue stores periodic grants and unicast request opportunities that must be scheduled in the following frame. UGS and ertPS service flows are served by the high priority queue. The uplink scheduler is executed at every frame, and it broadcasts the scheduling agenda to the SSs in the UL-MAP message.

Every time the scheduler is executed, it computes a priority value for each request at the intermediate queue, considering the *deficitMinimum* value of each connection. By doing this, the scheduler tries to compensate the deficits created by the lack of bandwidth. After migrating requests with positive *deficitMinimum*, it computes a priority value for the remaining requests in the intermediate queue, considering the per connection: minimum reserved traffic rate, backlogged requests (number of bytes requested by a connection), and traffic rate received in the current window. Low priority values are assigned to the requests of connections which have already received the minimum reserved traffic rate in the current window. For the remaining requests, the lower the rate received by the connection, the higher is the priority value.

The DBQUS guarantees that the sum of the bandwidth allocated to a single connection is less or equal to the maximum traffic burst requirement. Moreover, the scheduler does not allocate bandwidth for a connection if it results in violation of the maximum sustained traffic rate. As in the MBQoS scheduler [14], a dual leaky bucket is used for maximum burst and maximum rate policing.

The Algorithm DBQUS describes the scheduling scheme. After inserting the periodic grants in the high priority queue, the algorithm checks which rtPS and nrtPS requests should migrate from the intermediate queue to the high priority queue (lines 2, 3 and 4). In line 5, the scheduler distributes the available resources among the BE connections if there is no demand from other service flows, and, in the final step, the scheduler serves all the requests in the high priority queue when there is available bandwidth.

The **checkGrants** procedure prioritizes UGS and ertPS connections that have bandwidth deficit. First, it verifies if there is any UGS flow with positive *deficitMinimum*, i.e., if some previous request was not attended. These requests have the highest priority and they are inserted in the high priority queue while there is available bandwidth for that (lines 1 to 3). Then, periodic grants for UGS flows that must be served in the next frame are granted

Algorithm 1 DBQUS Algorithm

```
1: checkGrants
2: checkMinimumBandwidth(deficitMinimum)
3: checkDeadline
4: checkMinimumBandwidth(deficit)
5: distributeFreeResources
6: schedule the requests in the high priority queue starting from the head of the queue;
```

(line 4). After that, this process is repeated for ertPS flows, prioritizing flows with positive *deficitMinimum* (lines 5 to 8).

The **checkMinimumBandwidth** (*deficitMinimum*) tries to meet the bandwidth requirement of rtPS and nrtPS connections with positive *deficitMinimum*. First, it calculates a priority value for each request in the intermediate queue (line 25). Then, it sorts the intermediate queue by non-decreasing priority values (line 31). Finally, the scheduler tries to migrate the requests to the high priority queue using the migrateBWRequest procedure according to the requests priority values (lines 32 to 35).

In the **checkDeadline** procedure, the scheduler tries to migrate rtPS request in the intermediate queue to the high priority queue using the procedure migrateBWRequest if there is available bandwidth. Requests that are migrated are those with deadline expiring in the frame (line 14) that follows the next one and those that have not received the minimum reserved traffic rate (minTR[CID]) in the current window.

The **checkMinimumBandwidth** (deficit) procedure is similar to the **checkMinimumBandwidth** (*deficitMinimum*) procedure. They differ on how to determine the priorities of a request (lines 18 and 19). At this point, no request has *deficitMinimum*, so request are sorted by the deficit value to achieve the Minimum Reserved Traffic Rate requirement (line 23).

The **migrateBWRequest** procedure checks whether or not the amount of bandwidth solicited by the request being migrated is available in the uplink subframe. In case the amount of available bandwidth is less than the requested amount, only the available bandwidth will be allocated at this scheduling time (line 43). The allocation of part of the requested bandwidth will be deferred in case it results in violation of the maximum traffic burst requirement. Once the amount of bandwidth that can be allocated to the request is defined (*grantSize*) and if the *grantSize* value is less than the bandwidth requested by a connection, a new request is created with size equal to the amount of bandwidth that will be migrated and, after that, it is inserted at the end of the intermediate queue (lines 46 to 48). The amount of bandwidth solicited by a request is updated to *grantSize* and the request is migrated to the high priority queue (line 50).

The **distributeFreeResources** procedure distributes the available bandwidth, if any, among the BE requests by migrating the chosen requests from the low priority queue to the high priority queue (lines 36 to 39).

Algorithm 2 Procedures

```
checkGrants
for each UGS connection $u$ do
    if availableBW $> 0$ and deficitMinimum[$u$] $> 0$ then
        MigrateBWRequest($u$);
Insert the UGS grants while availableBW $> 0$
for each ertPS connection $e$ do
    if availableBW $> 0$ and deficitMinimum[$e$] $> 0$ then
        MigrateBWRequest($e$);
Insert the ertPS grants while availableBW $> 0$
checkDeadline
for each request $i$ at the intermediate queue do
    if avilableBW == 0 then
        break;
    if service[CID] == rtPS then
        frame[i] = ⌊(deadline[i] - currentTime) / frameDuration⌋;
        if frame[i] == 3 and TwndTR[CID] $<$ minTR[CID] then
            MigrateBWRequest(i);
checkMinimumBandwidth (priority type)
for each connection of type rtPS ou nrtPS do
    backlogged_tmp[CID] = backlogged[CID];
    TwndTR_tmp[CID] = TwndTR[CID];
    bucket2_tmp[CID] = bucket2[CID];
for each request $i$ at the intermediate queue do
    if minTR[CID] $\leq$ TwndTR_tmp[CID] or bucket2_tmp[CID] == 0 then
        priority[$i$] = 0;
    else
        if priorityType == deficitMinimum then
            priority[$i$] = backlogged_tmp[CID] - (TwndTR_tmp[CID] - minTR[CID]);
        else
            priority[$i$] = minTR[CID] - TwndTR_tmp[CID];
        TwndTR_tmp[CID] = TwndTR_tmp[CID] + BR[$i$];
        bucket2_tmp[CID] = bucket2_tmp[CID] + BR[$i$];
        backlogged_tmp[CID] = backlogged_tmp[CID] - BR[$i$];
Sort the intermediate queue by priority in non-decreasing order.
for each request $i$ at the intermediate queue do
    if avilableBW == 0 or (priorityType == deficitMinimum and priority[$i$] $\leq 0$ ) then
        break;
    MigrateBWRequest($i$);
DistributeFreeResources
for each connection of type BE do
    if avilableBW = 0 then
        break;
    MigrateBWRequest(i);
MigrateBWRequest(i)
if BR[$i$] $>$ avilableBW then
    grantSize = availbleBw;
else
    grantSize = BR[$i$];
if grantSize $>$ bucket2[CID] then
    grantSize = bucket2[CID];
if $0 <$ grantSize $< BR[i]$ then
    Create a new request $j$ for connection CID with BR[$j$] = BR[$i$] - grantSize;
    Insert request $j$ in the end of the intermediate queue;
BR[$i$] = grantSize;
Move the request $i$ to the high priority queue;
TwndTR[CID] = TwndTR[CID] + grantSize;
bucket2[CID] = bucket2[CID] - grantSize;
backlogged[CID] = backlogged[CID] - grantSize;
availableBW = availableBW - grantSize;
```

6 Simulation

The effectiveness of the DBQUS was assessed by simulation using the WiMAX module of the Network Simulator (NS-3) based on [16][17][18] and the EPON module was designed in Java. The duration of each simulation was 1200 seconds. Confidence interval with 95% confidence level were derived by the method of independent replication.

The simulated network consisted of 15 ONUs, 1 ONUBS and a set of 25 SSs. The capacity of the ONU-BS is 30Mbps and the EPON channel is 1Gbps and the maximum cycle time is set to 5ms. Each SS has only one service flow. The experiments used different types of traffic: voice, voice with silence suppression, video, FTP and WEB, which were associated with UGS, ertPS, rtPS and nrtPS and BE services. The distance between the OLT and the splitter is 20km.

The traffic was generated in the WiMAX network as follows. The voice model used was an exponential "on/off" model. The mean duration of the "on" and of the "off" periods equals to 1.2 s and 1.8 s, respectively. During the "on" periods, 66-byte packets are generated at every 20-ms. The voice with silence suppression model used the Enhanced Variable Rate Codec (EVRC) [19], with packets generated every 20 ms employing Rate 1 (171 bits/packet), Rate 1/2 (80 bits/packet), Rate 1/4 (40 bits/packet) or Rate 1/8 (16 bits/packet). Video traffic was generated by real video traces [20]. FTP traffic was generated using an exponential distribution with a mean of 512 KBytes. The WEB traffic was modeled by a hybrid Lognormal/Pareto distribution, with the body of the distribution corresponding to an area of 0.88 modeled by a Lognormal distribution with a mean of 7247 bytes and the tail modeled by a Pareto distribution with mean of 10558 bytes.

To generate the ONU's traffic, CBR sources generate 24 byte packets at every 125s as well as ON-OFF pareto sources. Inter burst generation time is exponential distributed and the burst duration is Pareto distributed and packet lengths were of 594 and 1518 bytes long [21].

The maximum latency requirement for rtPS connections was 300 ms and each connection had its own minimum reserved traffic rate requirement and maximum sustained traffic rate which varied according to the rate of the transmitted video. The nrtPS service had minimum reserved traffic rate requirement of 200 Kbps, and maximum sustained traffic rate requirement of 800 Kbps. The unsolicited grant interval requirement for UGS and ertPS was 20ms. The BE service does not have any QoS requirement.

7 Numerical Results

This section shows the results obtained with the simulations. The aim of these experiments is to analyze the DBQUS ability to furnish QoS under the variability of the EPON channel. The simulation scenario includes one ONU-BS, 5 UGS connections, 5 ertPS connections, 5 rtPS connections, 5 nrtPS connections and 5 BE connections. Table I shows the simulation parameters used in the simulation. The aim of this scenario is to verify whether or not DBQUS supports the QoS requirements of the service classes under different traffic loads provided by the EPON network.

Table 1: Simulation Parameters

Number of ONUs	15
Number of ONU-BS	1
Number of SSs	25
WiMAX Maximum data rate	30Mbps
EPON Maximum data rate	1Gbps
Buffer size in ONU	10Mbyte
Maximum cycle time	5ms
Wimax frame length	5ms

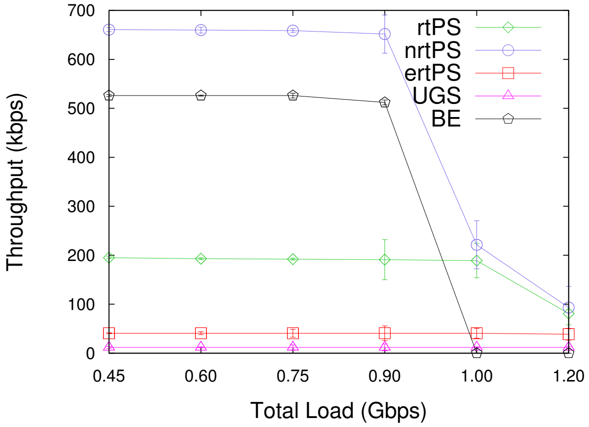

Figure 2: Throughput of UGS, ertPS, nrtPS, rtPS and BE connections.

Figure 2 shows the throughput achieved by UGS, ertPS, nrtPS, rtPS and BE connections. The UGS and ertPS throughput did not change, since these classes have high priorities showing that periodic grants are given at constant intervals. The nrtPS throughput stayed between the minimum reserved traffic rate requirement (200Kbps) and the maximum reserved traffic rate requirement (800Kbps). As the traffic load increases, the throughput achieved decreases since there are more connections competing for the same resource, however, the minimum reserved traffic rate requirement is supported. The minimum reserved traffic rate of 150Kbps for rtPS connections is also supported. In despite of bandwidth variabilities and the number of connections, the throughput requirements are supported under DBQUS. The BE connections achieved high throughput because they used slots not used by higher priority classes, but when the traffic load approximates of 1Gbps the throughput of these connections decreases when the system is overloaded reaching a null value. It is important to note that DBQUS was able to support QoS even when the offered load was greater than 1Gbps.

Figure 3 shows the latency for the UGS, ertPS and rtPS connections. The latency of UGS were not affected, even under the variability of channel capacity since these connections have higher priority. The latency of ertPS flows were almost constant, but it slightly increased

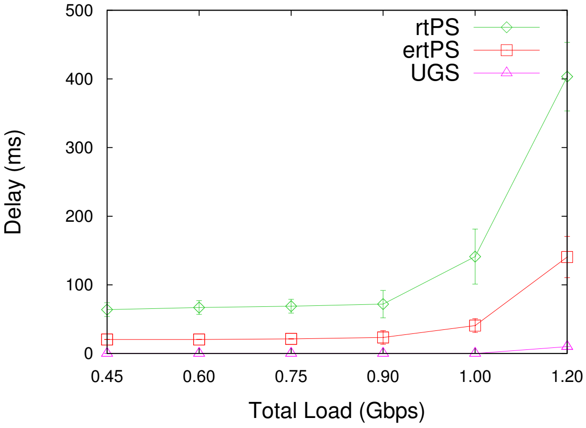

Figure 3: Latency of UGS, ertPS and rtPS connections.

when the traffic load in the EPON network approximated of 1Gbps. Besides that, the delay values of rtPS connections are below the maximum delay bound of 300ms when the total load is 1 Gbps. The latency of nrtPS flows are not showed in the figure since these connections do not have latency requirements. Both nrtPS and the performance of BE connections suffered high latencies. It is important to note that DBQUS was able to provide delay values below the required bound even when the offered load was greater than 1Gbps.

8 Conclusion

In this paper, the performance of a standard-compliant WiMAX scheduler for the integrated EPON-WiMAX network was assessed. The DBQUS furnishes the QoS requirements of different services flows specified by the standard, in despite of the variability of the channel capacity provided by the EPON network. The DBQUS was efficient in distributing bandwidth among different WiMAX service flows when the bandwidth available may be insufficient to provide the QoS requirements of all connections.

As a future work, the maximum time cycle of EPON network will be investigated and an EPON bandwidth allocation scheme will be developed to work jointly with the DBQUS.

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