Quality of Service in Ultrabroadband (UBB) Models

Elias ARAVANTINOS
Columbia Institute for Tele-Information (CITI) and Howe School of Technology Management, Stevens Institute of Technology, USA

John PAPAGIANNOPOULOS (*)
Department of Information and Communication System
University of Aegean, Greece

Abstract: In this paper we study and analyze need for Quality of Service (QoS) over the current fiber technologies and the role of the user and his Quality of Experience (QoE). We conclude that the current QoS models for multiplay services could get very complicated and the UBB technology could only simplify certain processes that are related to throughput and bandwidth. Finally we conclude that the role of the QoE is very important to assure the ultimate experience but also to help constructing cost models from the user's perspective and his needs, especially when these shift beyond his pre-agreed levels.
Keywords: ultrabroadband networks, QoS models, QoE metrics.

The "*last mile*" for residential broadband services has been the "Holy Grail" for carriers. Today, the broadband penetration is progressing rapidly in most of the countries, thus it is time to think ahead to the next stage, and where broadband transmission rates of over 1Gbps on the consumer level will likely be the driver of major changes in Information Technology, mass media, and consumer electronics. Envisioning the capacity and high speed needs for the future, we are introducing the "Ultrabroadband" (UBB) concept that defines the Next Generation broadband (BB) transmission for the 'last mile' and the home network. UBB is supposed to serve as the Next Generation of the Next Generation Networks (NGNGN) pushing a total digital experience to the households by offering 'unlimited' downloads and other similar capabilities to the end-user.

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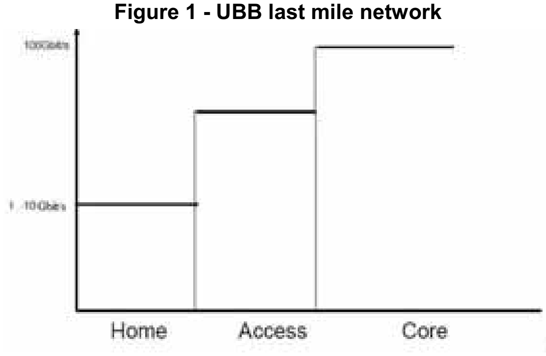
In this paper we are introducing the UBB idea and describing the issues related to the QoS in the last mile and making recommendations. Based on our UBB assumptions, we expect that converged networks supporting multiplay services based on voice, video, Ultra HDTV and data over a single link layer will require support beyond 1Gbps data rates in addition to the broadcast bandwidth. The use of fiber as a medium over Fiber To The Home (FTTH) and the different variations of EPON and GPON networks could serve the need for this speed, envisioning that more than 10Gbps burst rates in the backbone would be available in FTTH applications. Additionally super-computers should be able to accommodate the above speed with super power chips, network cards and memory chips. Also we should expect standardized consumer devices including 'smart' residential gateways, operating with a high-performance distributed processor architecture with superior connectivity and smart operating system to manage the new bandwidth and capacity requirements. However, today most of the vendors and operators or even network planners clearly do not envision most of these plans, as some could easily describe them out of scope.

A very critical and important area of research over the last years has been the Quality of Service (QoS), which becomes extremely sensitive when it refers to the 'last mile' link. The last mile is defined as the access link that connects the end user to the internet (backbone or core network). There are different ways to implement the data transfer over that link and this paper is trying to look into a heterogeneous converged environment, where the type of technology if fiber or wireless is not that important. Our main research question, answered in this paper, "Does the QoS problem still exist in such vast capacity access networks?" and "What would be the role of the user?" To answer these questions, we are reviewing some recent scenarios from the literature that mostly refer to the entire internet and apply them into the UBB access network.

Currently, QoS is a vague term that is used to guarantee the communication's performance. Network QoS is ideal to perform media communications, because it can support several functions such as provisioning for media data, prioritizing delay-sensitive data (voice vs. video). QoS is a set of quality requirements and a number of ways these requirements can be configured to interoperate in a stable and consistent fashion. In the engineering terms, it refers to the probability of the telecommunication network meeting a given traffic contract, or the probability of a packet succeeding in passing between two points in the network. On another similar issue we need to define the Quality of Experience, as "[…] the totality of the Quality of Service mechanisms, provided to ensure smooth transmission of audio and video over IP networks" (NIKIL *et al.*, 2005). Finally it is the overall acceptability of an application or service, as perceived subjectively by the end-user. In our proposed scenario, we are suggesting a general QoS/QoE scenario that allows the Service Quality Management to support a high level of Service Level Agreement (SLA). That is a contract that exists between subscribers and their service provider, client or between service providers and records the common understanding about services, priorities, responsibilities, and guarantees.

Today there are certain applications that are pushing the need for higher bandwidth such as streaming video on the internet, Video on Demand (VoD), Video telephony and conferencing, digital cameras and camcorders, Peer to Peer (P2P) and the increasing need for exchanging pictures and videos. From a social perspective, users are very impatient; need everything as fast as possible, especially when it comes to entertainment (games, movies) and most importantly for free or at a very low cost. All these could fit into a new landscape the UBB network or UBB 1.0 (figure 1) and will allow the users to enjoy ultraspeeds at the last mile assuming that the backbone could fulfill that need. That is mostly an economic or supply/demand problem, since it depends on the operators willingness to build new infrastructure to cover those needs.

Figure 1 - UBB last mile network



One of the first world's commercial deployments that is close to the UBB speed is in Hong Kong, by HKBN that offers a package of 1Gbps to the home [1]. The provider offers via the "bb1000" service, symmetric, 1Gbps FTTH connectivity to the last mile supported by Cisco. It should be noted that 1 Gbps service is up to 166x faster downstream and 1,950x faster

1 www.hkbn.net.

upstream than the advertised bandwidth of the incumbent's ADSL service. Hong Kong and Japan are among the few places in the world that are currently delivering 1Gbps residential broadband service.

Briefly, we are introducing the benefits of the ultraspeed; for example, under the Gbps scale the download time for a DVD movie is only a few secs (table). We should also keep in mind that the example of the table does not consider different compression techniques, that could compress the content up to 70 times or even more upon the application but these constraints might have a negative impact on the QoE.

Approximate download time for a DVD movie

DVD movie download time	
Link	Delivery time
Modem (56kbps)	13 days
Cable modem (1.5 Mb/s)	11hrs.36min
T-1 (1.54 Mb/s)	11hrs.12min
DSL(8Mb/s)	2hrs.12min
PON OC 48/32 (80Mb/s)	18min
Etherent 100	10min
GbE	1min
10GbE (UBB)	6secs

Source: Tim Holloway, World Wide Packets presentation, FTTH conference, November, 2002

In this paper we are mainly introducing the UBB concept, describing its QoS dimension to the last mile. Thus we highlight the need for QoS in the UBB models even in this vast capacity network, suggesting several scenarios that should be applied in the future. The remainder of the paper is organized as follows: in the following section, we are explaining the need for QoS in UBB, then we are reviewing and analyzing the QoS issues over FTTH, in the section after we describe the role of the QoE in the QoS and mainly the user and close the paper with our conclusions and future directions.

■ The need for QoS in the UBB

Unfortunately, the current internet is suffering from the lack of the QoS, therefore it is called 'best effort'. Thus, it provides a basic function with no guarantee of the packet delivery. However, as the user needs for speed and performance are increasing, there are different forms of QoS developed that should mainly focus on the last mile. The last mile broadband access and the home networking are a tightly knit couple, with the one covering the other. In a broadband wireless environment, the typical services include internet access, multiline voice including voice over IP (VoIP), audio and streaming video. In that case, QoS is always needed to guarantee for some data and real time applications as voice. Additionally, the role of the residential gateway, as a networking device or a smart home network node, is emerging, as it could serve different tasks including multimedia and internet delivery. In order to deliver high capacity communication it is assumed that the residence has the infrastructure to accept, manipulate, store and display the incoming vast and enormous UBB information. Therefore, the residential computers and terminals need to have super chips and enough memory to handle all this information.

One of the main research questions we are raising in this paper is if we really need QoS mechanisms in the 'last mile'. The answer is positive; we really need QoS and perhaps in a more sophisticated way targeting simplicity. For example, there are the three fundamental challenges in media streaming over the today's broadband networks: unknown and time-varying bandwidth, delay jitter, and loss (NIKKIL, 2005). However, in the UBB case, there is no constraining bandwidth limitation, providing a smoother QoE experience that is always based on proper QoS setup and SLA over the last mile. Also there are three main constraints, we need to guarantee in the UBB QoS and these are fairness for all users, efficiency regarding the bandwidth and resources allocation and cost concerning the pricing models. Therefore we need to develop simple QoS models in the near future to assure the user's happiness over the new UBB speed.

The services we need to manage and assure, play a significant role in the QoS and could be described from the following three different types:

- real time services, such as IPTV that have strict latency requirements;
- interactive data and streaming services, such as web browsing that can take advantage of the ultraspeed but could tolerate limited amount of delay;
- delay tolerant services, such as email that could provide average QoE and does not require any significant QoS.

The current QoS mechanisms that are mostly studied for an IP network (LORENZ, 2004; SCHOLLMEIER *et al*., 2004) are as follows:

- integrated Services (IntServ): an architecture that specifies the elements to guarantee QoS on networks at the transport layer;

- differentiated services (DiffServ): which packets to delay or drop at the expense of others in a situation where there is not enough network capacity at the transport layer;
- multi Protocol Label Switching (MPLS) Traffic Engineering: efficient use of available bandwidth between a pair of routers at the network layer;
- resource ReSerVation Protocol (RSVP): is used by routers to deliver QoS and to reserve sources in each node along a path at the transport layer;
- overprovisioning, prevents potential overload that may be caused, e. g., by fluctuations of the traffic rate on a link due to its normal stochastic behavior (a), by traffic shifts within the network due to popular contents (b), or by redirected traffic due to network failures etc.

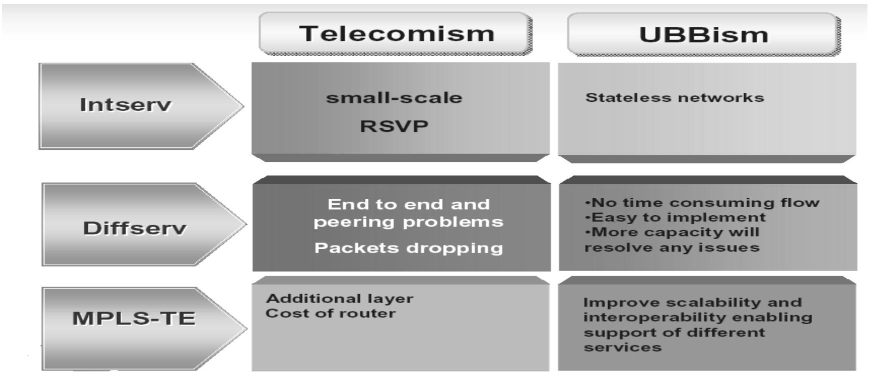
But in the UBB environment, we still require a high level QoS. The ultraspeed is expected to remove the bottleneck from the last mile; remove the risks of the jitter and delay or even the dropped packets. Are there any other remaining issues to consider? First we need to manage and guarantee a consumer driven experience (i.e. Video 2.0 or Ultra HDTV). Also the presence of QoS is needed to prioritize and manage the complexity and information packages' anarchy as they stream in the pipeline, including some potential minor congestion issues. Finally we need to guarantee and secure any type of service that reaches the end-user, standardizing a SLA that could be defined, based on his QoE and an index of minimum values of certain metrics such as bandwidth, delay, packet loss etc. as we explain in the QoE section. All these suggestions will be feasible assuming that in the core or backbone network we have some vast capacity available in the scale of Terra that could accommodate the UBB's Gigabit demand.

■ QoS over FTTH

In the last mile of the UBB, we are expecting a heterogeneous environment with different technologies. A QoS scenario should be able to respond to 'anywhere-anytime' conditions of a mobile and fixed multimedia environment. However, in this section we are discussing the issues over FTTH, describing two cases, the Ethernet Passive Optical Network (EPON) and the Gigabit Passive Optical Network (GPON), these are also the two most popular and massively tested technologies that could deliver an ultraspeed to the end-user [2]. GPON has a higher bandwidth efficiency compared to EPON especially for high-bandwidth services like IPTV (RASHID, 2006).

Considering the UBB, we need to address the differences between the current QoS of Telecomism that refers to the traditional networks, which today are responsible for any kind of service and the future mechanisms of the UBBism that targets to optimize the QoS/QoE levels to the end node or the home network supporting ultraspeed beyond 1Gbps (figure 2). In the UBBism the end user is more responsible for his needs, critical, emerging, or just entertaining and his relative willingness to pay for those needs, having more control. In that case he will be acting as the Chief Information Officer of his home network based on his QoE.

Figure 2 - QoS mechanisms before and after UBBism



In our QoS analysis, we discuss first the DiffServ weaknesses, such as E2E peering problems. Usually this is a traffic management sort of contract issue that derives from the different kinds of agreements between peers and includes details of how traffic is to be exchanged, along with a list of expected activities which may be necessary to maintain the peering relationship and details concerning how the relationship can be terminated. All these are dramatically increasing the QoS complexity. Also via the DiffServ there is no guaranteed bandwidth levels due to delays, jitter or even due to the lack of speed or capacity that will be improved over the UBBism.

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[2] The authors believe that based on the current broadband market conditions, the UBB would be first deployed via the fiber medium, thus the current analysis is focused on that technology.

In technical terms, the DiffServ is implemented in the edge routers and needs to be customized to serve the UBBism needs. Thus, in the case of the EPON, the new UBB Diffserv will consist of only two agreed packet forwarding behaviors (Per-Hop-Behavior); the assured forwarding (AF) and the expedited forwarding (EF) (HASSAN *et al*., 2006), dropping the best effort behavior.

A more efficient dynamic bandwidth allocation (DBA) scheme is mostly preferred to support multiplay services and to adapt the bursty nature of the network traffic. The efficiency derives from the DBA algorithms that should support the priority queues in various traffic classes, upon their requirements, but also fairness regarding the load of the Optical Network Units (ONUs). As a result to overcome the model's weaknesses more algorithms are needed maintaining a maximum value of fairness index through the DBA operation, (XIAOFENG, 2006; MA, 2005; SATTAR, 2008) increasing dramatically the system's computational processes and even more the overall complexity. The role of the UBB would be positive contributing and simplifying some of the processes that are related to throughput and speed, but still the police and priorities functions could still be a challenge as higher bandwidth and greater efficiency will be requested from the applications and end-user.

On the other hand GPON, besides the fact that it supports more bandwidth than EPON, makes it possible to separate up to eight different types of traffic, where traffic can be queued according to service. QoS is applied based on priority queuing and bandwidth allocation complying with the GPON Encapsulation Method (GEM) protocol. There are several intelligent systems supported as discussed in ANGELOPOULOS (2004) and JIANG (2006), in terms of traffic quality guarantees. The service based priorities are following the order, such as voice, TV and data. When there is only one operator, the QoS model is quite simple, but also in that case due to the traffic fluctuations the use of a DBA algorithm is mandatory. This problem could be easily resolved in the UBB with the vast speed and capacity, simplifying the model's behavior.

In the case of a GPON network shared by several operators and managed by a neutral operator the complexity increases. For example, in the multiplay services, several operators can offer services over the GPON, or a user can use different operators per service. Then, an end-user might have more than one VoIP lines and for video operators could offer different VoD sessions or simultaneous TV with different channels. The future scenario and most likely revenues model for the operators is no more in connectivity but mainly in supporting and offering advanced services over the last mile. Thus, no matter the high speed connectivity, the prioritization issue will be a QoS problem that currently increases the complexity in the multioperators scenario. In that case more advanced solutions and algorithms are needed to guarantee the SLAs for operators and maintain the proper QoS even in the UBB networks (GERMAN, 2006).

There are two QoS control models in the Telecomism:

- Guaranteed QoS: it is configured on the access network, guaranteeing absolute bounds of parameters such as throughput or jitter. All the services are delivered with previously reserved resources.
- Relative QoS: it is provided by class based differentiation (DiffServ) by means of separate queues dedicated to particular IP traffic classes and by performing priority scheduling between these queues.

Based on our assumptions, only the relative control QoS is closer to the UBBism conditions, since there is no jitter or throughput restriction over the UBB 'last mile'. Thus the system will have more resources available for supercomputing, and other multi-play services.

The MPLS also needs to be implemented over the network layer. MPLS is based on packet forwarding that is based on the packet's label value. In MPLS, the assignment of a particular packet to a particular Forward Equivalency Class (FEC) is done just once, as the packet enters the network. The FEC to which the packet is assigned is encoded as a short fixed length value known as a "label". When a packet is forwarded to its next hop, the label is sent along with it. At the MPLS nodes we can implement also DiffServ. This solution is very practical, since NTT' has already decided to combine the Passive Optical Network (PON) and MPLS in the last mile, suggesting that a worldwide shift may be taking place concerning full-service access network architectures.

Finally, we could suggest that the DiffServ in combination with MPLS and under certain customization could qualify as a potential QoS suggestion for the future UBB last mile access network. The UBB DiffServ will include AF and EF as agreed forwarding behaviors; relative QoS control model and the Premium service in case of the EPON. Even in the GPON, that includes the prioritization and police functions, we need advanced QoS that should assure the fairness and efficiency among the multiple operators' case.

■ The role of the user in QoS

Currently, the satisfaction of user is becoming one of the most important topics concerned by the service providers. The measurements and provisioning of the quality of service (QoS) are generally defined in terms of network delivery capacity and resource availability, not in terms of satisfaction to the end-user. The fundamental assumption behind such traditional provisioning is that the measured quality of service is closely related to the quality of experience (QoE) for the end-user.

Nevertheless the technology can only approximate the QoE cause since it is human. There are several studies that deployed psychological factors in audiovisual studies, as psychological factors, i.e., an aesthetic feeling and a feeling of activity. These helped to form opinion models for interactive multimodal services derived from the relationships among quality impairment factors, psychological factors, and overall quality (YAMAGISHI, 2006)

The home network is an IP-centric environment. The UBB user needs to have consistently the ultimate experience in the applications and E2E network connectivity. High availability and response time should guarantee the high levels of QoS. In other words the QoE is the mechanism to detect the high levels of QoS based on the human being's feelings and emotions. Thus the user should have full control of his experience with the assistance of smart operating systems with parametric planning systems as defined from ITU (TAKAHASHI, 2008)

For example the end user terminals with smart operating systems could serve the QoE and proper SLA of the QoS based on a scoring system. For example, a VoIP system could be evaluated with certain metrics and maintain a certain level of satisfaction; these metrics could be clarity, potential delay, echo, measured usually with a 0-5 scoring system. The ultimate QoE system should reach the maximum and that could be any number in that scale that is assured by the SLA that the customer is paying for. Thus if the customer pays for a satisfaction level of '4' and the QoE drops below '4' then the user should ask for more bandwidth via QoS to maintain that certain level, or the system should predict and identify and resolve problems before they have a negative impact on the customer experience.

On a similar case, to ensure that IPTV services meet the high expectations of end users, certain factors affecting the QoS directly related to the QoE must be properly considered. A variety of factors can affect the quality of IPTV audio and video, such as the content preparation process, network reliability, and terminal performance. Again smart operating systems should be created with tools designed to assess the QoE of IPTV services. Therefore, objective means to predict subjective quality solely from physical characteristics are necessary. These are called objective quality assessment methods as described in (TAKAHASHI, 2008; YAMAGISHI, 2008).

A smart operating system should have all the audiovisual modules embedded. In that way it assures the user's transactions such as critical business transaction but also should allow the user to ask for more bandwidth if he is willing to pay for more. For example, if we assume that the user is under a certain SLA that provides average QoE based on the scoring system and he wants to switch into a higher 'ideal' level, then he is supposed to be able do that in a dynamic, seamless way and certainly under different and higher cost. For example if the user wants to access a critical medical application, requesting high clarity in the pixels to make a decision, then he needs to ask for a different service with the maximum QoE, stretching the system out to receive that ultimate service for a certain duration.

The operator needs to maintain a certain level of QoS guarantee based on the SLA. In that case, the UBB QoS could be priced based on two simple classifications that serve as identification of the expected performance, guaranteeing certain levels of QoS. Hence the users could 'travel' on a premium class, based on the unlimited capacity notion, but even in that case we need to prioritize the traffic and organize the packets. When the traffic is marked as urgent or high priority, then we travel in the premium class, and the rest is bulk. Then, we could suggest a scheme based on the Paris Metro Pricing (ODLYZKO, 1999) the following two classes that seem the best match to the ultraspeed scenario:

- *Premium:* is defined as the elite class or business class. Only traffic that requires the most priority should receive this classification, such as VoIP traffic. The premium serves inelastic traffic, where real-time voice and video applications usually employ constant bit rate coding, requiring a fixed amount of bandwidth.

- *Bulk:* Economy class, low priority traffic, such as traditional data applications (email), can be classified as bulk. The class is characterized by elastic traffic that could even take advantage of minimal amounts of bandwidth.

The Residential Gateway or any other 'smart' network device could set the price using a policy-based approach via a smart algorithm or a broker.

To implement that, the broker could use advanced provisioning using statistical prediction, predicting the service and the resources needed by each time collecting and handling a request from the user (terminal agent). Thus, the user is responsible; sending his network and bandwidth needs based on the applications he wants to execute. Then, the broker should charge a price to the user, the value of which could be a combination of the service class, premium or bulk and also the time of the day. The broker will keep track of the charging price each time in the domain price table that is accessible from the ISP or the network operator (HAN, 2008).

Extending the class of service solution, a different pricing scheme could be considered for the introductory phase, when the operators will not know how much the users are willing to pay. In that case we can either apply a flat-rate pricing scheme for unlimited speed, but then it would be hard to classify the information that is not going to be properly controlled and managed in the channel. There are several other pricing models for the internet and its services that could be selected as discussed in DASILVA (2000), FAKNER (2000), COURCOUBETIS (2003).

■ Conclusions and research directions

UBB is still in uncertainty but there are certain broadband constraints in the Telecomism such as the lack of speed and capacity that could push the UBB deployment and use. In this paper, we have explained the need for an effective, fair and cost efficient QoS model that could be implemented over the UBB last mile. It should definitely include a customized DiffServ and MPLS scheme assuring certain levels of QoS under standardized SLAS, improving the QoE of the multimedia transfer for the users.

Furthermore, we did an analysis of the FTTH QoS on EPN and GPON and we realized that there is lots of complexity, thus simpler models are needed in the future that could be more easily implemented, releasing network and end-user resources for other uses.

Finally more research and new simple models on QoS and QoE should be suggested especially on multioperators scenarios and even more on multiplay services resolving prioritization and other DBA issues.

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