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Context-aware QoE-based multimedia network architecture

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***Abstract*— User QoE can be used to provide context-awareness to multimedia networks as it is the most valuable parameter to identify the needed network resources and provide an adaptation which offers an optimum service for each user. This article provides a brief survey of techniques that can be used to deal with QoE adaptation, and an end-to-end context-aware architecture proposed in R2D2 multimedia network (developed within European CELTIC program). The QoE support and the role of the Home Gateway (HG) within this network will also be highlighted.**

***Index Terms*—Home Gateway, QoE Management, QoS Management, Multimedia.**

I. INTRODUCTION

During the last few years, services and applications that require real-time Internet have grown in terms of popularity and necessity. Nowadays, as a result of the growing FTTH (Fiber to the Home) deployment, a great number of services have moved to the Internet (i.e. Voice over Internet Protocol (VoIP) or Internet Protocol Television (IPTV), and the necessary user devices are located at the user's home getting access to the Internet through the Home Gateway (HG). However, current access network architectures do not allow operators or household owners to dynamically control which services at what quality level should be delivered to the access link (i.e. static virtual circuits are used for IPTV). Services are delivered in a best-effort fashion and, in case of bandwidth failures or link congestion, all services used by the household would be impacted, presenting long delays and a lack of quality in terms of Quality of Service (QoS) parameters. This decrease in QoS usually leads to a poorer user experience, referred to as Quality of Experience (QoE) [1]. Nevertheless, the same QoS parameters can lead to different QoE (for different users) because the user experience is personal and the subjective perception might be slightly different. Similarly, the same QoE (e.g. "good" experience) for different users can involve different QoS parameters. Thus, it is crucial to take into account not only the QoS parameters but also the individual QoE perception. This means that QoE is an optimal parameter to provide context-awareness. Traditional adaptation solutions are based on Quality of Service (QoS) parameters such as packet losses, jitter, delay, etc., but perceptual user QoE is not taken into account. Moreover, these solutions become suboptimal due to the measurement uncertainty and the different perceptual criteria that each user has. A promising solution is a resource manager that dynamically optimizes the network resources based on the QoE of the customers. The role of the HG is crucial in this architecture as it is the household entry point where different services with heterogeneous requirements merge. Consequently, traffic differentiation techniques need to be applied in the HG in order to achieve user-dependent QoE. This article provides a brief survey of techniques that can be used to deal with QoE adaptation. It also describes an end-to-end context-aware QoE-based network architecture and introduces the role of Home Gateway, based on the R2D2 multimedia network developed under the European R&D CELTIC program.

II. RELATED WORK

Traditional adaptation techniques are based on Network Quality of Service (NQoS) [1, 2], but the user Quality of Experience (QoE) is the most meaningful quality evaluation about user satisfaction with an application or service. A detailed description of QoE and QoS parameters is explained in [3]. Network, data encoding, protocols, terminals, etc. establish objective factors that determine QoS performance; however, QoE cannot be univocally translated into objective network factors because it is also affected by subjective factors that involve sociological and psychological aspects. Consequently, in order to achieve a satisfactory QoE, an according set of QoS parameters, that could be different for each user, has to be provided. It determines that QoE is a parameter that determines the context of the whole network. Many techniques could be applied in order to achieve a QoE-aware architecture. This architecture might be a QoS layered architecture, where its QoS parameters are dynamically adjusted based on a user-dependent QoE, providing a context-aware system. Adaptive source rate control is an adaptation technique in real-time services which involves matching the transmission rate to the available network resources [4-6]. The multimedia bit rate can be dynamically adjusted taking into account the network congestion based [7, 8], for example, on RTCP packets and speech properties, as audio and video encoding parameters have a significant importance in QoE [9]. The relationship among the sent bit rate, content and QoE are being studied, as shows [10], where the impact of video content dynamics in video quality level is studied. Also, H.264 SVC (Scalable

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Video Coding) streaming scheme using adaptive layer-switching provides a tool for rate control [11]. However, these schemes do not consider the intermediate multimedia network elements neither a direct user based QoE. In addition to adaptation in intermediate multimedia network elements, actions in home network, specifically in the HG, need to be considered. This is based on the fact that the HG is the only point in the whole network architecture where all the traffic generated by the home network is passing through. Thus, monitoring and acting at HG provides the interaction information between services demanded from the home network, and service control access to the link between HG and ISP, which usually presents the uplink and downlink bandwidth bottleneck. There are many articles that propose QoS adaptation techniques at HG, such as [12] and [13] that purpose and analyze traffic queuing techniques, but these proposals do not use a multimedia network with special capabilities to assure an optimum QoE to the final user. In addition, the optimum end-QoE depends on each user, so "good" QoE for one user can be "bad" for another user.

III. CONTEXT-AWARE QOE-BASED MULTIMEDIA NETWORK: THE R2D2 NETWORK

As an example of context-aware network, R2D2 multimedia network is described. A diagram of R2D2 architecture is shown in Fig. 1, where the following physical networks are considered: home network, access network, aggregation network and core network. Home network is placed at user's home environment, and it is composed of the user's devices which are going to use services that reclaim a determined bandwidth. The HG is located at the home network and its main focus is to apply QoS policies in order to manage the available bandwidth among the required services; and to mark packets to classify them into the according service, so that the upwards network can easily identify it. LAN side and WAN side of HG are Ethernet interfaces. The Optical Network Terminator (ONT) is located at user's home and its aim is to mark the traffic with user identification and encapsulate it to be compliant with the Gigabit-capable Passive Optical Network (GPON) standard through Optic Fiber. At this point, the traffic enters into the access network. The goal of the access network is to maintain the traffic associated to the collection {user, service} using FTTx (Fiber To The x) technology. This way, adaptive actions could be carried out in order to reconfigure the network QoS parameters. Optical Line Terminator (OLT) is the end of the access network and where packets are sent to the aggregation network. The aggregation network contains the Home Configuration Manager (HCM) and the Auto-Configuration Server (ACS), which manage the home network elements. Both are connected to the management network and, therefore, to the Network Resource Manager (NRM), which is the element in charge of managing and controlling the rest of network elements. Together, these devices manage the logic control of the multimedia network, and they monitor, upgrade and assure the QoS parameters of the network taking into account the user profile and providing context-awareness, so that an optimum QoE is obtained by the final user. The logic network "Management Network", where these devices are present, is described later.

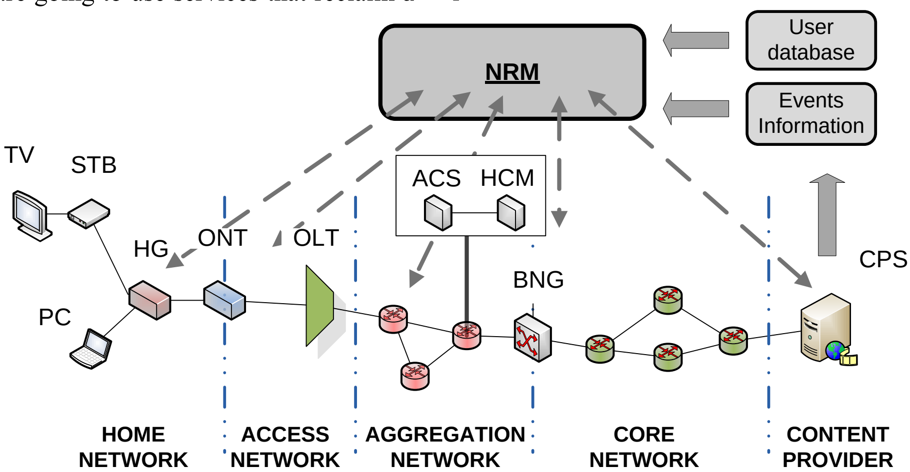

Fig. 1. System architecture of R2D2 Network. Figure describes R2D2 sub networks and network elements. Also, the interface of the network devices with the NRM is showed.

Between the aggregation network and the core network, the Broadband Network Gateway (BNG) is found. The BNG is responsible for translating the core network protocol (Internet Protocol/Multiprotocol Label Switching (IP/MPLS)) into the transport/aggregation protocol and vice versa. The MPLS acts as transport technology within the telecom operator network. It addresses data between networks nodes based on short path labels rather than on complex lookups in a routing table. However, the MPLS domain in each aggregation network is different from the MPLS domain of the network core and normally their control planes are not coordinated. Moreover, access nodes are just beginning now to include MPLS functionalities. Very recently, in the MPLS standardization forum [14], some proposals have appeared to converge all the network elements, including the access nodes in the same MPLS domain. Unfortunately, the support of the associated functionalities that the MPLS standardization forum proposes is not yet complete in the industry, so it has

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not been possible to set up a test bed complying with such architecture. That is the reason why architecture with a fully layer-2 aggregation network is proposed, as the possibility of combined Ethernet over MPLS would complicate the design of the NRM. The implemented solution, which will be explained in detail later, is based on the standard 802.1Q and 802.1ad which are the most used protocols for Virtual LANs (VLAN). The main goal of the BNG is to maintain the service differentiation established from one interface to the other and carry out the translation with efficiency and low latency. Depending on the core network physical layer technology, the BNG could also act as a medium converter. In the test bed architecture, both segments will be Ethernet over optical fiber. However, core networks, especially today's implementations, may have several other solutions such as SDH, PDH, lambda switching, etc., that could be also used in R2D2 network. The Content Provider Server (CPS) is positioned in the core network or in the aggregation network, and it can notify that a specific content demands specific requirements to be ensured by the network elements. The content provider can offer information such as: the type of content, the required bandwidth and the time interval in which this requirement should be enforced. In order to assure an optimum end-to-end QoE, the multimedia network management system must support a traffic differentiation system and monitoring and adaptation mechanisms. The next points detail the management network and how the traffic differentiation is done from the HG until the BNG. Management Network The management network is composed of the Home Configuration Manager (HCM), the Auto-Configuration Server (ACS), the Network and Resource Manager (NRM) and the Content Provider Server (CPS). The CPS streams video contents to the home users and, additionally, it can also receive feedback concerning the desired/expected quality of the contents it is currently distributing. This feedback will be defined in qualitative terms, suggesting to the content provider that it should decrease/increase the content quality. The identifier of involved content and the user downloading the content will be also specified in the feedback. In such a system, the most important module is the NRM. This module is responsible for the decision taking, so QoE is always corrected, helping to foster the users' satisfaction at all levels. The NRM interfaces with the network elements, the monitoring tools, the service providers and the user profiles as it is shown in Fig. 1. The NRM functions involve: traffic monitoring, network management and performance analysis. The ACS is required for HG remote control and configuration, whereas the HCM is required for the Set-Top-Box (STB) in home network. When the HCM receives a user's alarm indicating that QoE is regular or bad, it will request the ACS to check if the problem could have been due to congestion in the HG. The ACS will check the HG queue status and it will assign more output bandwidth to the IPTV services if possible. Regardless of any local action, the HCM will transfer the user's alarm to the NRM for resolution of the problem from a global network perspective.

A. Traffic Differentiation

Traffic differentiation, as it has been explained before, has a special relevance in this kind of multimedia network. Traffic differentiation is needed in order to apply an optimum QoS at the different points of the network and for this purpose a marking system is used. This system starts in the home gateway and is also carried out by access network and aggregation network. In home network domain, Virtual LAN (VLAN) has been chosen as a marking technique because VLAN tagging is one of the most common mechanisms used in aggregation networks, and it allows establishing traffic service differentiation across the network. It is important to remark that this traffic marking system resides in a Layer-2 scheme and this avoids the use of very complex and expensive devices with high charge of processing. In addition to IEEE 802.1Q, the standard IEEE 802.1ad VLAN Q-in-Q allows to make double VLAN tagging. VID (VLAN Identifier) field of the VLAN tag is the most relevant one. It is the identifier of the VLAN. Value 0 indicates that the frame does not belong to any VLAN (in this case VLAN tagging is used to assign a priority to the frame). Except 0xFFF value, other values can be used to define VLANs, although VID 1 is usually defined for network management. So, a single network can provide connectivity to multiple service providers, and each of them to multiple clients, ensuring bandwidth, quality of service and priorities for both supplier and customer. It also ensures the privacy of the operator because, although physical network is shared, different networks are isolated and segmented from a logical point of view, a frame from a service provider will never go to another provider's equipment. At access network, Optic Fiber is used, so at this point Gigabit-capable Passive Optical Network (GPON) replaces Ethernet. GPON is an access network technology to provide traditional and new services to the customer premises over passive optic fiber [15]. Traffic is encapsulated in GPON Encapsulation Method (GEM) ports, which represent logical connections between the OLT and each ONT, identified by a label called Port-ID. This encapsulation allows the devices to distinguish the different transport services. An illustration of how the traffic tagging works in the proposed R2D2 system architecture is presented in Fig. 2.

At home network, the HG marks outgoing traffic with a VLAN identifier according to the service. When packets arrive at the ONT, traffic is scheduled to a GEM Port, which identifies uniquely the user and the service according to it. Besides, VLAN IDs are exchanged and added in ONT and OLT respectively. By doing this, traffic is identified with the pair {user, service} and this identification pair is going to be maintained across the network to easily apply QoS policies according to these identifiers. Nevertheless, double-tagging is not a feasible solution and its implementation is not a trivial issue, as Q-in-Q aware equipment with capabilities to apply QoS or bandwidth limit policies are required. That equipment

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should be able to classify the packets according to outer and inner label, which is not a common feature. Fortunately, same concept can also be applied using a single tag: splitting VID field into two parts: one containing the service information, and the other one containing the user information. In conclusion, an implementation of double tagging can be done over only one VLAN tag.

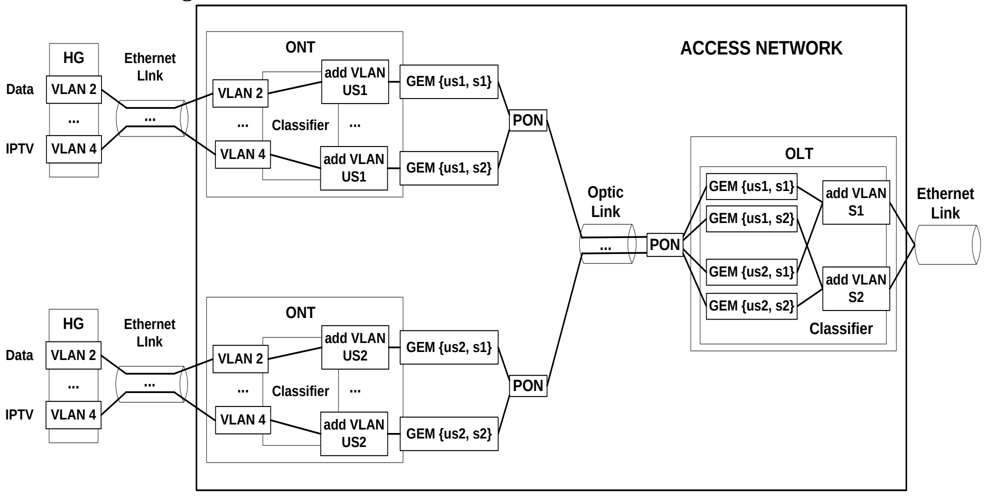

Fig. 2. Tagging system in R2D2 network. VLAN tags are applied as end-to-end differentiation technique. A pair {user, service} is maintained along the network. The figure shows the VLAN double tagging technique, although same concept can also be applied using single tagging with customer and service identifiers mixed. Thus, in the latter case, the ONT puts/extracts the single VLAN tag with customer and services identifiers, but OLT does not add or extract any VLAN tag.

The most promising splitting is 9/3 bits. 9 bits for users permit up to 512 users, and 3 bits for services permit 8 services. In fact, some VLAN IDs are forbidden due to special cases of the standard, so the number of users is reduced to 510 users. The reason of this splitting is that VLAN ID=0 and VLAN ID=4095 are reserved to special cases. The HG is placed at home network and its main aim within R2D2 Network is to apply the local VLAN tagging and manage QoS policies according to the services and user preferences (context). VLAN tagging for traffic management allows an easy differentiation between services; secondly, in case of congestion, it assigns more resources to traffic with higher priority; and thirdly, it provides a Layer-2 identifier to the network traffic which permits cheaper and less complex devices. As it has been mentioned before, VLAN tagging is used for service differentiation in the interface between the ONT and the HG, being the highest VLAN identifier the one with the highest priority. Since the home network devices do not usually support VLAN tagging, the traffic coming from the LAN to the HG, which has not been previously tagged, is tagged with the correct VLAN identifier by the HG before sending it to the ONT. In both directions, the HG arranges each packet in a different priority queue according to the packet VLAN tag. The queues associated to the same interface are then served following the priority mechanisms explained later. The main purpose of the ONT is to act as an intermediate converter between the GEM encapsulation of the GPON and the local ports of the ONT, in this case, Gigabit Ethernet ports. Packets that arrive from the HG to the ONT have been previously tagged with local service identifiers by the HG. In case of considering the scenario with Q-in-Q frames proposed initially, the ONT would replace the tag inserted by the HG with the User-VLAN (US-VLAN) tag.

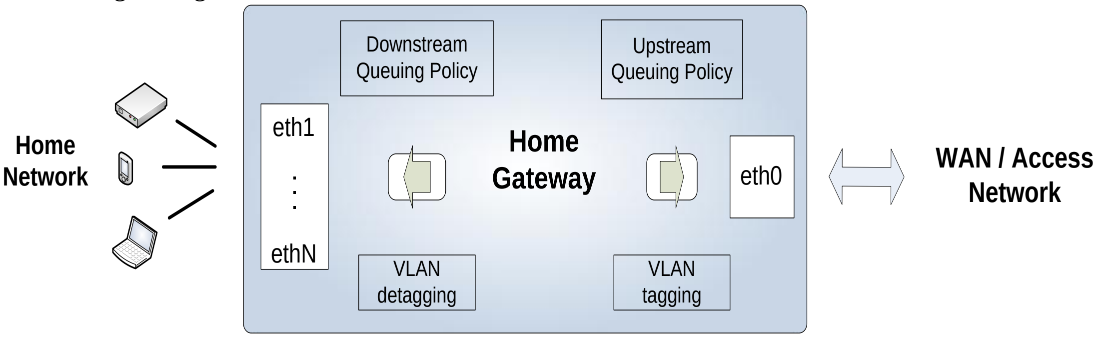

Fig. 3. Illustration of HG queuing and tagging functions in R2D2 network. In upstream direction, the HG applies VLAN tags to packets and classifies them into an upstream queuing tree. In downstream direction, the HG acts in a reverse way, detagging packets.

The OLT translates the frames received from the GPON access network protocol into the Ethernet frames used in the aggregation network and vice versa In case of considering the scenario with Q-in-Q frames, the OLT would add the Service-VLAN (S-VLAN) tag.

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IV. QOE FUNCTIONALITY AND THE ROLE OF HOME GATEWAY

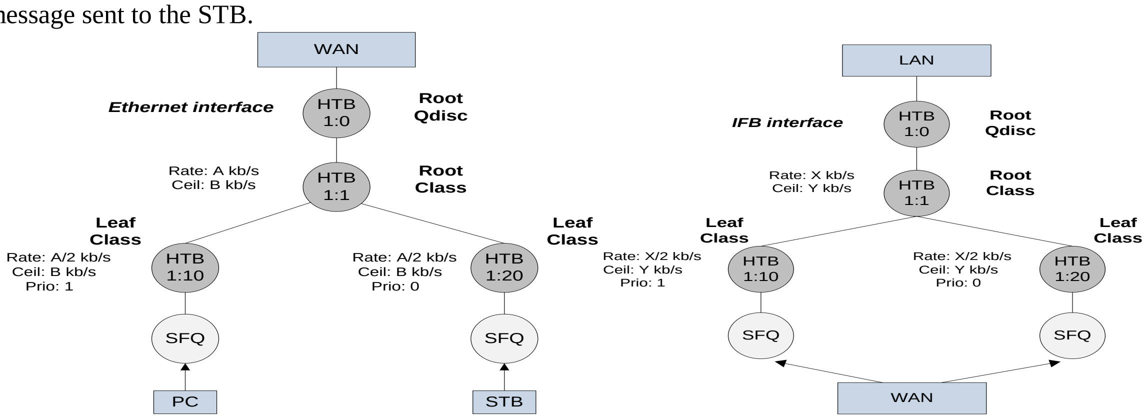
Home Network is a LAN composed by user's devices. These devices will send and receive traffic to and from the Internet through the HG, so the HG must manage the available WAN bandwidth among these devices located at LAN side. Network resources needs to be dynamically reconfigured based on the user's QoE feedback as shown in the following use case. A user can report its perceived decreased QoE to the NRM, triggering the adoption of appropriate actions to correct this situation, which makes the system context-aware. For example, the user reports the perceived QoE by pushing a button on the remote control of the STB:

1) The user will report the perceived QoE by using the STB's remote control and selecting a value from the menu displayed on the TV screen. The user can select poor, regular, good and very good QoE. **Fig. 4** shows the STB's QoE report interface.

Fig. 4. STB graphical interface for user's QoE report. Four types of QoE are shown to the user (poor, regular, good, very good). According to the QoE, the final user must select one option, and system reacts consequently.

2) Before processing the user's request, NRM has to decide if it is dealing with a new request from the user and if the QoE has decayed or not from the previous user's request. If the request is a new one or, in case the QoE has worsened, it is transferred to the next processing stage. In any other case the query is discarded and the user notified by a message sent to the STB.
3) The NRM has to check if the reported user's QoE matches the measured QoS parameters.
4) If the analysis of the QoS probe measurements confirms that the reported QoE is actually bad (this is, if the QoS is not acceptable at one point of the transmission chain), the NRM determines whether more resources can be allocated at HG or any point of the network. The user is notified of the result of this operation by a message sent to the STB, whether it was successful or not.
5) Visible Results: The Quality of the content is visibly improved, so the user does not have to retry the complaint, or, the user is notified about why the quality cannot be corrected.

As mentioned, NRM can update the HG configuration based on the user's QoE feedback. HG has several queuing disciplines with configurable parameters to manage QoS based on the context (user preference and service). Also, upstream traffic and downstream traffic follow different structures to offer VLAN marking and demarking. A general diagram of how upstream and downstream traffic is queued by the HG is shown in Fig. 3. The Linux queuing disciplines that have been used in upstream and downstream queuing structures are Hierarchical Token Bucket (HTB), Stochastic Fairness Queuing (SFQ) and Intermediate Functional Block (IFB). HTB is a Linux "classful qdisc" queuing discipline whose main goal is to manage the outgoing bandwidth on a given link. It is based on Token Bucket Filter (TBF) and Deficit Round Robin (DRR) [16]. One of the most common applications of HTB involves shaping transmitted traffic to a specific rate. A fundamental part of HTB is the borrowing mechanism: the remaining bandwidth is distributed to classes which request more bandwidth. SFQ balances traffic flows (TCP sessions or UDP streams) when a link is completely full [17]. IFB (Intermediate Functional Block) device is a virtual device that is not associated to any physical interface but qdiscs can be attached to this device.



(a) (b)

Fig. 5. Example of HG uploads (a) and download (b) queuing tree. Fig. 5 (a) shows a HTB queuing tree with a SFQ applied to leaf classes. Fig. 5 (b) shows a IFB where a HTB queuing tree is applied and a SFQ is attached to leaf classes. In (a) and (b) figures *rate*, *ceil* and *prio* would be configurable parameters.

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This way, the incoming traffic can be redirected to an intermediate virtual device with a global queuing tree. In upstream direction, the HG must send VLAN tagged packets to the OLT and share the upload bandwidth among all services according to their priority. As it has been explained before, in the architecture presented in R2D2 a VLAN is associated with a service, thus the first issue to be done by the HG is to tag the upload traffic coming from the home network. Once the packets are tagged, they are classified and sent to the corresponding SFQ in the upload queuing tree. This queuing tree is HTB based and the consequent rate (assured maximum rate), ceil (maximum achievable rate) and priority parameters can be set according with the service requirements. Fig. 5(a) describes an example of this upload queuing tree: a simple case is presented, where two leaf classes are related to two different VLANs and services (a PC generating TCP traffic and STB claiming IPTV service). The assured maximum rate is distributed in the same percentage among all leaf HTB classes, but a priority is applied. This way, when exceeded bandwidth exists, it is shared among VLANs, but the VLAN with a higher priority is served first by the scheduler. In downstream direction, the HG must remove the VLAN tag from packets coming from the ONT and prioritize traffic in order to adjust rates of TCP client-server connections so that UDP traffic, which it is related to IPTV service, can have enough bandwidth to achieve a good user QoE. When packets arrive to the home network from the WAN side, the HG removes the VLAN tag and, after this, the packets enter into the corresponding SFQ in the download queuing tree using IFB. As in upstream structure, a HTB based queuing tree is used and rate, ceil and priority HTB parameters can also be set according with the queuing necessities. Fig. 5(b) illustrates an example of this downstream queuing tree. Again a simple case is presented, where two leaf classes are related to two different VLANs (one for the PC and the other for the STB). In this structure an IFB is used with the purpose of setting a global HTB tree for all the possible LAN interfaces; this way, it is possible to share the download bandwidth between all services (in all LAN interfaces).

V. CONCLUSION

QoE has been shown as an effective parameter to provide context-awareness in a multimedia network. Numerous effective techniques to adapt QoS parameters to network capabilities exist in the actual state of the art; however, in order to achieve the optimum performance for the whole system is extremely important to deploy an optimum QoE aware multimedia infrastructure; thus, deploying a context-aware network. This article has presented R2D2 as an example of context-aware QoE-based multimedia network and an innovative HG inserted into this architecture. This system is capable of managing and controlling a variety of network elements, streaming media content and monitoring QoE and QoS parameters at several points of the network. In addition, an optimum traffic differentiation system has been applied in case of congestion or bad QoE experienced by the final user. This architecture makes use of the available equipment in the actual market, and it does not require very expensive devices with a lot of processing capabilities. An intelligent management system is also used to assure good QoS parameters along the network, but always maintaining its aim to be user-dependent QoE-based context-aware. Future work includes enhancements in the HG to support QoS-based QoE acceptability testing methodologies.

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Jon Goya was born in San Sebastián, Spain, in 1987. He received the M.S. degree in Telecommunication Engineering from Tecnun (School of Engineering of San Sebastián), Spain, in 2011.

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