Bandwidth reservations in home networks: Performance assessment of UPnP QoS v3

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***Abstract*—Service providers are facing the challenge of assuring their users benefit from high quality services, which requires provisioning quality of service (QoS) guarantees. In this paper, we describe how a Universal Plug-and-Play (UPnP) based home network architecture solves this problem in a heterogeneous home network. We outline how it both relieves the end user from troublesome configuration and still offers controllable mechanisms to the service provider. We particularly present performance assessment results for UPnP QoS v3, based on a fully operational experimental implementation. The quantitative measurement results are further used in extensive simulations demonstrating acceptable response times and clear QoS differentiation.**

I. INTRODUCTION

The constant development of telecommunication networks caused rapid growth of bandwidth availability at the user's premises. That induced the creation of a wide range of services accessible over the data networks, and also allowed increase of user generated content and services. In a situation where an access link is not a narrow bottleneck anymore, the management of the home network resources becomes an important issue, especially in light of high bandwidth multimedia applications.

One of the challenges in providing end-to-end QoS is that the home network is not entirely controlled by the service provider or network operator. Thus, there is a need for QoS mechanisms in the home network, while relieving the end user of troublesome configuration. Recently various home network technologies emerged that support bandwidth reservation (e.g., HomePlug AV, IEEE 802.11e, HomePNA). To be able to control end-to-end Quality of Service in a heterogeneous home network comprising one or more segments of these technologies, a common framework is needed to provide an interface to actual physical properties of the network. This is exactly addressed by the UPnP QoS framework, as discussed in this paper. Hence, plug-and-play functionality is desirable which is exactly the aim of the UPnP (Universal Plug-and-Play) Forum. There, the UPnP QoS working committee recently finalized version 3 of the UPnP QoS framework. Nevertheless, no commercial implementations exist yet.

In this paper, we present an architectural solution to solve the service provider's problem of dynamically providing QoS guarantees up to and including the home network. In particular, this comprises UPnP QoS v3, for which we present performance measurement results on our proof-of-concept implementation [1]. In addition, we assess the viability of UPnP-based QoS differentiation through extensive simulations.

Related work

The management of home networks has been of an interest due to the access network development described earlier and growing in-home data traffic. In the access networks well-known mechanisms such as (G)MPLS ((Generalized) Multi-Protocol Label Switching) can be used to setup the necessary reservations, e.g. based on Carrier Ethernet [2]. Providing these reservations in both backbone and access have been successfully addressed, even considering variations in the required bandwidth [3], [4].

In the home however, the provider has only limited control, and the complexity of dealing with a heterogeneous home network comprising multiple layer-2 technologies (e.g. WLAN, HomePlug, etc.) arises. While this could be addressed by a so-called Inter-MAC approach with a layer-2 based approach [5], we can capitalize on numerous attempts aiming at the automation of the home network creation; DPWS [6], IGRS [7], Bonjour [8], Jini [9]. While Bonjour does not explicitly consider QoS, IGRS and Jini are more focused on the end devices' resources than network's resources, UPnP and DPWS are clearly defining network QoS mechanisms. Early versions of UPnP QoS specifications were described in [10], the authors present a possible solution based on UPnP QoS v1 and Remote Management in Diffserv (RMD). Non-standardized extensions towards parameterized QoS, providing absolute guarantees rather than (relative) prioritization, are proposed in [11]. Lee et al. [12] propose extensions to UPnP QoS v2 for monitoring and also consider temporal scaling (frame rate reduction) as video adaption technique, which they assume is provided by the media server providing the video stream (from within the home). The authors of [13] presents distributed video game streaming system relying on UPnP QoS to overcome network performance issues and [14] proposes a modifications to UPnP A/V aiming at enabling multicast of HD content. The home network's QoS is also investigated considering other protocols. The authors of [15] point out the importance of QoS provisioning in the home network and address them on the MAC layer in 802.11. In [16] the authors propose enhancements for

IMS (IP Multimedia Subsystem) QoS framework using SIP (Session Initiation Protocol) information to issue reservations in the home. The design idea of home appliances control service based on DPWS is proposed in [17], where automatic detection of device QoS parameters is addressed.

This paper advances by showing the performance of (to our knowledge) the first complete UPnP QoS v3 implementation. Our models allow verification of the differentiation level among the different priority classes and enable easy usability assessment of future functionalities.

The remainder of the paper is structured as follows: first, in Section II we introduce an end-to-end QoS architecture and particularly focus on the components in the home network. Section III presents our full UPnP QoS v3 implementation, including measurements and performance optimizations. These measurement data are used as a basis for a simulation study assessing the QoS metrics in Section IV. We summarize our conclusions in Section V.

II. ARCHITECTURE

We present an architecture for a service provider to manage in-home network resources for services they provide. The local network resource reservation mechanism is responsible for in-home network resources, and can be remotely managed by the service provider through the use of a remote management protocol. Reservation of resources in the home network ensures qualitative services as perceived by the customer. By enforcing policies, the service provider can guarantee premium services like Video on Demand or streaming local content to the STB-controlled television set to be protected against services that have less stringent QoS constraints. Examples of these services are Internet connectivity, peer-to-peer networks, etc.

One of the major problems when managing in-home network resources, is the heterogeneity of the networking technologies used. Home networks grow naturally, users can buy wireless access points to extend their network to include a laptop, but can as easily opt for powerline communication. As opposed to the access network where one single party controls the resources, the home network can be composed of multiple networking segments. All these segments can possibly have a different admission mechanism, this problem needs to be solved by the local QoS management framework.

Figure 1 shows the actions called for a UPnP QoS request. In case of prioritized or hybrid QoS the QosPolicyHolder (QPH) service is queried for the policy parameter TrafficImportanceNumber (TIN) which indicates the relative importance of the traffic on segments where prioritized QoS is requested. The QosManager (QM) entity will subsequently query all QosDevice (QD) services for path information so it can calculate the path the stream traverses. To enable the decomposition of the QoS requirements, the QoS state of all QD services on the path will be retrieved after which the actual admission will take place. In case of failure, a couple of things can happen depending on the parameters the Control Point (CP) provided. The CP can indicate to do preemption or to only report which streams on the network are currently blocking reservation of resources. Figure 1 shows what happens when the CP specifies preemption has to be done. First of all, the policies for all blocking streams (which were returned as a result of the failed QD:AdmitTrafficQos() action) are retrieved from the QPH service. Based on the UserImportanceNumber (UIN) of each of the streams, Quality of Service for the preemption candidates is released after which admission is tried once again.

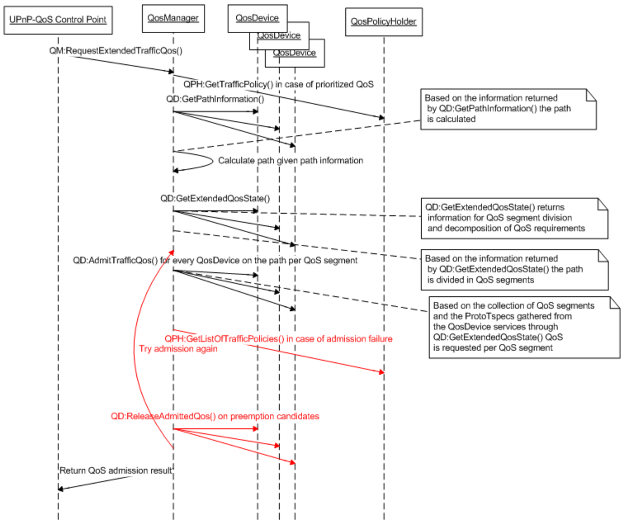

Fig. 1. Sequence diagram of QoS request with optional contention resolution (preemption)

III. EXPERIMENTAL IMPLEMENTATION

Ghent University – IBBT has implemented the complete UPnP QoS v3 specifications, including an implementation of the QosManager and QosPolicyHolder services together with a framework that simplifies the implementation of QosDevice services (for details see [18]). To highlight the necessary steps for reliable, policy based resource reservation on a heterogeneous home network, we successfully demonstrated the following scenarios in a UPnP QoS v3 over MoCA demonstration [1]:

1) Basic QoS reservation: This scenario shows that the differences in technological capabilities can be abstracted to offer a unified resource reservation mechanism across the home network (see Figure 2). QoS is requested for a stream originating outside the home network. Due to the fact QoS has been reserved for the VoD stream, the best effort IP traffic within the home network will be restricted to the remaining bandwidth.

2) Resource contention: A second scenario covers resource contention detection, where a QoS reservation is made when resources are scarce. This scenario will present the end user with a message indicating there was a problem when trying to provide Quality of Service. In a third scenario (depicted in Figure 3) contention is solved without user interaction, based on predefined policies, and resources are released to make room for the reservation at hand.

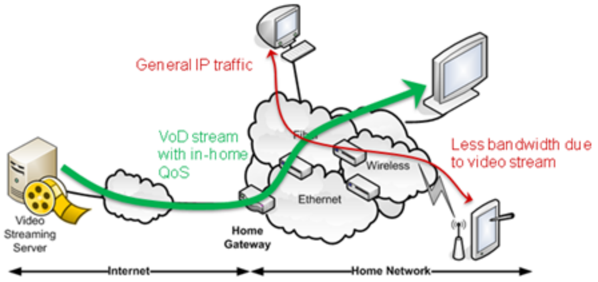

Fig. 2. Basic QoS reservation use case

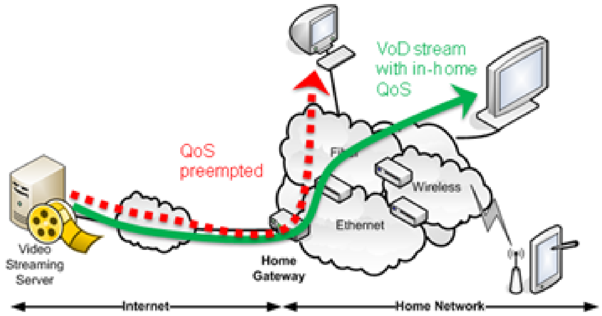

Fig. 3. Resource contention use case

Table I shows the results of the tests performed on the aforementioned MoCA implementation. Note that parsing refers to processing of the action responses received by the caller (i.e. the QosManager entity). Clearly, parsing times are only non-neglible for the GPI and GEQS actions, since their responses contain a significant amount of state information from the QosDevice.

It is interesting to note that MoCA uses a Network Coordinator to do actual admission of QoS requests. Our measurements indicate that the response times significantly depend on whether or not the reservation request is initiated by the Network Coordinator in the MoCA 1.1 network. As expected the results for GPI and GEQS are comparable since no interaction is needed with the MoCA network. The results for ATQ and RAQ however, reveal an interesting observation: there is a considerable penalty for having to contact the Network Coordinator. This observation is valid for invocations to ATQ which performs a QoS request as well as for invocations to RAQ which release resources.

IV. SIMULATION ANALYSIS

A. Model

The topology of the model developed for the purpose of the simulations is presented in Figure 4. We assume the QM, QPH and CP functionality are implemented at a single node, issuing the QoS requests. This node (e.g. a home gateway) is interconnected with three end QDs by the intermediate QD with switching functionality. All the links in the model provide 70Mbps full duplex connectivity. The CP generates the request in exponentially distributed intervals with a mean value used as a parameter of the simulations. The requests are uniformly distributed between four priority groups on the signalling level. The data plane resources being reserved are randomly assigned a TrafficImportanceNumber (0-7, see UPnP QoS standard) and are uniformly distributed in a range of values between 2.5 and 10% of the link bandwidth. The source and destination of the flow are randomly chosen. The holding time of the soft-state reservations is 480 seconds, the simulation time is 200 minutes with a 25 minutes warm-up period. The QD response time used in the model is based on the network coordinator MoCA QosDevice. The described model was developed using OPNET modeling tool [19].

TABLE I
INVOCATION TIMES, I.E. RESPONSE TIMES AND PARSING, FOR UPNP QOSDEVICE ACTIONS ON MOCA IMPLEMENTATION: (I) GPI: GETPATHINFORMATION, (II) GEQS: GETEXTENDEDQOSSTATE, (III) ATQ: ADMITTRAFFICQOS, AND (IV) RAQ: RELEASEADMITTEDQOS.

MoCA node	GPI	GEQS	ATQ	RAQ
Network Coordinator	25 ms	110 ms	429 ms	72 ms
parsing:	7 ms	18 ms	-	-
non-Network Coordinator	18 ms	110 ms	908 ms	120 ms
parsing:	7 ms	19 ms	-	-

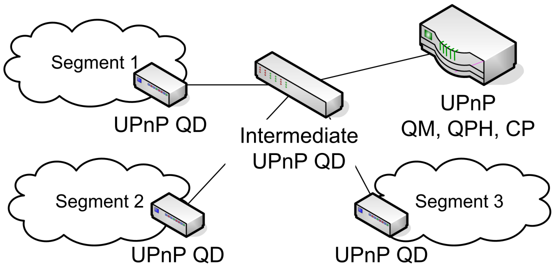

Fig. 4. Topology of modeled UPnP QoS enabled network

B. Simulations

The motivation behind the performed simulations was to verify the QoS differentiation for requests with different priorities in a dynamic scenario. Figure 5 represents the QoS request rejection ratio, measured as the number of rejected requests over the total request number, in one of the four classes. It is clearly visible that a good level of differentiation on the signaling level can be achieved using the UPnP QoS Architecture. One can notice over 40% reduction in the rejection for high priority classes compared to low priority classes. This is archived for uniform distribution of traffic in all classes and if required could be easily improved by a more selective classification of traffic to a high priority class.

Lower request rejection values for the high priority requests are the consequence of the preemption. The preemption procedure, on the other hand will prolong the QoS establishment. Figure 6 presents the average QoS setup time results for different priorities, in a range of QoS request rates. The increase of the setup time due to preemption is reflected in

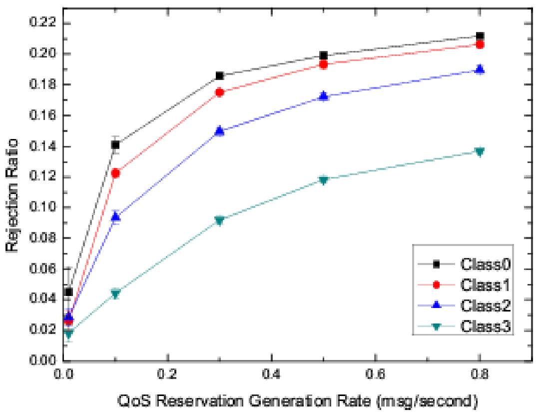

Fig. 5. Rejection ratio for different priority flows as a function of the flow initiation rate

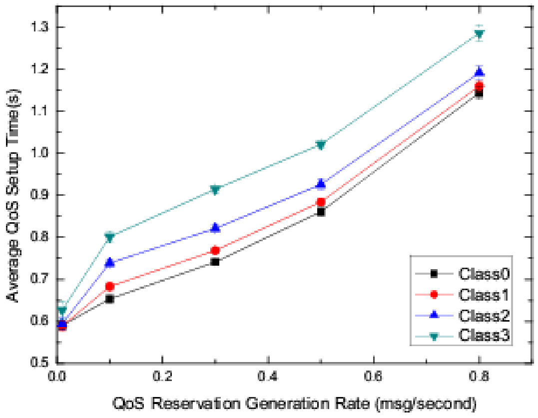

Fig. 6. Setup time for flows of different priority in function of traffic QoS request message generation rate

different setup times across the request priorities, as a high priority request is more likely to cause the preemption its average QoS setup time should be higher comparing to low priority classes. The results also show that the increase of the CP's request rate causes the extension of the time required for the QoS establishment independent of the priority. In the range of parameters that were used for the simulation this is caused by growing probability of preemption after the QoS Request Rate is high enough to cause high resource utilization.

All the graphs present the results with 90% confidence intervals.

V. CONCLUSION

To solve the problem of offering QoS control even within the (heterogeneous) home network, we propose to use a plug-and-play approach using UPnP QoS. In this paper, we have presented quantitative performance assessment results based on the first complete implementation of the recent UPnP QoS v3 standard on MoCA devices. Extensive simulation results, using that measurement data, proved clear QoS differentiation and acceptable response times (in the order of one second for a home network with 5 QosDevice services involved).

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