Extending UPnP QoS Standard for Reducing Response Delay in Multimedia Home Networks

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Abstract. A model has been developed to provide an UPnP communication implementation that reduces QoS negotiation delay. The proposed model extends the UPnP QoS Architecture standard by adding status information about the network topology and the established traffic flows. The introduced extensions are compatible to the existing UPnP standard. The implementation has been tested under different conditions and the obtained results confirm that response time can be reduced with respect to the standard architecture of about 60% to 92%. Furthermore, the implementation demonstrates that redundant queries can be avoided while the management and distribution of the multimedia content will be optimized.

Keywords: UPnP, Middleware, Multimedia, QoE, QoS.

1 Introduction

The number of mobile devices providing multimedia support is growing continuously; several devices provide UPnP (Universal Plug and Play) functionality [1], implementing the UPnP Audiovisual (AV) architecture [2] that allows to act as a multimedia server or render (e.g. Nokia Nseries devices).

The UPnP AV architecture defines interactions between an UPnP AV Control Point and multimedia devices. A Control Point coordinates and manages control messages sent to or received from multimedia devices. In a local network, all UPnP multimedia devices can be automatically discovered by the Control Point and any multimedia content will be directly transmitted from a server device to render device and not via the Control Point. UPnP Media Server and UPnP Media Renderer are two device types defined in the UPnP standard [3] in order to share and reproduce multimedia content.

The UPnP Forum defined a specification for a QoS architecture for local networks [4] that is illustrated in Fig 1. This architecture allows deploying a system that is in charge of managing the quality for each communication request within the UPnP device network.

Three types of entities are specified in the UPnP QoS architecture:

- QosManager: manages the QoS provisioning for a certain traffic specification and calculates the path from origin to destination.
- QosPolicyHolder: stores and manages traffic policies that will be applied to any reserved flow.

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- QosDevice: stores the status of any QoS traffic in a device and it provides information about the state and capabilities of a node. This entity is available for any device that supports a certain quality of service (e.g. mobile phone, PDA, PocketPC, etc).

The QoS architecture provides a better quality for content reproduction, but it is important to reduce the response time when a user wants to assign a new stream. That means, the time a user needs to wait until the system will enable or deny a request. This is reflected by a factor called quality of user experience (QoE). The standard QoS Architecture does not take in account this parameter, so it is one of the objectives of proposed model to reduce the response time and thus increase QoE. This goal is achieved by introducing states that extend the standard model. A state stores both devices capabilities and network topology. With this new extension, the QoS Manager will provide faster response times. The extensions are implemented in a modular way in order to maintain the compatibility to the original standard.

This work is focused on optimizing the QoS Manager. Several recent publications address different aspects of service oriented architectures to improve the performance of the UPnP QoS Architecture in different ways. Some of them, like Choi [5], introduce just an implementation of the basic elements of the UPnP AV and QoS architectures. Others suggest extensions to allow the adaptation of the content. Ditze [6] considers adaptation after event-based detection of bottlenecks caused by variable bandwidth flows. Lee [7] dynamically adapts the characteristics of requested or established flows after refusals to establish new traffic due to resource limitations. Other works deal with the OSGi framework [8] like N. Goeminne [9], who proposes an implementation of the UPnP QoS architecture over OSGi, but without any extension. All alternative solutions should be considered and tested to maintain the compatibility with the Standard.

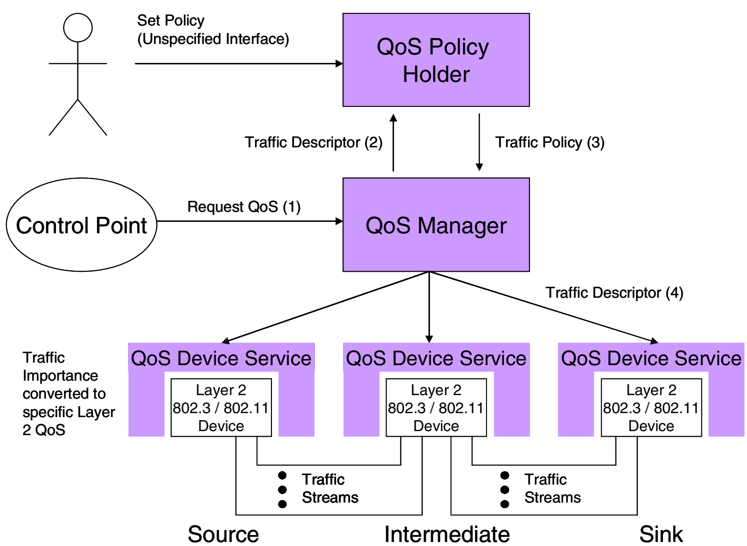

Fig. 1. UPnP QoS Architecture

The rest of the article is organized as follows. In the next section the whole model is presented underlining extensions, and each path is described in detail. Section 3 presents the results of the new model evaluation and finally the conclusions and the directions for future works are presented.

2 Quality of Service Extension of the UPnP Standard

When two UPnP AV devices want to exchange multimedia contents, the AV Control Point acts as a mediator that demands a QoS reservation for the transmission. Always when a new traffic request arrives, the AV Control Point checks with the QoS Manager whether it is possible to establish the traffic stream or not. Therefore, all involved devices must be checked for spare capacity and capability to establish the requested flow. Also a route between source and destination must be computed. This process will result in submitting redundant queries because the results of (derived from device requests and routes) already obtained information will not be maintained (nowadays, the QoS UPnP specification considers that already obtained information expires after submitting a new request).

Now, the proposed extension intends to develop a new model based on a centralized storage and update of all data above mentioned: This will accelerate the respond time in the future, i.e. for new requests. As a result, there is no need to repeat the submission of queries already sent nor to derive and rebuilt the network topology information or any data from already assigned flows.

The next subsections characterize the features introduced by the new model. Firstly all implement variants of the extended model are described, regarding both the new functionality and the new modules introduced. Afterwards, the new operation modes are explained together with their advantages and problems.

2.1 QoS Architecture Extension

The extension proposed by this architecture is based on the implementation of a centralized storage of the local network capabilities and topology, maintaining its state updated at any time. To achieve this objective, the current state of the network must be locally updated and maintained by the QoS Manager, using, for instance, a model that provides database support. As proposed in [10], two conceptually differentiated informational sets have to be stored and managed. Firstly, a topology holder describes the structure of the network by means of the storage of links and nodes and capabilities of both of them. Secondly, traffic flows configured by the QoS subsystem are managed and stored by a flow holder.

This differentiation between the concepts of available resources of the network (topology) and QoS reservation information (flows) focuses on modularity which is the main guideline for the deployment of this model. As a result two modules will be implemented in the QoS Manager: Topology Holder and Flow Holder.

Another important element of the extended architecture (see Figure 2) is the Information Agent Subsystem (IAS). The IAS is in charge of updating any data managed by Topology Holder and by the Flow Holder. This will help to maintain the consistency between the real network status and the correspondent image stored by QoS Manager.

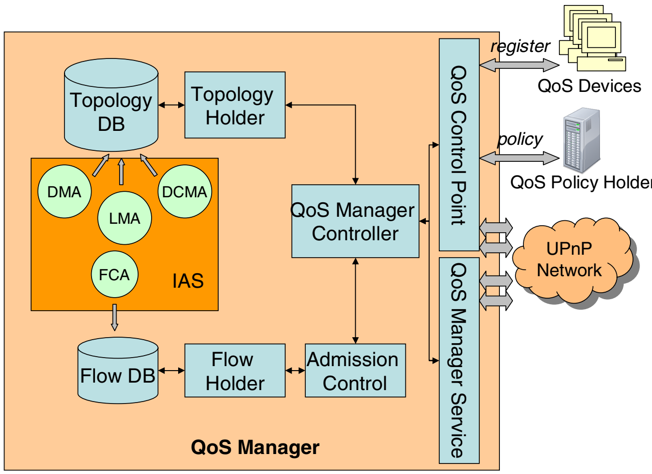

Fig. 2. Block diagram of the extended model of QoS UPnP standard. Details of the QoS Manager modules.

The IAS consists of a set of dedicated agents running as daemons in background and listening to UPnP events. They analyze state variables delivered by QoS Devices to extract and filter relevant data for databases (DB) associated to each of the agents, in order to provide real-time information about the home network.

All these new modules together with those ones implementing the QoS system will be described in the next sub-sections.

2.1.1 Topology Holder

Calculates the route for a traffic flow, and stores the capabilities of devices in this path. This module maintains a topology DB that stores previously calculated routes, network topology and devices capabilities. Three agents are in charge of updating this DB in three different ways.

Devices Management Agent (DMA)
The DMA listens to events associated to attachment and registration of new QoS Devices which are sent during the discovery phase in the UPnP protocol; DMA integrates new QoS Devices into the Topology DB and creates initial connections between every reachable node.

Link Management Agent (LMA)
The LMA updates the links between QoS Devices. The state variable associated to this agent is called *PathInformation*, defined in the UPnP QoS Device specification [11]. This agent indicates links between nodes. When a QoS Device has added to or removed from a home network, an event dispatches the value of the *PathInformation*. Once an event is detected by the LMA, it invokes routines from the Topology Holder that update connections between QoS Devices on the Topology DB.

Device Capabilities Management Agent (DCMA)
This agent monitors available resources in each device attached to the network and updates this information in the topology DB. The information is obtained from a new state variable, called *TrafficState*, that is implemented in the new QoS Device model. This agent manages events published by all devices related to this variable, and it will update related values.

2.1.2 Flow Holder

The Flow Holder manages traffic flows currently configured in the UPnP QoS subsystem, allowing the Admission Control module to submit queries about the flow status. In order to do this, the Flow Holder module implements the required routines to manage a centralized Flow Database. It stores every flow introduced into the network and all QoS Devices involved.

Its execution is based on the "*Flow Control Agent*" (FCA) which runs in the background in order to catch events from the TrafficState variable to update the Flow Database with these values.

2.1.3 QoS Manager Controller

The QoS Manager Controller is the operational center of the QoS Manager. It acts as a scheduler that sequentially invokes tasks on the rest of modules in order to reserve, release or update traffic flows. When initializing the QoS subsystem, the QoS Manager Controller starts every internal module specifying witch configuration is desired by user.

2.1.4 Admission Control

It implements the necessaries routines in order to decide whether a flow can be reserved or not. Before the operation can be invoked, the Topology Holder and the Flow Holder must contain updated information that is reflecting the current network state.

2.1.5 QoS Manager Service

This module acts as an UPnP device towards any UPnP client (e.g. AV Control Point). It publishes all services necessary for instantiating, releasing or updating certain traffics within the UPnP network by redirecting all requests to the QoS Manager Controller.

2.1.6 QoS Control Point

This module implements an UPnP client, being in charge of registering all QoS devices attached to the local network and querying for all services they may offers. It acts as a proxy towards the QoS Manager Controller. It provides information about registered UPnP services, so that the QoS Manager Controller can access to the functionality.

2.1.7 Policy Holder

This module centralizes the storage and manipulation of admission policies of the network. When required, it provides the Admission Control with information needed to make a decision about accepting any flow.

UPnP QoS Policy Holder specification [12] defines only one action to recover policies from the Policy Holder database. The Admission Control module can query for policies related to one traffic specification that is included in the AV Control Point request (Traffic Descriptor). Typically, the QoS Manager receives several possibilities configurable specifications from the AV control point, so it needs to obtain more than one policy in order to take a decision on the admission of a particular flow. Therefore, the extended model implements a new functionality that allows the QoS Manager to ask for a list of policies at the same time. This feature saves processing time and avoids unnecessary iterations with the policy holder.

2.1.8 QoS Device

A new QoS Device only adds a one new state variable. Firstly, it consists of an eventing variable that reflects available resources per interface. This is a consequence of possible QoS actions (setup, release, and update traffics) and information derived from the last successfully completed action. Now, the 'getQosState' action belongs to the UPnP QoS Device specification that allows obtaining the same information from a specific QoS Device, but only on demand.

This new feature provides QoS Device eventing directed to the QoS Manager. It is always executed when a request, a release or an update action has been submitted by the control point, and thus allowing the QoS Manager to keep track of all changes in devices.

2.2 Operational Modes

The operational modes describe several configurations of the QoS subsystem. They refer to the fact how modules work and how they cooperate to complete the QoS functionality. In the following, we enumerate some objectives that justify the definition of different operational modes:

- Maintaining compatibility to the UPnP QoS v2 specification
- Adapting to the home network environment behavior
- Allowing administrators or advanced users to configure the QoS subsystem conform to the most suitable configuration and according to given circumstances

2.2.1 Admission Control Operational Modes

The Admission Control module implements several variations depending on which devices which will be part of the decision process in a traffic flow. In this paper, the admission control mode that is defined in the UPnP QoS specification will be called *hybrid mode*. The extended model also includes the centralized and distributed Admission Control modes. Next, the three configurable modes will be described in detail.

Hybrid Mode

The admission control responsibility is shared between the QoS Manager and QoS Devices which are currently part (in the route) of the traffic flow. This mode avoids inconsistency when the QoS Manager counts on expired information about traffic in the network. This situation can occur when some of the QoS Devices of the network do not follow this QoS extended model.

In this way, the Admission Control module filters the traffic specifications from the traffic descriptor that the AV Control Point provides. The filter is based on the information provided by the Topology Holder. Then, the decision is communicated to QoS Devices waiting for the response to accept or reject a traffic reservation. Full agreement is required before a traffic flow can be accepted.

Distributed Mode
The QoS Manager delegates the responsibility of admitting or refusing a specific traffic flow to the QoS Devices. It only preserves the role of a router, looking for the nodes in the path from the source to the destination. Once a path has been identified, it obtains the list of the QoS Devices that will be asked for admission control as a result. The QoS Manager does not make any previous analysis, so it is possible that many traffic specifications must be requested before obtaining acceptance positive response from every device. Distributed admission control does not require that the QoS Manager previously knows about the traffic status because the admission algorithm is applied only for QoS Devices based on their own real-time registration of the network status and traffic reservation. So, this is the most robust mode in the sense of consistency. Despite this advantage, distributed admission control generates high control overhead affecting other factors as e.g. efficiency.

Centralized Mode
In this mode, the QoS Manager is the only admission control authority. The admission action is supported by the information retrieved from the Topology Holder and the Flow Holder. Once the network and device capabilities are retrieved, this module uses this information to implement the admission routines and checking the possibility of introducing a new stream into the network. High efficiency improvement is expected due to the next two facts:

- Control traffic reduction because of delegating the approval request to the devices.
- Exploitation of major QoS Manager computing capabilities due to the fact that it runs in a device providing high potential of computation capacities. This is different from QoS Devices that may run on devices with computation limitations.

Due to the fact that decisions are not corroborated by the devices, this mode is vulnerable to possible mistakes in the information offered by the Topology Holder and Flow Holder. So, it is important to establish this modality always when an exhaustive network control is carried out.

2.2.2 Information Agent Subsystem Operational Modes

The operational modes of the IAS module refer to how agents are working and whether their main function is enabled or disabled. This main function, called eventing, has been explicitly explained before. So the different modes are:

- The event-based mode: listening to events coming from QoS Devices and triggering update tasks within databases.
- Based on polling mode: forcing periodic checks. Agents ignore events but they periodically invoke actions from the QoS Devices that return values for each of the state variables assigned to each of the agents in the IAS. This operational mode makes sense in an environment that suffers from a high rate of non-UPnP traffic. This is because the QoS Device only throws an event when resources

have been increased or reduced after any UPnP traffic has been released or reserved by the QoS subsystem. By forcing periodic polling, the QoS Manager is aware of any resource variation due to other kind of traffic, reducing inconsistent data between the state of the network and its image stored in the QoS Manager. Furthermore, efficiency of the QoS subsystem is affected by the polling interval.

- The third mode allows merging the eventing operational modes and the periodic polling ones, depending on the device typology. In this way, a periodic polling for devices can be configured that is related to the QoS v2 standard and to the eventing mode for all others. This operational mode is justified by the objective of being compatible with QoS Devices from UPnP QoS v2, which do not include the TrafficState variable, which is needed by the Devices Capabilities Management Agent in order to execute database updating tasks, and to offer almost the same performance like the eventing mode.

2.2.3 Topology Holder and Flow Holder Operational Modes

Both the Topology Holder and the Flow Holder are continuously serving information to the Admission Control module. Independently of each other, they can be configured to extract data from different sources, so they can be configured for two possible operational modes: *local* and *remote*. Whenever the Topology Holder and the Flow Holder are configured as *local*, they will receive data from the local databases (Topology DB and Flow DB) of the QoS Manager. If they work in remote *mode*, each one queries the correspondent QoS Devices in order to extract information about their current state.

In the extended model explanation, the Flow Holder and the Topology Holder have been considered working in a local mode, saving control overhead because configuring the remote mode involves several disadvantages which involve higher respond times:

- Anytime a traffic reservation is requested, they must query all QoS Devices about topology and flow data. In a similar way, when a traffic release is requested not only the devices in the path but every device must be informed.
- Previously calculated routes by the Topology Holder are lost after each iterated traffic request.

Nevertheless, the remote mode is a good decision whether a home network suffers from continuous changes.

3 Evaluation Methodology

In this section, the features offered by the extended UPnP QoS model are going to be analyzed. Table 1 lists a significant configuration subset that will be tested and compared to the current UPnP QoS specification (#1 in Table 1). This makes it possible to observe individual improvements introduced by each of the new extensions.

The evaluation scenario was composed of various UPnP devices working as QoS Devices, one QoS Manager and one QoS Policy Holder deployed at the same domain of a LAN network.

Table 1. Description of a subset of possible configurations for the QoS UPnP extended model. Configuration #1 works as the UPnP QoS standard.

	Configuration modes	***Description***
#1	**Topology Holder:** Remote **Flow Holder**: Remote **Admission Control:** Hybrid	*UPnP QoS Standard configuration. No topology or flow state are locally stored in the QoS Manager*
#2	**Topology Holder:** Local **Flow Holder:** Local **IAS:** Event-based (DMA and LMA are enabled) & Polling (DCMA and FCA are disabled). **Admission Control:** Hybrid	*Fully compatible with the QoS UPnP standard. The TrafficState variable is not evented in this configuration.*
#3	**Topology Holder:** Local **Flow Holder:** Local **IAS**: Event-based (DMA, LMA, FCA and DCMA are enabled) **Admission Control:** Hybrid	*Complete extended model with hybrid admission control*
#4	**Topology Holder:** Local **Flow Holder:** Local **IAS**: Event-based (DMA, LMA, FCA and DCMA are enabled) **Admission Control:** Centralized	*Complete extended model with centralized admission control. This configuration deploys the most efficient mechanisms of the extended model.*
#5	**Topology Holder:** Local **Flow Holder:** Local **IAS**: Event-based (DMA, LMA, FCA and DCMA are enabled) **Admission Control:** Distributed	*Complete extended model with distributed admission control*

Efficiency assessment of each configuration was checked by measuring the response time to a traffic request and calculating the average (a.r.t.). Then, these values will be compared with those obtained with the UPnP QoS standard (#1 in Table 1) in order to show the efficiency improvement (e.i.) introduced by the new extensions.

In the following two subsections, firstly the efficiency introduced by the new centralized storage of both topology and flows, will be studied. Finally it will discuss the modes in which the Admission Control can be configured, in addition to their capabilities and problems.

3.1 Centralized Topology and Agents

The configurations #2 and #3 will be evaluated in this section. These configurations keep up the same admission control mode like the UPnP QoS standard. It allows centering the analysis in how the following features affect in the efficiency improvement:

- The local support of topology and flow states.
- Enabling or disabling event-based mode for different agents in the IAS.

Table 2. Topology storage evaluation

Configuration	a.r.t. (ms)	e.i. (%)
#1 (reference configuration)	1400	**-**
#2	1196	**14%**
#3	554	**60%**

As it can be seen in Table 2, when enabling the QoS UPnP standard behaviour (#1) with no local storage of topology and flow state, the QoS subsystem generate worse response times than in any other configuration.

In the second configuration #2, the centralized management of the network state as well as agents DMA and LMA are enabled. This is a configuration fully compatible with UPnP QoS standard, so no extensions of the QoS Device service are required. This results in a noticeable improvement of the response time (14 %) with respect to the configuration #1 due to the reduction of queries to the devices in order to obtain relevant information about their types and characteristics. However, the absence of DCMA makes it necessary to query for each device and about its capacities in order to receive its state.

The configuration #3 deploys all the potential of the extended model (except for the hybrid admission control mode), which is based on a centralized management of the network state and an event-based updating model. This configuration requires that the QoS Devices of the network fit into the QoS extended model of the TrafficState variable. The results show that configuration #3 presents the best performance, because it substitutes network messages with databases queries in order to obtain the network topology and the devices capabilities.

Therefore, the last two configurations (#2 and #3) show substantial improvements over the first one. In this way, it can be said that the new QoS Manager and QoS Device extended models, introduce a remarkable improvement regarding the delays introduced by the QoS negotiation. Furthermore, in the last case the relative efficiency, in terms of response time, is close to the 60% compared to the UPnP QoS standard.

3.2 Admission Control Functionality

This section evaluates the efficiency improvement obtained by the introduction of new Admission Control operational modes. To do this, all modules and agents responsible for the centralized management of the UPnP network state will be activated. The results will be compared to those ones obtained for the configuration #1, the UPnP QoS standard.

Analyzing the results (see Table 3) for the different Admission Control operational modes, it appears that the centralized one (configuration #4) generates the best results,

Table 3. Admission Control modality evaluation

Configuration	a.r.t. (ms)	e.i. (%)
#1 (reference configuration)	1400	**-**
#3	554	**60%**
#4	99	**92%**
#5	714	**45%**

since it does not require communicating to devices in order to perform traffic management operations. However, this mode is vulnerable to inconsistent data received from the Topology Holder.

The hybrid mode (configuration #3) presents a slightly higher response time because of the interactions between the Admission Control module of the QoS Manager and devices in order to compare the admission decisions. This pattern is also vulnerable to inconsistent data received from the Topology Holder. Bit it prevents possible traffic admission errors.

Finally, the distributed admission control mode (configuration #5) presents greater robustness but worse response times than the previous configurations. Robustness is due to the fact that admission decisions are only made by devices, independent of the state stored into the QoS Manager. The worse response time is due to the fact that devices must filter every traffic specifications. Furthermore, the interaction between the QoS Manager and the devices increases regarding to other configurations. In this way it can be said that this configuration is the less efficient but the surest.

Thus, depending on the activity of the network and its features, a suited mode will be recommended. In very heterogeneous networks with a high degree of congestion, it is advisable to select distributed or at least hybrid admission control modes, which avoids problems due to potential inconsistencies within the database. On the other hand, networks with static features and not saturated status may go for a centralized admission control, benefiting from the high performance that this modality is capable of achieving.

Finally, if the efficiency improvement of configurations #3, #4 and #5 are compared to the QoS UPnP standard configuration (#1), it can be seen that any of the admission control procedures proposed in this paper have response times substantially better than those offered by the standard.

4 Conclusions and Future Work

The usability of multimedia services mainly depends on the capability to manage three aspects: the integration features of a multimedia infrastructure, the propagation and access to services and the ability to establish a QoS connection between a service provider and a consumer (device). The presented approach is focused on the third aspect, proposing a modular model, which extends the current UPnP QoS standard, capable of carrying out a centralised management of the network state, taking into account both flows and topology.

The implemented system is fully configurable and capable of deploying different operation modes characterized by the retrieval of path and devices capabilities in a centralized or distributed way. The retrieval of the flows instantiated within a device in a centralized or distributed way, and the possibility to enable different admission control strategies is reflected by the following possibilities: centralized (decided by the QoS manager), distributed (decided by the devices) or hybrid (decided by the devices & QoS manager).

After a subsequent evaluation, it has been shown that the centralized storage paradigm introduced in this system, shows substantial improvements in response time compared to the standard UPnP.

The future work is aimed at providing the QoS Manager with the ability to maintain a control of the streams' priorities. It will allow the AV control point evict lower priority flows for those with higher priority. The new model focuses on devices located in the same domain. In the future this model can be extended to provide QoS between two devices located indifferent sub networks.

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