DTU Library

Cross Layer QoS Provisioning in Home Networks

Wang, Jiayuan; Brewka, Lukasz Jerzy; Ruepp, Sarah Renée; Dittmann, Lars

Link back to DTU Orbit

Cross Layer QoS Provisioning in Home Networks

Jiayuan Wang, Lukasz Brewka, Sarah Ruepp, Lars Dittmann
Technical University of Denmark
E-mail: jwan@fotonik.dtu.dk

Abstract

This paper introduces an innovative QoS provisioning scheme in home networks, by utilizing Optical Wireless (OW) MAC specification proposed by Home Gigabit Access Project (OMEGA) project. The specification is characterized by its resource reservation protocol and the use of Time Division Multiple Access (TDMA). By adopting OW MAC to the widely supported Universal Plug and Play – Quality of Service (UPnP-QoS) Architecture in the simulated home domain, algorithms for cross layer mapping QoS requirements are proposed. Compared to utilizing WLAN MAC, our scheme is able to provide guaranteed QoS levels to streams with different priorities, especially to delay-sensitive services. Efficiencies of the algorithms and network performance are validated by analyzing the results collected from OPNET simulation models.

Introduction

As one of the specifications raised by OMEGA [1], Optical Wireless (OW) MAC aims to provide a faster connection and guaranteed QoS support in the home network environments. We adopt OW MAC standard to UPnP-QoS architecture, and we study the performance of the MAC protocol in the home environment. Based on the unique characteristics of OW MAC, the standard functions of UPnP-QoS architecture are slightly revised and simplified to better adopt to the OW MAC layer. At the same time, the strict reservation mechanism requires an algorithm to map the QoS requirements of specific applications to the number of Time Slot (TS) reservations in the MAC layer. Guarantee of QoS is mainly through the complex admission control mechanism based on the request from different applications.

In this paper, a simulation model using the above mentioned mapping method is implemented with OPNET, and the model shows a satisfactory result of cross-layer QoS. The process of building the model and the approaches for achieving cross-layer QoS provisioning are our main focus in this paper.

In section II and III, UPnP-QoS architecture and OW MAC structure are briefly introduced. The implementation process is described in section IV, and related discussions are given in section V.

UPnP-QoS Architecture Overview

Figure 1 shows the architecture of UPnP-QoS. The admission process is shown in the figure with each process number. Three kinds of services are defined by UPnP-QoS, which are *QosManager* Service, *QosPolicyHolder* Service, and *QosDevice* Services.

The Control Point, which represents the application functionality, is responsible for initializing QoS requests. *TrafficDescriptor* structure is used to describe the traffic nature and the QoS requirements of the stream to be transmitted. After

the request is formed, it is sent to *QosManager* Service (this is represented by step (1) in Figure 1). *QosManager* Service will ask *QosPolicyHolder* Service for returning *Traffic Descriptor* after receiving the request from Control Point. This is shown in step (2) and (3). The returned *Traffic Descriptor* (step (4)) normally consists of a *TrafficImportanceNumber* and a *UserImportanceNumber*, which indicate the priority level of the traffic and the user importance level. The *TrafficImportanceNumber* and the *UserImportanceNumber* are used in *QosDevice* Services to convert to specific L2 QoS technology.
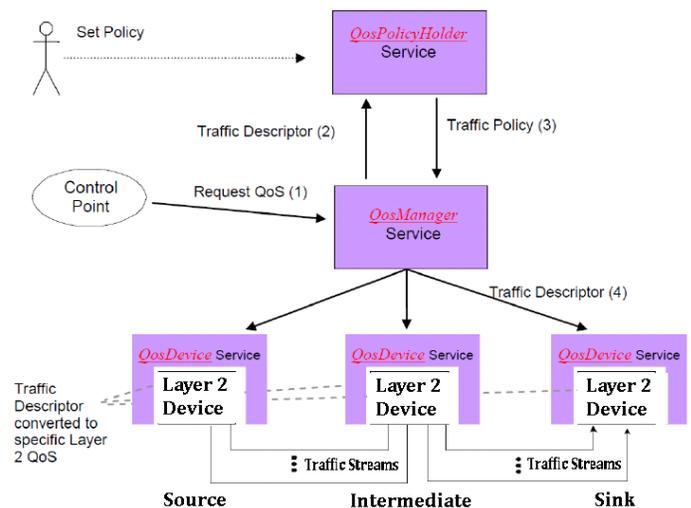

Figure 1: UPnP-QoS Architecture[2]

OW MAC Overview

OW MAC specification is one of the outcomes of the seventh framework program – OMEGA. The first version was released in November 2008, and the specification reached its final version in November 2009, undergoing many changes.

OW MAC uses a distributed, reservation based channel access method [3]. Through a reservation period, each cooperating device within the optical range is informed of other devices' reservations. No central controlling function is defined. The reservation is achieved by exchanging beacon frames. The beacons carry the necessary reservation and scheduling information of devices. As TDMA is the access method defined, synchronization is needed among devices. Collision is also effectively avoided in this way.

OW MAC defines specific packet formats and MAC frame structure, as shown in Figure 2. The total superframe duration is 67ms, with each superframe composed of 1024 TSs. Each superframe starts with a beacon period, composed of eight beacon slots, and each beacon slot occupies two TSs. During the

beacon period, only beacon frames are sent. Once the reservation is successful, the device is allowed to send data traffic during its reserved TSs in data period.
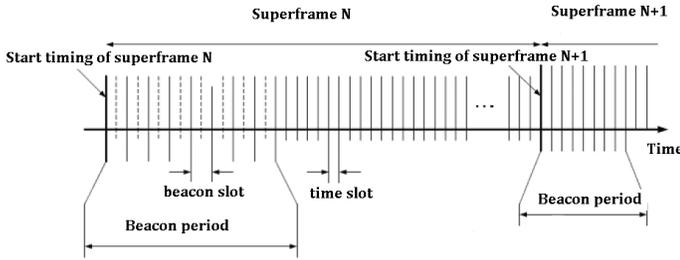

Figure 2: MAC superframe structure [3]

OW MAC specification also defines its frame formats for different usage, among which, beacon frame, control frame, command frame, and data frame are used in this paper. Beacon frames carry the crucial information for resource reservation, and are also responsible for negotiation between neighbors. The QoS requirements from UPnP-QoS are mapped by the *QoSDevice* Service and carried in beacon frames. In the standard UPnP-QoS specification, traffic admission decision is made by *QoSDevice* Service, because *QoSManager* Service has not sufficient knowledge of Layer2 for admitting the traffic. In this paper, in order to simplify the admission process, the traffic admission decision is made by QoS Manager directly, since the simulated network has only one QoS Manager entity, and QoS Manager has full awareness of Layer2 reservations due to processing of beacon frames.

An OPNET Cross Layer QoS Mapping Model

The network simulation model is developed in four different stages:

- Network model
- Node model
- Process model
- PHY link model

The home environment simulated consists of three end devices and a home gateway. For simplification, three end devices are considered to be enrolled automatically to the network from the beginning. The end devices start to generate traffic at different time with different traffic pattern (the starting point can be reassigned). Thus, the network state could change between "idle" and "busy" state with time. Home gateway is the only destination for the traffic generated from end devices. The amounts of traffic generated and total delay parameters are recorded at home gateway for statistic usage. Queuing delay parameters are recorded at OW MAC entity of end devices.

The node model describes the internal components of end devices and home gateway. For simplification of implementation, each end device enrolled is allocated the initial signaling slots by default.

End Device Node Model

End device node model consists of a traffic source, a UPnP Control Point, a UPnP QoS Device, a OW MAC, a receiver and

a transmitter. Traffic sources generate traffic patterns similar to different home devices. They could represent a digital TV, a VoIP phone, a laptop or a stationary computer. UPnP Control Point and UPnP QoS Device are UPnP-QoS entities, which represent UPnP functionalities in end devices. OW MAC is the entity that implements OW MAC specification. The actual mapping from UPnP-QoS requirements to OW MAC specifications is implemented in the UPnP QoS Device. The node model is shown in Figure 3.
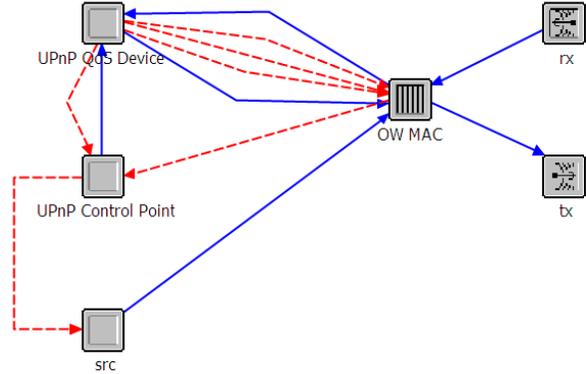

Figure 3: End device node model

Traffic Source

Traffic source (src) is used for generating traffic. However, depending on the nature of traffic of different applications, traffic source can have different traffic behaviors, imitating the traffic pattern as it is from a laptop or a stationary computer (src1), a VoIP phone (src2), or a digital TV (src3).

A code is attached before sending the packet from traffic sources to the OW MAC, indicating the packet sequence. Code 0 means the first packet of this stream. Code 2 means the last packet, while code 1 is attached to the rest of the packets in the stream. The code is further used in the OW MAC functionality for releasing resources.

Name	Description
RequestedQosType	Prioritized, parametrized or hybrid QoS
Data Rate	Bytes per second
Time Unit	This integer field specifies the smallest time interval (μs)
Peak Data Rate	Maximum data rate, bytes/s
MaxBurstSize	Bytes
MinServiceRate	Bytes/s
ReservedServiceRate	Bytes per second
MaxPacketSize	Bytes
E2EMaxDelayHigh	Desired upper bound of the end-to-end delay, in microseconds
E2EMaxJitter	Maximum jitter requirement, in microseconds
E2EMaxDelayLow	Express that packet delays smaller than *E2EMaxDelayLow* are not necessary, in microseconds
QosSegmentSpecificParameters	Interface ID, QosSegment ID and segment specific delay and jitter values

Table 1: UPnP TSPEC Parameters

UPnP Control Point

UPnP Control Point in the end device is responsible for communicating with QoS Manager in home gateway to negotiate QoS. To initiate a possible transmission, UPnP Control Point forms a *TrafficDescriptor* structure (including traffic class, the source and destination IP addresses for the stream, the TSPEC structure, application name, username, etc.), and sends the requests to Qos Manager via *RequestTrafficQoS()* action. The TSPEC structure describes the traffic nature and QoS requirements of the traffic stream. An explanation of parameters used for UPnP-QoS is given in Table 1. The request is sent to QoS Manager via QoS Device. In this work, it is QoS Manager that decides, based on the condition of devices in the network, whether to accept or decline the TSPEC.
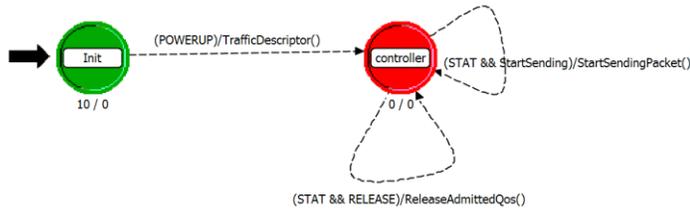

Figure 4: Control Point process model

After receiving a positive answer from QoS Manager, admitting certain TSPEC, UPnP Control Point uses UPnP *QoSDevice* Services to form a beacon frame. The beacon frame carries the necessary reservation information using specific L2 technology, which is based on OW MAC specification.

Once this action is acknowledged by the QoS Manager, Control Point sends signals to the traffic source to start sending packets. *ReleaseAdmittedQos()* is invoked when it is the last packet sent. Control Point uses *QoSDevice* Service to form a control frame to inform QoS Manager in home gateway, and to release the resources allocated. QoS Manager will send *QosStateUpdate()* to every device after the release of resources. The process model of Control Point is shown in Figure 4.

UPnP QoS Device

One of the key functionalities of *QoSDevice* Service is to start reservation process in MAC layer. With OW MAC, it requires *QoSDevice* Service to convert the requirements in TSPEC to the number of slots reservation in TDMA. As a minimum transmission time needed without causing accumulated delay, slots reservation for certain stream can be calculated through the following calculations using the information from TSPEC:

$$T_{pkt} = \frac{S}{\tau} \tag{1.1}$$

$$N = \frac{T_{pkt}}{T} \cdot P_s \tag{1.2}$$

$$P_s = R \cdot T_s \tag{1.3}$$

where T_{pkt} is the time needed per packet, S is the packet size in bits, τ is the throughput, N is number of slots needed per superframe duration, T is the time of one slot duration, T_s is the duration of one superframe, R is the packet generation rate, and P_s is the packets number per superframe duration.

An example is given as below.

We assume the following network parameters,
$\tau = 100$ *Mb/s*,
R = 100 *packets/s*,
S = 1100 *bytes*=8800 *bits*,

Thus,
T_{pkt} = 8800 *bits* / 100 *Mb/s*=88 *μs*,
P_s = 100 *packets/s* * 0.067 *s* = 6.7 *packets* = 7 *packets*.

Therefore,
N = (88 *μs* / 65.536 *μs*) / 7 *packets* = 2 *slots/packet* * 7 *packets* =14 *slots*.

That is to say, in this case, a reservation of 14 slots can guarantee a basic transmission. Other possibilities are shown in [3].
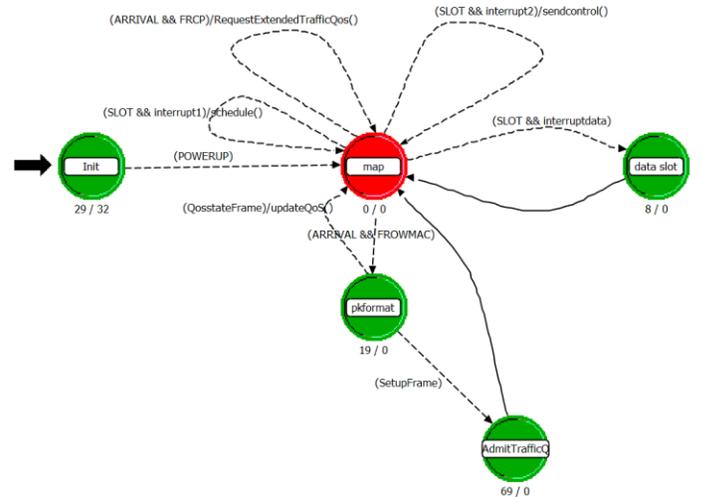

Figure 5: UPnP QoS Device process model

A reservation number of less than this can cause a growing delay in transmission. The delay in Round Robin scheduling algorithm is normally caused by queuing, thus in transmission, an average queuing delay of one superframe duration, 67ms, can be expected. When the network is busy, only the slot reservations of high priority traffic can be guaranteed, which means that the low priority traffic may get less or no slots available and suffer from higher delay. In actual implementation, extra slots can be allocated for reservations in order to achieve a shorter queuing delay. However, it also depends on the network state and the priority of the traffic class. The judgment can be made upon a combined consideration of all these factors.

In actual transmission, the packet cannot use the full duration of time slots due to the guard times and possible time required for

3

ACK. For audio and video traffic, which is configured without ACK in our model, at the end of each TS, 2 * SIFS (Short Interframe Space, 8*us*) time is required to be guard time to ensure a full SIFS interval between transmissions in adjacent TSs. It means that the actual transmission time is reduced to: 1 Time slot – Guard Times = 65.536 *μs* – 16 *μs* = 49.536 *μs*. This value is considered together to be the maximum length of packets. For best-effort traffic (since we assume acknowledgement for this type of traffic), the same value is reduced to: 1 Time slot - Guard Times – 1*SIFS - ACK Times = 65.536 *μs* - 16 *μs* - 8 *μs* - ACK Times = 41.536 *μs* - ACK Times. The value is important when considering the maximum packet length of best-effort packet size within one TS.

The process model of UPnP QoS Device is shown in Figure 5. All the commands from UPnP Control Point are encapsulated into OW MAC frame format in OW MAC. All the control frames from OW MAC are then decapsulated and processed in the higher layer. In order to map UPnP-QoS to OW MAC, UPnP QoS Device maintains the system clock used by OW MAC. It translates QoS requirements from specific TSPEC to the number of slot reservations, see Equations (1.1) and (1.2). Adjustment of system clock for Control Point and QoS Manager is ignored due to the very short distance between the two entities.

Upon receiving *UpdateAdmittedQos()*, TS allocation is updated. In this way, the *QoSDevice* Service always keeps track of the network state, such that duplicated reservation of slots can be avoided.
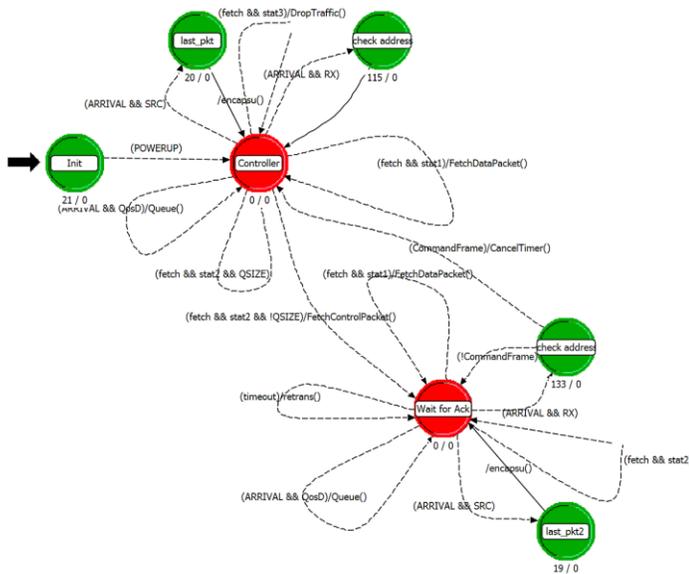
OW MAC in End Device

Figure 6: OW MAC in End Device process model

OW MAC implements the MAC layer functionality of the end devices. Five different types of packet formats are supported and used here. After receiving packets from the traffic source, packets are encapsulated to a specific OW MAC frame format and put into the corresponding queue. OW MAC will not send any packet without receiving the reserved TSs. Slot reservations are calculated by QoS Device after receiving a positive

AdmitTrafficQos() from QoS Manager. When the packet received from sources has code 2, OW MAC will inform UPnP Control Point to initiate the release of resources. Thus, another controlling packet is sent to QoS Manager to inform about the end of the transmission. During the transmission, each controlling/signaling message is acknowledged by command frames. The process model of OW MAC in end devices is shown in Figure 6.

Home Gateway Node Model

Home gateway node model consists of a QoS Manager, an OW MAC, a traffic sink, a receiver and a transmitter. QoS Manager controls and implements the UPnP-QoS functionalities, while OW MAC implements OW MAC functionalities. The node model is shown in Figure 7.
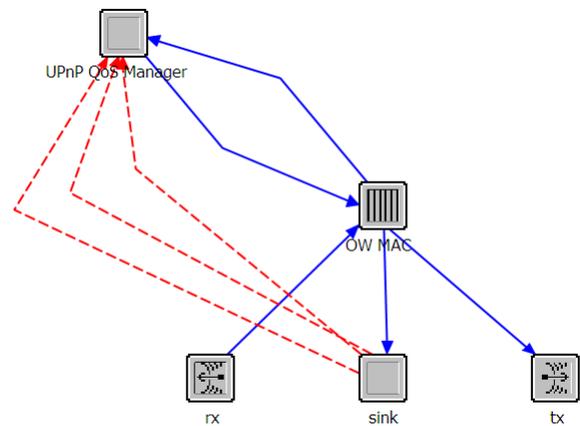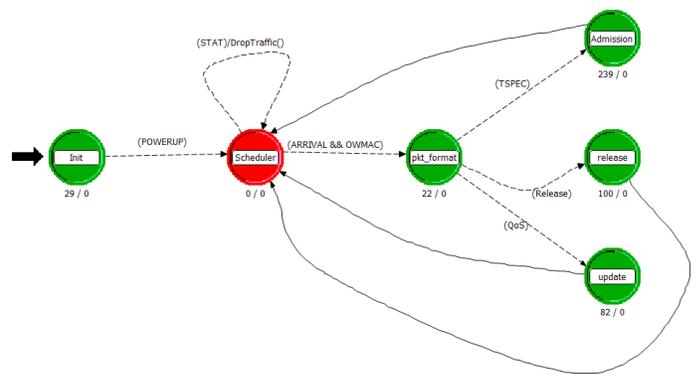
QoS Manager

Figure 7: Home gateway node model

Figure 8: QoS Manager process model

QoS Manager is the key controlling entity for implementing UPnP-QoS requirements in home gateway. It receives and processes the controlling information from end devices and negotiates network resource allocation for different streams. The process model is shown in Figure 8.
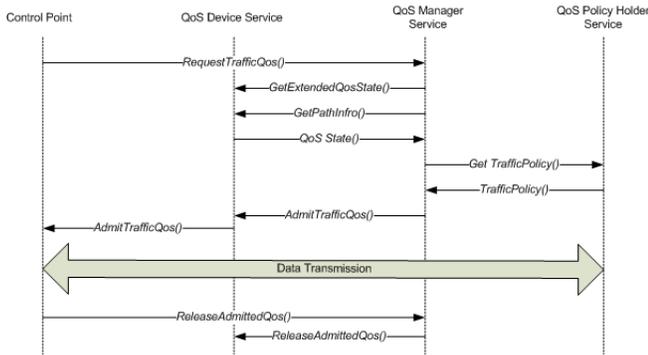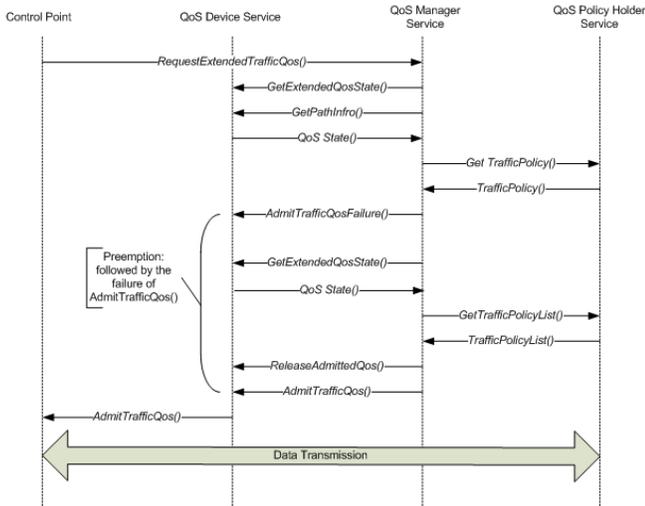
4

Figure 9: Simplified message flow without preemption

Figure 10: Simplified message flow with preemption

Figure 11: Program logic of QoS Manager

Resource allocation is based upon the request carried in the TSPEC. Once a request for QoS of specific TSPEC is received from UPnP Control Point, QoS Manager decides the *TrafficImportanceNumber* / *UserImportanceNumber* based on the information from Policy Holder Service (in this model, included in QoS Manager). QoS Manager checks the QoS state of each device in the network to decide if the new TSPEC can be accepted. Depending on the QoS type requested, preemption can be considered when admitting a high priority stream. In this paper, parameterized QoS [2] is used as default QoS method. Thus, preemption is considered under the situation of insufficient network capacity. For example, when three different traffic streams are competing in the system, voice and video traffic always have higher priority than best-effort traffic. In this case, capacity allocated for best-effort traffic might be reduced or even preempted if there is not enough bandwidth for all the traffic streams. QoS Manager always maintains the QoS State of each device from the information of beacon frames and release requests. The simplification of the admission process is shown in Figure 9 and 10. For a comparison, see the standard message flow in [2].

Figure 9 is an example without preemption. The example shows a case with successful admission at the first try. No further
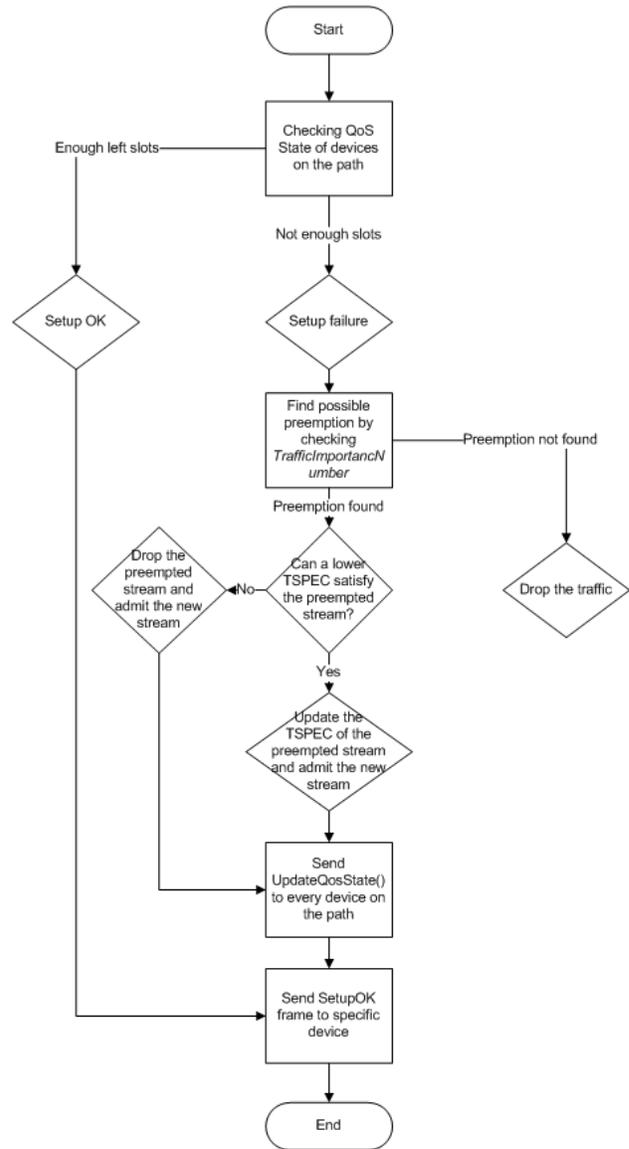
action is required by QoS Device regarding the admission decision made by QoS Manager. If the admission failed, QoS Manager will respond with *AdmitTrafficQosFailure()* message.

In case preemption is supported, QoS Manager will automatically start the preemption process after the failure of *AdmitTrafficQos()*, which is shown in Figure 10.

The difference compared to the standard process is that QoS Device Service does not send back *Admission Success/Failure* after QoS Manager made the admittance decision. For the example with preemption, preemption starts automatically after QoS Manager failed to admit the TSPEC. The admission decision is made by QoS Manager in both cases, as explained in the simplification made by this model (See section OW MAC Overview).

The algorithm implemented in QoS Manager is shown in Figure 11. The figure illustrates the programming logic for admission control process.

OW MAC in Home Gateway

OW MAC implements MAC layer functionality of home gateway. All the traffic sent from end devices need to go through home gateway. All the control frames received from end devices are de-capsulated here and sent to QoS Manager. Command frame is sent back in allocated signaling slot to the end devices. All data frames received are sent to sink for statistic usage. If ACK response is required, an ACK packet is sent immediately after receiving a data packet, such that the end devices can send next data packet before the next scheduled TS comes. OW MAC maintains a system clock for sending and receiving at allocated TSs. The process model of OW MAC in home gateway is shown in Figure 12.
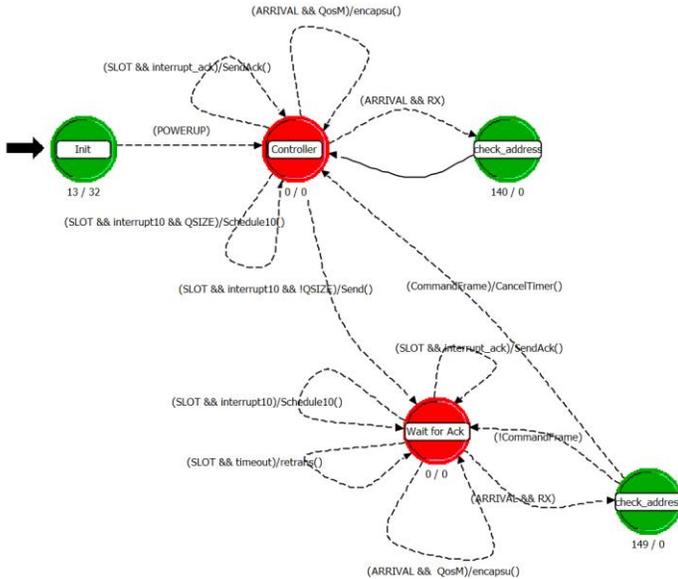

Figure 12: OW MAC in Home Gateway process model

PHY Link Model

The wireless link of the PHY layer is defined in [4]. OPNET provides a 14-stages radio transceiver pipeline to simulate the wireless environment. See [4], Section Radio Transceiver Pipeline for details.

The pipeline stages define the behavior of the wireless links. Each setting of the particular stage can influence the network behavior. Stages 0 to 5 define the transmitter side, and stages 6 to 13 define the receiver side. As the behavior of PHY layer is not the main focus of this work, the pipeline stages are simplified to a large extent, leaving only basic stages enabled.

Table 2 shows the settings of pipeline stages used in this work. For each detailed pipeline stage, refer to [4]. One thing worth noting is, instead of using modulation schemes to calculate the possible error rate, the defined stage puts a bit error rate directly into the transmitted traffic stream. Performances under different bit error rates can be easily manipulated by changing the bit error rate fed to the pipeline stage. The parameters for other noise, power and antenna are not set since they are not the main focus.

Transmitter pipeline stages	Setting	Receiver pipeline stages	Setting
receiver group	dra_rxgroup	rx antenna gain	NONE
transmission delay	dra_txdel	received power	NONE
link closure	dra_closure	interference noise	NONE
channel match	dra_chanmatch	background noise	thesis_wireless_error
tx antenna gain	NONE	signal to noise ratio	NONE
propagation delay	dra_propdel	bit error rate	NONE
		error allocation	NONE
		error correction	NONE

Table 2: Settings of radio transceiver pipeline stages

Simulation Results

In this section, the QoS performance of the implemented model is discussed and evaluated. As delay is one of the most important QoS parameters in assessing real time applications, the impact of OW MAC on delay parameter is discussed with the results obtained from the implemented model.

Below we present results collected aiming to investigate the queuing delays using the model. As the minimum TS number is used to make reservations in the first place, higher numbers of slot reservation are attempted. Parameters and the corresponding results are shown in Table 3 and Figure 13.

Parameters	Traffic Class	Value Assigned
Input: Packet rate (packets/s)	Best-effort	50
	Audio	50
	Video	50
Input: TS allocation allowed	Best-effort	(1.0 TO 2.0 BY 0.1) × *Minimum TS number*
	Audio	(1.0 TO 2.0 BY 0.1) × *Minimum TS number*
	Video	(1.0 TO 2.0 BY 0.1) × *Minimum TS number*
BER		0.0

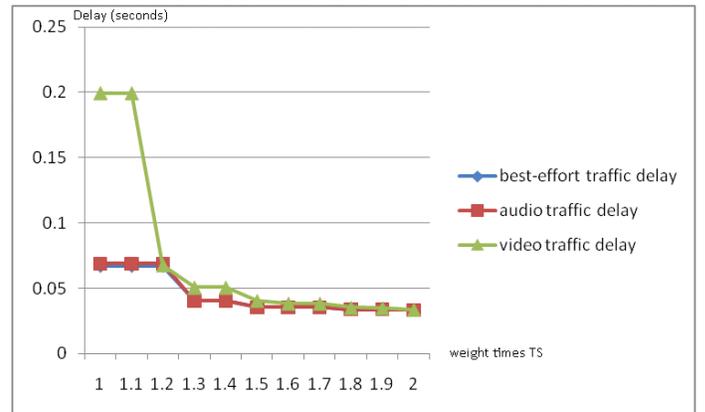**Table 3: Parameter settings under scenario 1**

Figure 13: Delay under scenario 1

As only the impact of the number of TSs reserved are considered in scenario 1, the same packet generation rate is chosen. The reservations for TSs increase from minimum TS number to 1.8 times the minimum TS number, and the results are shown in Figure 13.

In theory, queuing delay decreases with more TSs assigned, since each packet waits shorter time in the queue to be sent. From Figure 13, a dramatic decrease in delay happens when the number of reserved slots reached between 1.1 and 1.3 times the minimum TS number. However, further increase in TS allocation number after 1.3 does not make much improvement of the delay. In this case, 1.3 times the minimum TS number is an optimal number for allocating TSs. Similar results are collected

with a transmission speed of 70 packets per second, which is shown in Figure 14.
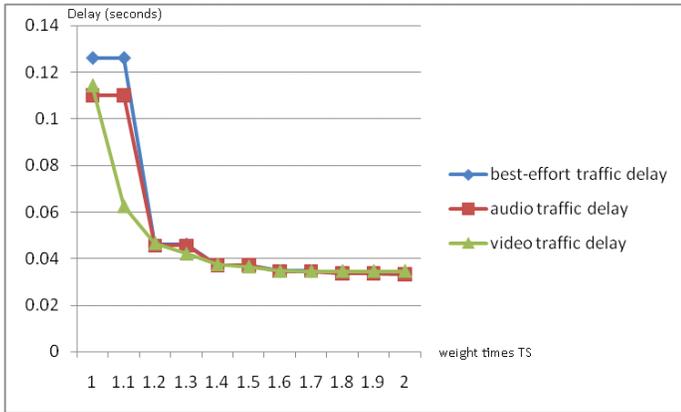

Figure 14: Delay under scenario 2

Compared to Figure 13, a decrease in delay is again found between 1.1 and 1.3 times the minimum TS number. However, the delay in Figure 14 has a different starting point, which indicates that packet generation rate might influence the delay performance. By collecting results with changing packet generation rates, Figure 15 and 16 are obtained. Figure 15 shows the delay performance when TS allocation number follows the minimum TS number. Figure 16 shows the delay performance when TS allocation number is 1.3 times the minimum TS number, which is the optimized TS allocation number in the above cases. Figure 15 does show different delays with different packet generation rates, ranging from approximately 0.05s to 0.24s. However, the reason for the delay variation, still lies in the fact that the actual number of TSs reserved might be larger than the minimum TS number. Because the TS reservation number is decided on a per superframe basis, a smaller float number from the TS mapping calculation result (see Equations (1.1) and (1.2)) is always rounded up to a higher integer number. E.g., slot reservation of 6.3 slots per superframe is added up to 7 slots per superframe. One possible way to diminish the delay variation is to make reservations based on many superframe basis. That is to say, having different slots reservation number per superframe to compensate for the extra slots. However, since the optimized lower delay that can be reached is almost the same (Figure 16),
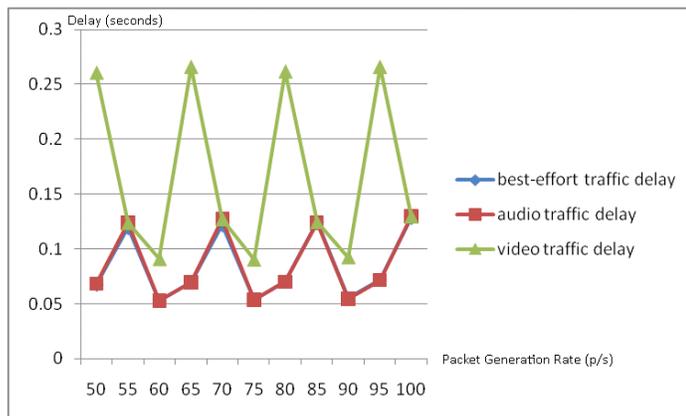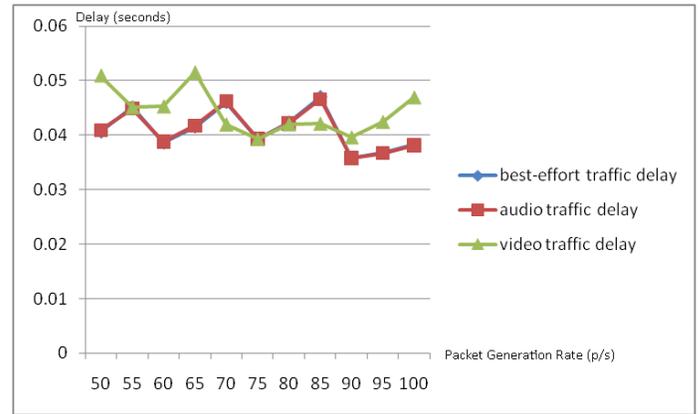

Figure 16: Delay under scenario 4

this compensation is not implemented further.

Another important issue to influence the delay parameters is the bit error rate. For a comparison with the results under scenario 1, the parameters are set as shown in Table 4. With the error rate of 10^{-4}, the results shown in Figure 17 are collected. Compared to Figure 13, the delays are not changed for audio and video streams, since retransmissions are not performed for audio and video traffic. Best-effort traffic is configured to have ACK response and to retransmit the lost packets. Thus, best-effort traffic is influenced by the error rate. From Figure 17, best-effort stream suffers from the heaviest influence when the TS reservation number is low. The trend goes down at 1.3 times the minimum TS number, showing a better ability to keep the QoS for the specific stream. One should be aware that only delay is considered in this scenario. When it comes to packets loss, introduction of bit error rate would also influence the overall quality of video and audio traffic.

Parameters	Traffic Class	Value Assigned
	Best-effort	50
Input: Packet rate (packets/s)	Audio	50
	Video	50
	Best-effort	$(1.0 \text{ TO } 2.0 \text{ BY } 0.1) \times \textit{Minimum TS number}$
TS allocation allowed	Audio	$(1.0 \text{ TO } 2.0 \text{ BY } 0.1) \times \textit{Minimum TS number}$
	Video	$(1.0 \text{ TO } 2.0 \text{ BY } 0.1) \times \textit{Minimum TS number}$
BER		10^{-4}

Table 4: Parameter settings under scenario 5

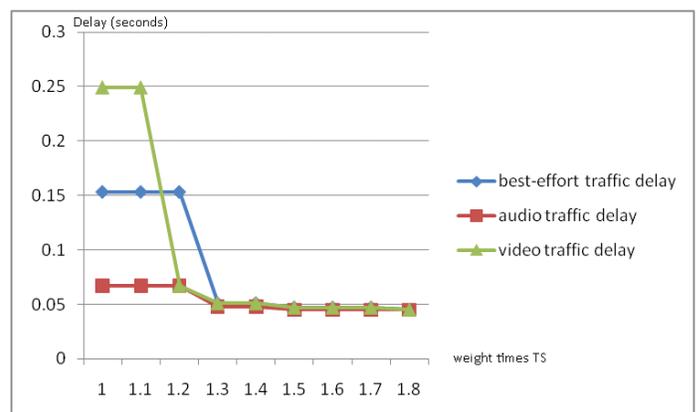Figure 15: Delay under scenario 3

Figure 17: Delay under scenario 5

Conclusion

In this paper, a new MAC standard, OW MAC is implemented in the home environment. In the system implemented, a queuing delay around 40*ms* can be guaranteed when allocating 1.3 times the minimum TS number. Compared to WLAN 802.11 MAC, the queuing delay is easier to predict, due to the TS allocation algorithm used in OW MAC. Furthermore, with a control over the time slot allocation policy (to grant a minimum TS number or more), a QoS for various streams can be guaranteed. The results show a dramatic decrease in delay after a certain number of TS allocation is reached. However, a continuous increase in TS allocation also means a growth in bandwidth consumption, and the decrease in delay is not apparent anymore after a certain increase in TS allocation number. Thus, an optimal TS allocation number is found through simulation. In the actual implementation, the granted TS number is always a trade-off between the QoS requirements of the traffic stream and the amounts of resources consumed. A high number of slots granted can guarantee a better performance, but might diminish the chance for admitting more traffic streams.

OW MAC gives a good way to guarantee QoS requirements of different applications by using its reservation based transmission scheme. OW MAC is more capable of providing a guaranteed QoS even when the network is in lack of capacity. Thus, OW MAC has the clear advantages in supporting real time applications at home. The scheduling scheme used in OW MAC also provides a good way to avoid collisions. However, it also means that the reserved slot cannot be used for any other streams before it is released, which creates the challenge for a fast response in the releasing process. In the systems that do not inspect the actual capacity usage, it may also happen that some of the network resources are booked, but not used. Despite a more complex signaling process, the capacity usage may be low if the packet length is not long enough to fill the whole TS duration, or longer than one TS duration but unable to fill in the next. This is the case in this paper. One efficient way to solve the problem is to do fragmentation based on the current transmission speed in the MAC layer. This part of implementation can be done as part of the future implementation.

References

[1] OMEGA homepage. OMEGA – Home Gigabit Access project. http://www.ict-omega.eu/, available on the internet.
[2] UPnP Forum. UPnP-QoS Architecture: 3. Standardized DCP, November 30, 2008.
[3] ICT. Deliverable D4.3 Optical Wireless MAC Specification, ICT-213311 OMEGA, Seventh Framework Programme Theme 3. Information & Communication Technologies(ICT), November 16, 2009.
[4] Inc OPNET Technologies. OPNET Modeler Documentation Set. Version: 16.0, November 20, 2009.