QUALITY OF SERVICE OVER HOME NETWORK USING CABLEHOME™ 1.1

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Abstract

CableHome™ 1.1, the latest version of the CableHome specification by CableLabs®, has defined a Quality of Service (QoS) solution for home networks. The key challenges in designing the CableHome 1.1 QoS system were: varying degrees of QoS support from home-networking technologies, support for legacy home LAN devices, and backward compatibility with CableHome 1.0. The CableHome team specified a priorities-based QoS system in the CableHome 1.1 specification that addresses these key challenges. The main functionalities of this QoS system are prioritized queuing, prioritized media access, and provisioning of application specific priorities. The first functionality resides only in a residential gateway whereas the later two are part of both a residential gateway as well as home LAN devices. Provisioning of application specific priorities is a very simple process. Hence the CableHome 1.1 QoS solution is easy to deploy and implement by cable operators. In addition, since this design allows legacy home LAN devices to co-exist with complaint QoS-enabled devices it is a convenient solution for consumers too.

INTRODUCTION & BACKGROUND

CableLabs, a research and standards development consortium for the cable industry, has initiated the CableHome project at the direction of its member cable television companies. The project is aimed at developing a managed infrastructure that enables cable operators to offer high-quality, value-added broadband services to their subscribers over any available home-networking technology in a seamless and convenient manner. The CableHome 1.0 Specifications were released in April 2002 and certification testing of the products began in October 2002. CableHome 1.0 specifications also gained international acceptance via International Telecommunications Union (ITU) in 2002 when ITU document J.191, that adopted CaleHome 1.0 specifications almost entirely, was consented as a fully approved ITU recommendation.

The CableHome 1.0 specification standardizes functionality for a residential gateway device that simplifies manageability of subscriber's home network [1]. The following are some of the key features offered by CableHome 1.0:

1. Remote configuration and management of residential gateway in a secure manner.
2. Hands-off authentication and provisioning of residential gateway.
3. Application and cable friendly standardized NAT/NAPT
4. Secure download of software images
5. Firewall management and rule set download.
6. Remote home LAN devices visibility and connectivity tests
7. Local Name Service
8. Protection of cable network from home network traffic

A follow on version of the specification is CableHome 1.1. In addition to enhancing capabilities of the residential gateway, CableHome 1.1 extends its reach beyond the

residential gateway to devices in the home LAN. CableHome 1.1 specifies a new set of functionalities for home LAN devices that enable several new key features including: 1. Quality of Service (QoS) over home networks, and 2. Device and services discovery. In general new capabilities that CableHome 1.1 enables are as follows:

1. Standardized firewall configuration
2. Configuration file authentication
3. Simple Parental Control
4. Static Port Mapping
5. VPN Support
6. QoS over the home network
7. LAN Management Messaging
8. Device and Services Discovery

This paper focuses on the home network QoS functionality designed in CableHome 1.1. The paper first discusses key challenges involved in designing a generic QoS system that could be overlaid on any OSI layer-2 home-networking technology in the second section. The third section describes in detail the CableHome 1.1 QoS solution and how cable operators can implement it. The implications of this QoS solution are discussed in the fourth section and the last section presents the conclusions.

CHALLENGES IN DESIGNING A GENERIC QoS SYSTEM OVER HOME LAN

A quality of service system over home networks can be provided via three main functionalities:

1. **Management of shared media access:** When multiple devices are sharing the same transmission media some mechanism is required to manage the access to this media. This involves manageability of various traffic QoS characteristics such as traffic priorities, bandwidth, jitter, and latency. In order to implement such management a certain set of functionality needs to reside in a residential gateway as well as in home LAN devices to be able to manage and obey these characteristics.
2. **Packet Forwarding and Queuing**: This is a functionality of a residential gateway or a bridge in which packets arriving at multiple interfaces are to be retransmitted through another outgoing interface. This functionality needs to be enhanced so that packet forwarding is performed to meet the necessary QoS requirements.
3. **Management of QoS Characteristics**: This functionality deals with assignment of QoS characteristics to various devices and applications in the home and remote manageability of these characteristics. This functionality is a part of both residential gateway and home LAN devices.

There are two main QoS paradigms that can be utilized to provide the aforementioned functionalities: **parameterized** (planned, guaranteed) QoS and **prioritized** (differentiated) QoS.

- **Prioritized QoS**: The prioritized QoS paradigm entails providing differentiated shared media access to the traffic based on priorities and prioritized queuing and forwarding in a residential gateway and in a bridge. This mechanism does not provide performance guarantees for QoS parameters such as bandwidth, jitter and delay.

- **Parameterized QoS**: In this paradigm, performance guarantees for QoS parameters can be provided to the traffic over the network. This is a planned approach for allocating resources on a network. Such planning is done based on the prior knowledge of resource requirements of various devices and applications in the network.

There are pros and cons for each of these paradigms and it was necessary that the

methodology chosen for CableHome 1.1 QoS solution satisfy the requirements set forth by cable operators for CableHome 1.1. The key cable operator requirements for CableHome 1.1 QoS solution were:

- It should be able to support legacy home LAN devices and best effort traffic such that they can coexist with new QoS-enabled devices.
- It should be OSI layer-2 home-networking technology independent
- It should be software upgradeable from CableHome 1.0

There were several challenges in fulfilling these requirements. The rest of this section is dedicated to discuss these challenges.

Varying Degrees of Qos Support From Different Standards Based OSI Llayer-2 Home-Networking Technologies

The requirements for the CableHome 1.1 QoS solution mandated that cable operators should be able to overlay the QoS system on any standards based OSI layer-2 technology. This requires that the QoS system should be designed strictly at OSI layer-3 and above. Due to this fact such a system is dependent on the underlying home-networking technology for its QoS support at the MAC layer. However, the support for QoS in different standards based home-networking technologies varies from technology to technology. It is essential to assess this support in order to design a QoS system that could be OSI layer-2 home-networking technology independent and is still realistic. *(See Appendix 1 for information on QoS support in leading standards based home-networking technologies.)*

Shared vs. Point-to-point Media

With respect to QoS considerations different OSI layer-2 home-networking technologies can be categorized into two main categories: point-to-point technologies and shared media technologies. For a point-to-point technology there is a direct connection between two devices that are communicating with each other, e.g. Switched Ethernet. However, in case of shared-media technologies all of the devices share the same media for all of their communications. Most of the home-networking technologies such as 802.11 a/b/g, HomePNA, HomePlug, are shared-media technologies. For such shared media technologies some mechanism is required to control how and when devices transmit data on the media. This can be achieved by employing either parameterized or prioritized QoS paradigm.

Support for Prioritized QoS

Most of the standards based shared media technologies- 802.11 a/b, HomePNA and Powerline (HomePlug) have support for priorities based QoS scheme. 802.11 a/b and HomePNA supports 802.1p/q [2] priorities while HomePlug has native priorities support. In general, for these technologies, prioritized media access is accomplished by providing preferential media access for higher priority traffic. The highest priority traffic gets first opportunity to transmit its data on the shared media and then, depending upon the bandwidth availability, lower priority traffic gets subsequent opportunities to send their data.

Support for Parameterized QoS

The amount of bandwidth consumed by higher priority traffic cannot be controlled by using a prioritized scheme. A parameterized scheme is necessary for such a control.

Parameterized QoS requires that the underlying PHY/MAC technology be able to deliver constant bandwidth and jitter. It is very difficult to achieve this for home networking technologies based on wireless, phoneline, and powerline as underlying throughput and jitter can be strongly influenced by rapidly changing interference. Perhaps due to these reasons, at the time when CableHome 1.1 QoS system was being designed, none of the standards based home-networking technologies supported a truly parameterized QoS scheme.

Special Case of Ethernet:

Most existing Ethernet hubs in home LANs today do not support either a 802.1p/q priority scheme or a parameterized scheme and it is more than likely that Ethernet will not support these capabilities in future. However, when CableHome 1.0 is deployed in a consumer's home, existing hubs are likely to be replaced with switches that are integrated in the CableHome 1.0 residential gateway devices. For switched Ethernet, differentiated media access is not of much value, in many cases; since traffic is essentially point-to-point and it is likely that such a link is less contentious. Finally, 100Mbps bandwidth seems to be sufficient to address most of the needs of home networking applications, especially when it is for each point-to-point link. Hence QoS functionality adds very little value in the case of CableHome residential gateways that have Switched Ethernet interfaces. Thus while designing CableHome 1.1 QoS solution Ethernet was considered as an outlier among other available shared media home-networking technologies.

Supporting Legacy Home LAN Devices and Best Effort Traffic

A key cable operator concern was that newly designed CableHome 1.1QoS system should not incur substantial inconvenience to either customers or to cable operators when it has to co-exist with legacy devices. Additional cost for hardware or software upgrades of legacy home LAN devices so that they can coexist with QoS-capable CableHome complaint devices was considered highly undesirable, e.g. requiring a "QoS adapter" for best effort devices adds additional cost and is inconvenient for the customer. Thus the challenge was to devise a QoS solution that will not require an upgrade to the legacy devices and will make sure that best effort traffic from these legacy devices will not interfere with the traffic from QoS-enabled devices in the home.

Prioritized Approach

A prioritized media access system can be overlaid on existing shared-media home networks. Even though most of the current standards based home-networking technologies support prioritization of traffic, in general, these prioritization schemes are not consistent and there is no central entity managing the priorities in the home. A residential gateway in the home LAN can perform the function of priority assignment, on behalf of a customer, for various applications and devices, at the direction of cable operators. Thus, if priorities based QoS functionality is added to a residential gateway and to new compliant home LAN devices, then traffic originating from the these devices can utilize priorities to take advantage of the prioritized media access capabilities of underlying OSI layer-2 home-networking technology. Traffic from legacy non-compliant home LAN devices will continue to use best effort priority and therefore typically will not interfere with the media access opportunities for prioritized traffic from compliant devices. Thus with a prioritized QoS system compliant CableHome devices as well as legacy non-compliant devices can co-exist in the home

network without compromising the integrity of QoS for the applications that are taking advantage of the QoS system.

Legacy (non-compliant) devices do not have a means of requesting and using media access priorities for the packets. Thus these devices cannot perform prioritized media access while transmitting their data. However, with manual (operator or consumer) set-up of priorities for legacy devices in a residential gateway, it can be instructed to perform prioritized media access for traffic that is destined to legacy device. Thus prioritized QoS can be provided for a sink-only legacy home LAN device, sinking traffic from a residential gateway. Also with such manual settings a residential gateway can perform prioritized queuing for traffic to and from a legacy device going through the residential gateway.

Parameterized Approach

The parameterized QoS paradigm entails planned opportunities for media access and queuing. This requires that all of the devices and applications on the home network convey their requirements for various parameters such as bandwidth, jitter, and delay to a centralized network controller such as residential gateway. When a device or an application needs to transmit data over the network it sends a request to this centralized controller (termed as Admission Controller) [3]. Based upon the set policies and available network resources, an admission controller either accepts or rejects the request in such a manner that guaranteed QoS could be maintained over the network. However, such QoS guarantees can be provided only if all the devices in the network obey decisions of the admission controller.

Through specifications, new complaint home LAN devices can be instructed follow the process of sending their QoS parameter requirements to the centralized admission controller (implemented in the residential gateway) and to follow its decisions before sending traffic over the network. However, using available standards based OSI layer-2 home-networking technologies residential gateway cannot have any control on legacy home LAN devices as to when they should send the traffic and how much; unless the legacy devices are upgraded with hardware or software addition that instructs them to obey the admission controller in the network. Thus, without this hardware or software adapter, legacy home LAN devices will interfere with the planned transmitting intervals of complaint devices and as a result will compromise parameterized QoS system over the home network. Without appropriate support for legacy devices from underlying OSI layer-2 home-networking technologies this limitation could not be overcome while implementing parameterized scheme. This particular limitation of parameterized QoS paradigm is very undesirable from cable operator and consumer convenience point of view.

Software Upgradeability of Existing Cablehome 1.0 Devices

One of the key overriding requirements for CableHome 1.1 was that it be software upgradeable from CableHome 1.0. This would enable cable operators to upgrade CableHome 1.0 residential gateway devices in the field to CableHome 1.1 via remote download of a new software image, thus avoiding the need for a truck roll. This gives substantial cost advantages to cable operators, allows new complaint functionality to evelove, and enables them to offer new products and services with CableHome 1.1. Thus a CableHome 1.1 QoS system should be such that any newly specified residential gateway features could be added to the CableHome 1.0 device using just software implementation.

Upgradeability of Prioritized Approach

If a prioritized QoS paradigm were to be employed for CableHome 1.1 additional features that need to be added in the CableHome 1.0 residential gateway would be: prioritized media access, prioritized queuing and management of QoS priorities over the home LAN. To perform prioritized media access the residential gateway could be software upgraded to set priorities for packets transmitted on the shared interfaces. Similarly, prioritized packet queuing and forwarding could be accomplished through a software upgrade. For queuing and forwarding functionality, additional network protocol stacks are not required but additional processing steps would be required for existing CableHome 1.0 packet forwarding process. Management of QoS priorities would require additional MIBs in the residential gateway to store priorities and additional software to manage and communicate those priorities to various complaint home LAN devices connected to the residential gateway. The software footprint of this functionality can be minimized by using the same communication protocols as those used for the in-home device management and discovery features of CableHome 1.1.Thus, the various required features of a prioritized QoS system can be implemented applying software upgrade to a CableHome 1.0 residential gateway. Preliminary estimates indicate that the footprint of such implantation doesn't seem to be substantial enough to warrant a hardware upgrade.

Upgradeability of Parameterized Approach

If a parameterized QoS system were to be specified for a CableHome 1.1 residential gateway, implementation of an admission controller feature would be required as well as a communication protocol to communicate parameter requirements and network admission decisions. Additional MIBs would also need to be implemented to store and manage the QoS parameters required for applications on the home network. The admission controller feature could be implemented using Subnet Bandwidth Manager (SBM) [3] and QoS parameter communication and reservations could be performed using the RSVP [4] network protocol stack. Accurate estimates of the software footprint of these additional protocol stacks for residential gateway weren't available. However, it was clear that comparatively it is heavier than the functionality required for prioritized QoS system. Thus it was uncertain if parameterized QoS system could be implemented on existing CableHome 1.0 residential gateways by just upgrading software.

THE CABLEHOME 1.1 QoS SOLUTION

After analyzing different challenges in providing in-home QoS as well as key requirements for CableHome 1.1 QoS system, prioritized QoS paradigm was chosen as the most appropriate solution. Due to the lack of adequate support for parameterized QoS from underlying OSI layer-2 home-networking technologies parameterized QoS based solution for CableHome 1.1 seemed unrealistic. In addition, a QoS system based on a parameterized scheme would potentially require additional hardware or software upgrade to legacy best effort devices to maintain the integrity of in-home QoS. Taking into consideration these facts a priorities-based QoS solution was specified in the CableHome 1.1 specification. The later part of this section describes in detail various elements of the CableHome 1.1 QoS solution.

CableHome 1.1 QoS Architecture

The CableHome 1.1 QoS architecture consists of various logical elements and sub-elements as shown in Figure 1:

1. Portal Services Element (PS): This is a logical element in the CableHome architecture [1] that represents CableHome specified functionality within a residential gateway device.

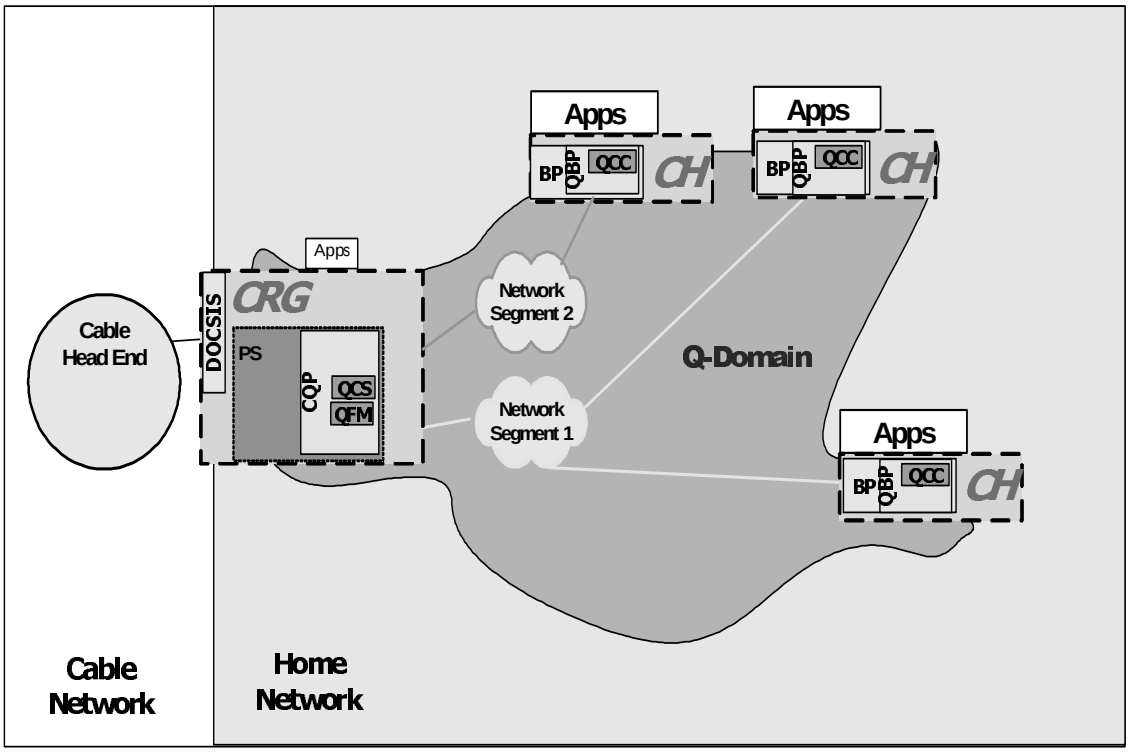

FIGURE 1: CableHome 1.1 QoS Architecture

2. Boundary Point Element (BP): This is a logical element in the CableHome architecture that represents CableHome specified functionality within a Home LAN device.

3. CableHome QoS Portal Sub Element (CQP): CQP is a sub element of the PS logical element. The CQP acts as a CableHome QoS portal for CableHome compliant applications. Its primary function is to enable priorities based QoS for the devices within the home network. It performs priorities based queuing/forwarding and media access for the traffic originating from the PS as well as for the traffic transiting through the PS. It is also responsible for communication of QoS characteristics to various devices within the home (described later in this section).

4. QoS Boundary Point Sub Element (QBP): QBP is a sub element of the BP logical element. It performs priorities based media access for the traffic originating from the BP. It is also responsible for the reception of QoS characteristics from the PS.

In addition, these logical elements described above contain QoS related functionalities (QFM, QCS, and QCS) that are described later in this section.

CableHome Priorities

CableHome 1.1 defines the following three different types of CableHome QoS priorities:

1. CableHome Generic Priorities
2. CableHome Queuing Priorities
3. CableHome Media Access Priorities.

CableHome Generic Priorities:

CableHome 1.1 introduces the concept of Generic Priorities. This is primarily due to the fact that OSI layer 2 priority approaches are not consistent as the number of priority levels supported varies from technology to technology. A generic priorities scheme gives cable operators a consistent approach, which is abstracted from the particular OSI layer 2 home-networking technology. In addition, this single generic priority can serve to indicate both media access priorities, as well as queuing priorities (described below).

CableHome 1.1 defines eight CableHome Generic Priority levels, 0 through 7, 7 being the highest and 0 being the lowest. Cable operators assign one of these eight priorities to an application. Application is identified using an application ID, which could be an IANA assigned port number for the application [5]. Of the three types of priorities defined by CableHome, a cable operator sets only the CableHome Generic Priority value for an application based on its ID. The other two priorities - CableHome Queuing Priorities and CableHome Media Access Priorities - are derived from this CableHome Generic Priority depending on the capabilities of the hardware and software in the device.

CableHome Queuing Priorities:

Packets can be transmitted from multiple incoming interfaces to single outgoing interface in the residential gateway. Hence each interface implements a queuing function. In order to provide prioritized QoS for in-home traffic passing through the PS, CableHome specifies prioritized queuing functionality per physical interface in the PS. A physical interface will have one or more queues associated with it and each individual queue is designated with a certain queuing priority. This is defined as the CableHome Queuing Priority. The CableHome Queuing Priority needs to be identified for each packet to be transmitted on each PS interface so that the packet can be placed in an appropriate queue. This CableHome Queuing priority is derived from the CableHome Generic Priority using the number of queues supported per interface on the PS. Implementation of number of queues per interface is vendor specific.

CableHome Media Access Priorities:

This is the media access priority of a packet and is derived from its CableHome Generic Priority based on the number of media access priorities supported by interface's layer-2 shared media technology. Since the number of priorities supported by different OSI layer-2 home-networking technologies varies, such mapping is necessary. CableHome Media Access Priority values are logical levels that represent a level of preference that a packet should receive for media access.

CQP QoS Functionality:

The CableHome QoS Portal (CQP), which resides in the PS element, consists of two main functionalities as shown in figure 1: QoS Forwarding and Media Access (QFM) and QoS Characteristics Server (QCS).

QoS Forwarding and Media Access (QFM):

The QFM element provides the PS with a mechanism to order and transmit packets out of a PS interface to a LAN host according to assigned priorities. The PS exercises QFM functionality on any packet that is transmitted out of the PS on any LAN interface. The QFM performs following three actions on the packet once it is received in the PS:

1. **Packet Classification:** The PS examines the destination IP address and destination port number of the packet. Using these values the PS looks up a corresponding CableHome Generic Priority for the packet from the classifier table stored in the PS database. If no matches are found for that destination IP and port, then the PS assigns priority 0 to the packet.

2. **Prioritized Queuing:** The PS then maps CableHome Generic Priority of the packet to CableHome Queuing Priority based on the number of queues implemented for the interface on which the packet is to be transmitted. Multiple queues implemented for the interface are designated with different CableHome Queuing Priorities. The PS puts the packet in an appropriate queue based on its queuing priority. The QFM polls all of the queues on each interface according to their priorities to extract packets. The packets are extracted from the queuing system by employing a methodology of First in First Out with Priorities, Highest Priority Queue First.

3. **Prioritized Media Access:** After the packet is extracted from the set of queues associated with an interface, the packet needs to be transmitted on the shared LAN media with the appropriate media access priority. The QFM performs the mapping of the CableHome Generic Priority value of the packet to the CableHome Media Access Priority. The packet is then transmitted on the shared media with the appropriate level of preference as indicated by the CableHome Media Access priority.

QoS Characteristics Server (QCS):

The QCS element provides a mechanism for the cable head-end to communicate desired QoS Characteristics (for particular applications) to the PS and then further to BPs in the home. In CableHome 1.1 QoS characteristics refer to priority information for different applications over the home network. The overall functioning of the QCS is explained below.

1. **Application Priority information to the PS**: The cable head-end provides mapping of application IDs to CableHome Generic Priorities to the PS either using a PS configuration file or via SNMP MIB interface. This mapping in the PS serves as a master table in determining priorities for various applications or services on the home LAN.

2. **BP Application Information to the PS:** The QCS receives information about the applications associated with a BP in the form of an XML message, called the BP_Init message, which is sent using SOAP over HTTP [6]. This message contains the list of application IDs that a BP supports. It may also contain a list of destination IP address and port number pairs for which a particular application on the BP likes to request destination specific priority. Such a request for destination IP and port specific priority is sent by a BP to the PS after an application session has been established.

3. **Application Priority Information to the BP**: Upon receipt of the application

information from the BP, the QCS consults the priority master table provided by the cable operators and determines appropriate priorities for different applications on the BP. If there is no entry for a particular application in the priority master table, then the QCS assigns a default priority of 0 (best effort) for that application. QCS also determines the destination specific priority information as requested. Both these priorities are determined using applications IDs. The QCS sends this updated priority information to the BP in the XML format using BP_Init_Response message (SOAP over HTTP). The QCS also stores all of this updated priority information in the PS database (which is accessible to cable operators via the MIB interface).

Thus through these three main processes the QCS manages and communicates priority information to various applications on the home network

QBP QoS Functionality:

The QBP is a logical sub element of a BP that resides in a CableHome compliant home LAN device, termed as CableHome Host. The QBP consists of only one QoS functionality: QoS Characteristics Client (QCC).

QoS Characteristics Client (QCC):

The QCC has two main responsibilities: obtaining application priority information from the PS and using this priority information for prioritized media access. These two functions of the QCC are explained in detail in the subsequent paragraphs.

1. **Requesting priority information to the PS:** As explained earlier in the QCS section, the BP sends its application information to the PS in the BP_Init Message. The QCC entity in the BP is responsible for that message exchange. Also if an application needs a specific destination IP address and/or port specific priority, then the QCC sends a request for such destination IP and port priority in the BP_Init Message, after the application on a BP establishes a connection with another application. In addition, the QCC is responsible for communicating to the PS any updates (addition/deletion) to the application information in the BP. After the PS sends updated application priority information to the BP, the QCC makes sure that priority information for applications on the BP gets updated appropriately.

2. **Prioritized Media Access**: Once the application on the BP starts communicating, the QCC uses the priority assigned to it for prioritized media access. If a destination IP and port specific priority is requested then QCC uses destination specific priority otherwise it uses the default priority assigned to the application. The QCC maps the CableHome Generic Priority to CableHome Media Access priority based on the number of media access priorities supported by underlying layer-2 home–networking technology and then delivers the packet on the shared media.

IMPLICATIONS OF THE CABLEHOME 1.1 QoS SOLUTION

As explained in the earlier sections, the CableHome 1.1 QoS system is a simple and elegant solution that cable operators can provide on CableHome devices easily. The only additional provisioning step that cable operators need to perform is provisioning of the application priorities master table in the residential gateway. Applications on compliant CableHome devices will receive appropriate priority information that they can use for subsequent management of prioritized traffic flow. With CableHome 1.1 QoS,

legacy home LAN devices can co-exist with complaint QoS-enabled devices without collapsing QoS of the entire network. Thus it is a convenient solution for both consumers and cable operators. Minimal additional functionality is required to implement CableHome 1.1 QoS on residential gateway and home LAN devices.

The benefits of the CableHome 1.1 QoS solution are significant and compelling, however there are a number of implications associated with the chosen approach. Since this QoS solution is based on a prioritized paradigm it does not provide absolute guarantees for QoS parameters such as bandwidth, jitter, and delay. It provides preferential media access to certain traffic, classified as higher priority. Thus two traffic streams that have the same priority would contend with each other for media access and thus they might get best effort treatment between themselves. Also, if a top priority application consumes the entire bandwidth of the home network then it is possible that access to the shared media could be denied for all applications. Considering the bandwidth provided by typical home-networking technologies today and services that CableHome 1.1 plans on enabling it seems that this scenario is unlikely. However, in future if cable operators decide to offer bandwidth intensive services such as video distribution over the home network, this scenario may occur and in that case the applicability of a prioritized QoS scheme may need to be revisited. [See Appendix 2 for typically expected QoS requirements for various applications and services]

CONCLUSIONS

CableLabs has defined priorities based QoS solution for its home networking project-CableHome 1.1. The CableHome 1.1 QoS solution can be deployed on any layer-2 home-networking technology that supports priorities. Cable operators and consumers can take advantage of this solution in a convenient and seamless manner, as it does not require any additional hardware or software upgrade for legacy devices in order to maintain QoS over the home network. Additional functionality required to implement this solution is minimal. Hence it is attractive and cost effective for vendors to build products for this specification. Cable operators can provision QoS for their applications in the home network by a simple configuration of application specific priorities in the CableHome 1.1 based residential gateway. Thus, CableHome 1.1 QoS is a simple, cost-effective and easy-to-use solution that enables cable operators and consumers to take advantage of QoS over the home networks.

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ACKNOWLEDGEMENTS

The author wishes to acknowledge the following individuals for their valuable contribution, inputs and assistance.
Ralph Brown, Steve Saunders, Kevin Luehrs, Stuart Hoggan, Jennifer Doran, Liz Weeks

APPENDICES

Appendix 1: Features summary of various leading standards based OSI layer-2 home-networking technologies

Home Networking Technology	**Specifications and Standards Group**	**PHY Layer Modulation**	**Data Rates**	**QoS Capabilities**
Ethernet	IEEE 802.3	Baseband	10Mbps,100Mbps, & 1Gbps	None
Wireless LANs	IEEE 802.11a	OFDM	54Mbps	802.11 e Working group (Prioritized & Parameterized Proposals)
	IEEE 802.11b	DSSS	11Mbps	
	IEEE 802.11g	OFDM	54Mbps	
Powerline	HomePlug 1.0, Home Plug Powerline Alliance	OFDM	10Mbps	Prioritized
Phoneline	HomePNA 1.0 & HomePNA 2.0, Home PhoneLine Networking Alliance	FDQMA	1Mbps & 20Mbps respectively	Prioritized

Appendix 2: Expected QoS requirements for various applications and services

Service	Input Parameters of Performance Testing				Output Parameters of Performance Testing		
	Number of Streams	Payload Rate (per stream)	Header Type	Packet Size (bytes)	Max PER	Max Latency (ms)	Max Jitter (ms)
HQ Voice Calls	2 per call	64 kb/s	IP/UDP/RTP	120	$1.5*10^{-3}$	10	+/-5
MQ Voice Calls	2 per call	8 kb/s	IP/UDP/RTP	80	$1.5*10^{-3}$	30	+/-20
HQ Video Conference Call	2 per call	1.5Mb/s	IP/UDP/RTP	228	$3.6*10^{-5}$	10	+/-5
HDTV	1	19.68 Mb/s	IP/UDP/RTP	228	$3.6*10^{-5}$	90	+/-10
SDTV	1	3 Mb/s	IP/UDP/RTP	228	$3.6*10^{-5}$	90	+/-10
CD Quality Audio	1	256 kb/s	IP/UDP/RTP	360	$5.8*10^{-5}$	100	+/-10
High Speed Data	1	10 Mb/s	TCP/IP	1540	0	>100	>100
Med. Speed Data	1	2 Mb/s	TCP/IP	1540	0	>100	>100
Low Speed Data	1	500 kb/s	TCP/IP	1540	0	>100	>100

NOTES:

1. Voice Packet = (IP/UDP/RTP Header) + (voice payload)

IP/UDP/RTP Header: 40 bytes (20 bytes IP Header + 8 bytes UDP Header + 12 bytes RTP Header) without RTP header compression. If RTP header compression is applied header reduces to 2-4 bytes. In this table we assumed no RTP header compression.

Voice payload: variable size depending on codec, considering the end-to-end latency budget, typically 10-40 ms voice samples can be used. Given the Max Latency/Max Jitter in HN portion and to keep packet overhead to its minimum, we assume 10 ms voice samples for HQ voice and 40 ms voice samples for MQ voice.

Video Packet = (IP/UDP/RTP Header) + (video payload)

IP/UDP/RTP Header = 40 bytes (20 bytes IP Header + 8 bytes UDP Header + 12 bytes RTP Header).

Video Payload size = MPEG packet size which is 188 bytes.

Data Packet = (IP/TCP Header) + (Ethernet payload)

Packet Error Rate (PER): is measured at MAC-SAP for packets delivered from MAC layer to higher layer. For data, since packets in error should be discarded and only error free packets are passed to the MAC-SAP, then for data PER=0.

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