PERFORMANCE ANALYSIS OF QOS OVER CATV NETWORKS BASED ON THE EUROPEAN CABLE MODEM PROTOCOL (DVB/DAVIC) FOR THE SUPPORT OF DELAY-SENSITIVE APPLICATIONS

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ABSTRACT

This paper presents an overview of some key QoS features that will enable the DVB/DAVIC protocol with a superior performance and efficiency at the Media Access Control (MAC) layer for the support of delay-sensitive applications. We show the deficiencies of the basic reservation request mechanism provided by the DVB/DAVIC MAC protocol and present a performance optimisation via simulation results in terms of mean packet access delay and system throughput. Initial results show that the number of delay sensitive streams supported can be increased considerably by considering QoS features.

I. INTRODUCTION

CATV Network operators, motivated by the recent phenomenon growth of the Internet, are now in the process of updating and extending their cable networks in order to offer bi-directional data communication services to residential subscribers. For the European market, the Digital Video Broadcasting (DVB) / Digital Audio Visual Council (DAVIC) protocol (v1.2.1) [1] and (v1.3.2) [2] is one of the most recent developments which provides the baseline specification of the interaction (or return *DVB-RCC*) channel. Unfortunately, this protocol uses a limited reservation-access mechanism by default for the transmission of reservation requests that is not ideal for the delivery of delay-sensitive applications or high-speed data transmissions, due to the increased risk of collisions with reservation requests (among EuroModems [3]) on congestion periods as discussed in [4] and [5].

By making slight changes to the MAC protocol and adopting new QoS features such as traffic Prioritisation and Reservation, a significant performance increase can be sustainable for the support of delay-sensitive applications, including, Voice over IP (VoIP) for IP Telephony service, compressed video over IP for video on demand, video conferencing and interactive multimedia, to name a few. Therefore, in this paper we study two QoS features that will provide to the DVB/DAVIC protocol with increased network efficiency.

Related work focused on the optimisation of the two contention resolution algorithms (CRAs) adopted by the DVB/DAVIC protocol [6]. Here the authors presented the *backoff windows* for the exponential backoff algorithm, and the *entry spreading factors* for the splitting tree algorithm that provided optimal system performance. In [7] the authors introduced a performance optimisation based on enhanced contention slot allocators, which dynamically adjust the number of contention slots to the contention-based access region based on the current traffic load. A further performance increase was achieved in [5] through the use of enhanced-reservation-request mechanisms (such as enhanced pure reservation request, continuous reservation request, piggyback request, continuous piggyback request and unsolicited grant slot) that reduce or avoid the increased risk of collisions as the network load is increased. The piggyback mechanisms have been now adopted in the latest specifications of the DVB/DAVIC protocol [2].

The rest of this paper is structured as follows. Section II presents a general overview of the DVB/DAVIC MAC protocol. Then a description of the QoS features is presented in Section III. Finally, Section IV outlines the results in terms of performance analysis demonstrating the advantages and characteristics of QoS Prioritisation and Reservation techniques, followed by the conclusions.

II. DVB/DAVIC MAC PROTOCOL

The upstream channel uses Time Division Multiple Access (TDMA) for the transmission of data. This channel is divided into fixed slots of 64 bytes and its frame structure is based on the Asynchronous Transfer Mode (ATM) protocol. In the downstream two signalling methods are used: in-band and out-of-band. In the in-band signalling the downstream channel is embedded in the broadcast channel and is oriented for the EuroModem solution. The transmission of data packets and MAC messages is based on Motion Pictures Experts Group (MPEG-2) transport stream frames. In the out-of-band method the downstream is separated from the broadcast channel and is mainly oriented for the Set Top Box solution. This method uses a Signalling Link Extended Super frame (SL-ESF) framing structure based on ATM cells. Ten ATM cells are mapped into 24 sub-frames with additional signalling and error correction information. For a full description of the upstream and also downstream packet formats refer to [1] and [2].

In the MPEG-2 frame or SL-ESF structure (according to the solution adopted: in-band or out-of-band), a "*signalling information field*" is used for synchronisation of the upstream slots. The main functionality of this field is to co-ordinate the usage, assign access modes, and indicate if reception of contention-based slots has been successful. Each slot is assigned one of the four following classifications from the headend (which is also referenced as Interactive Network Adaptor -INA): ranging (for synchronisation and calibration purposes), contention (for light traffic load and MAC messages transmission), reservation (for bursty or high traffic load) or fixed slots (for constant bit rate traffic). These frames are transmitted in the downstream channel (at least) every 3 ms when the upstream data rate is 12.352, 6.176, 3.088 or 1.544 Mbps, and every 6 ms for 256 Kbps.

The reservation-access mode with its dynamic slot-allocation feature is the main access mode of the DVB\DAVIC MAC protocol for the transmission of data packets via the upstream channel. For this access mode, the DVB/DAVIC group has adopted two CRAs, which are used to resolve collisions: the exponential backoff and splitting tree algorithms. The splitting tree algorithm takes advantage of the exponential backoff algorithm in the sense that feedback and allocation information allows a station, (with new incoming arrivals) to compete for contention-based slots without risk of collision with backlogged stations. In addition, this algorithm makes use of minislots, which decreases the risk of collisions, since one contention-based slot is divided into three minislots (of 21-bytes long transferring shortened reservation request messages), increasing the probability of successful request transmissions and consequently improving the system performance. In [6] a detail description of the operation and the performance of these two CRAs is presented.

As introduced in [1] and [12], the authors have reported that several functions are performed by the MAC protocol for connection control and data transmission as illustrated in Figure 1. On power-on or reset the initialisation and provisioning procedure sees that a

Network Interface Unit (NIU) or EuroModem, is capable of tuning to the correct channel in the upstream and downstream directions and that it can receive the basic network parameters. Then, the sign-on and calibration are performed in order to adjust the internal clock and the transmission power of the NIU according to the specific transmission delay and cable attenuation. The initial connection is also established by default. The MAC protocol carries out the establishment and release of logical connections and allows for readjustment of transmission parameters as well as performing an exchange of encryption keys and the establishment of a secure connection. Here, *Diffie-Hellman* and *Data Encryption System* security techniques are used.

Once the NIU has initialised and registered with the INA, bandwidth reservation is provided by both per-packet and per-session (or connection) basis. The former is known as Reservation Access and is provided by sending reservation requests to the INA as illustrated in Figure 2. The first version of EuroModems *class A* will support this functionality as a mandatory access mode. The latter is known as Fixed-rate access, where the INA provides either a finite amount of slots (in the fixed-rate access region) to a specific NIU or a given bit rate requested by a NIU until the INA stops the connection on NIU's demand. This access mode will be an optional functionality for EuroModem *class A*, and mandatory for EuroModem *class B*.

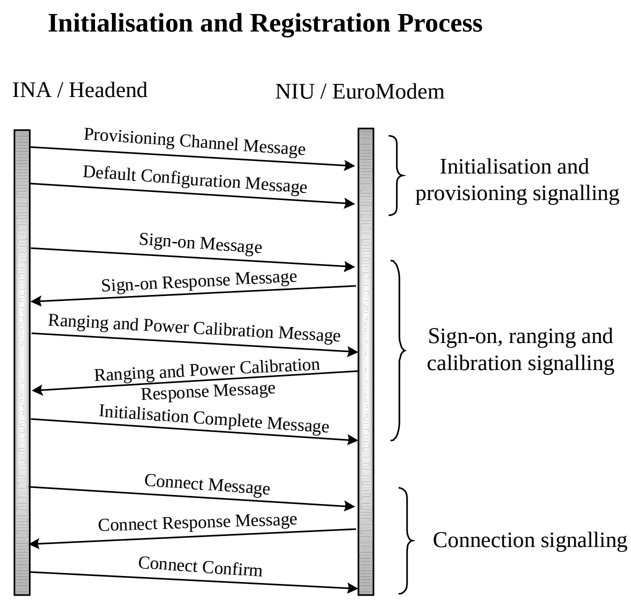

Figure 1. Initialisation and Registration Process.

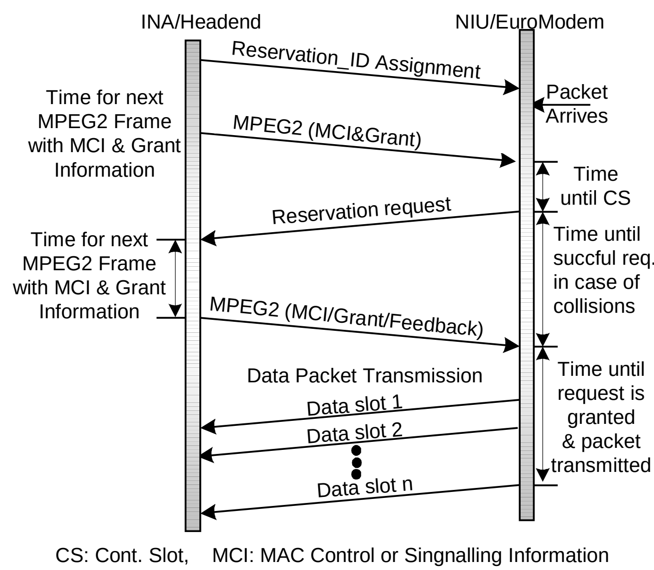

Figure 2. Contention-Resolution-Grant Cycle.

QUALITY OF SERVICE FOR THE DVB/DAVIC PROTOCOL

This section outlines the main issues related to QoS and how a cable network compliant to the DVD/DAVIC protocol specification can make use of QoS characteristics for the provision of guaranteed bandwidth. Two methods for QoS are presented. They are complementary, designed for use in combination in different network contexts and are known as Prioritisation and Reservation.

QoS-Prioritisation

One approach for QoS is to use the Type of Service (*ToS*)-based relative priorities of the IPv4 header (or the 4-bit Priority field of the IPv6 header), which indicates the desired usage of the packet. The field itself contains a 3-bit precedence indicator for the priority of the packet and 3 flags (D, T and R) to show whether delay, throughput or reliability are relevant for the transmission. Unfortunately, since little has yet been proposed, the first version of EuroModems [3] (compliant to the DVB/DAVIC protocol specification) are set to ignore the *ToS* filed. In this paper we demonstrate that a faster transmission for the delivery of delay-sensitive streams can be provided by making slight changes to the reservation-access mechanism. A significant performance improvement can be obtained by mapping the *ToS* field with at least 2-levels of priority at the DVB/DAVIC MAC layer. This method gives delay-sensitive streams higher priority than data packets but it still does not provide any guarantee of bandwidth availability or latency.

QoS-Reservation

The second approach for QoS (with a guaranteed service) uses a Fixed-rate access connection. Here, delay-sensitive streams are sent in slots assigned to the fixed-rate based access region in the upstream channel. These slots are uniquely assigned to a connection by the headend (also referenced as Interactive Network Adaptor, INA). The number of slots needed by a connection and the periodic intervals is negotiated during the connection setup as illustrated in Figure 3. When an EuroModem requires a new fixed-rate connection (or needs to change fixed-rate parameters), a *Resource Request* message is first sent to the INA by the EuroModem, including the new parameters. Example parameters are *new cyclic assignment needed*, *requested bandwidth, distance between slots* and *connection identifier* - CID). The INA answers such requests by sending a *Connect* message to the EuroModem, indicating whether the *new cyclic assignment* is granted and if so, a new set of fixed-rate parameters are provided, such as: *frame length*, *fixedrate start*, *fixedrate distance*, *fixedrate end* and *CID*.

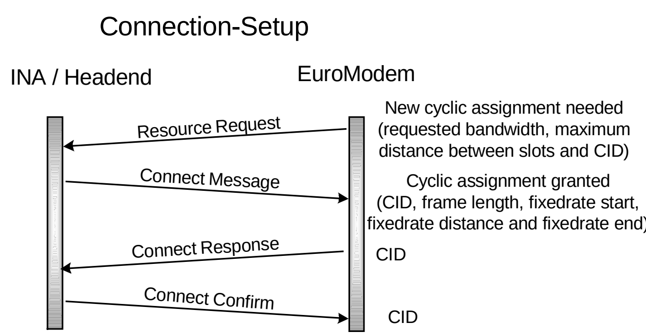

Figure 3. Connection-Setup for fixed-rate access.

PERFORMANCE ANALYSIS

The analysis to follow examines to what extend the system performance can be improved upon when Prioritisation and Reservation QoS characteristics are used for the support of delay-sensitive applications over the DVB/DAVIC protocol. A detailed simulation model was implemented using the OPNET Package v.6.0 for the results. For a further description of this simulation model the readers are referred to [6].

In all simulations, one upstream channel with a capacity of 3 Mbps and one downstream channel with a capacity of 42 Mbps were used. The splitting tree algorithm as defined in [1] and [6] was used to resolve collisions due to its increased performance over the exponential backoff algorithm. In addition, a novel and topical mixed traffic configuration (at 41.7 Kbps per EuroModem) was used for the analysis formed by Internet traffic and VoIP traffic. The packet distribution for Internet traffic was as suggested by the IEEE 802.14 Working group [8], (depicted in Figure 4), with a mean data rate of 32 Kbps.

For VoIP traffic we used codec G.723.1 [9], which is the preferred speech codec for delivery over the Internet, according to the ITU consortium. This codec generates a data rate of 5.3 Kbps where 20-byte voice frames are generated and encoded every 30 ms. In a study carried out in [10], it was found that as the number of audio frames per packet increases, the packet overhead decreases. Some H.323 terminals use a value of 3 or 4 for the number of frames per audio packet in order to improve the network efficiency [11]. Therefore, in order to be consistent with these figures for H.323 terminals, 4 audio frames will be used per packet. Then, the protocol overheads presented in Table 1 are added in order to yield a complete VoIP packet.

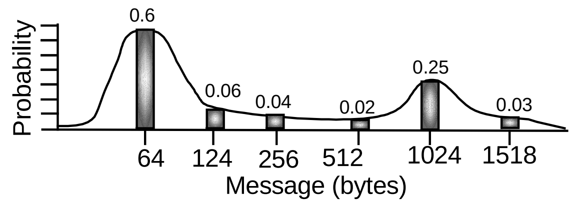

Figure 4. IEEE 802.14 IP packet size distribution.

Frame/Header	9.7 Kbps Streams
Voice frame	80 bytes (120 ms)
RTP header	6 bytes
UDP header	12 bytes
IP header	8 bytes
LLC header	3 bytes
SNAP header	5 bytes
Ethernet MAC header	18 bytes
Total Size	146 bytes (4 ATM cells)

Table 1. VoIP Encapsulation.

Figures 5 and 6 presents a performance analysis when the default reservation request mechanism (named here as PRA) is compared with the mechanisms provided by QoS. In terms of mean packet access delay, Figure 5 shows that delays yielded by the default PRA mechanism are almost the same for both traffic types. This is to be expected, since both traffic types are treated equally. The maximum number of streams supported resulted in approximately 40 VoIP streams (with tolerably mean packet access delays under 50 ms) and 42 Internet streams (with access delays under 120 ms). However, if traffic *Prioritisation* was implemented, the number of VoIP streams could be extended to approximately 54 connections, while still offering mean access delays under 50 ms. The best results were obtained when QoS with a fixed-rate connection was used for VoIP streams, which extends significantly the number of voice streams supported (from 42) up to 160 and provides bounded access delays under 5ms.

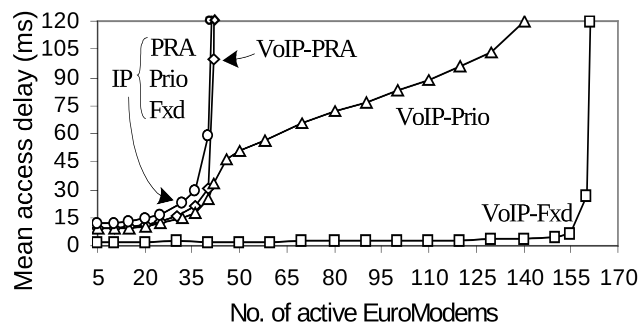

Figure 5. Mean access delay for PRA and QoS mechanisms.

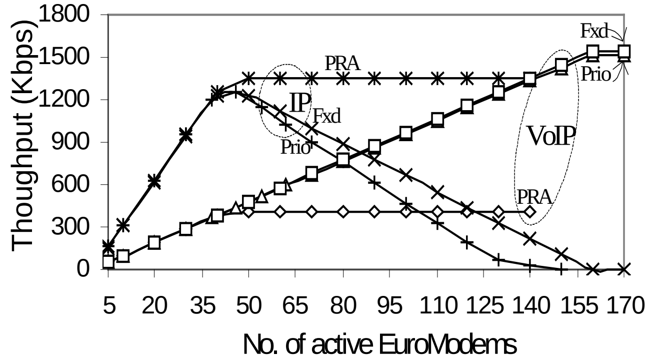

Figure 6. System throughput for PRA and QoS mechanisms.

In terms of system throughput, Figure 6 revels that with the PRA mechanism, on congestion periods the buffer capacity of the EuroModems saturates very rapidly and packets from both traffic types begin to be dropped equally. The maximum throughput achieved by this mechanism resulted in 1.3Mbps Internet traffic plus 0.4 Mbps VoIP traffic, which corresponds to 57% of the channel capacity. Conversely, when QoS was used, the Prioritisation and Reservation mechanisms make sure that all traffic for VoIP streams is always delivered (up to the point when the maximum capacity is reached) and that any packet lost will be only for Internet traffic as illustrated in Figure 6. With these two mechanisms provided by QoS, the maximum throughput achieved is about 50% of the channel capacity. The system throughput for Internet traffic when the prioritised mechanism is used resulted slightly lower that the throughput yielded with a fixed-rate connection, this reduction was caused by the increased number of contention slots allocated by the dynamics of the splitting tree algorithm to resolve collisions.

CONCLUSIONS

This paper has presented a performance optimisation for the DVB/DAVIC protocol when QoS features are used for the delivery of delay-sensitive applications. The major contribution of this paper is that by making slight changes to the MAC protocol and implementing QoS features, such as traffic Prioritisation, a significant effect on system performance can be obtained. The major drawback of this prioritised technique proposed is that it cannot provide any guarantee of bandwidth availability or latency. However, the Reservation technique through the use of a fixed-rate connection, a reduced packet access delay for the delivery of delay-sensitive streams in the range of 2-5 ms could be guaranteed by the DVB/DAVIC protocol before large periods of congestion are experienced, supporting up to 160 VoIP streams.

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Biography

Victor Rangel received the B.Eng (Hons.) degree in Computer Engineering in the Engineering Faculty from the "Universidad Nacional Autónoma de México (UNAM)", Mexico in 1996 and the M.Sc. in Telematics from the University of Sheffield, U.K. in 1998. He is currently reading for a Ph.D. at the Centre for Mobile Communication Research, EEE Department, at the University of Sheffield, U.K. He was a Contractor at NETTONICS Ltd, Sheffield, UK from February to April 2000, and a visiting researcher at ARRIS Interactive, MA, USA from June-August 2000. His research interests include modelling, design and analysis of CATV and wireless networks, QoS over IP and communication protocols. Victor Rangel is a student member of the IEEE.

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