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Title:	Serving IP Quality of Service with HiperLAN/2
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Serving IP Quality of Service with HiperLAN/2

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Abstract

The European project BRAIN investigates system concepts to provide wireless broadband access to the QoS-based Internet. As basis for the BRAIN radio access HiperLAN/2 is considered. In this paper we propose functions enhancing the HiperLAN/2 radio interface to support IP QoS. Thereby our special focus is on the system ability to schedule the various connections dedicated for IP traffic according their QoS requirements, whereby the specific characteristics of the wireless access such as transmission error control and link adaptation will be regarded.

1 Introduction

Quality of Service (QoS) refers to the ability of a network to provide better service to specific network traffic over various underlying wireline or wireless technologies. Internet QoS can be expressed as the combination of network imposed *delay*, *delay variation*, *bandwidth* and *reliability*. Reliability is a property of the transmission system and is affected by the average loss ratio of the medium and by the routing/switching design of the network. In the fixed Internet packet loss is caused mainly by congestion. In wireless networks both congestion and the burstiness of errors on the radio link and the delay introduced then by *Automatic Repeat Request (ARQ)* protocols impact the QoS and have to be taken into account.

IP QoS focuses on end-to-end QoS, whereby the network elements have to serve the respective requirements on a per hop basis. Wireless networks may provide only one or two hops of an end-to-end connection.

The cellular radio access investigated in the European project BRAIN (*Broadband Radio Access for IP-based Networks*) bases on *HiperLAN/2 (H/2)* and will be able to support QoS on a per connection basis [1, 2]. An IP *Convergence Layer (CL)* tailored to the BRAIN radio access will have to provide the functions needed for mapping the QoS requirements of the individual to the QoS parameters available for their respective *Data Link Control (DLC)* connections (see Figure 1). Furthermore, this IP CL has to support segmentation and re-assembly to adapt variable length IP packets to fixed length DLC *Protocol Data Units (PDU)*.

Mechanisms like error control by means of an ARQ protocol and dynamic link adaptation aim to reduce the radio specifics on the packet loss rate but introduce additional delay and overhead to the radio access system that decreases the capacity. To meet the QoS requested by an IP application at the radio interface algorithms in the DLC layer must decide how to schedule the related data.

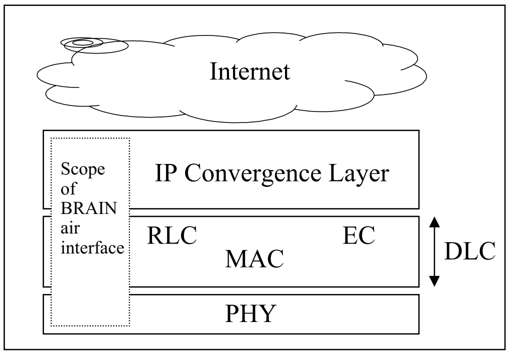

Fig. 1: BRAIN Protocol Stack

In the following we discuss the potential of H/2 radio access systems to support IP QoS parameters like *throughput* and *delay* and propose a mechanism to schedule IP connections of various QoS types in the DLC layer.

2 Quality of Service in IP

A service model describes a set of end-to-end QoS capabilities defining the ability of the network to deliver data packets according to the service required by the specific traffic from one end of the network to another. For IP traffic the following service models have been defined: *Best Effort Service*, *Differentiated Services* and *Integrated Services*.

2.1 Best Effort Service

Best Effort Service provides basic connectivity with no guarantees, so it is also known as lack of QoS. Best Effort is a single service model where an application sends data whenever it has to and in any quantity. This is done without requesting permission or informing the network. For Best Effort Service, the network delivers the data as best as it can without any assurance of delay bounds, throughput and reliability.

2.2 Differentiated Services

In this service model traffic is grouped in service classes that are served differently by the network, whereby one class may be treated better than another, i.e., with higher bandwidth or lower loss rate. This results in a statistical preference and not in a hard guarantee, so that Differentiated Services are also called *Soft QoS*. For the Differentiated Services, the network tries to deliver the IP packets according to the QoS assigned to a specific service class indicated by each individual packet [3].

2.3 Integrated Services

This model represents an absolute reservation of network resources for specific traffic. It is also called *Hard-QoS*. Integrated Services is a multiple service model that can accommodate multiple QoS requirements. In this model the application requests a specific kind of service from the network before sending data. The request is made by explicit signaling [4, 5]. This means, that the application informs the network nodes of its traffic profile and requests a particular kind of service that can encompass its bandwidth and delay requirements.

Integrated Services support both *Controlled Load Service* and *Guaranteed Service*. The Controlled Load Service guarantees to provide a level of service equivalent to best effort service in a lightly loaded network, regardless of the actual network load [6]. This service class is designed for adaptive real-time applications. These applications work well on low loaded networks but their performance degrades quickly under overloaded conditions. Guaranteed Service guarantees a maximum end-to-end delay and bandwidth [7]. It is intended for audio and video applications with strict delay requirements.

3 Properties of HiperLAN/2

Scheduling in the H/2 DLC layer has to take care of the QoS requirements of a specific IP traffic and the capabilities of the H/2 radio system, such as the *Medium Access Control (MAC)* and the ARQ protocol. Furthermore the physical layer supports a set of modulation schemes with various coding rates that can be adapted dynamically by link adaptation in the DLC.

3.1 Medium Access Control

MAC protocol functions are used for organizing the access to and the transmission of data on the radio link [8]. The control is centralized to the *Access Point (AP)* that informs the *Mobile Terminals (MT)* at what point in time in the *MAC Frame (MF)* they are allowed to transmit their so-called *PDU trains*. The lengths of the PDU trains vary depending on the *Resource Requests (RRs)* received at the AP from the MTs. The radio interface is based on *Time-Division Duplexing (TDD)*. The dynamic *Time Division Multiple Access (TDMA)* structure used in the MF allows simultaneous communication via a number of DLC connections in both directions downlink and uplink. The time slots are grouped to MFs of constant length of 2 ms. The assignment of resources for the individual MTs and their connections is not static but may change dynamically from one MF to the other. Each MF consists of different phases as shown in Figure 2.

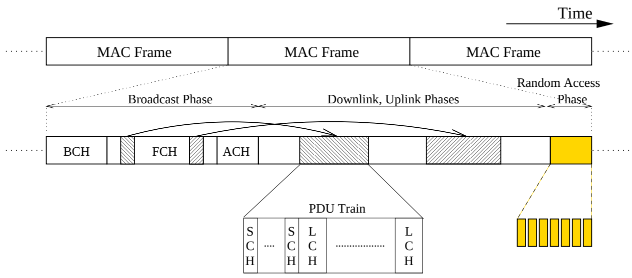

Fig. 2: Transmission Phases in a MAC Frame

The *Broadcast Phase* carries the *Broadcast CHannel (BCH)*, the *Frame CHannel (FCH)* and the *Access Feedback Channel (ACH)*. The BCH transmits control information in each MF and to all MTs. The FCH contains an exact description of how the resources of the current MF have been allocated (and thus granted) in downlink and uplink. The ACH provides information on access attempts made by MTs in the *Random Channel (RCH)* of the previous MF. The downlink phase carries user specific control information and the user data, transmitted from an AP to one or more MTs. The uplink phase carries control and user data from the MTs to the AP. In the random access phase MTs that do not have capacity allocated in the current uplink phase may use the RCH to transmit a RR. Non-associated MTs get in first contact with an AP via the RCH that is also used by MTs during handover to have access to a new AP. For the RCH a *Slotted ALOHA* protocol with a binary-exponential back-off collision resolution algorithm is used.

Two kinds of *Protocol Data Units (PDU)*, the *Long PDU (LCH PDU)* and the *Short PDU (SCH PDU)* are specified. A LCH PDU is 54 byte long and contains, besides header and tail information, 48 byte *payload*. A SCH PDU is 9 byte long and contains 52 bit for signaling data, e.g., RR or ARQ acknowledgments.

In order to reduce overhead, all LCH and SCH PDUs in an MF belonging to connections of the same MT are combined to a PDU train (Figure 2).

Owing to this structure the H/2 MAC protocol provides the flexibility to accommodate a large variety of MTs and connections on the one hand and different QoS requirements on the other. The actual data rate supported by the MAC protocol can be defined by an AP for each MT connection individually over time by defining the size of a PDU train and the PHY modes used for transmission (see Section 3.3).

3.2 Error Control Functions

Error Control (EC) functions are responsible for detection and recovery of transmission errors on the radio link and ensure that all frames are delivered to the Convergence Layer in the proper order. EC in the H/2 standard is based on Selective Repeat ARQ with CRC checksum [8].

3.3 Physical Layer

H/2 applies *Orthogonal Frequency Division Multiplexing (OFDM)* transmission in the 5 GHz frequency band. A key feature of the H/2 physical layer is to provide several *Physical Layer Modes (PHY modes)* with various coding and modulation schemes that are selected by a link adaptation mechanism. BPSK, QPSK, 16QAM are mandatory subcarrier modulation schemes whereas 64QAM is an optional mode [9]. *Forward Error Correction (FEC)* is performed by a convolutional code of rate ½ and constraint length seven. Other code rates like 9/16 and ¾ are obtained by puncturing. Accordingly, different transmission rates result as shown in Table 1.

Modulation	Code rate	Capacity of an OFDM-Symbol	Transm. rate
BPSK	½	3 byte	6 Mbit/s
BPSK	¾	4.5 byte	9 Mbit/s
QPSK	½	6 byte	12 Mbit/s
QPSK	¾	9 byte	18 Mbit/s
16QAM	9/16	13.5 byte	27 Mbit/s
16QAM	¾	18 byte	36 Mbit/s
optional:			
64QAM	¾	27 byte	54 Mbit/s

Table 1: Modulation and Coding Dependent Transmission Rates

Link adaptation in the DLC layer assigns a specific PHY mode to the PDUs dedicated for one connection regarding the current radio link conditions. Each connection and its directions can be addressed individually and the assignment can vary from one MF to the other.

The *PDU Error Ratios (PER)* of the LCH-PDUs have been evaluated for different PHY modes and *Carrier-to-Interference ratio (C/I)* values. Results from literature are shown in Figure 3 and were used in the calculations and simulations to reflect C/I dependent errors [10].

3.4 H/2 Functions determining QoS Parameters

Adaptive scheduling of IP traffic requires to prioritize and to guarantee specific DLC services for the various connections or groups of connections dedicated to the IP traffics. The DLC scheduling algorithm has to take into account the various properties of the H/2 radio access that are mutually dependent:

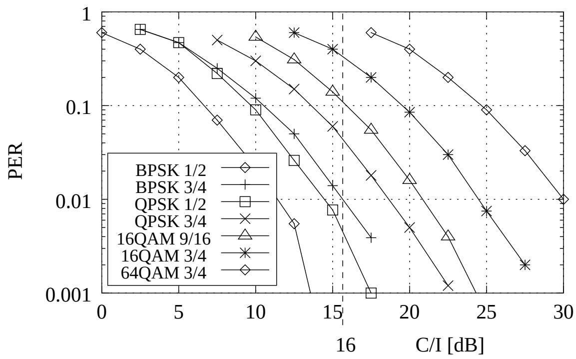

Fig. 3: PER vs. C/I

ARQ is used to react on transmission errors by re-transmission. However, in case of a poor radio link the transmission delay increases. Re-transmission have to be considered as additional DLC signaling overhead, so that the net system capacity will be reduced.

Discarding of PDUs allows to skip re-transmission of specific PDUs, e.g., when due dates expire.

Link Adaptation: In case of a poor link quality the PHY mode chosen for LCH PDUs can be adapted to a more robust one. However, PDUs coded with a more robust PHY mode require more capacity in the MAC frame, resulting also in a degradation of system capacity.

Total system throughput, transmission delay and IP packet loss ratio of an individual connection are the most important parameters determining the performance of the H/2 radio access. The total system throughput can be calculated considering the protocol overhead introduced by MAC and ARQ re-transmissions. In [11] it is shown that the MAC throughput can be calculated by:

$$Throughput_{MAC} = \left\lfloor \frac{L_{LCH}}{\left\lceil \frac{54}{BpS_{LCH}} \right\rceil} \right\rfloor \cdot \frac{48 \cdot 8}{2\,\text{ms}} \quad (1)$$

L_{LCH} is the number of OFDM symbols available in the MF for data PDUs (LCH-PDUs) and is the net MF capacity excluding the MAC protocol overhead needed for BCH, FCH, RCH, etc. BpS_{LCH} is the number of bytes to be transmitted per OFDM symbol. This value is determined by the PHY mode chosen (see Table 1).

Equation 1 shows that the net MAC throughput is mainly determined by the PHY mode selected. However, the net DLC throughput is also influenced by ARQ. To include the influence of ARQ into the calculation an ideal Selective Repeat Reject ARQ is assumed, that decreases the system throughput by $1 - PER_{PHYmode}$ [12], where $PER_{PFYmode}$ determines the current PDU error ratio experienced by the individual connection using a specific PHY mode.

$$Throughput_{DLC} = Throughput_{MAC} * (1 - PER_{PHYmode}) \quad (2)$$

Figure 4 shows the influence of link adaptation and ARQ on the total system throughput at the DCL layer. The $PER_{PHYmode}$ values from Figure 3 have been considered. The influence of the H/2 MAC on the system throughput can be derived from Figure 4. Considering a high C/I value ($> 30dB$) the PER can be neglected (see Figure 3) and ARQ has almost no impact. For example, in case the PHY mode 16QAM¾ (36 Mbit/s PHY rate) is used for the LCH PDU the system throughput is 28 Mbit/s. With decreasing C/I, i.e., increasing PER, the ARQ re-transmission overhead increases, so that the total system throughput will be reduced. From a system throughput perspective link adaptation should switch the PHY mode at $C/I = 16\,\text{dB}$ to 16QAM9/16. At this point a high PER is reached with 16QAM¾ (about 25%, see Figure 3) and, owing to ARQ re-transmissions, a high transmission delay will be experienced by the respective traffic flow.

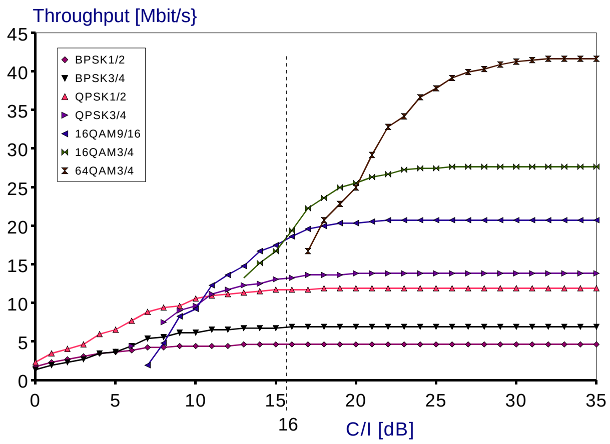

Fig. 4: System Throughput, MAC Signaling and ARQ Retransmission Regarded

In computer simulations of the H/2 DLC the influence of ARQ re-transmissions on the transmission delay have been analyzed. In the example presented here the specific C/I value 16 dB has been chosen. Figures 5 and 6 show the resulting uplink and downlink transmission delay, respectively, for various PHY modes. Poisson sources have been chosen with a traffic load below maximum system capacity so that packet losses owing to buffer overload are avoided. Considering these results the transmission delay on DLC level is mainly determined by the PHY mode selected. Using BPSK½ almost no re-transmission occurs owing to the low PER. However, a large amount of system resources is bound for data using this PHY mode, so that the total system throughput is reduced. Using 16QAM¾ will optimize system throughput, but the connections will experience a rather

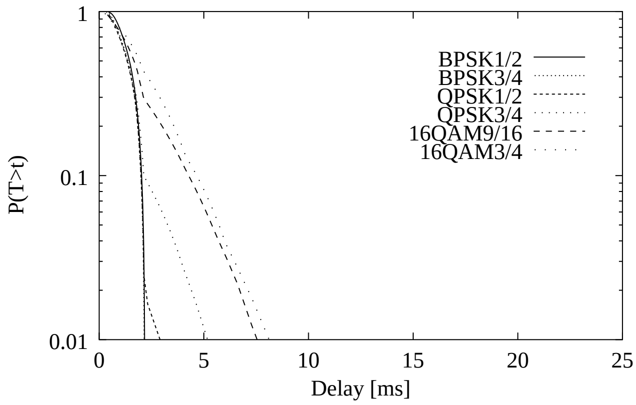

Fig. 5: Complementary Distribution Function (CDF) of Transmission Delay, Downlink, $C/I = 16\,\text{dB}$

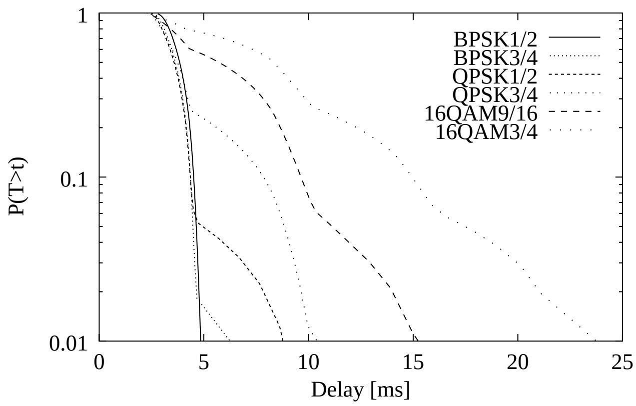

Fig. 6: CDF of Transmission Delay, Uplink, $C/I = 16\,\text{dB}$

high transmission delay. This high delay may be tolerable for best effort traffic, but not for real time traffic.

4 Serving IP QoS Models in BRAIN DLC

Serving various IP QoS traffics in parallel requires to find an appropriate PHY mode by link adaptation for each connection fulfilling the delay and loss requirements while keeping the allocated resources for the individual connection low. DLC scheduling has to prioritize the individual connections and has to allocate system resources considering the individual demands of the traffic source as well as additional resource requirements resulting from ARQ re-transmissions.

4.1 Scheduling IP QoS Models

The DLC scheduling algorithm considered here takes the three IP QoS models into account (see Figure 7): *Best Effort*, *Differentiated* and *Integrated Services*. To accommodate the various QoS requirements a two-staged scheduling strategy is chosen. In the first stage *Priority Scheduling* is performed for Best Effort and Differentiated Services classes with higher priorities for the Differentiated Services

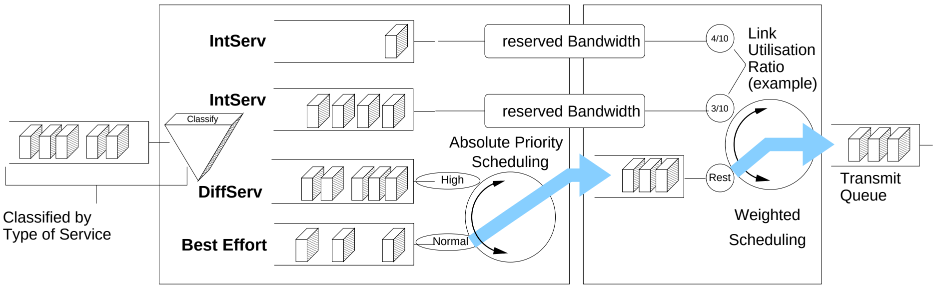

Fig. 7: Concept of IP QoS Model Scheduling

classes. In the second stage *Weighted Scheduling* is carried out where specific amounts of capacity are allocated for the Integrated Services traffic flows. The remaining capacity is used by the traffic resulting from the first stage. Call admission control takes care that sufficient resources are available for Differentiated Services traffic.

4.2 Performance of QoS Scheduling and Link Adaptation

In computer simulations the performance of this scheduling strategy has been analyzed. According to the IP QoS models three different traffic generators have been used ranging from low to high QoS requirements:

Best Effort LAN traffic has been modeled by using a trace file of Ethernet traffic [13]. The mean inter arrival time of packets has been varied in the simulation to create various traffic load conditions.

Video A video traffic source has been derived from a trace file based on the coding of the "Star Wars" movie according to MPEG-1 standard [14]. This video source provides variable bit rate by producing IP packets of variable lengths in constant intervals.

Voice A N-ISDN voice source with a constant bit rate of 64 kbit/s has been modeled by generating a packet of 48 byte every 6 ms.

Segmentation and re-assembly is performed to cut long packets into the fixed length H/2 PDUs.
Different scheduling priorities have been assigned to the traffic sources according to Figure 7. Thereby, highest priority was given to N-ISDN traffic serving a constant bit rate, whereas LAN traffic was served with lowest priority.
Figure 8 shows the reference scenario studied by simulation. It consists of an AP serving a video stream (MPEG) and a duplex voice connection (N-ISDN). The two MTs exchange Ethernet packets with the core network.
It is considered that the MTs are located at certain locations in the radio cell where they experience specific C/I values. In the following examples $C/I = 16$ dB is assumed.
Figure 9 shows the influence of the PHY mode, and hence the PER, on N-ISDN and MPEG packet delay. With BPSK½ almost no PDU errors occur, so that no re-transmissions have to be performed. Using QPSK¾ the

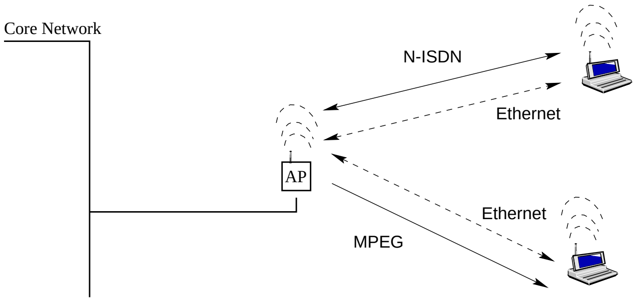

Fig. 8: Simulation Scenario

PER increases, so that 2% of the N-ISDN packets require at least one re-transmission. The higher transmission delay of MPEG packets results from the re-sequencing of DLC PDUs in the receiver. Owing to their short size, N-ISDN packets are transmitted within one MAC frame, whereas large MPEG packets are segmented and may require transmission over several MAC frames.
From these results rules for dynamic link adaptation are derived allowing to maintain the QoS of a connection for changing radio conditions.

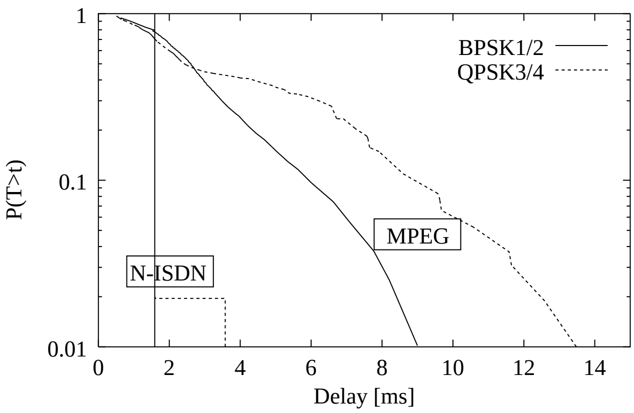

Fig. 9: CDF of the Packet Delay (N-ISDN and MPEG)

For best effort connections (Ethernet) the DLC serving strategy is different, as the PHY mode with the highest throughput shall be chosen in order to increase system capacity. Considering Figure 4, 16QAM¾ is best suited for a C/I value of 16 dB. Figure 10 shows a rather high transmission delay for 16QAM¾. 1% of the packets experience a transmission delay above 36 ms. This may be acceptable for non-delay-sensitive connections. Nevertheless, a more robust PHY mode will be chosen, when there are sufficient resources for best effort traffic available.

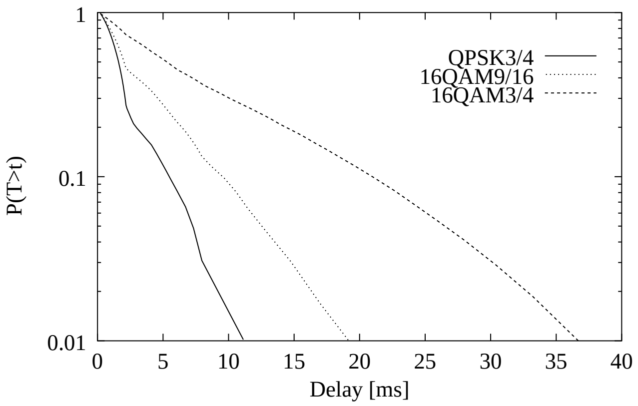

Fig. 10: CDF of the Packet Delay (Ethernet)

5 Conclusions

The H/2 standard in its current version does not consider IP QoS. However, its connection oriented nature helps to define enhancements to serve IP connections according their individual QoS requirements. It has been shown that DLC functions as link adaptation and ARQ allow to adapt the H/2 transmission performance to a connection's delay requirements for given radio conditions. Selecting a suitable modulation scheme and coding rate is a trade-off between delay minimization and throughput optimization. We presented a strategy for IP QoS scheduling in the DLC layer by weighting the traffic and QoS parameters such as throughput, delay and loss against each other to serve IP connections according to their QoS requirements.

6 Acknowledgements

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8 Biographies

ARNDT KADELKA received his Diploma in Electrical Engineering in 1993 from University of Dortmund. From 1993 to 1996 he worked at Alcatel, Stuttgart/Germany, in the Product Management department of the Mobile Communication Devision. During this time he worked on the aspects of for Radio Resource Management in GSM. In 1996 he joined the Chair for Communication Networks at Aachen University of Technology, where he is working towards his Ph.D. degree. He participated in ETSI/BRAN, where he was involved in the standardization of the Radio Link Control protocol of HiperLAN/2. Areas of research interest are protocols to support wireless broadband packet networks. Currently his focus lies on the extension of HiperLAN/2 to support interconnection with IP considering mobility and Quality of Service aspects.

ARNO MASELLA received his Diploma in Electrical Engineering in 1999 from Aachen University of Technology. During his thesis he worked at the Chair of Communication Networks. His focus was on the ARQ protocol of HiperLAN/2, which he extended for serving IP. Currently he works at Ericsson Eurolab Germany in the Department for GPRS Verification and Maintenance.