BRAIN Enhancements for the HIPERLAN/2 Air Interface to support QoS in Wireless Communications

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Abstract: *This paper presents the approaches considered in the framework of the IST project BRAIN (Broadband Radio Access for IP based Networks) to enhance the HIPERLAN/2 based air interface, aiming to fulfil the requirements of Quality of Service (QoS) and bandwidth efficiency in wireless communications.*

1 Introduction

Recently the possibility of wireless broadband multimedia data transfer has been enabled with the development of several W-LAN technologies, such as HIPERLAN/2 and IEEE802.11a. However, previous technologies deal only with the lower layers of a complete wireless system and leave unspecified the means for delivering end-to-end services over existing heterogeneous networks. Given that parts of the overall system tend to be independently specified, the provision of high quality mobile services meeting the user demand is nowadays still an open problem.
In the framework of the IST programme the Broadband Radio Access for IP-based Networks (BRAIN) project follows a top-down approach starting from services and user requirements and from today's most flexible technologies, e.g. IP at the network layer and HIPERLAN/2 (H/2) [1],[2] at the radio layers. Consequently BRAIN aims to support and to integrate the user demands, such as mobility and end-to-end QoS at application level. Therefore, enhancements on all OSI layers of the communication system are needed. In more detail, concepts for enhancing the air interface are addressed within this paper, whose scope is the radio link, including Physical Layer (PHY), Medium Access Control (MAC) and Data Link Control (DLC) and IP Convergence Layer (IP-CL).

2 BRAIN requirements, usage scenarios and channel models

First, a brief summary of the overall BRAIN requirements on usage scenarios, key-services, environments and mobility aspects are presented, underlining the worthiness to state Quality of Service (QoS) criteria and the impact on the definition of the new BRAIN air interface is discussed. Within BRAIN three typical usage scenarios are considered, which result from the coincidence of different parameters such as the most popular key-services and the particular environment e.g. the deployment scenario. Moreover, the usage scenarios are classified by generic QoS requirements, the required mobility, the type of handover and an indicative value on how many users are sharing the same bandwidth. The main characteristics of these usage scenarios are defined as follows:

- **Indoor:** The BRAIN user is stationary but wireless using conventional office equipment and he expects fixed network QoS. The environment is typically an office or a home environment where transmitter and receiver are spatially separated from 1 m up to 30 m.

- **Nomadic:** The BRAIN user works with a portable PC at different locations like meeting rooms, dining facilities or waiting halls and is stationary while working. Usually, the PC is switched off while changing the location. However, file transfer or some other services that don't need user interaction may be performed also, while the user is moving. Typically the spatial transmitter-receiver separation can range up to 30 m, whereas 5 km/h is the maximum pedestrian speed to be supported by a moving terminal.
- **Portable:** The BRAIN user is moving and has (simultaneously) access to internet and multimedia services via a PDA. Due to low resolution of those terminals QoS requirements are quite modest. Consequently, the corresponding environment is a large open space area. Ranges up to 300 m and mobile speeds up to 30 km/h are required to be supported.

As the H/2 based BRAIN air interface is not intended for a full coverage cellular network but in geographically limited areas (hot spots, indoor, etc.), handover to other systems like UMTS is needed to serve this coverage. Hence, in terms of coverage, mobility and in terms of the supported services BRAIN complements 2nd and 3rd generation mobile systems.

The physical layer requirements of the BRAIN air interface concern the user environment, the portable computing and multimedia devices applicable to mobile communication (up to 30km/h), the system configuration (cellular systems with access points connected to a wired IP core network including the facility, that the multiple access points may share the same RF carrier) and are based on H/2. Due to the envisaged enhancements for the H/2 physical layer, BRAIN enables net data rates higher than 20 Mbit/s on top of the PHY with a defined level of QoS. Based on system environment and configuration, suitable channel models in the 5GHz range (which is the H/2 frequency range) have to be adopted, in order to enable a coherent design and evaluation of the enhancements introduced into the air interface. The evaluation of the performance is done by simulations on link level and system level, which require different types of channel models. For link level simulations, it is reasonable to describe the channel characteristics by multipath fading models. Within BRAIN the five discrete multipath channel models designed by ETSI BRAN for H/2 are used. Furthermore, an additional multipath is derived, which takes into account also small delay spreads and thus represents small office and home environments. In Figure 1 the discrete and the continuous model for the small office scenario is given. The delay spread of the power density profile (PDP) is around 13 ns in contrast to 50 ns of the ETSI BRAN model A (the H/2 model with the lowest delay spread).

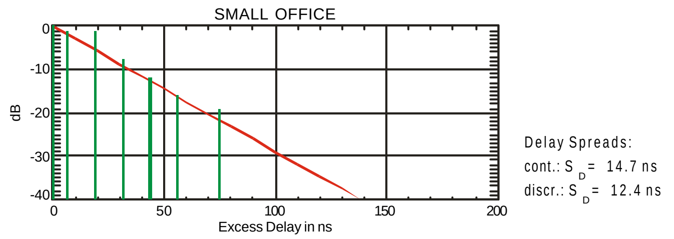

Figure 1: BRAIN channel model for the small office environment

In addition to the link level investigations, where a single link on the physical layer will be considered, system level simulations will be carried out to investigate the impact of typical scenarios including numerous users and access points by considering the path loss and interference situation. Within BRAIN a simple one slope model is chosen for the large open space environment, whereas a multi-wall model with a non-linear behavior of the total wall attenuation is used for the office environment:

$$L_{Path} = L_{FS} + \sum_{i=1}^{I} k_{wi}^{\left[\frac{k_{wi}+1.5}{k_{wi}+1} - b_{wi}\right]} L_{wi} \;, \qquad \text{with } b_{wi} = -0.064 + 0.0705 L_{wi} - 0.0018 L_{wi}^2$$

where L_{FS} is the free space loss, k_{wi} is the number of penetration walls and L_{wi} is the attenuation due to the wall type.

For the application of smart antennas directional channel models are required. To allow a performance comparison between systems with a single antenna and systems using smart antennas, directional channel models are used, which are direct extensions of the multipath models mentioned above.

3 QoS in the air interface framework

The radio link is the most crucial hop within the IP-based network. Due to the limited radio resources and to the transmission over error-prone multipath fading channels other QoS strategies are necessary

than in wired networks where high bandwidth and nearly error-free transmission can be guaranteed. However, choosing the radio link QoS strategies close to those in wired networks (such as the IntServ and DiffServ concepts [3,4]) it is expected to have a beneficial effect on the transparency of QoS-based connections. A wanted peer-to-peer QoS on application level can only be guaranteed if also the lower layers are able to provide the required QoS. Thus, beyond the peer-to-peer management an inter layer QoS negotiation, which means a mapping from IP QoS criteria on DLC QoS criteria, is needed.
The strict requirement of a granted or guaranteed type of QoS leads to the demand of a sufficient large bandwidth on the radio link as well as to the demand of a QoS based access to the radio channel, by means of an optimized DLC layer design [4,5]. Enhancements consisting in the deployment of turbo and space-time codes, link adaptation, adaptive modulation, smart antenna and diversity techniques, are then proposed to increase bandwidth efficiency. Within the context of this paper the description of turbo-coding schemes, of adaptive modulation techniques and of the QoS concepts on the radio link are portrayed as techniques likely to improve the overall system performance. Moreover, related results are discussed. As for other techniques aiming at the same goal, their description and impact on the system performances is object of [5],[6].

4 Enhancements at the Physical Layer

Turbo Coding

The Forward Error Correction code specified in the H/2 standard is a classical convolutional code of rate 1/2, constraint length 7. Turbo-codes are a more recent coding scheme introduced by Berrou et. al. in 1993 [7]. The very good performance of turbo-codes raised a large interest in the coding community and they were included in several standards (such as UMTS [8] and DVB-RCS [9]) in the last years in order to provide the protection required for high QoS.
Turbo-codes are worth being studied as an alternative to the convolutional codes because they require a lower Signal-to-Noise Ratio (SNR) to reach a given Packet Error Rate (PER) than a convolutional code. This higher coding gain enables to use a more efficient transmission mode (combination of coding rate and modulation scheme) more often and therefore to improve the system throughput. Alternatively, turbo-codes enable to significantly lower the PER at the top of the physical layer and therefore to use Automatic Repeat reQuest (ARQ) algorithms less often, which improves the overall system efficiency as well.
The turbo-code used in the current section consists of two elementary Recursive Systematic Convolutional (RSC) encoders of rate R=1/2 and constraint length 4, defined by the octal code generators (1, 15/13), concatenated in parallel and separated by an interleaver. Since the mother rate of this turbo-code is R=1/3, a puncturing mechanism is used to reach code rates R=1/2 and higher. Initially designed to deal with continuous stream of data, turbo-codes can be adapted to block transmission by adding tail bits to close the trellis. For the turbo-code studied in the current section, 12 additional tail bits are transmitted together with the N=K/R coded bits associated to a block of K useful bits. This turbo-code can be adapted to various information block sizes by adapting only its internal interleaver pattern. The Soft-Input-Soft-Output (SISO) algorithm used in the iterative decoding process is the Max-Log-MAP suboptimal version of the MAP algorithm [10]. The following curves result from the simulation of the transmission of Long transport CHannel (LCH) packets (consisting of 54-bytes) with the ETSI BRAN channel model A. The mapping on OFDM symbols is made as defined in H/2 standard (48 data sub-carriers, 4 pilot sub-carriers, 64-point FFT, guard-interval of 800ns). On each OFDM sub-carrier, the used signal modulation is QPSK and the coding rate is R=1/2. The channel estimation is assumed to be ideal. The convolutional code specified in H/2 and the turbo-code decoded in six iterations are compared. If the gain provided by the use of turbo-codes is small in terms of Bit Error Rate (BER), the gain in terms of PER is of 1.5 dB for PER=1%. This gain justifies to continue

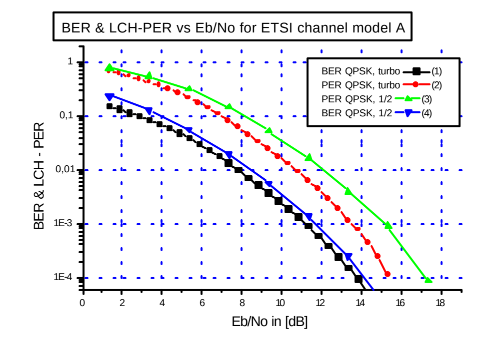

Figure 2: Turbo-code performance

studying turbo-codes for OFDM packet transmission. It is expected, that the performance gain increases with the frequency selectivity of the channel and with higher modulation schemes such as 16QAM and 64QAM, which need to be studied in more detail.

Adaptive Modulation

In the H/2 system different modulation schemes can be chosen for link adaptation purposes. However, the H/2 modulation scheme is identical for all sub-carriers. In an OFDM system, it is possible to perform a sub-carrier specific allocation of the bits to the different sub-carriers, thus switching the modulation scheme individually for each sub-carrier. This principle is referred to as *adaptive modulation*.

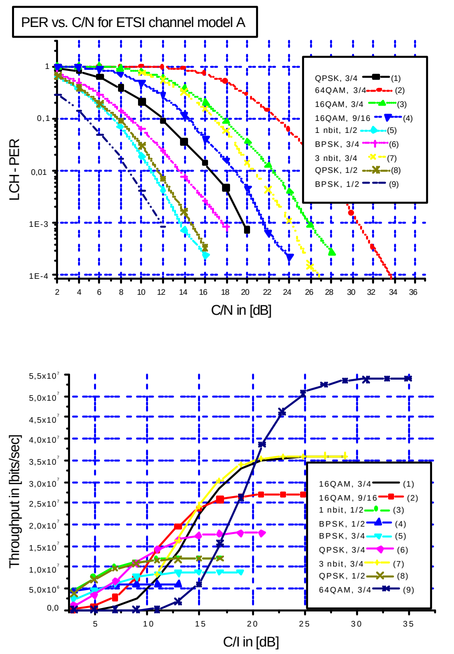

Figure 3: LCH-PER performance and throughput for ETSI channel A

The allocation of bits (and additionally of the transmit power) is performed by so-called loading algorithms. The principle consists of allocating many bits to sub-carriers with a high signal-to-noise ratio, whereas on sub-carriers with low SNR, only few bits (or no bits at all) are transmitted. In this way, compared to fixed modulation, the PER can be significantly reduced in the uncoded case. From literature, a number of different algorithms is known, such as the Hughes-Hartogs algorithm [13], the algorithm of Chow, Cioffi and Bingham [11], and the algorithm of Fischer/Huber [12]. They mainly differ in their optimization criteria and also in their computational complexity.

In H/2, as in most other wireless systems, channel coding is applied. Consequently, an interesting aspect is to compare the performance of a H/2 system with fixed and adaptive modulation *in the coded case*.

When applying adaptive modulation in the coded case, the question arises which combination of code rate R and average modulation level m, leading to a given bandwidth efficiency $E = m \cdot R$, shows the lowest PER. In Figure 3 the examples of $E = 1$ and $E = 3$ net bit per sub-carrier are considered. Compared to the uncoded transmission, the average modulation level is raised, where it turns out, that the tuples $(m, R) \in \{[2, 1/2], [4, 3/4]\}$ offer the best results for $E = 1$ and for $E = 3$, respectively. It is worth noting that unlike in a fixed modulation, also non-integer values can be chosen. Here, the algorithm according to Chow et al. has been implemented. The transmit power has been scaled in this example, but has not been adjusted individually per sub-carrier. The simulation results for ETSI channel model A are plotted in Figure 3. Comparing curves of identical bandwidth efficiency, it can be observed that the additional gain amounts to about 1 dB for $E = 1$ and 2dB for the $E = 3$ at a PER of 10^{-3} in comparison to the fixed modulation scheme, which is equivalent to an increase of the system throughput of 1 Mbps and 2 Mbps respectively.

5 Concepts for the DLC Layer Enhancements

In the following the DLC layer concepts envisaged for further investigation within BRAIN will be presented. In addition to the improvements of bandwidth efficiency on the PHY layer, a revision of the structure of the H/2 DLC layer is also required, targeting to improve network capacity and to establish QoS-based radio links.

QoS-based DLC scheduling strategies

In BRAIN services are intended which go beyond the basic best-effort service of the current Internet. The internet engineering task force (IETF) is currently exploring several different approaches that should provide these advanced services. Two of them are Integrated Services (IntServ) and Differentiated Services (DiffServ) [3, 4]. Figure 4 shows the principles of these strategies. However

QoS support for wired internet is different to wireless network extension. In wireless networks packet loss can also be caused by an error-prone radio link while in the fixed network congestion and overflow in the routers mostly lead to packet loss. Moreover, delay of IP packets is introduced due to ARQ of DLC packets on the air interface. The end-to-end IP QoS is based on the network layer and has to be tunneled through the wireless hop. DLC and CL architectures including protocols are needed to map the IP QoS to DLC QoS classes.

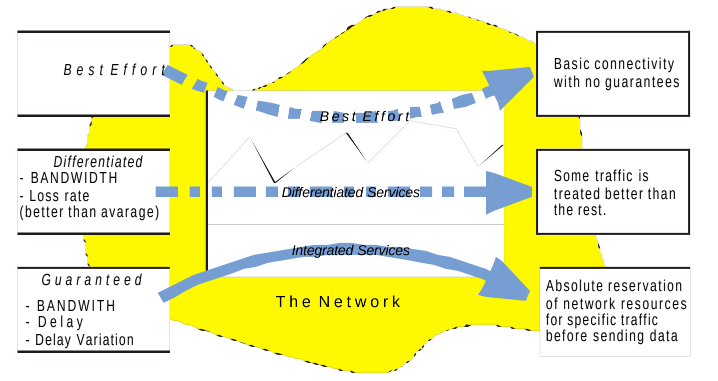

Figure 4: Different QoS strategies provided in the internet

Serving IP QoS requires to prioritize and to guarantee specific DLC services for the various IP connections or groups. The respective IP QoS parameters have to be mapped onto DLC specific QoS parameters, describing:

- bandwidth requirements of single services or groups of services (e.g. peak cell rate, mean cell rate, burstiness) and
- QoS requirements (e.g. delay, delay variance, packet loss ratio).

Mapping of IP QoS is basically performed in the Service Specific Convergence Sublayer (SSCS) but needs to be extended also to DLC scheduling. Different algorithms will be investigated which should maintain the end-to-end IP QoS over the radio hop [6] by using the scheduling approach depicted in Figure 5. These approaches are based on different functions of H/2, that have to be taken into account and are mutually dependent:

- PER: Packet Error Ratio at the radio interface
- ARQ: ARQ helps to avoid transmission errors by retransmission. However, in case of a poor radio link the transmission delay increases. Furthermore, because of re-transmission the net throughput of user data will be reduced.
- Link adaptation: In case of a poor link quality the PHY mode can be adapted to a more robust one. However, DLC protocol data units coded with more robust PHY modes require more capacity in the MAC frame.

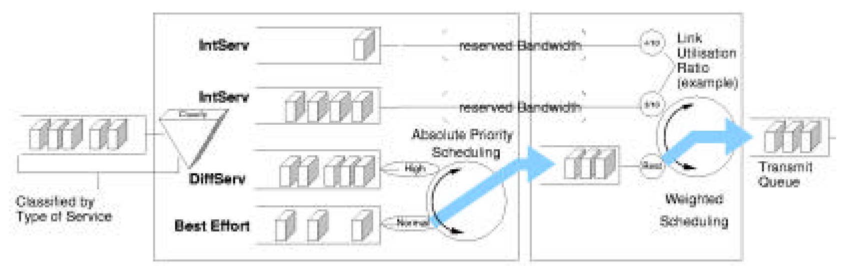

Figure 5: DLC scheduling strategy to provide end-to-end IP QoS over the radio link

Enhanced DLC scheduling concepts of H/2 envisage to integrate a priority mechanism for queuing and a medium access control entity which enables a discrimination of packets according their QoS class. In order to hold the QoS once guaranteed a QoS management scheme is needed especially in the DLC layer of the radio link.

Dynamic Frequency Selection, Dynamic Channel Allocation and Connection Admission Control algorithms

In addition to DLC layer scheduling, including Radio Link Control (RLC) functions, link adaptation and ARQ techniques, also the available network capacity has an essential impact on the QoS. As network capacity highly depends on the interference situation it is worth to minimize interference by means of radio network function, located in the radio resource control (RRC) part of the DLC layer. Promising functions aiming at interference reduction on a system level are Dynamic Frequency Selection (DFS), Dynamic Channel Allocation (DCA) and Connection Admission Control (CAC). DLC scheduling algorithms, link adaptation and ARQ are targeting on the optimization of radio channels allocation to users on a per MAC frame basis (single cell oriented), DFS, DCA and CAC algorithms are targeting on the reduction of inter-cell interference (multi-cell environment oriented).

Consequently, to meet the QoS requirements a combination of both optimized scheduling (RLC functions) and interference reduction methods (RRC functions) are required.

6 Conclusions

A thorough overview of the BRAIN air interface has been presented, strengths and limitations of the existing H/2 air interface have been discussed and enhancements have been accordingly introduced, in order to ensure a well defined QoS at the wireless link. Preliminary results have been presented, related to the application of turbo-coding and adaptive modulation, and QoS criteria at the DLC level have been carefully analyzed. More detailed results in the scope of the (enhanced) BRAIN air interface will be shown in [5],[6]. In the framework of the IST BRAIN project, different academic and industrial teams are involved in contributing to the BRAIN Air Interface work group (WP3). Their results will allow a further development of H/2 technologies and will give a significant contribution to standardization.

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