First Performance Results of BRAIN

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Abstract: In this paper several different performance studies are presented dealing with the investigation of the H/2 air interface which was taken as the basis for BRAIN and its possible enhancements on the network and scheduling functions of the DLC as well as on the physical layer in order to increase the spectral efficiency.

1 Introduction

The project Broadband Radio Access for IP based networks (BRAIN) started in January 2000. One goal of BRAIN is the development of an open architecture for an IP-capable broadband radio access as completion to second and third generation radio systems. Another goal is the seamless access to IP-based applications which facilitates new business opportunities for operators, service providers and content providers to offer high-speed service complementary to existing services.

ETSI has standardized the broadband radio access system High Performance Radio Local Area Network type 2 (H/2) which provides a very efficient air interface supporting data rates up to 54 Mbps and the facilities to cope with Quality of Service (QoS) requirements. Therefore it was decided to take H/2 as a basis for BRAIN.

BRAIN will extend on one side the H/2 air interface to hand through the high data services and QoS from wired IP network to mobile users. Thus, a mapping of currently upcoming QoS approaches like IntServ and DiffServ onto DLC specific QoS parameters is needed. On the other side, BRAIN will propose further enhancements to H/2 concerning both physical and data link control (DLC) layer to increase the spectral efficiency in order to provide high data rate coverage in hot spot areas. A more detailed description of the proposals for the BRAIN air interface can be found in [2].

In this paper several different performance studies are presented dealing with the investigation and possible enhancements of the H/2 air interface on the DLC as well as on the physical layer.

2 Performance on system level

The Medium Access Control (MAC) scheme [7] of H/2 applies a centralized controlled concept, where the Access Point (AP) assigns the radio resources for up- and downlink phase. In H/2 a dynamic TDMA/TDD scheme is used. The capacity assignments are grouped to MAC-frames with a fixed length of 2ms. The MAC-frame consists of different phases shown in Fig. 2-1. The length of each phase can be adapted to the current requirements.

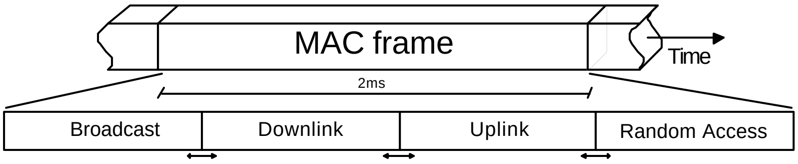

Fig. 2-1: H/2 MAC frame

In H/2 Dynamic Frequency Selection is used to assign a complete frequency carrier to an AP. To adapt to the current interference condition different modulation/coding schemes (PHY modes) are available which provide data rates from 6 Mbps to 54 Mbps. Since the interference increases at the boarder for the radio cell, the selected data rate decreases with the distance between AP and mobile terminal (MT).

An exhibition hall scenario (large building with one floor and no inner walls) with 16 APs placed in a rectangular grid was evaluated. The size of the exhibition hall is 240qm with site-to-site distance of 60m. Fig. 2-2 shows the probability for selection of a PHY mode depending on distance between AP and MT. In the left figure 8 frequencies were available while in the right only 4 frequencies were available. In both cases the frequency carriers were fully loaded (maximum load). The shift towards lower modulation schemes caused by higher interference level can be seen clearly.

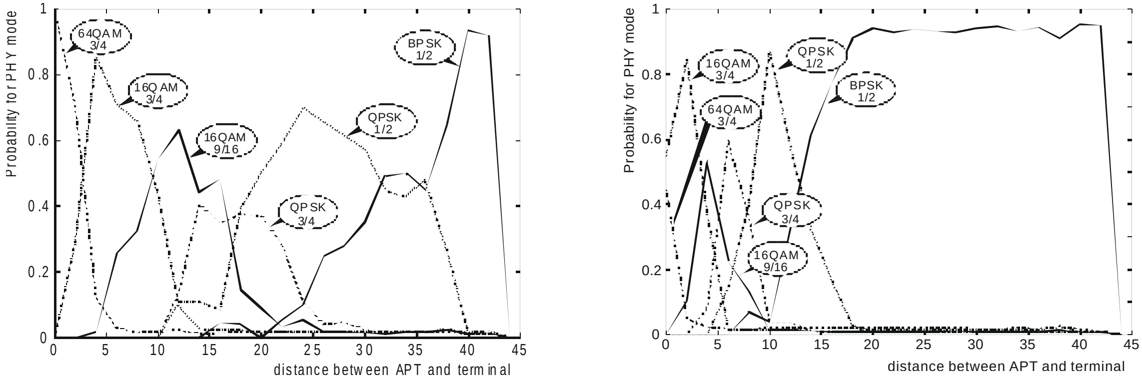

Fig. 2-2: Probability for PHY mode selection in case of 8 (left) and 4 (right) frequency carriers (downlink)

To increase the system capacity, the AP should be able to allocate capacity according to the traffic density in the cell and to share the capacity of one carrier with several APs. This allows the AP to use higher modulation schemes and to reduce the transmission activity. Using a TDMA approach the H/2 MAC-frame (2ms) can be divided into orthogonal channels with reduced bandwidth which can be allocated by the APs according to the capacity requests of its MTs. Once an AP has assigned such a channel it tries to keep it as long as possible so that other APs are able to recognize the availability of these channels. In areas with low traffic less channels are used to shift the capacity to areas with high traffic load. This approach also reduces the number of carriers which can be used to build up a BRAIN system.

In case of low load the MAC-frame is not completely used and can be mapped onto the TDM channels. The distance between two consecutive broadcast phase remains unchanged (2ms) which is an important aspect for the physical layer. The remaining TDMA channels can be used by other APs shown in Fig. 2-3.

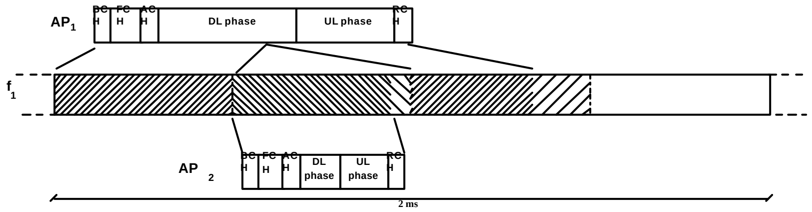

Fig. 2-3: Multiplexing of several APs on the same frequency band

This approach has been evaluated for the exhibition hall scenario using 4 frequency carriers divided into 4 TDMA channels each. This means that each AP can uses one fourth of a frequency carrier without an interfering AP. Comparing with original H/2 approach the maximum system load can be increased by 50%.

# frequencies	# TDMA channels per frequency	Maximum throughput per AP
4	1	6 Mbps
4	4	9 Mbps

3 Serving IP Quality of Service by BRAIN Data Link Control Layer

3.1 Requirements of IP QoS on a Wireless Access

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 by Automatic Repeat Request (ARQ) protocols in DLC impact the QoS and have to be taken into account.

3.2 Strategies for Serving IP QoS

Adaptive scheduling of IP connections requires to prioritize and to guarantee specific DLC services for the various IP connections or groups of connections. Beside this, the DLC scheduling algorithms have to take the various properties of the BRAIN radio access into account that are mutually dependent:

Link Adaptation: In case of a poor link quality the modulation and coding scheme (PHY mode) chosen for the transmission of DLC Protocol Data Units (PDU) can be adapted to a more robust one. However, PDUs coded with a more robust PHY mode require more capacity.

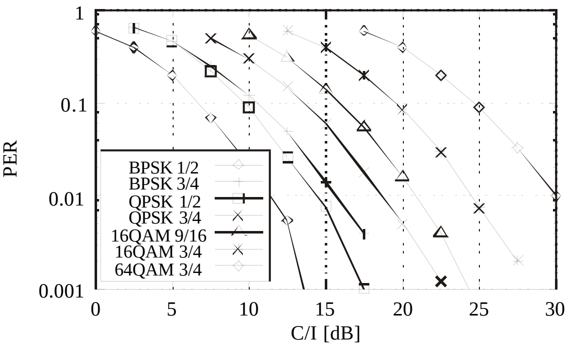

Fig. 3-1: PER vs. C/I

ARQ is used to react on transmission errors by re-transmission. However, in case of a poor radio link the transmission delay increases. Re-transmissions have to be considered as additional DLC signaling overhead, so that the net system capacity will be reduced. Fig. 3-1 shows results from literature [6] giving the PDU Error Rate (PER) versus the Carrier-to-Interference ratio (C/I) for an office environment.

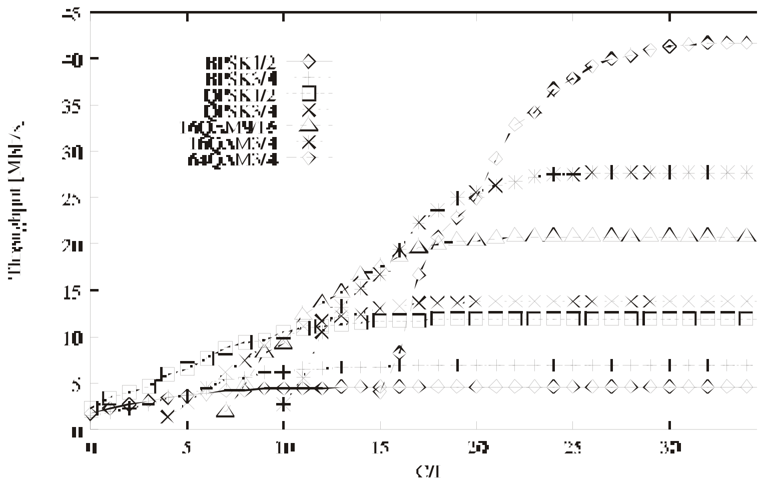

Fig. 3-2: System Throughput, MAC Signaling and ARQ Re-transmission considered

Fig. 3-2 shows the influence of link adaptation and ARQ on the total system throughput at the DLC layer. The curves result from calculation of the H/2 MAC performance [5], whereby the overhead introduced by an ideal ARQ owing to re-transmission has been included and the PER values from Fig. 3-1 have been considered. The influence of the MAC on the system throughput can be derived from Fig. 3-2. Considering a high C/I value (> 30dB) the PER is very low and ARQ has almost no impact. For example, in case the PHY mode 16QAM3/4 is used for the data PDUs the system throughput is 28 Mbps. With decreasing C/I 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

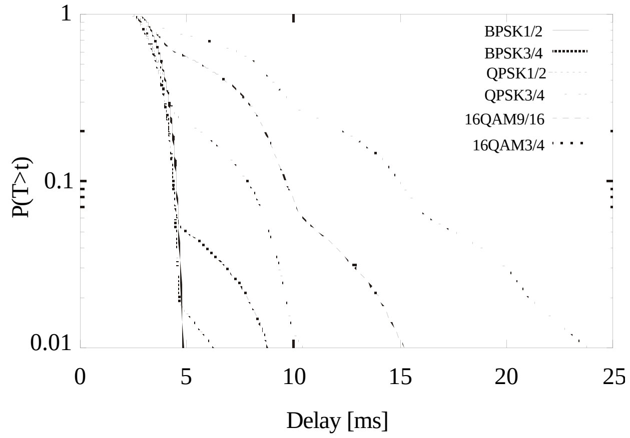

Fig. 3-3: Complementary Distribution Function of Transmission Delay

C/I = 16dB to 16QAM9/16. At this point a high PER has to be served with 16QAM3/4 (about 20%, see Fig. 3-1) and, owing to ARQ re-transmissions, a high transmission delay will be experienced by the respective traffic flow.

In initial computer simulations of the DLC protocols the influence of ARQ re-transmissions on the transmission delay at the radio interface has been analyzed. In the example presented here the specific C/I value 16 dB has been chosen. Fig. 3-3 show the resulting uplink transmission delay 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. When using BPSK1/2 almost no re-transmissions occur owing to the low PER. However, a large amount of system resources is bound, so that the total system throughput is reduced. Using 16QAM3/4 will optimize system throughput, but the connections will experience a rather high transmission delay. This high delay may be tolerable for best effort traffic, but not for real time traffic.

Further investigations in the BRAIN project will investigate strategies to select the appropriate PHY mode by link adaptation for each connection fulfilling the delay and loss requirements while keeping the allocated resources for the individual connections low.

4 Performance on the physical layer

In the framework of BRAIN several physical layer enhancements will be studied. In the following two examples will be presented. Other proposals for enhancements of the physical layer can be found in [2].

4.1 Space-time coding

A very simple and attractive space-time block coding (STC) scheme was proposed by Alamouti [1]. It achieves full diversity for two transmit antennas. This coding scheme may be easily combined with arbitrary outer coding schemes and requires only little additional complexity.

This coding scheme may be appropriate for the extension of H/2 and therefore for BRAIN because typical BRAIN scenarios are used to be slow-fading environments. In addition to that BRAIN, one user scenario are small office environments where the expected delay spread is rather low. This means that there is both low time and low frequency diversity available.

STC provide means to overcome low time and low frequency diversity by providing space diversity, namely at the transmitter. Therefore the performance of H/2 will be increased by STC in the case where only low other diversity is present.

In Fig. 4-1 the parts concerning space-time coding of an OFDM system are depicted.

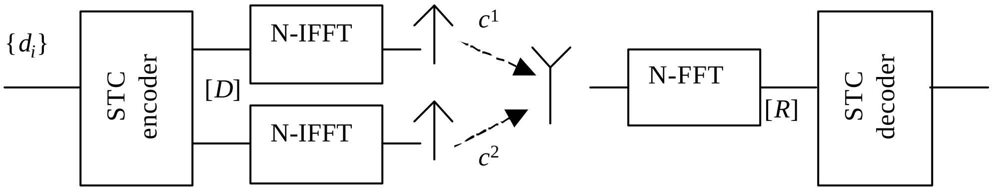

Fig. 4-1: Parts of an OFDM system including space-time coding

The serial complex symbols d_i are space-time encoded by the following rule:

$$D = \begin{bmatrix} d_i & d_{i+N} \\ -d^*_{i+N} & d^*_i \end{bmatrix} \quad \text{with} \quad i \in \{1,2,..N\}.$$

This means that two OFDM symbols are used to generate one STC code word. The date rate is not changed by this STC scheme because the duration of one STC code word is equal to the duration of two OFDM symbols. At the receiver the signal

$$R = \begin{bmatrix} r_i \\ r^*_{i+N} \end{bmatrix} = \begin{bmatrix} c^1 & c^2 \\ c^{2*} & -c^{1*} \end{bmatrix} \begin{bmatrix} d_i \\ d_{i+N} \end{bmatrix} + \begin{bmatrix} n_i \\ n^*_{i+N} \end{bmatrix}$$

is decoded to obtain the estimations $\hat{d}_i$ for the complex symbols d_i by the following rule:

$$\begin{bmatrix} \hat{d}_i \\ \hat{d}_{i+N} \end{bmatrix} = \frac{1}{\left|c^1\right|^2 + \left|c^2\right|^2} \begin{bmatrix} c^{1*} & c^2 \\ c^{2*} & -c^1 \end{bmatrix} \begin{bmatrix} r_i \\ r^*_{i+N} \end{bmatrix}$$

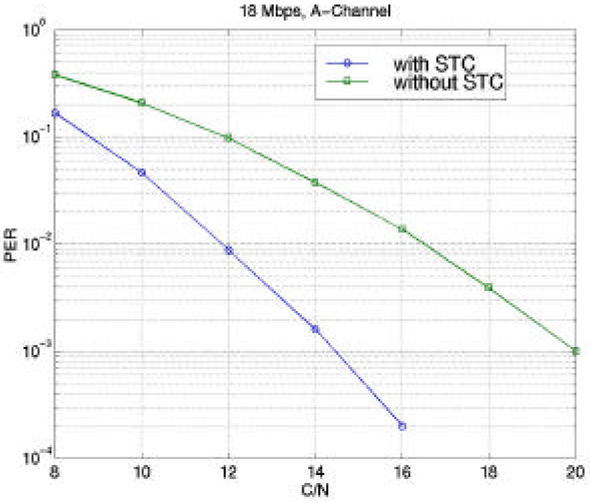

Fig. 4-2: PER versus C/N for the A-Channel (office environment) [8]

Hereby means c^i the channel coefficient of the channel between the i-th transmit and the receive antenna. For the investigation it was assumed that the transmit antennas are sufficiently far apart to provide uncorrelated channel conditions. At the receiver ideal channel estimation was assumed. In order to have the same total transmit power, the transmit power per antenna was halved in the case of using STC.

Fig. 4-2 shows the high performance gain in terms of PER versus carrier-to-noise ratio (C/N) for H/2 obtained by additional STC using two antennas at the transmitter and one at the receiver. This is the very attractive case where only the AP uses two antennas. To improve the uplink well known receive diversity techniques can be applied using both antennas at the AP.

4.2 Adaptive Antennas

The utilization of adaptive antennas is considered to be one of the most important methods to increase capacity in mobile radio systems and is presently studied worldwide [3]. Adaptive antenna techniques are capable of decreasing the required transmission power and combating interference.

In the current section a basic adaptive receiver antenna concept which consists of the combination of multiple omnidirectional receiver antennas and an adaptive signal processing algorithm is applied to the H/2 air interface. The multiple antennas are arranged in a macro structure, i.e. the antennas are so far apart that at each of the antenna locations different wave fronts impinge. Macro antenna structures enable the reception of additional signal paths and, therefore, provide spatial macro diversity [4]. The multiple received signals are processed by the Zero Forcing (ZF) algorithm.

The performance of the adaptive antenna concept is evaluated on the link level in terms of PER vs. Signal-to-Noise-Ratio (SNR). The considered PDU type is the Long Channel (LCH) and the filters, the channel estimation, the frame- and frequency synchronization are assumed to be ideal. The H/2 channel model A was applied [8]. Furthermore, the channel impulse response is assumed to be time invariant within a burst. H/2 provides seven transmission modes. In this evaluation only the most robust mode (BPSK, code rate $R_\mathrm{c} = 1/2$, data rate $R_\mathrm{d} = 6\,\mathrm{Mbps}$) and the least robust mode (64 QAM, $R_\mathrm{c} = 3/4$, $R_\mathrm{d} = 54\,\mathrm{Mbps}$) are considered. The particular OFDM symbol to be transmitted contains the data vector $\underline{\mathbf{d}} = \left(\underline{d}_1, \underline{d}_2 \ldots \underline{d}_N\right)^\mathrm{T}$ that consists of N complex subcarrier modulation symbols. The K_a radio channels between the single transmitter antenna and the K_a receiver antennas are characterized by the frequency responses $\underline{\vec{\mathbf{h}}}^{(k_\mathrm{a})} = \left(\underline{\vec{h}}_1^{(k_\mathrm{a})}, \underline{\vec{h}}_2^{(k_\mathrm{a})} \ldots \underline{\vec{h}}_N^{(k_\mathrm{a})}\right)^\mathrm{T}$, $k_\mathrm{a} = 1 \ldots K_\mathrm{a}$. The interference vector and the received signal at the k_a-th antenna in the frequency domain are denoted by $\underline{\vec{\mathbf{n}}}^{(k_\mathrm{a})} = \left(\underline{\vec{n}}_1^{(k_\mathrm{a})}, \underline{\vec{n}}_2^{(k_\mathrm{a})} \ldots \underline{\vec{n}}_N^{(k_\mathrm{a})}\right)^\mathrm{T}$ and $\underline{\vec{\mathbf{e}}}^{(k_\mathrm{a})} = \left(\underline{\vec{e}}_1^{(k_\mathrm{a})}, \underline{\vec{e}}_2^{(k_\mathrm{a})} \ldots \underline{\vec{e}}_N^{(k_\mathrm{a})}\right)^\mathrm{T}$, respectively. With the SNR values $\tilde{a}_i^{(k_\mathrm{a})} = |\underline{\vec{h}}_i^{(k_\mathrm{a})}|^2 \big/ \mathrm{E}\{|\underline{\vec{n}}_i^{(k_\mathrm{a})}|^2\}$, $k_\mathrm{a} = 1 \ldots K_\mathrm{a}$, at the K_a receiver antennas the ZF detection of the particular OFDM symbol is performed by $\underline{\hat{\mathbf{d}}}_i = \sum_{k_\mathrm{a}=1}^{K_\mathrm{a}} \tilde{\mathrm{a}}_i^{(k_\mathrm{a})} \underline{\vec{h}}_i^{(k_\mathrm{a})^{-1}} \underline{\vec{e}}_i^{(k_\mathrm{a})} \Big/ \sum_{k_\mathrm{a}=1}^{K_\mathrm{a}} \tilde{\mathrm{a}}_i^{(k_\mathrm{a})}$, $i = 1 \ldots N$, yielding the estimated data vector $\underline{\hat{\mathbf{d}}} = \left(\underline{\hat{d}}_1, \underline{\hat{d}}_2 \ldots \underline{\hat{d}}_N\right)^\mathrm{T}$.

Fig. 4-3 shows the simulation results in terms of PER vs. SNR curves for the two considered modes in the case of one, two and four antennas. Utilizing a single receiver antenna the desired PER of 1% is achieved at 12.5 dB and 23 dB for the mode with $R_\mathrm{d} = 6\mathrm{Mbps}$ and $R_\mathrm{d} = 54\mathrm{Mbps}$, respectively. In the case of two antennas the desired PER of 1% is achieved at 6 dB and 16 dB for the modes with $R_\mathrm{d} = 6\mathrm{Mbps}$ and $R_\mathrm{d} = 54\mathrm{Mbps}$, i.e. the gain is 6.5 dB and 7 dB, respectively. With 4 antennas another 5 dB can be gained at $R_\mathrm{d} = 6\mathrm{Mbps}$ compared to the two antenna case and another 6dB at $R_\mathrm{d} = 54\mathrm{Mbps}$. The results clearly show the high potential of the considered adaptive antenna technique to improve the performance of H/2 significantly. However, the results shown in Fig. 4-3 represent the maximum achievable gain assuming ideal conditions, i.e. in a real system the gain is reduced by several factors like channel estimation errors and correlation between the antenna signals. However, due to the significant gain achieved under ideal conditions the author expects that the application of the evaluated adaptive antenna technique is very powerful also in a real system with respect to the improvement of the BRAIN system efficiency.

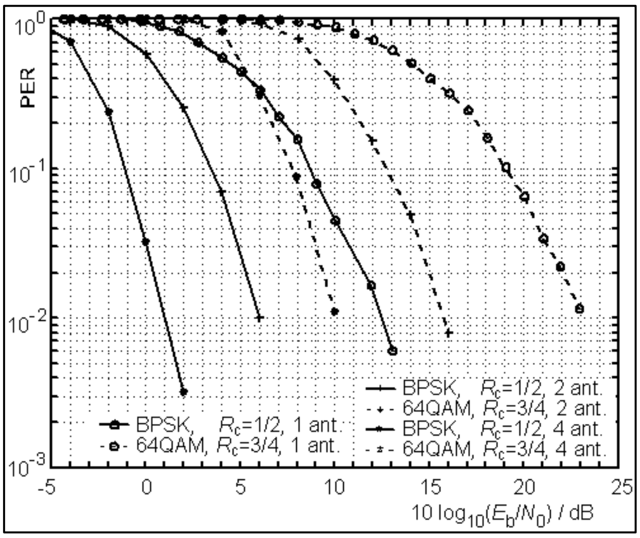

Fig. 4-3: PER vs. SNR in the case of $K_\mathrm{a} \in \{1,2,4\}$ for $R_\mathrm{d} = 6\mathrm{Mbps}$ and $R_\mathrm{d} = 54\mathrm{Mbps}$.

5 Acknowledgement

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