Adaptive Modulation for the HIPERLAN/2 Air Interface

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***Abstract*—In the IST project BRAIN (Broadband Radio Access for IP based Networks), different enhancements for the HIPERLAN/2 air interface are studied with the goal to guarantee a certain Quality of Service (QoS) and to increase the bandwidth efficiency of the considered broadband system. In this paper, aspects of *adaptive modulation* are analysed in detail and a new loading algorithm is introduced which shows a slightly better performance and lower computational complexity compared to the well-known technique described in [1]. Furthermore, the loading algorithm is used in combination with a *blockwise* allocation of modulation levels to the subcarriers. This approach can result in a smaller signalling overhead in comparison with a subcarrier-specific modulation.**

I. Introduction

In recent years, activities in research on high-speed wireless LAN systems have resulted in the standardization of new W-LAN technologies, such as HIPERLAN/2 (H/2) in Europe and IEEE 802.11a in the United States. In contrast to the 3G system UMTS, which supports high mobility and data rates up to 2 Mbit/s, the W-LAN systems provide much higher data rates (e.g. up to 54 Mbit/s) and are designed for stationary and portable usage, mainly in hot spot areas.

In the framework of the IST programme of the European Union the BRAIN project works on a broad-band extension to 2nd and 3rd generation mobile systems like UMTS and GSM especially aiming at supporting and integrating the user demands, such as user mobility and end-to-end QoS at application level [6] [7]. Starting from available technologies, the access network is fully based on IP wheras the air interface is based on the ETSI HIPERLAN/2 [5] standard.

Aiming at the support of a defined Quality of Service (QoS) over the wireless link, which is the most crucial part of an end-to-end connection across a heterogeneous network, adaptive modulation strategies are applied to the H/2 air interface in order to further improve bandwidth efficiency and to increase system performance. The physical layer of H/2 is based on the Orthogonal Frequency Division Multiplexing (OFDM) technique. Section II describes the principle of adaptive modulation for OFDM transmission. Furthermore, the basic idea of the introduced simple loading algorithm is presented.

In section III, the performance of the proposed algorithm is analysed and discussed in detail. As it will be shown, the new loading technique has a similar or slightly better performance than the algorithm in [1], while leading to a lower computational complexity. In addition, the option of a *blockwise* allocation of modulation schemes has the potential to decrease the signalling overhead.

II. Adaptive Modulation

A. Principle

In the H/2 system, the modulation level can be selected according to a link adaptation scheme. However, the modulation level is identical for all subcarriers in this case. In an OFDM system, it is possible to adjust the modulation level for each subcarrier individually. This method is normally referred to as *adaptive modulation*. The principle consists of allocating many bits to subcarriers with a high signal-to-noise ratio (SNR), whereas on subcarriers with low SNR only few or no bits at all are transmitted. The allocation of bits (and of transmit power) is performed by *loading algorithms* (e.g. [1],[2],[3]), which mainly differ in their optimization criteria and computational load. Here, the well-known algorithm of Chow et al. [1] is used as a reference. Applying such an adaptive modulation method, the bit error rate can be drastically reduced in the uncoded case compared to fixed modulation techniques.

B. Considered Approach: Simple Blockwise Loading Algorithm (SBLA)

In H/2, different physical (PHY) modes are defined (see [5]), each one comprising a modulation scheme (BPSK, QPSK, 16-QAM, 64-QAM) and a code rate (1/2, 3/4, 9/16). Thus, different bandwidth efficiencies are associated with the specified modes. To extend the table of possible modes towards adaptive modulation, it seems reasonable to propose alternative PHY modes which lead to a certain fixed bandwidth efficiency. This, in turn, requires the loading algorithm to allocate a fixed number of bits to the subcarriers.

The algorithm of Chow et al. [1], which is used as a reference here, distributes the bits according to the channel capacity. A number of iterations is needed to make the allocated number of bits R_{total} converge to the desired value R_{target}. If the condition $R_{\text{total}} = R_{\text{target}}$ is not fulfilled after a maximum number of iterations, R_{total} is successively in- or decreased to ensure $R_{\text{total}} = R_{\text{target}}$. Finally, in a third step the transmit power is adjusted to compensate for the quantization of the number of bits.

Instead of the channel capacity, the algorithm of [2] uses a more plausible optimization criterion by minimizing the bit error rate (BER), which is achieved if the error rates are equal on all subcarriers. This criterion has also been applied in the modified loading algorithm presented in [4], which showed comparable or better performance than the algorithm of Chow et al.

Here, a further simplification of the loading algorithm in [4] is proposed. Furthermore, it is combined with a blockwise allocation of modulation schemes. This *simple blockwise loading algorithm* (SBLA) is described in the following.

The given number of K useful subcarriers is first divided into n_B blocks of b adjacent subcarriers. The goal of the loading algorithm is to find a modulation level m_i for each block i such that for a given bandwidth efficiency E [net bit/subcarrier], a code rate R and a given number of blocks n_B, the equation

$$\frac{R}{n_B}\sum_{i=0}^{n_B-1} m_i = R \cdot m = E$$

is fulfilled, where m denotes the average modulation level.

Assigning the same modulation level to adjacent subcarriers within one block is based on the observation that the channel transfer factors and consequently the SNR of neighbouring subchannels are highly correlated in general.

Each block is allocated a modulation level according to its (mean) SNR. To simplify the allocation compared to [1], SNR intervals for each modulation level are used. In contrast to [4], where the sizes of the SNR intervals as well as the absolute SNR thresholds are varied until the target bit rate is reached, here *fixed* SNR interval sizes are applied. The size of these intervals is derived from the BER curves of the considered modulation schemes at a raw BER of 10^{-3} assuming AWGN conditions. This way, an SNR grid is produced that is illustrated in Figure 1. The absolute position of this grid on the SNR axis, i.e. the absolute threshold value for each modulation scheme, is determined by calculating the mean SNR for the given channel and shifting the grid appropriately, taking into account the average modulation level m. It should be emphasized that the fixing of the SNR grid and thus the first allocation of bits is a procedure which works without any iterations.

If after this first loading step $R_{\text{total}} \neq R_{\text{target}}$, bits are successively added/subtracted, depending on the size of a block-SNR relative to the thresholds. This second step is identical to the one applied in the algorithm of Chow et al.

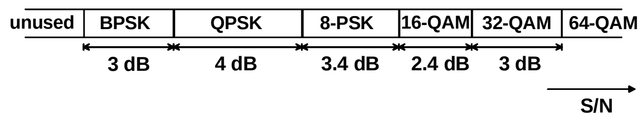

Figure 1: SNR intervals for the allocation of modulation levels to subcarriers in the proposed algorithm. The absolute position of the grid is determined by the average modulation level *m* and the average SNR.

III. QUANTITATIVE ANALYSIS

A. Computational Complexity

To get a rough estimate of the expected computational complexity, especially in comparison with the one of Chow et al., the number of multiplications/divisions and comparisons is calculated in the following. Since the second algorithm step is identical in both cases (compensation of quantization errors) and since this step does not cause significant additional computational complexity, only the first step is considered.

On the assumption that the calculation of a logarithm is done by a power series of degree d, the estimates given in Table 1 result. Here it is assumed that I iterations are needed for the algorithm of Chow et al.

From the numerical example, it becomes obvious that due to the high number of multiplications/

divisions for Chow et al., the computational load is expected to be much lower for the SBLA.

Table 1: Rough estimation of the computational complexity for the different loading algorithms; K = number of subcarriers, I = number of iterations, d = degree of the power series used for calculation of the logarithm, L = number of SNR thresholds. The numerical example is given by K = 48, I = 6, d = 4, n_B = 24, L = 6

	Chow et al.	SBLA
Number of multiplications/ divisions	$K \cdot I(2d-1)$ 2016	$n_B + 1$ 25
Number of comparisons	-- 0	$n_B \cdot L$ 144

B. General Remarks for BER/PER Analysis

To assess the performance of the proposed SBLA, simulations have been performed that are based on the H/2 system parameters. A number of K = 48 useful subcarriers is chosen, and two different channel models are considered. The H/2 channel models A (typical office) and C (large open space) defined in ETSI BRAN are used for the quantitative analysis.

For the comparison, first the uncoded case is considered. In a second step, channel coding is applied. Here two “physical modes” are defined which correspond to 2 existing modes [5] with respect to their bandwidth efficiency (see Table 2).

The calculation of the protocol data unit (PDU) error rate (PER) is based on the transmission of a long transport channel (LCH). Channel estimation and synchronization are assumed to be ideal.

Table 2: Choice of bandwidth efficiencies for adaptive modulation and corresponding H/2 PHY modes

E [net bit/subc.]	Code rate R	Corresponding H/2 PHY mode
1	1/2	QPSK, R = 1/2
3	3/4	16-QAM, R =3/4

When applying adaptive modulation, 7 different modulation schemes (unused, BPSK, QPSK, 8-PSK, 16-QAM, 32-QAM, 64-QAM), ranging from $m_i = 0$ to $m_i = 6$, are used.

C. Uncoded Case

The first analysis shows the performance of the proposed adaptive modulation scheme for different block sizes b. As can be seen from Figure 2 and Figure 3, when considering a subcarrier-specific allocation (i.e. b = 1), the SBLA shows a similar or even slightly better performance than the reference method of Chow et al. This is due to the different criteria (equal bit error rate instead of channel capacity) used for bit loading. Although the proposed algorithm – because of its fixed SNR interval sizes – does not guarantee an equal BER on the subcarriers for all given SNRs, the simplification still leads to good performance results.

Furthermore, the influence of the block size b can be seen in Figure 2 and Figure 3. For channel A, increasing b only entails a moderate increase in the BER even for a blocksize of b = 4 (Figure 2). This can be explained by the small delay spread of the channel model which implies a high correlation of the channel transfer factors of adjacent subcarriers. Accordingly, the results of channel C (Figure 3) show that due to the larger delay spread of this channel, the considered block sizes have a more significant impact on the BER. In this case, values b > 2 should be avoided.

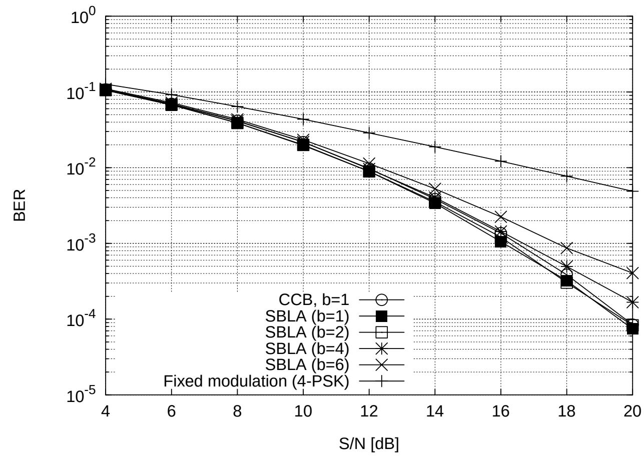

Figure 2: BER with adaptive modulation (proposed algorithm) and different block sizes b; channel model A (typical office), uncoded case, E = 2 bit/subcarrier. For comparison, the result for the algorithm of Chow et al. is also shown.

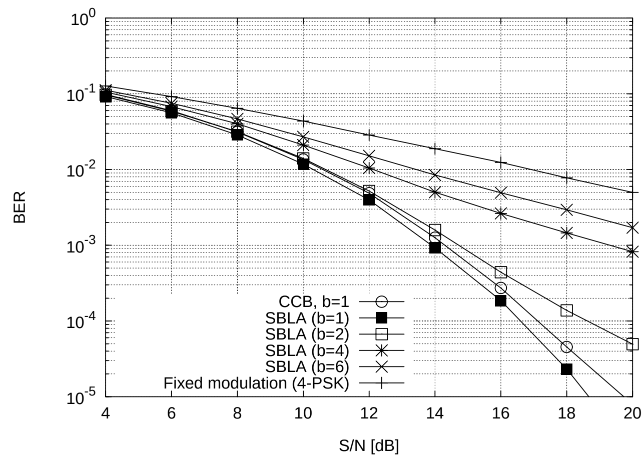

Figure 3: BER with adaptive modulation (proposed algorithm) and different block sizes b; channel model C (large open space), uncoded case, E = 2 bit/subcarrier. For comparison, the result for the algorithm of Chow et al. is also shown

D. Coded Case

After the basic analysis of the discussed loading algorithm, the coded case is to be considered. Two different examples with bandwidth efficiencies of E = 1 net bit/subcarrier and E = 3 net bit/subcarrier are applied, as already mentioned above. These new "physical modes" correspond to existing ones with respect to bandwidth efficiency, as listed in Table 2. The existing modes are also used for comparison.

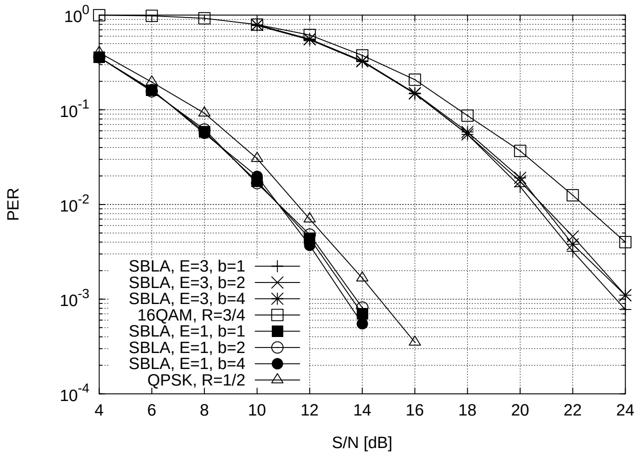

Figure 4: PER with adaptive modulation (proposed algorithm) in the coded case for different block sizes *b*; channel model A (typical office). For *E* = 3 net bit/subc. (*E* = 1), a code rate of *R* = 3/4 (*R* = 1/2) is applied. For comparison, the curves of the two corresponding H/2 PHY modes are also shown.

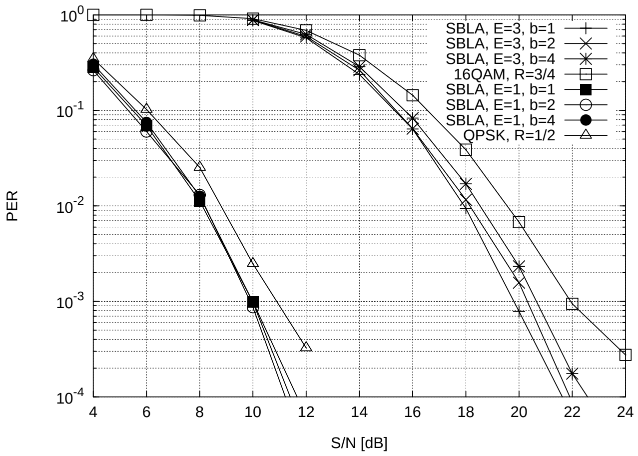

Figure 5: PER with adaptive modulation (proposed algorithm) in the coded case for different block sizes *b*; channel model C (large open space). For *E* = 3 net bit/subc. (*E* = 1), a code rate of *R* = 3/4 (*R* = 1/2) is applied. For comparison, the curves of the two corresponding H/2 PHY modes are also shown.

Figure 4 and Figure 5 summarize the results for channel model A and C, respectively. It can be noted that the gain for the adaptive modulation technique amounts to approx. 1 dB for E = 1 and 2 dB for E = 3, compared to a fixed modulation scheme (channel model C, BER of 10^{-3}). Furthermore, after error correction the influence of a "coarse" allocation (i.e. $b > 1$) is only modest, so that the choice of $b = 2$ in both scenarios can be justified. In this case, the amount of signalling overhead for the allocation technique can be reduced.

IV. Conclusions

In this paper, adaptive modulation has been analysed as a potential enhancement for the HIPERLAN/2 air interface. The proposed simple blockwise loading algorithm (SBLA) was introduced and quantitatively analysed. It turns out that this algorithm, in spite of its simple structure, performs well and even gives slightly better results than the algorithm of Chow et al. used as a reference. Furthermore, the concept of a blockwise allocation appears to be suitable for the given scenario since it still leads to acceptable results while decreasing the overhead of signalling, which is required for transmitting the allocation information. In the coded case, the gain of an adaptive modulation strategy amounts to approx. 1 dB for E = 1 net bit/subcarrier and 2 dB for E = 3 net bit/subcarrier (BER of 10^{-3}).

V. Acknowledgements

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VI. References

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