Performance of Adaptive Modulation in HIPERLAN/2 for Frequency-Selective and Time Variant Channels Assessing Combined Physical Layer and Signaling Aspects

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Abstract – In this paper, a joint PHYsical-layer and Protocol-level simulation analysis of Adaptive Modulation (AdMod) including the specific signaling is carried out. AdMod is a well-known technique which can be applied to an Orthogonal Frequency Division Multiplexing (OFDM) system, which variably adapts the modulation scheme to the Signal-to-Noise-Ratio (SNR) on a per sub-carrier basis. To decide if AdMod is capable of introducing an overall system enhancement, its performance will be determined for a HIPERLAN/2 system in the presence of a frequency-selective and time-varying radio channel. Furthermore, real system effects like performance degradations due to preamble-based channel estimation, zero-forcing equalization and the impact of non-perfect bit-loading are considered.

Keywords: **Adaptive Modulation, HIPERLAN/2, Higher Velocities, Link Level-/ Protocol Level Investigation**

I. INTRODUCTION

Observing the activities targeting on systems Beyond 3G it becomes obvious that there is a great desire for broadband radio systems which are able to provide data rates ≥ 100Mbit/s, even at increased terminal velocities. High spectral efficiency is a figure of merit considering the scarce spectrum. In this context Orthogonal Frequency Division Multiplexing (OFDM)-based systems are already well established and seem to be the favorite choice for future systems. Especially WLAN (Wireless Local Area Network) systems like IEEE802.11a and HIPERLAN/2 (High PERformance LAN) are in the public focus and are likely to complement existing 2G and upcoming 3G networks. Additionally these systems could be enhanced to work under more mobile conditions. Conventionally using the same modulation scheme (Fixed Modulation, FixMod) on all sub-carriers, the channel capacity is not exploited optimally due to the frequency-selective property of the radio channel. It is thus appropriate to perform a different loading scheme such that less interfered sub-carriers transport more bits than more interfered ones. This technique is referred to as Adaptive Modulation (AdMod). Although this technique is well-known (e.g. [5]) in general, the overall system enhancement of AdMod including the necessary signaling overhead still needs to be well investigated.

Therefore the goal of this paper is to determine the overall system performance of AdMod for the example of HIPERLAN/2 and compare it to the standard performance of FixMod. In a first part a short overview of the principles of AdMod is given. Afterwards the necessary signaling procedures are introduced, a detailed description of the HIPERLAN/2 layer 2 procedures and its protocol-inherent delay is given, and their impact on the AdMod performance is investigated, with a special focus on higher terminal velocities. The simulation results are described next, including an overview of the simulation set-up. The paper is concluded with a summary of the main results and a short outlook on issues for further study.

II. ADAPTIVE MODULATION

The reference configuration of the PHY layer applying adaptive modulation to an OFDM system is depicted in Figure 1.

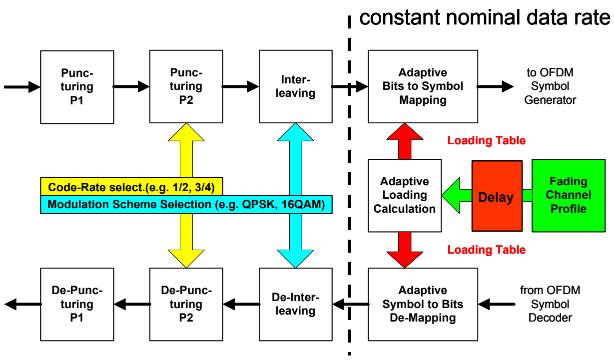

Figure 1: Adaptive Modulation Configuration

Adaptive modulation in OFDM systems defines a technique that adjusts the modulation on a per sub-carrier basis. This allocation is performed by estimating the SNR per sub-carrier and calculating a bit-loading table in a way that sub-carriers with a high SNR are assigned more bits than those with a low SNR. The bit-loading algorithm applied here is targeting on keeping the nominal i.e. the user data rates (available at the layer 1-2 interface) constant.

III. SIGNALING PROCEDURES FOR ADAPTIVE MODULATION

A. BASIC SIGNALLING SCHEME

In HIPERLAN/2, during connection set-up some Uplink/Downlink Link Control Channels (UL/DL LCCH) are established in order to allow for the exchange of link adaptation information. As the LCCH is usually mapped onto a Short Transport Channel (SCH) the most efficient way to transport bit-loading information for AdMod is via the SCH.

Based on the received quality e.g. of the DL signals the MT calculates the bit-loading table and sends the bit loading to the sender during the next possible MAC frame. The logical channel used herein will subsequently be addressed as the Adaptive Modulation LCCH (AM LCCH). Once the bit loading is known at both sides, AdMod is applied to all User Data CHannels (UDCH), which are exclusively mapped onto Long transport Channels (LCH).

B. REDUCTION OF SIGNALING OVERHEAD

In order to reduce the amount of bit loading information, adjacent sub-carriers can be allocated the same modulation scheme, in contrast to modulating each sub-carrier individually. In the investigations, (8 modulation schemes, "clustering" of 3 sub-carriers), this results in a total amount of 48 bits, which can be mapped onto one SCH (52 bits).

In the presence of a stationary channel the signaling data transfer could be further reduced by updating the bit loading only every *p* MAC frames (p>1), with *p* depending on the coherence time T_C.

IV. SIMULATION SET-UP

The message exchange required to convey the bit-loading table from the receiver to the transmitter is depicted in Figure 2.

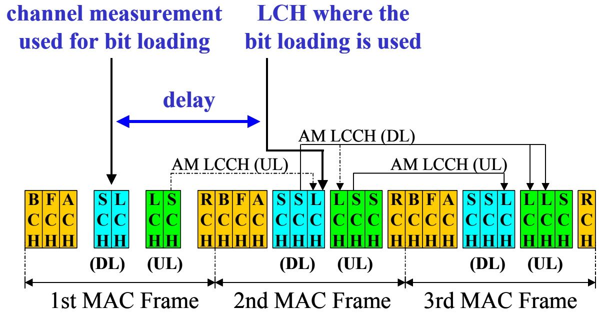

Figure 2: AdMod information exchange/delay

The bit-loading table is conveyed via the AM-LCCH and is applied in the next possible time slot. As shown in Figure 2, a certain delay between the SNR measurement period, based on which the bit-loading table is calculated, and the utilization of the bit-loading table is introduced. In the case of (at least nearly) symmetrical UL and DL traffic, this delay is considered to amount approximately to one HIPERLAN/2 MAC frame duration (i.e. 2 ms).

It is expected that in the presence of a time-varying radio channel this delay will introduce a noticeable mismatch between the SNR measurements used for calculating the bit-loading pattern and present SNR conditions on the mobile channel when AdMod is applied, rendering AdMod not appropriate for very high terminal velocities. This result is not surprising, as the technique of AdMod has been designed for stationary usage and slow time-varying channels. Within the context of the present paper its upper limits in terms of the maximum supported terminal velocities will be determined.

According to [6] the coherence time T_C at a coherence level of 0.5 can be evaluated as follows:

$$T_c \approx \frac{9}{16\pi \cdot f_{D_{\max}}} = \frac{9 \cdot c}{16\pi \cdot f_c \cdot v} \qquad (1)$$

In Eqn. (1), $f_{D\max}$, f_c, v, c denote the maximum Doppler frequency, carrier frequency, velocity of the mobile terminal and speed of light, respectively. Based on Eqn. (1) and on the restriction that the coherence time of the channel shall not be smaller than one HIPERLAN/2 MAC frame duration, a maximum supported terminal velocity for AdMod of approx. 15-20 km/h is expected.

The simulation set-up taking into account the frequency selectivity of the channel and the protocol inherent delay is depicted in Figure 1. According to this link level simulation set-up a correct reception of the AM-LCCH i.e. the bit-loading table is assumed. The calculation of the bit-loading table is done based on the C-part of the HIPERLAN/2 preamble and is (ideally) fed back to the adaptive QAM modulator and demodulator. The MAC inherent delay is considered by applying the bit loading with a delay of 2ms. At the receiver end, channel estimation is assumed either to be ideal or is done preamble-based.

V. Simulation Results

A. *LINK LEVEL SIMULATIONS*

The Adaptive Modulation technique has been applied such that the nominal (user) data rate remains constant. The mobile channel has been modeled according to the ETSI Channel model C, which has extensively been used during the HIPERLAN/2 specification procedure. The time variance of the channel has been introduced by varying the terminal velocity from 3 to 30 km/h (carrier frequency of 5.25GHz).

Simulation results of the 36 Mbit/s PHY mode are depicted in Figure 3 comparing FixMod and AdMod in terms of the LCH Packet Error Rate (LCH-PER) vs. Signal-to-Noise-Ratio (SNR) at the terminal velocities 3, 10, 20 and 30km/h. For velocities smaller than 20km/h, the AdMod scheme achieves better results than ordinary FixMod.

Regarding a PER of 0.01 as demanded for e.g. speech services, the adaptive modulation scheme at 3km/h only needs an SNR of approximately 16.7dB, whereas FixMod needs about 2.5dB more (19.2dB) to achieve the same PER. Even for 10km/h the AdMod still performs 1dB better. However, by further increasing the velocity, AdMod is not able anymore to compete with the performance of FixMod. This is due to the fact that the channel coherence time T_C is constantly decreasing with increasing terminal velocity and hence the layer 2 protocol-inherent mismatch of the bit-loading to the current receiver end SNR becomes more noticeable. As FixMod schemes do not adjust their modulation alphabet on a per sub-carrier basis, FixMod is not as strongly susceptible to changes of the channel transfer function over time, and the mean PER over all sub-carriers stays almost the same for the considered velocities. This result also indicates that Inter-sub-Carrier-Interference (ICI) is obviously negligible (Doppler frequency is small compared to the sub-carrier spacing). Additionally it is important to mention that even in the presence of a preamble-based channel estimation, no significant degradation due to an old channel estimation occurs, because of the rather short PHY burst (conveying 2 LCHs).

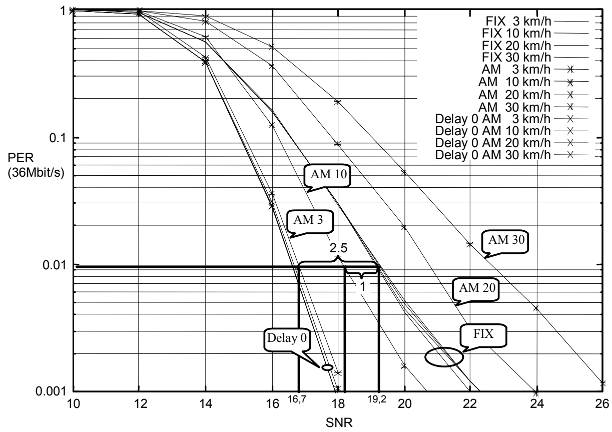

Figure 3: 36 Mbit/s PHY mode, v = 3, 10, 20 and 30km/h

As a reference, “ideal” results without any protocol delay are also depicted in Figure 3 (Delay 0 AM x km/h). The fact that they are nearly identical for all considered velocities supports the observation that degradations in the other AdMod curves are solely caused by the protocol delay.

In general the comparison illustrates that adaptive modulation is superior to fixed modulation up to a velocity of roughly 20km/h. Beyond, the use of adaptive modulation is highly affected by the inherent protocol delay and results in an inferior performance.

B. *PROTOCOL LEVEL SIMULATIONS*

To take into account the influence of the channel estimation, every AdMod related protocol simulation was performed both with ideal receiver/channel estimation (IC) and with a preamble based channel estimation (PC). Additionally every simulation was run with an idealistic adaptive modulation set-up to determine its upper performance bounds of AdMod as a reference. These idealistic AdMod set-ups consist of an ideal receiver and channel estimation and a bit-loading table delay of 0 ms (D0 AM) as already introduced in Figure 3.

For all simulations, one connection between AP and MT was assumed, loaded with traffic of 4 Mbit/s (constant bit rate sources) in the downlink, low enough to exclude the impact of other effects like e.g. the state of the data queues. The delay for the application of the bit-loading table for AdMod was set to 2 ms.

The presented results include the throughput/delay for a nominal data rate of 36 Mbit/s with adaptive modulation at 3-30 km/h and a fixed SNR value of 18dB, respectively for fixed modulation and idealistic (zero delay) set-ups. One can see from Figure 3 that the fixed modulation schemes do not show any influence concerning the velocity (PER=0.03 at SNR=18 dB). Therefore, the following curves for fixed modulation can be assumed to be the same for all velocities. Simulations driven for other velocities, respectively other SNR values, differ in their absolute performance, however they have the same basic tendency as presented in the following.

B.1 Simulations with ARQ

Figure 4 shows the resulting throughput and Figure 5 depicts the delay of the simulations with enabled ARQ. One can see that after a short period of time the carried throughput converges to the offered load. Due to ARQ, neither the different velocities nor the different channel estimations have an influence on the throughput, seen by the upper layers. This can be explained by the relation of load and used data rate. In these simulations there is enough capacity to retransmit defective data in the following frames, which on link level means, that there is a much higher throughput than the indicated 4 Mbit/s seen by the user.

In contrast to the resulting throughput, the measured delay clearly shows the influence of the retransmissions of defective data. Depending on the velocity, the maximum LCH packet delay can reach significantly higher values with adaptive modulation compared to fixed modulation. As it can be seen from Figure 5, for small velocities of 3 km/h 90% of the data can be transmitted within 2ms (1 MAC Frame) with the help of adaptive modulation (PC AM 3). The fixed modulation set-up however needs about half a MAC frame longer (+1ms). On further increasing the speed up to 30 km/h, fixed modulation now performs much better, since compared to PC AM 30, 90% of the data is delivered 4.3 ms less delayed (please consider that the curves for PC FIX at 3 km/h and 30 km/h were the same).

Besides the comparison of FixMod and AdMod, Figure 5 also contains delay information about the sensitivity of AdMod towards velocity and channel estimation. Regarding a fixed speed of 30 km/h, the difference of the delay when applying IC or PC is almost 2 MAC frames (3.8ms). Thus, an improvement of performance is heavily related to a proper channel estimation.

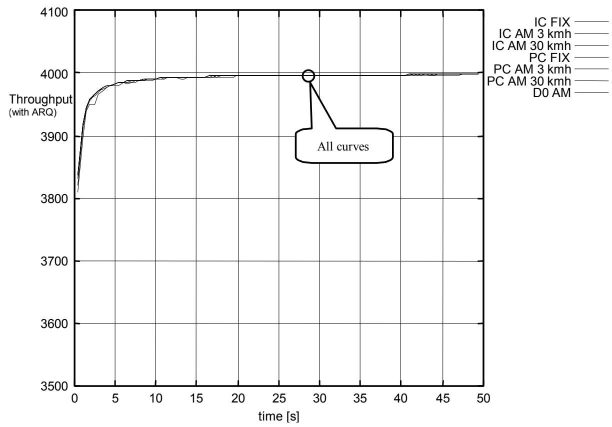

Figure 4: Throughput for 36 Mbit/s with ARQ

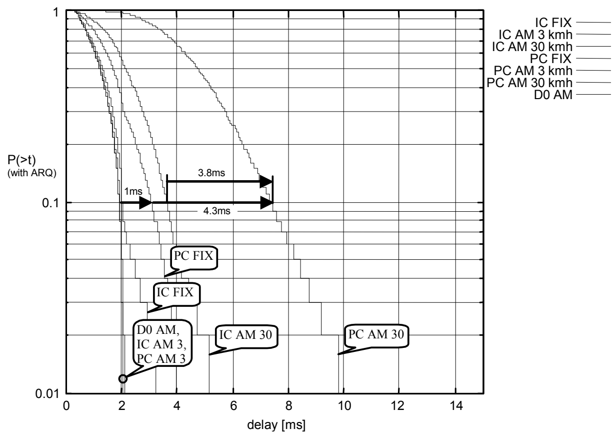

Figure 5: Delay for 36 Mbit/s with ARQ

Finally, Figure 5 also includes an idealistic AdMod set-up with a bit-loading delay of 0 ms (D0 AM), which shows no influence of the velocity on the delay at all and the maximum delay always resides below the one of FixMod. In fact, an asymptotic behavior towards 2 ms can be seen, which means that due to the very small PER no retransmissions are necessary.

B.2 Simulations without ARQ

Figure 6 shows the resulting throughput and Figure 7 summarizes the delay of the simulations without ARQ. These results illustrate the effect of the different PERs on the throughput. A defective transmission of data directly leads to a decrease in the resulting throughput as seen by the user.

Comparing again AdMod to FixMod shows that for small velocities of 3 km/h (PC AM 3) AdMod is able to carry about 120 kbit/s more traffic than PC FIX. Increasing the speed results in a respective loss of transmission capacity, as e.g. PC AM 30 is only able to carry 655 kbit/s less than PC FIX.

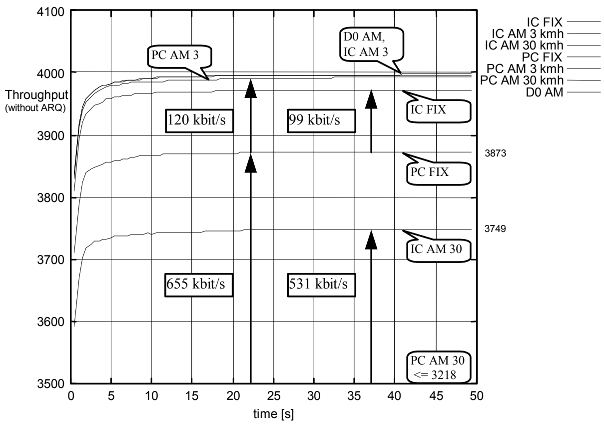

Figure 6: Throughput for 36 Mbit/s without ARQ

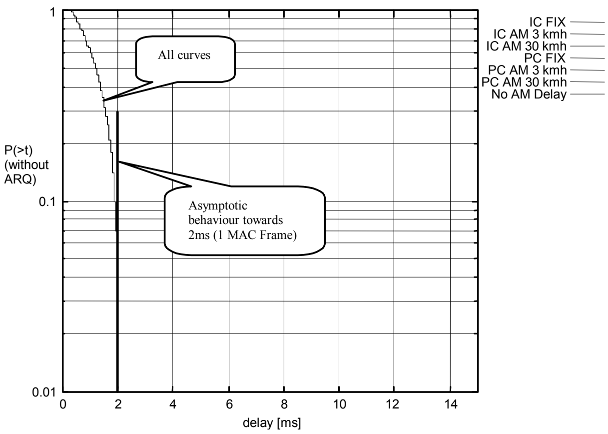

Figure 7: Delay for 36 Mbit/s without ARQ

Regarding the impact of the channel estimation once more shows that the difference between PC AM 30 and IC AM 30 is about 531 kbit/s. Comparing this to the respective gain achieved for an ideal channel estimation for FixMod (IC FIX → PC FIX) would only lead to a gain of 99 kbit/s.

As expected, all simulation results for the delay (Figure 7) show an asymptotic behavior towards 2ms (1 MAC frame). Since no ARQ is applied, disrupted data get lost, are not re-transmitted and thus cannot contribute to the delay distribution. Moreover, the chosen PHY mode with the resulting data rate of 36 Mbit/s is stable enough to carry the generated load of 4 Mbit/s, such that no additional delay due to queuing is introduced.

VI. CONCLUSION & OUTLOOK

As discussed in this paper, adaptive modulation holds a significant potential to improve the link level performance of OFDM-based systems, especially in stationary environments. Simulations have shown that the estimated upper speed performance bound is in line with the simulation results.

In order to use AdMod at noticeably higher velocities than pedestrian speeds, the protocol inherent delay boundary needs to be minimized. The protocols of future systems need to address this issue and find a trade-off between signaling overhead and inherent system delay. Also the advantage of channel reciprocity in Time Division Duplex (TDD) systems may further be used to reduce this delay.

Furthermore, it has been shown that AdMod applied to a HIPERLAN/2 connection can increase the total system performance including the complete signaling overhead. Especially, if an improved channel estimation is applied, the resulting gain for AdMod is comparably higher than for FixMod. An improved support of QoS in terms of either delay or throughput for the scenario investigated here was shown, depending on whether or not ARQ is used.

Starting from these early results new link adaptation schemes also taking new MAC schemes into account have to be developed, optimizing the application of adaptive modulation for higher terminal velocities.

VII. ACKNOWLEDGEMENTS

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VIII. REFERENCES

[1] ETSI DTS/BRAN-0023003, “HIPERLAN Type 2 Technical Specification; Physical (PHY) layer,” November 1999.

[2] Broadband Radio Access Networks (BRAN) ETSI TS 101 761-1. HIPERLAN Type 2; Data Link Control (DLC) Layer; Part 1: Basic Data Transport Function. April 2000.

[3] Broadband Radio Access Networks (BRAN) ETSI TS 101 761-2. HIPERLAN Type 2; Data Link Control (DLC) Layer; Part 2: Radio Link Control (RLC) sublayer. April 2000.

[4] P.S. Chow, J.M. Cioffi, and J.A.C. Bingham, “A Practical Discrete Multitone Transceiver Loading Algorithm for Data Transmission over Spectrally Shaped Channels,” *IEEE Transactions on Communications*, 43, S. 773-775, February/March/April 1995.

[5] Rainer Grünheid, Edgar Bolinth, Prof. Dr. Hermann Rohling, “A Blockwise Loading Algorithm for the Adaptive Modulation Technique in OFDM Systems”, VTC 2001 Fall, Atlantic City.

[6] Theodore S. Rappaport, "Wireless Communications: Principles & Practice", ISBN 0-13-042232-0, Prentice Hall, 2002.