Bit-Loaded H-OFDM Performance in WPAN Environments

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***Abstract*— In this paper bit-loading techniques have been applied to an H-OFDM system in an ad-hoc WLAN environment. The effect on the performance of the channel estimation errors has been analized showing that due to the channel estimation proposed procedure this effect is not very important. Those results show that the complexity introduced in order to manage the ad-hoc scenario and bit-loading techniques is worthwhile because of the good behaviour obtained.**

I. INTRODUCTION

Wireless Local Area Networks (WLANs) and Wireless Personal Area Networks (WPANs) are receiving a growing interest and they are being deployed worldwide. These technologies have clear advantages such as the low complexity and cost in the deployment and the mobility functionality. However in order to be competitive they have to provide similar capabilities as wired LANs. In terms of capacity wired networks are offering from 100 Mbps up to 1 Gbps whereas several comercial wireless standards such as IEEE 802.11b [1] already deployed in many companies and public places as airports or shopping centers can provide up to 11 Mbps (or 22 Mbps if two channels are used). Nevertheless new wireless standards are ready such as IEEE 802.11a/g [2], [3] or HiperLAN 2 B [4] offering up to 54 Mbps (or 108 Mbps by using two channels). And other wireless standards are comming up promising more than 100 Mbps as 802.15.G3a [5] (up to 480 Mbps). The way to increase the bit rates used by those standards is to increase the number of bits per symbol (selecting modulation and coding), the bandwidth and/or the number of sub-carriers in those that use multicarrier modulation. All of them fix the modulation scheme depending on how good the channel is seen as a whole, i.e. the bandwidth is not optimised.

In [6] the use of bit-loading techniques [7] in order to approach the capacity in an H-OFDM (Hybrid Orthogonal Frequency Division Multiplexing) system is briefly analysed. Results in [6] were obtained when the channel is perfectly known at both sides and the only errors are due to the AWGN (Aditive White Gaussian Noise) of the channel. Also in [6] a brief description for the H-OFDM system is shown. The present paper completes the simulations when errors are present in the channel estimation and shows their effects. Besides a more detailed explanation of the system and the communication procedures are given.

The paper is organised as follows. First in section II H-OFDM and the scenario in which it is being proposed will be described so that later on the approach proposed in section III for bit-loading can be understood. Then in section IV the performance obtained by using perfect and real channel estimation will be shown and discussed and finally some conclusions will be drawn.

II. H-OFDM: SYSTEM DESCRIPTION

PACWOMAN (Power Aware Communications for Wireless OptiMased Area Network) project [8] is oriented to provide a highly flexible WLAN/WPAN. Depending on the bit rates that they require terminals have been divided into three different groups, namely, Low Data Rate (LDR) from 0.1 kbps to 10 kbps, Medium Data Rate (MDR) from 0.01 Mbps to 1 Mbps and High Data Rate (HDR) above 1 Mbps. For Medium/High data rate devices a so-called H-OFDM (Hybrid Orthogonal Frequency Division Multiplexing) scheme has been defined which is a TDMA/OFDMA system (Time Division/Orthogonal Frequency Division - Multiple Access). The transmission is organized in frames. Each frame is divided into 16 slots and each slot can allocate a packet of up to 150 OFDM data symbols (with additional 5 symbols as a header for detection, synchronization and channel estimation purposes). Resources are defined by the pair [sub-carrier number, slot number] and are shared by every device and therefore a resource not occupied by one transceiver is available to be used by another one. Also several modulation schemes are possible from BPSK up to 64-QAM. It should be noted that discrete bit-loading will be able to choose from 0 to 6 bits per symbol.

The PACWOMAN scenario is supposed to be ad-hoc and therefore no access point or master device is present. In order to deal with this problem, the first slot is reserved as Control Slot (CS) which is divided into three different physical channels, namely, the Leader Channel (LCH), the Paging and Access Grant Channel (PAGCH) and the Resources Access Channel (RACH). Fig. 1 shows the structure of this CS. LCH is used for leader purposes as synchronization or device detection. It should be noted that in order to avoid Multi-user Interference (MUI) every transmitter in the system has to be synchronized to each other, i.e. the time and frequency references have to be common for all the transceivers. Therefore the first terminal switched on in the network will assume the *leader* role and it will establish the time and

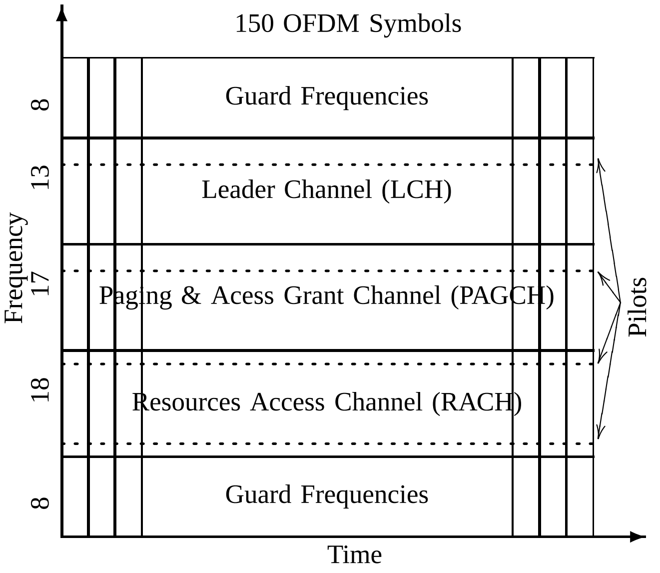

Fig. 1. ***Control Slot Structure***

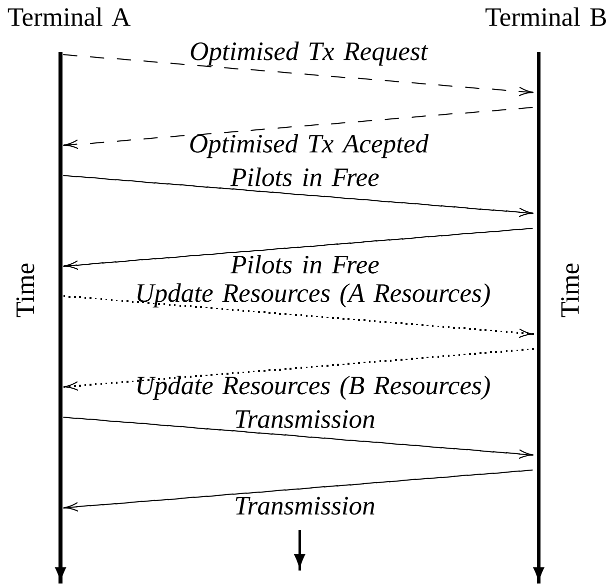

Fig. 2. ***Succesful Optimised Transmission Procedure***

frequency references. On the other hand, when a terminal is ready to send data to another one it uses the PAGCH for paging and the response is sent on it as well. From the point of view of the scope of this paper the most important channel is the RACH. Every user has to inform the rest of them about which resources are going to be used by sending this information into the RACH. In this way there is no need to design a centralized algorithm for transmission scheduling or bit-loading, every transceiver knows the resources being used by the others and they can run locally their scheduling and bit-loading algorithms.

The way a succesful *optimised* communication is carried out is as follows: First terminal A (origin) checks that there are enough free resources and it shows its willingness to transmit sending a special message *Optimised Transmission Request* (OTR) with the receiver's MAC address into the PAGCH. Terminal B (destination) sends the response in the same PAGCH during the next CS. Both devices know exactly the resources beeing occupied and therefore they can send pilots in free sub-carriers in order to allow to each other sense the channel. Once both transmitters have estimated the channel they send a special message *Resources Updated* (RU) in the RACH to inform the others about the resources that are going to be used. This procedure is depicted in Fig. 2 where dashed line represents message sent into PAGCH, dotted line is a message sent into RACH and solid one is the transmission in the others slots not the CS. After the transmission resources are released by sending a new message *RU* into the RACH.

III. BIT-LOADED H-OFDM: APPROACH

As it has been said before, every transceiver has to keep listening to the CS in order to have an overview about the situation of the system. It should be noted that if no terminal is transmitting the CS is empty, i.e. the leader does not transmit a beacon. In this way the device that assumes the leader role does not spend more power than the rest of active terminals in the network. When the transceiver is ready to send data and after it has indicated its willingness into the PAGCH, it informs the others about resources going to be used by sending a special message in the RACH which contains those resources and a set of pilots in free resources. By using those pilots the receiver is able to perform an accurate channel estimation. Note that using these pilots and those in the header the estimation can be improved. In this way, the receiver and also the rest of users know which resources are no more usable for transmitting until they will be released. Terminals can choose among two methods: *Simple* and *Optimised*. Common standards use the first one, i.e. the modulation scheme is equal for all the sub-carriers. But PACWOMAN PHY can support *optimised* communication: Both transmitter and receiver perform the channel estimation and, taking into account the upper layer requirements in terms of power and bit error rates, run the bit-loading algorithm (there are several proposals in the literature, e.g. [9]) in order to obtain the optimum number of bits per symbol on each resource. This operation is carried out individually for each user. Statistically by sharing the bandwidth for different transceivers resources are better exploited than in single-user utilization, bad sub-carriers for one specific user could be good for another one. However in order to manage the utilization of resources from different users a small loss in efficiency has to be sacrificed and a little complexity is introduced but as it will be shown later it is worthwhile.

IV. BIT-LOADED H-OFDM: PERFORMANCE

Several scenarios have been simulated in order to analyse the effect of the number of sub-carriers occupied and the channel type. Also the effect on the performance when the real estimated channel is used instead of the ideal has been studied. Simulations are dynamic (at the beginning there are no active transceivers but after a number of frames the

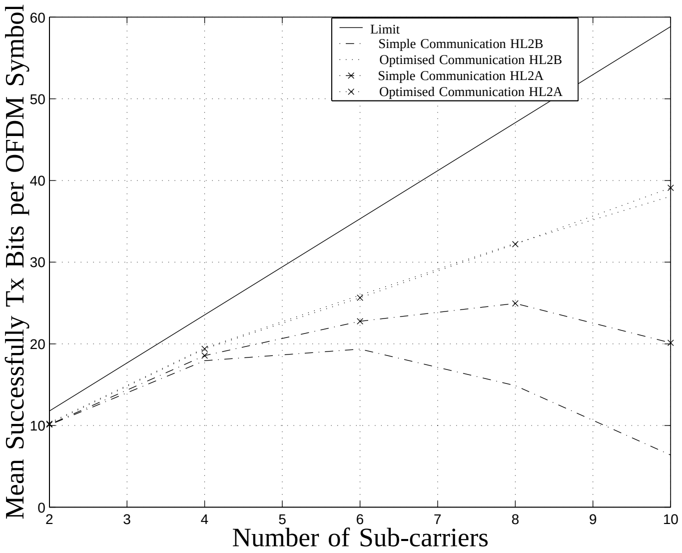

Fig. 3. ***Comparison between channels***

system is in stationary situation) and large enough for the results to be accurate. Physical Layer parameters are: 64 sub-carriers, only 44 of them useful, and a bandwidth of 10 MHz. For the results that are presented in this paper, all active users in the system have the same characteristics: they transmit over 20 frames each time they are ready using 2 slots and a variable number of sub-carriers depending on the simulation. The transmission is symmetric and both types of communications have been simulated for every channel realization. The Signal to Noise Ratio (SNR) has been fixed to 20 dB and a number of 10 terminals has been chosen (a reasonable value for a WPAN scenario). Two channel models have been used: HiperLAN 2 A and B [10]. Both channels are NLOS (No Line of Sight) but channel A is less frequency slective than channel B. It should be noted that simulations have been carried out without taking into account coding, i.e. the error probability is in raw bits. Every user needs to inform the others about which resources are going to be occupied. The way to do this is by using the control slot which is common. These effects and some others related to MAC (Medium Access Control) in ad-hoc environments (collisions,...) have been taken into account in simulations to compute the throughput. For this reason even though results for *optimised* communications are very similar for both channels, those for *simple* communications are better in channel A because of its less frequency selective behaviour. The differences between both channels for the *optimised* communication are not significant due to the lower number of sub-carriers as it will become more evident in the following analysis.

In Fig. 3 it can be seen the average number of bits per OFDM symbol depending on the number of sub-carriers and the channel type. This figure has been obtained with perfect channel estimation at both sides. Solid line shows only for reference the theoretical limit [11], i.e. the capacity. It can be observed that for a low number of sub-carriers results in both channels and communications (*simple* and *optimised*) are quite similar but as the number of sub-carriers increases the differences between *simple* and *optimised* communication increase as well. In *optimised* transmission differences between both channels are slight and they are larger as the number of sub-carriers increases. On the other hand differences in *simple* communication are significant in both cases: among the channel type and with respect to the *optimised*. The reason for the first case is that channel A is less frequency selective and then, the mean performed to the channel seen as a whole is more representative whereas the mean for channel B can be very different from one sub-carrier to another, i.e. the mean is not yet representative for every sub-carrier. For the second case the reason of this behaviour is that the error probability is fixed by the worst sub-carriers. In *simple* communication the number of bits per symbol is chosen depending on how good the channel is. If there are only few sub-carriers there will be fewer sub-carriers that are worse than the mean and probably not very far away. On the other hand when the number of sub-carriers is large enough there will be more sub-carriers that are lower than the mean and differences could be greater and therefore there will be more sub-carriers carrying much more information than they are able to and the probability of error will increase. In *optimised* transmission the number of bits per symbol is chosen depending on the specific sub-carrier and therefore that problem does not appear. Another aspect that can be seen is the breakpoint for the *simple* communication. It is due to the increment of BER when the number of sub-carriers allocating more bits than they can support increases. Also in Fig. 3 it can be seen that *optimised* communication approaches better the theoretical limit however the large difference between them is due to the fact that simulations have been carried out without any coding and therefore the distance to the capacity is large too. And finally this figure can be used to choose an empirical threshold in order to select *simple* communication or *optimised*. In channel A for example when the transceiver is going to use more than 8 sub-carriers it is much better to choose *optimised* communication than the simple one, and for the channel B this threshold is near to 6. These numbers could be taken into account at the higher layers to select one or the other communication type, e.g. lower data rates could be transmited in *simple* communication whereas higher data rates would be better optimised. It should be noted that both can coexist together at the same time without an inpact in performance, i.e. some devices can be transmitting by using *simple* communication whereas the others are sending information in *optimised*.

In Fig. 4 it can be observed the effect on the mean transmitted bits per OFDM symbol due to the channel estimation errors. Those results are for channel B at 20 dB of SNR. Similar behaviour has been obtained for channel A. The figure shows the impact if the channel estimation is not

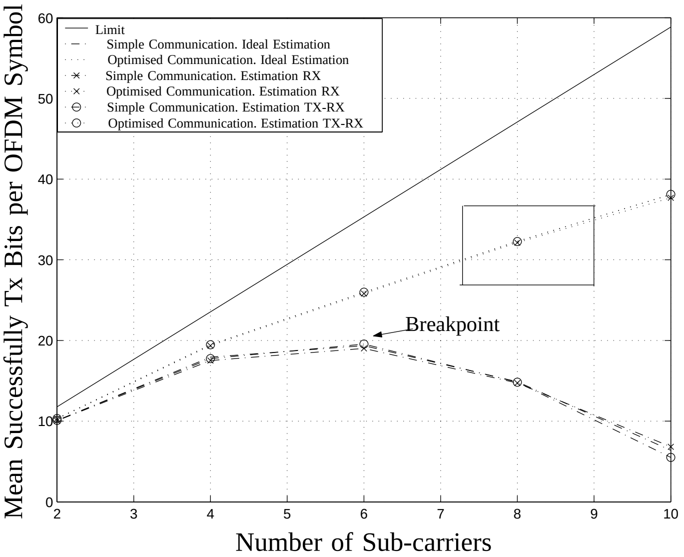

Fig. 4. ***The impact of channel estimation***

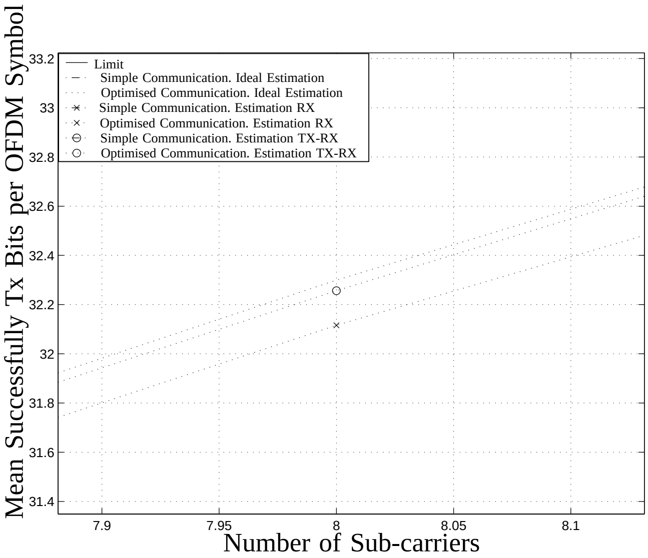

Fig. 5. ***Zoom of Fig. 4***

perfect and has small errors. The DFT algorithm [12] has been used for channel estimation at both sides. It can be seen that the differences in performance when only the receiver (RX) utilises the channel estimated or when both transmitter and receiver (TX-RX) use the estimation are very small. The reason is that the channel estimation is accurate enough by using the proposed scheme (with two symbols at the preamble and the pilots during the communication establishment), and also because the SNR is high. These differences can better be seen in Fig. 5 which is a zoom of the remarked area in Fig. 4. It can be observed that even though the differences are slight those are larger when the estimated channel is only used at the receiver. The reason can be easily understood, if the transmitter has the perfect knowledge of the sub-carriers it will allocate the optimum number of bits per symbol but at the receiver errors due to the channel estimation may degrade the whole performance. On the other hand, if the estimated channel is used at both sides errors may affect to the optimum number of bits per symbol. Nevertheless the effect is not very important because of the high SNR and the fact that we are using discrete number of bits and therefore the error in channel estimation has to be quite large in order to cause a change in this number.

V. CONCLUSIONS

A scheme to manage the ad-hoc problem in OFDM-based WLAN/WPAN networks and the use of bit-loading techniques have been proposed and simulated and promising results have been obtained. We have shown that improvements depend on the channel type: the more frequency selective the channel is the better results are obtained. And also depending on the number of sub-carriers per user: when users only transmit over 2 sub-carriers the results are almost equal but as that number increases better results are obtained by using *optimised* communications. Besides the effects on the performance due to channel estimation errors have been studied showing that due to the channel estimation proposed method and the integer number of bits those effects are not very important. And finally the benefits obtained are much larger than complexity introduced in order to manage the system so this effort is worthwhile.

VI. ACKNOWLEDGMENT

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