Bit-loading in Hybrid OFDM (H-OFDM)

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***Abstract*— In this paper the possibilities and benefits of using bit-loading techniques in WLAN/WPAN are presented showing that the improvement obtained is large enough to compensate the additional complexity introduced. Also a decentralized way to implement bit-loading in an H-OFDM-based ad-hoc environment is proposed.**

I. Introduction

Mobile communications are one of the key enablers of the Information Society. Wireless Local Area Networks (WLANs) and Wireless Personal Area Networks (WPANs) have to provide at least the same services as the wired communications networks not only in security issues but also in capacity. In terms of capacity wired networks are providing from 100 Mbps up to 1 Gbps. At the moment there are several commercial wireless standards that can provide from 11 Mbps such as IEEE 802.11b [1] up to 54 Mbps such as IEEE 802.11a/g [2], [3] or HiperLAN 2 [4]. Besides there are some other standards that can provide more than 100 Mbps as IEEE 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. Recently an H-OFDM scheme has been proposed to be used in WPANs [6]. In this paper the possibilities of using bit-loading [7] techniques in order to increase the capacity in H-OFDM will be explored.

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 will be discussed and finally some conclusions will be drawn.

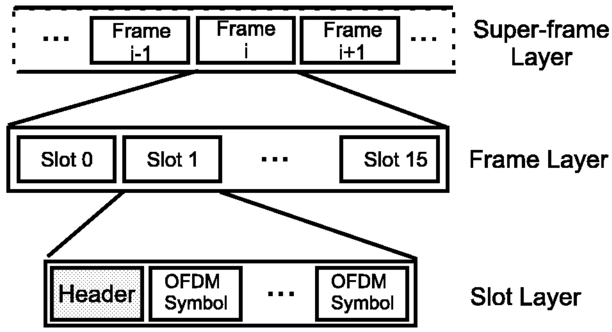

Fig. 1. ***PACWOMAN TDMA structure***

II. H-OFDM: System Description

PACWOMAN (Power Aware Communications for Wireless OptiMased Area Network) project [6] 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.

A. General Description

The TDMA (Time Division Multiple Access) structure is shown in Fig. 1. The OFDMA (Orthogonal Frequency Division Multiple Access) behaviour will be explained later.

As it is shown in Fig. 1 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 another 5 symbols as a header for detection, synchronization and channel estimation purposes). On the other hand, sub-carriers can be used for different transceivers, i.e. resources are defined by the pair [sub-carrier number, slot number] and every resource not occupied by one transceiver is capable of being used by another. Also several modulation schemes are possible from BPSK up to 64-QAM. It should be noted that the discrete bit-loading will be able to choose from 0 to 6 bits per symbol.

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. The first terminal switched on in the network will assume the *leader* role and it will establish that reference. It should be noted that this *leader* role can be played by any transceiver in the system.

B. Ad-hoc Management

Once a general view of H-OFDM has been seen a brief description on how the ad-hoc environment is managed will be explained. In order to deal with the decentralised problem of multi-user management the first slot of every frame is dedicated to control purposes. This first slot 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. 2 shows the structure of this control slot. LCH is used for leader purposes as synchronization. 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.

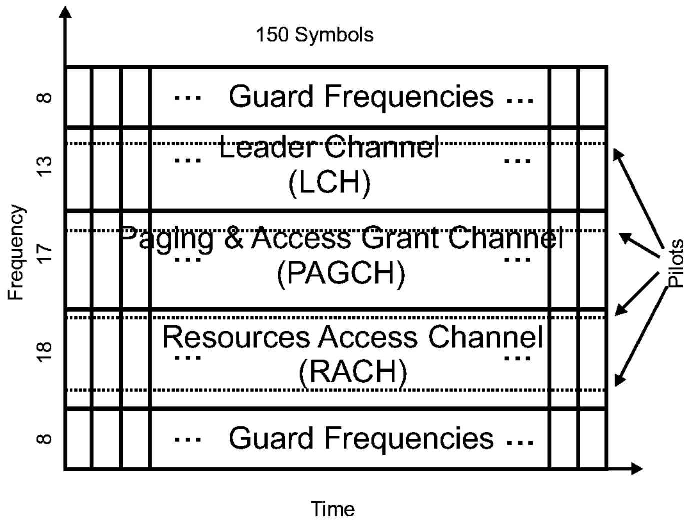

Fig. 2. ***Control Slot Structure***

III. Bit-loaded H-OFDM: Approach

Every transceiver has to keep listening to the control slot in order to have an overview about the situation of the system. When the terminal 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 in order for the receiver to be able to perform an accurate channel estimation. 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. That operation is also performed by using the RACH. Terminals can choose two communication methods: *Simple* and *Optimised*. The first one is the transmission used in common standards, i.e. the modulation scheme is selected depending on how good the channel is seen as a whole (the channel is estimated not only with the packet header but also using the pilots sent in the RACH). This kind of transmission is supported by the physical layer. But the PACWOMAN PHY can also support an 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 many proposals in the literature, e.g. [8]) in order to obtain the optimum number of bits per symbol on each resource. Assuming the perfect knowledge of the channel at each sub-carrier the spectrum is optimised. This operation is carried out individually

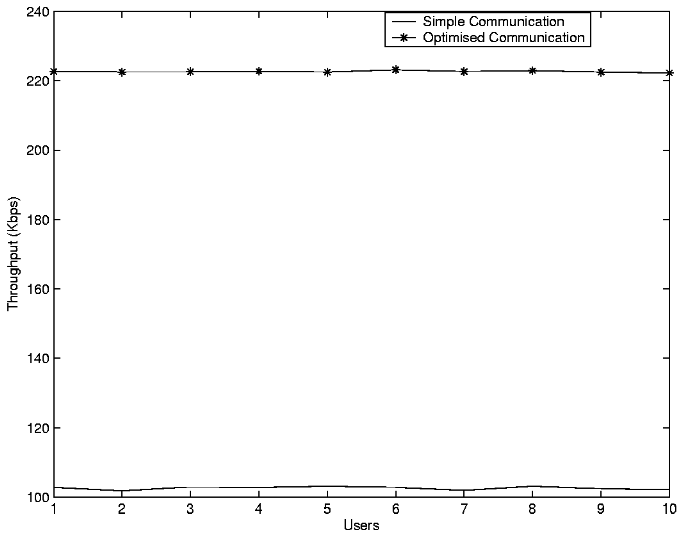

Fig. 3. ***Throughput for different users. HiperLAN 2 B Channel***

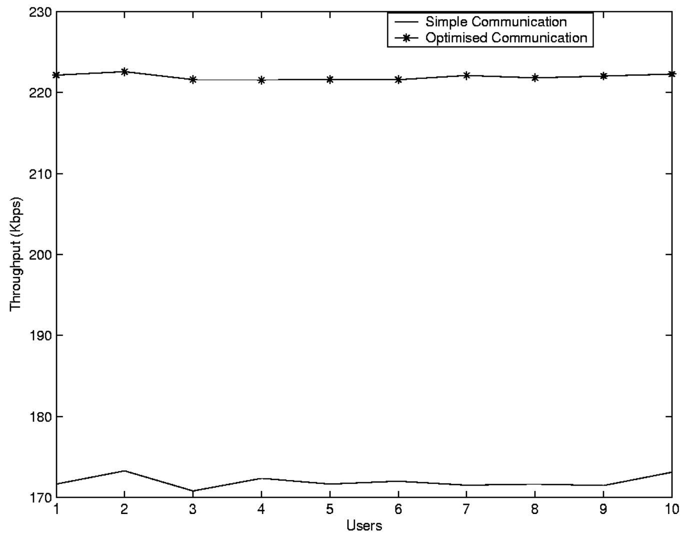

Fig. 4. ***Throughput for different users. HiperLAN 2 A Channel***

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. Simulations are dynamic 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. Communication is symmetric. 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). There are two channel models: HiperLAN 2 A and B [9]. Simulations have been carried out without taking into account coding, i.e. the error probability is in raw bits.

In Fig. 3 an example of the throughput obtained for the different users in the system is shown. This figure has been obtained for terminals using 8 sub-carriers over an HiperLAN 2 B channel. As it has been said before 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. It can be seen that optimising the transmission throughput can be increased up to 50 % or more, i.e. it is possible to allocate twice the number of users or rate in the same bandwidth and using the same physical layer if bit-loading is used. Fig. 4 shows the same results as in Fig. 3 when an HiperLAN 2 A channel is applied. Note that both channels are NLOS (No Line of Sight) but channel A has better behaviour than B. For this reason even though results for optimised communications are very similar 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.

Fig. 5 shows the mean allocable error-free bits

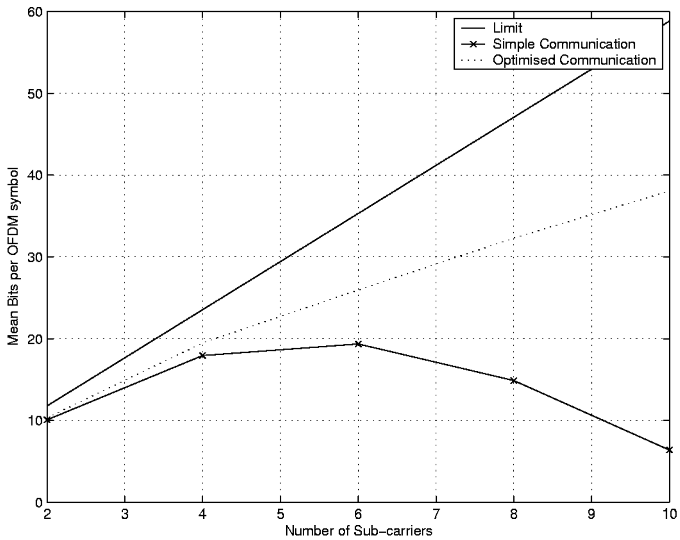

Fig. 5. ***Comparison between Simple and Optimised Communications***

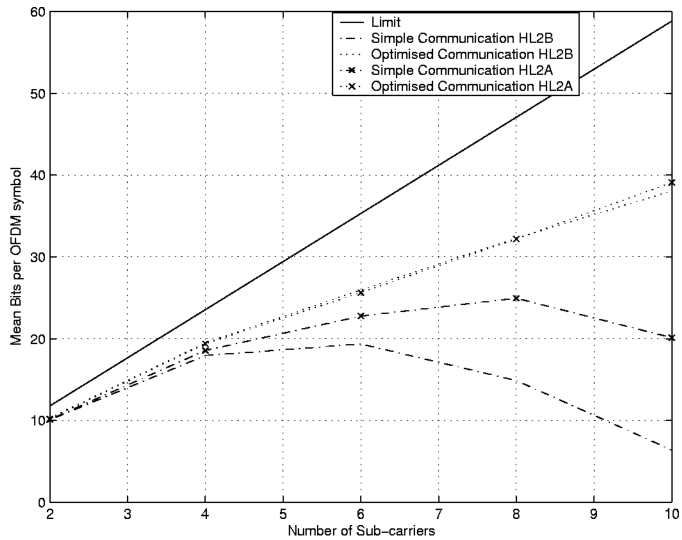

Fig. 6. ***Comparison between channels***

per OFDM symbol depending on the number of sub-carriers per symbol used in an HiperLAN 2 B channel. Solid line shows the theoretical limit [10] of bits per OFDM symbol taking into account the number of sub-carriers. It can be seen that for a low number of sub-carriers results are quite similar but as the number of sub-carriers increases the differences between simple and optimised communication increase as well. For more than 6 sub-carriers it is much better to choose optimised communication than the simple one. This number could be used for 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. Both can coexist together at the same time. The reason of this behaviour is simple, 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 seen as a whole. 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. Also in Fig. 5 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 differences from the capacity are large too.

In Fig. 6 a comparison between mean allocable bits per OFDM symbol for the two different channels studied is shown. In this figure several aspects can be seen. First, results obtained for both channels when optimised communication is performed are almost equal however the more number of sub-carriers are used the more differences. Anyway results obtained for channel A are slightly better than for channel B. In the case of simple communication similar behaviour is experimented for both channels: when the number of sub-carriers is lower the mean number of bits per OFDM symbol is quite similar to optimised communication, there is a breakpoint which is larger for channel A and then as the number increases the differences between optimised and simple increase too. As for channel B when the number of sub-carriers is lower than a threshold, in this case 8, it is better to transmit in simple mode and for a number larger than 8 the best choice is to optimise. And finally it should be noted that when channels are more AWGN-like (Additive White Gaussian Noise) both results tend to converge, indeed for AWGN optimised and simple communications obtain the same values. Another conclusion that can be extracted from these results is that for AWGN-like or in general for flat channels the improvements obtained by using the optimised communication are not enough to justify the complexity introduced. On the contrary, the complexity is absolutely justified in case of frequency selective channels.

V. Conclusions

The use of bit-loading techniques for OFDM-based WLAN/WPAN systems was simulated and promising results have been obtained. We have shown that improvements depend on the channel model (the more frequency selective the channel is the better results are obtained) and 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 benefits obtained are much larger than complexity introduced in order to manage the system so this effort is worthwhile.

VI. Acknowledgement

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