

A DISTRIBUTED ALGORITHM FOR DYNAMIC SUB-CHANNEL ASSIGNMENT IN A MULTI USER OFDM COMMUNICATION SYSTEM

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ABSTRACT

In this paper we propose and study a Sub-Channel Selective OFDM spread spectrum system and a distributed algorithm for sub-channel allocation. The proposed system is a combination of OFDMA and OFDM-CDMA systems. For each user the maximal ratio combining weights of the sub-channels are used as channel information. The algorithm implements a simple but sub-optimal version of the water filling power allocation, thus increasing the transmitter power efficiency and decreasing the interference generated for other users. This algorithm also provides the ability to offer different Quality of Service (QoS) levels for different users. The convergence of the algorithm and its performance have been studied through simulation. The proposed system has significant advantage in BER performance, over the conventional OFDM-SS system.

1. INTRODUCTION

Among various techniques used for communication over a wireless channel, Orthogonal Division Frequency Multiplexing (OFDM) is one of the most promising. In an OFDM system the data stream is divided into N parallel streams, which are transmitted over N orthogonal sub-carriers (sub-channels). In the spread spectrum version of OFDM (OFDM-SS, also known as Multi Carrier Spread Spectrum), the same data bit is transmitted over all N sub-channels. OFDM-SS achieves frequency diversity as well as processing gain. Furthermore, OFDM-SS is robust against jamming and interference and enables us to use Code Division Multiple Access (CDMA) as an efficient Radio Resource Allocation (RRA) scheme, for a multi user system. In an OFDM-CDMA system, orthogonal codes of length N are assigned to each user. These codes (signatures) are applied to the sub-channels, to reduce the interference generated by other users.

At the receiver, the output of the sub-channels are combined to obtain the decision variable. For linear sub-channels with additive Gaussian noise and/or interference, Maximal

Ratio Combining (MRC) provides the optimum Signal-to-Noise and Interference Ratio (SNIR) [1]. MRC combines the output of the sub-channels by giving less weight to sub-channels with low SNIR and more weight to those with high SNIR. i.e. if sub-channel i is modeled by

$$y_i = \alpha_i x + n_i, \quad (1)$$

where y_i is the output of the sub-channel, x is the data symbol, α_i is the sub-channel gain and $n_i \sim \mathcal{N}(0, \sigma^2)$ is the additive Gaussian noise, the MRC decision variable is given by

$$y = \sum_{i=1}^N w_i y_i, \quad (2)$$

where $w_i = \alpha_i^*$. In practice, the sub-channel gains are unknown and a Least Mean Square (LMS) or a Recursive Least Square (RLS) algorithm with decision feedback is employed to estimate these gains [2].

While MRC performs optimum detection, it does not consider the transmitted power efficiency. We observe that a sub-channel with smaller SNIR has smaller contribution to the decision variable compared to one with high SNIR, thus less benefit is gained from the transmit power spent on the sub-channel with low SNIR. The solution known as the water filling power distribution [3] gives the distribution of the power over N sub-channels which results in maximum channel capacity for given total transmission power. The water filling solution allocates more power to *good* (high SNIR) sub-channels and little or no power to the *bad* ones.

Several algorithms have been proposed to implement the water filling solution or a sub-optimal version of it for the multi carrier system. Optimal power and symbol size allocation, assuming that different sub-channels experience different fading and other channel effects, is derived in [4]. [5] proposes an adaptive sub-channel and bit allocation for the down-link of a multi user OFDM system. A dynamic sub-channel allocation for the down-link of OFDM system is proposed in [6] which assumes quasi-static channels. These algorithms are computationally complex, and assume that

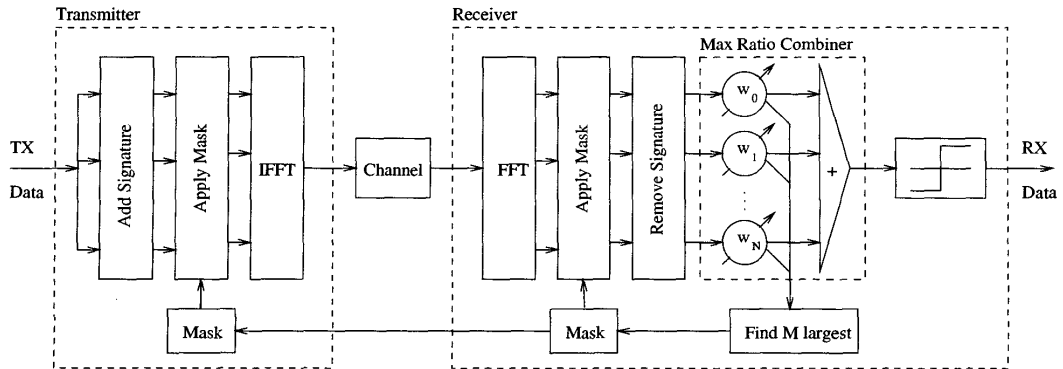


Figure 1: Sub-Channel Selective OFDM-SS system

the perfect channel information of all the users is known by the base station at all times.

In this paper we propose a Sub-Channel Selective OFDM-SS (SCS OFDM-SS) scheme that implements a sub-optimal but simple distributed algorithm for the sub-channel power allocation in a multi user OFDM system. The result is a hybrid of OFDM-CDMA and OFDMA systems [7][8]. An Orthogonal Frequency Division Multiple Access (OFDMA) system is one in which each sub-channel is assigned to one user.

The system is described in section 2. The proposed distributed algorithm is detailed in section 3, and in section 4 the convergence of this algorithm for specific cases is studied. Section 5 presents the simulation results for the performance of the proposed system and compares them with the performance of the conventional system. Finally in section 6 conclusions are drawn.

2. SYSTEM DESCRIPTION

In the SCS OFDM-SS system, the magnitude of the MRC channel weights, $|w_i|$, are used to distinguish *good* sub-channels from *bad* ones. At the receiver, M best sub-channels are selected and a set of binary mask variables are defined as $m_i = 1$ if the sub-channel i is selected and $m_i = 0$ otherwise. These variables are then reported to the transmitter via a feedback channel. The transmitter in turn allocates equal power to the selected sub-channels and no power to the unselected ones (Figure 1).

Although not using the *bad* sub-channels in the combining slightly deteriorates the resulting Bit Error Rate (BER), redirecting the power spent on these sub-channels to the *good* ones improves the over all BER performance. This is similar to the water filling algorithm if the value of the

assigned power to each sub-channel is limited to 0 or a constant value.

The more important benefit of this algorithm, however, appears in a multi user system. In this case, a *bad* channel for user k is not necessarily *bad* for user l , thus turning off such a sub-channel will reduce the interference that user l receives. In other words, the users try to avoid the sub-channels with high level of interference. This will result in less average interference for the users, and improves the over all performance.

Furthermore, by selecting different number of selected sub-channels for different users, different Quality of Service (QoS) levels can be provided for different users.

3. DROP AND ADD (DA) ALGORITHM

When the channel is time variable, or when the users enter and leave the system, the selected sub-channels must be updated periodically. The period of the updating of the *good* sub-channels must be short enough to allow the system to follow the changes in the channel and long enough to allow the channel weight estimator to obtain a good estimate.

Since the channel weight estimator uses the output of the sub-channels to estimate the weights, channel weights will not be calculated for the off sub-channels and these sub-channels should be probed before the selected sub-channels are updated. Here we propose the Drop and Add (DA) algorithm, in which each user drops the worst selected sub-channel (minimum $|w_i|$) and adds a random off sub-channel to the selected sub-channels with a period KT , where K is the total number of users in the system. If the new added sub-channel happens to be a *bad* one it will be dropped in a later iteration, otherwise the user has found a *good* sub-channel.

For faster convergence, we assume that all users are synchronized in such a way that user k performs the updating iterations in times $t_n = nKT + kT, n = 0, 1, \dots$, such that the next user has at least T seconds to adapt to the change.

4. CONVERGENCE OF THE DA ALGORITHM

The system can be modeled as a Markov Chain, where each state will describe a specific sub-channel selection for all the users. Thus the number of states in this Markov Chain will be

$$n_{MC} = \sum_{k=1}^K \binom{N}{M_k}, \quad (3)$$

where M_k is the number of selected channels for user k . Furthermore, since different users have different channel gains, the convergence analysis for such a system is complicated even for small number of users in the network.

In this paper we have studied the convergence of the DA algorithm through simulation. A Gaussian model has been used for the interference. Over time, the average SNIR of the users has been compared to the optimum case.

Figure 2 shows this comparison for a system with $K = 4$ users with flat channels (equal sub-channel gains), $N = 64$ sub-channels and $M_k = 16, k = 1, \dots, 4$ and Figure 3 shows the comparison with $K = 2$ users with different frequency selective channels, with $N = 64$ sub-channels and $M_k = 32, k = 1, 2$. For simplicity, these values have been chosen to satisfy $N = \sum M_k$, which means that sub-channel distributions exist which allow all users to communicate without any interference. In general $\sum M_k$ can be larger than N which will result in some overlap between the selected sub-channels of different users. Perfect synchronization and exact channel weight estimation has been assumed. Since in the down link the original and the interference signal have the same path, all sub-channels have the same SNIR and will be equally preferred by the selection process. In other words the down link can be modeled considering same (flat) channels for all users. On the other hand, for the up-link, the original and the interference signals have different paths, thus the channels used for the original and the interference signals can be frequency selective and different.

In both cases it can be seen that although the average SNIR resulting from the DA algorithm does not converge to the optimum value, the resulting average SNIR is close to optimum after a few iterations.

5. BER PERFORMANCE RESULTS

The BER performance of the SCS OFDM-SS system has been studied using Monte Carlo simulations of the system.

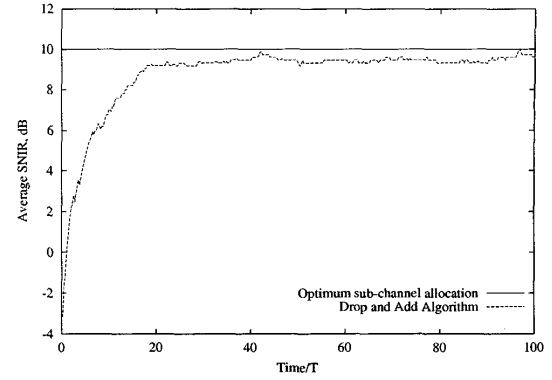


Figure 2: Convergence of the DA algorithm for $K = 4$ users with flat channels (down-link).

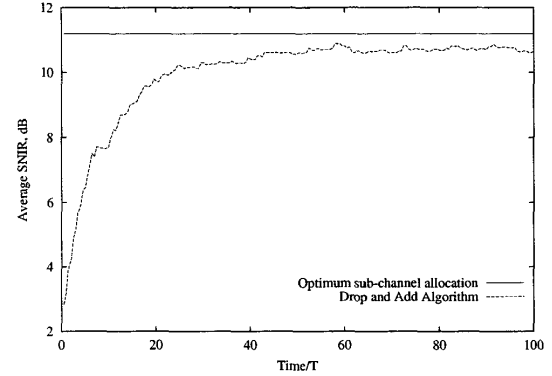


Figure 3: Convergence of the DA algorithm for $K = 2$ users with different frequency selective channels (up-link).

For these simulations it has been assumed that the synchronization and the channel weight estimates are perfect. Also it has been assumed that perfect power control exists, therefore the original and interference signals have equal power. A value of $N = 64$ sub-channels has been used, and a fair distribution of the sub-channels is considered, i.e. $M_k = N/K, k = 1, \dots, K$. Also random spreading codes (signatures) have been used.

Figure 4 shows the BER performance of each user for the down-link (flat channels) of a SCS OFDM-SS system with $K = 4$ users. The result has been compared with the BER performance in an equivalent conventional OFDM-SS system. Figure 5 compares the BER performance of the SCS and conventional systems for the uplink (frequency selective channels) for $K = 2$ user case. The frequency

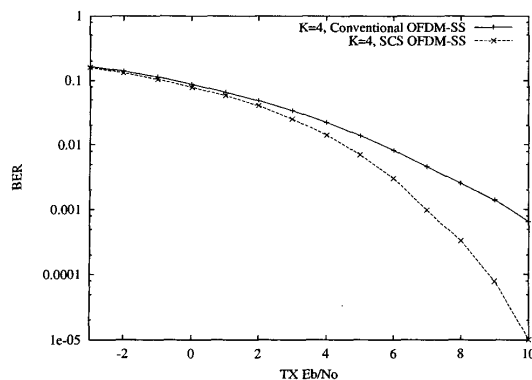


Figure 4: Comparison of BER performance of the down link of the SCS and conventional OFDM-SS systems for $K = 4$ users.

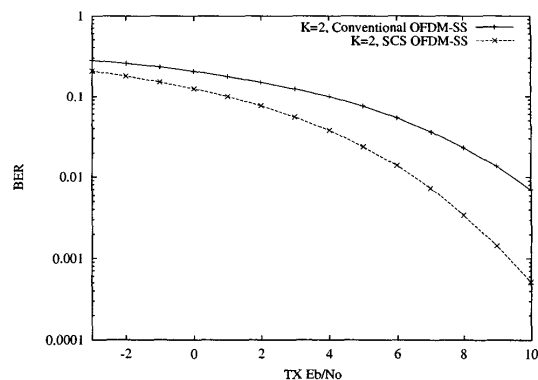


Figure 5: Comparison of BER performance of the up link of the SCS and conventional OFDM-SS systems for $K = 2$ users.

selective channels have been modeled by two rays, with equal power and different delays. The second ray delays of $D_1 = 16T_b/N$ and $D_2 = 4T_b/N$ has been used for users 1 and 2 respectively.

In both cases we can see that the SCS OFDM-SS system has a strong advantage in BER performance compared to the conventional OFDM-SS system.

6. CONCLUSIONS

A simple, sub-optimal distributed algorithm for sub-channel allocation in a OFDM-SS system has been proposed and simulated. The convergence of the algorithm has been studied. Also the overall BER performance of the system has been obtained and compared to that of the conventional system. The results show significant improvement in the BER performance of the users.

7. REFERENCES

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