Adaptive Resource Allocation in Multiuser OFDM Systems

Literature Survey

Multidimensional Digital Signal Processing

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Abstract

Orthogonal Frequency Division Multiplexing (OFDM) has successfully prevented ISI in a frequency selective wireless environment. An interesting application of OFDM is in Multiuser OFDM systems in which multiple users share the same channel and the total transmit power. Due to independent multipath fading characteristic for each user, channel diversity is also created. This survey studies the methods that have been proposed in the literature to allocate the resources and achieve better performances in data rates and Bit error rates and minimum transmit power levels.

I. Introduction

Next Generation wireless communication systems will support wireless multimedia and wireless internet access which require high data rate and complex designs. High data rate communication over wideband channels are significantly limited by inter-symbol interference (ISI) due to frequency selective or time dispersive nature of the channels. In a multiuser systems such as cellular systems, users experience ISI [1] as a result of multiple copies (multipath) of the transmitted signal created by the objects (such building, cars, etc) around them. To combat ISI, multicarrier modulation techniques, including Orthogonal Frequency Division Multiplexing (OFDM) are among the possible solutions that have been suggested.

OFDM [2] divides a broadband channel into narrow subcarrier (of the same width) such that the channel response on a particular subcarrier seems flat. Adding a guard band or cyclic prefix (CP), whose length equals the dispersion time of the channel, to the transmitted symbols, makes each of the subcarriers parallel independent additive white Gaussian noise channels. This setup allows the received signal to be ISI free.

II. Background

For tutorial purposes the allocation of bits for a single user OFDM system is briefly explained. It is assumed that the channel information for the subcarriers is known. Under the total power constraint a greedy algorithm, also known as the water-filling [3] algorithm is applied to maximize the total bit rate. It could also be run for a fixed data rate constraint while minimizing total power. Effectively, the algorithm assigns bit rates to the subcarriers depending on their channel gain, giving higher bit rates to higher gain channels. A subcarrier may be assigned no bits if it is in deep fade or low gain.

Users of multiuser OFDM systems observe multipath fading but have independent fading parameters due to their different locations. The probability that a subcarrier appearing to be in deep fade for one user may not be in deep fade for other users is quite high. Hence, multiuser system creates channel diversity which increases with the number of users. Therefore, in multiuser OFDM environment, the system needs to allocate bits as well as subcarriers to the users. There are two approaches to allocate these resources; fixed and adaptive allocation. Fixed allocations use time division multiple access (TDMA) or frequency division multiple access (FDMA) as multi-access schemes to allocate each user a predetermined time slot or frequency band for transmission. While applying fixed allocation the system neglects the channel diversity and does not use the deep faded subcarriers for other users which do not seem as deep faded to them. [4] discusses and compares these two fixed allocation schemes in much detail.

To exploit the channel diversity and achieve higher bit rates authors of [5, 6, 7, 8, 9, and 10] have suggest adaptive allocation of resources. They use the instantaneous knowledge of the channel for each user to allocate the subcarriers accordingly and then subsequently allocate the bits and transmit power for each subcarrier.

The rest of this report is divided into the following sections. Section III describes the adaptive scheme proposed in [5] which minimizes the total transmitted power with the fixed user data rate. Section IV discuses the scheme which maximizes the total capacity under fixed total power mentioned in [6]. Section V mentions the Quality of Service (QoS) which is neglected by [6] and discusses the solution proposed by [7]. In Section VI, results of simulations performed by the authors using each of these methods are compared. Finally conclusions and future plans for project are presented in section VII.

III. Margin Adaptive

[5] presents a multiuser subcarrier, bit and power allocation scheme where all users transmit in all the time slots. The authors use the given set of user data rates and attempt to minimize total transmit power, which is also know as Margin Adaptive. Following is the problem formulated in the paper

$$P_T^* = \min_{C_{k,n} \in D} \sum_{n=1}^{N} \sum_{k=1}^{K} \frac{1}{\alpha_{k,n}^2} f_k \left(c_{k,n} \right)$$

Where P_T^* is the total power, $c_{k,n}$ is the bite rate for kth user on the nth subcarrier, $\alpha_{k,n}^2$ is the channel gain squared for nth subcarrier for the kth user and f_k is the required received power. In the single user case, a subcarrier gets the additional bit if it requires the minimum power to transmit it. This is known as the greedy algorithm and the authors argue that a multiuser allocation problem is more complicated than a single user bit allocation. To make the above problem tractable the authors relax the single user per subcarrier constraint by allowing multiple users to share any subcarrier and also send non integer number of bits. With a new optimization problem and constraints, the paper applies the Lagrangian optimization technique [11]. The authors simplify the optimization problem by splitting the subcarrier allocation from the bit allocation. The subcarrier allocation is performed first and then the single user bit allocation is applied on each user, using the assigned subcarriers.

IV. Rate Adaptive

The authors of [6] present an algorithm that maximizes the total data rate of the multiuser OFDM system by adapting the transmit power for each user and each subcarrier. The total transmit power for the system is fixed and represented by

$$\sum_{k=1}^{K} \sum_{n=1}^{N} s_{k,n} = \overline{S}$$

where $\overline{S}$ is the total transmit power and $s_{k,n}$ is the transmit power for kth user and the nth subcarrier. This paper differs from the other two key papers [5, 7], by formalizing the problem initially with multiple users sharing the same subcarrier. Hence, the system model takes into account the interference caused by other users on the same subcarrier. To reduce the complexity of maximizing the data rate while keeping the transmit power limited, the authors first find the subcarrier for each user and then apply the power allocation. The maximum number of bits in a symbol to be transmitted for the kth user's mth subcarrier is expressed as

$$q_{k,n} = \log_2\left(1 + \frac{\gamma_{k,n}}{\Gamma}\right)$$

where $\gamma_{k,n}$ is the Signal to interference plus noise ratio (SINR) and Γ is the function of the required Bit Error Rate (BER). The problem is formulated as

$$R = \sum_{k=1}^{K}\sum_{n=1}^{M}\frac{q_{k,n}}{T} = \frac{B}{M}\sum_{k=1}^{K}\sum_{n=1}^{M}\log_2\left(1 + \frac{\gamma_{k,n}}{\Gamma}\right)$$

where T is the OFMD symbol duration. In subcarrier allocation the authors determine which user would transmit on a subcarrier, to maximize the data rate on that subcarrier. They present a theorem to maximize the data rate for a subcarrier. It states a subcarrier should be assigned to that user only which has the best channel gain for the subcarrier. Eventually the authors disallow any subcarrier to be shared among other users, similar to the approaches of [5, 7]. The authors indicate that data rate may be increased with the increase in the number of users in the system.

The second step is to allocate power level to the assigned subcarriers and is treated as a single user OFDM system. With the total power constraint, the Lagrangian optimization technique [11] is applied and the problem is made into a water-filling transmit power adaptation method. To reduce the complexity the paper suggest a simple equal power allocation method which gives a marginal performance difference as shown below in the simulation section

V. Rate Adaptive and Quality of Service

Although the objective of [7] is similar to [6] discussed in section II, the paper addresses the Quality of Service neglected by the former paper. Having constraint on the power with adaptive data rates, does not ensure a good share of the total data rate for each user. This paper adds a set of nonlinear constraints to enforce the control of capacity ratio among the users.

The optimization problem is similar to [6] with the sharing of subcarriers by multiple users being assumed. The nonlinear constraints or the proportional fairness is given by

$$R_1 : R_2 : \ldots : R_K = \gamma_1 : \gamma_2 : \ldots : \gamma_K$$

where R_i are the individual user's data rates and γ_i are predetermined values to ensure proportional fairness between users. If all γ_i terms are equal then it represents a special case which has been presented in [8]. [8] maximize the sum capacity while forcing all the R_i terms to be equal. To reduce the complexity, the paper derives a suboptimal algorithm by separating the subcarrier and power allocation. The subcarrier allocation is partially similar to the previous paper where a particular subcarrier is assigned to the user which has the best channel gain among the other users. The additional part to the algorithm finds and then allows a user with the lowest proportional capacity to pick the best subcarrier. This process is suboptimal and offers course proportional fairness.

The power allocation scheme is equivalent to finding the maximum of the cost function. Given the total power constraint, this optimization problem is solved by obtaining the Lagrangian optimization problem [11]. Solving the power distribution for single user leads to a water filling problem [3] in the frequency domain. With the total power for single user and the total power constraint, the capacity ratio constraints are expressed as nonlinear equations. The authors mention the complexity of the solving these equations and analyze two such cases where the solution is found in one iteration.

VI. Simulation Results

OFDM-TDMA, ODDM-FDMA, and OFDM-CDMA have been described and analyzed in [4] and simulation results in terms of bit error rate performance have been quantitatively. The adaptive allocation schemes indicate that they have outperformed the fixed allocation schemes. Fig.1 plots shows three static multiuser subcarrier allocation methods and the adaptive allocation presented in [5] for five-user system with an RMS delay spread equal to 100ns. The BER performance shows that the proposed solution has at least 3-4 dB advantage over the other static schemes.

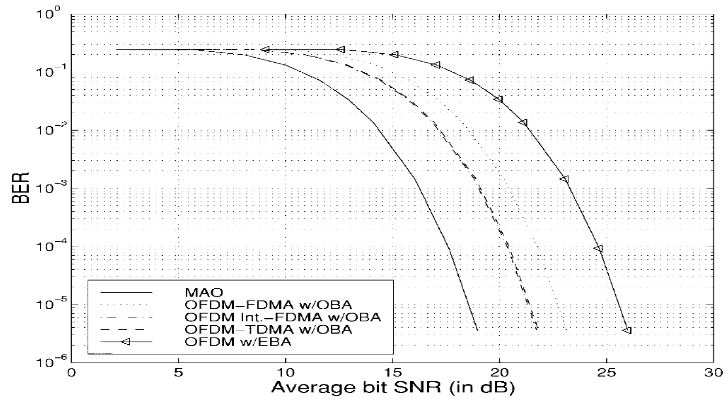

Figure 1: BER versus average bit SNR for various subcarrier allocation schemes.

The proposed solution in [6] defines a simple equal power allocation method instead of water-filling transmit power adaptation to reduce the complexity. Left side of Fig.2 dipicts the average data rate versus average SNR for the solutions from [6] and fixed allocation schemes. The right of Fig2 shows the average data rate as number of users are increased in the systems. Both parts show that the adaptive schemes outperform the fixed counterparts and also, there is very less difference between the proposed schemes which have different transmit power allocation strategies.

For simulation purposes [7] compares the performance results with [8] and [6]. [8] is special case for [7] but uses a different power allocation scheme. Left part of Fig.3 compares the capacity vs. number of users for the two adaptive and the static schemes; this paper and [8] and static TDMA scheme. The adaptive schemes outperforms the static one by 17% and the proposed allocation scheme in [7] performs better than [8]. In the right part of Fig.3 the proposed solution maintains the capacity ratio where as [6] puts all the bits on the subcarrier of user 1 since it sees the best channel among the other users.

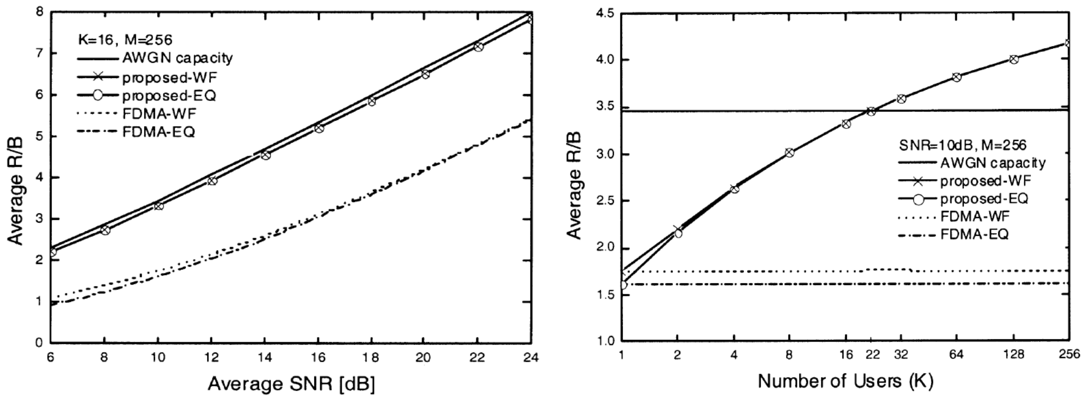

Fig2 (i) Normalized Average data rate versus average SNR,
(ii) Normalized Average data rate versus number of users K,

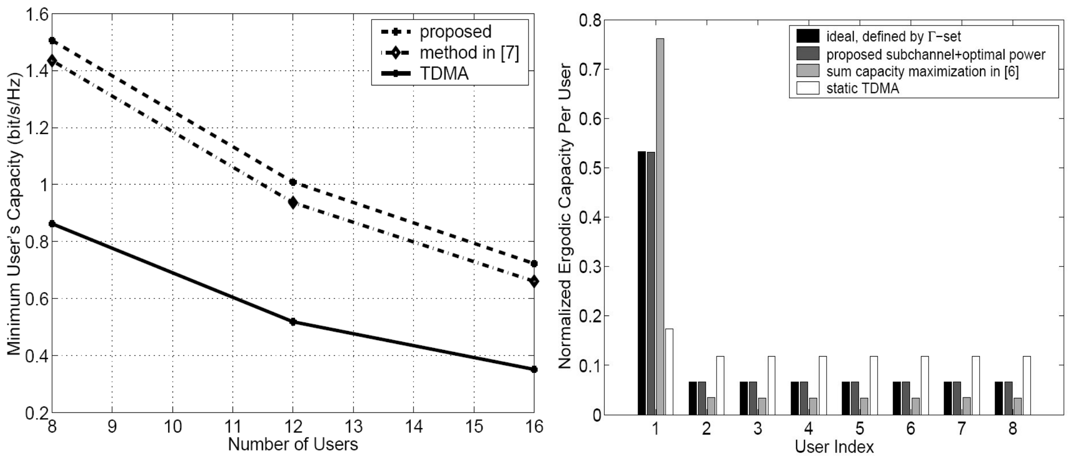

Fig3. (i) Capacity vs. number of users for the two adaptive and the static schemes
(ii) Capacity per user

Table 1: Qualitative comparison of different methods to allocate resources in multiuser OFDM systems

Methods	Bit Error Rate	Sum Capacity	QoS	Increase in users increases performance?
Margin Adaptive	Better	NA	Fixed	Increases
Rate Adaptive	Better	Very Good	Bad	Increases
Rate Adaptive & Prop. Fairness	Better	Good	Very Good	Increases
Rate Adaptive & Equal Rates	Good	Good	Good	Increases
TDMA/FDMA	Ok	Bad	Bad	Increases

VII. Conclusion

OFDM represents a successful approach to mitigate ISI from wireless communication. Multiuser systems create channel diversity which increase with the number of users in the system. Exploiting the channel diversity in a multiuser OFDM system increases the performance of the system. Due to the varying conditions of the channel between the transmitter and receiver it is essential to adaptively allocate the subcarrier, bit and power levels based on instantaneous channel knowledge. This survey presents the various adaptive allocation algorithms with different constraints and their simulation results. In the end a qualitative analysis of the various methods including fixed and adaptive schemes is presented. I propose to study [6] and [7] in detail and simulate them with controlled parameters and compare them on BER/signal quality, sum capacity, the number of users, average channel power per user. I will also compare sum capacity of [6] & [7] to TDMA/FDMA approach in multiuser OFDM systems.

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