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Two-Stage Algorithm for Subcarrier, Bit and Power Allocation in OFDMA Systems

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ABSTRACT

Orthogonal Frequency Division Multiple Access (OFDMA) is considered as a modulation and multiple access method for fourth generation wireless networks. This scheme tries to minimize the required transmit power while satisfying the rate requirement and data error rate constraint of each user. It is based on the assumption of knowing the channel characteristics of all users at the base station. This algorithm shows that performance can be improved with initial subcarrier assignment followed by enhanced subcarrier allocation scheme. In proposed two-stage scheme, in first stage subcarriers and bits are allocated to users by the enhanced subcarrier allocation and in second stage iterative improvement schemes are used to improve the performance. The main advantages of proposed one are no need to predetermine the number of the assigned subcarriers for each user and reduces the total transmit power. Simulation results shows that the initial subcarrier assignment scheme with iterative improvement scheme (IIS2) achieves better performance and is close to that of optimum solution.
Keywords: Orthogonal Frequency Division Multiple Access (OFDMA), Initial Subcarrier Assignment Scheme (ISA), Iterative Improvement Schemes (IIS)

1. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) system divides a broadband channel into many narrowband subchannels. In OFDM systems, only a single user can transmit on all of the subcarriers at any given time, Multiuser-OFDM systems enhance this problem. Orthogonal Frequency Division Multiple Access (OFDMA) is a multiple access technique that allows multiple users to transmit simultaneously on the different subcarriers per OFDM symbol. In this technique a subset of all subcarriers are assigned to each user by the allocation algorithms. Multiuser diversity is achieved by adaptively adjusting subcarrier, bit and power allocation depending on channel status among users at different locations.

In the allocation of subcarriers and power to users we have two types of allocations (i)Margin-Adaptive (MA) resource allocation and (ii) Rate-Adaptive (RA) resource allocation processes. Margin-Adaptive (MA) resource allocation process objective is to minimize the total transmit power given a set of fixed user data rates and bit error rate (BER) requirements. The Rate-Adaptive (RA) resource allocation process objective is to maximize the total data rate over all users subject to power and BER constraints. The existing subcarrier allocation algorithms are investigated and enhanced in this paper [1],[2] and [4]. Based on the subcarrier allocation algorithm proposed by Chen et al.[4] an enhanced version of the allocation algorithm to solve subcarrier, bit, and power allocation problems with polynomial time of computational complexity is taken. It is a difficult problem to determine the numbers of subcarriers for each user. The subcarrier allocation algorithm proposed by Zhang [6] avoid this drawback and it is the first step in our proposed algorithm. The numbers of subcarriers for each user should be set adaptively according to mobile channel variations and transmit data rate requirements. Its major advantage is that there is no need to pre-determine the number for each user. The simulation results show that the new proposed algorithm outperforms those proposed by Wong [4] and Chen [5]. The performance is closer to that of the optimum solution with polynomial computational complexity

2. SYSTEM MODEL

The base station of the OFDM system estimates the instantaneous channel information of all users from the received signals on uplink transmission and adapts the transmit power, subcarriers, and bits on downlink transmission for all users by an allocation algorithm. Those control signals, such as subcarrier and bit allocation information, are sent to the destination receivers via a separate control channel. Perfect channel estimation is assumed in our development.

A system with K users and N subcarriers is considered. A subset of N subcarriers is assigned to a user, and the number of bits is also determined on downlink transmission. $\{h_{n,k}\}$ denotes the channel gains over all N subcarriers for the k^{th} user at subcarrier n. The number of bits of the n^{th} subcarrier assigned to user K is

$r_{n,k}$. The required received power f_k at a particular data error rate is a function of bits per symbol $r_{n,k}$. The power of noise is normalized to one. If the nth subcarrier is used by the k^{th} user, the required transmit power for the specified BER at $r_{n,k}$ bits per symbol is equal to

$$p_{n,k} = \frac{f_k(r_{n,k})}{h_{n,k}^2} \qquad (1)$$

In multiuser OFDM systems under consideration, we do not allow more than one user to share a subcarrier. To formulate the allocation problem, we define

$$\rho_{n,k} = \begin{cases} 1 \;\; if \;\; r_{n,k} \neq 0 \\ 0 \;\; if \;\; r_{n,k} = 0 \end{cases} \qquad (2)$$

The constraint is expressed as

$$p = \sum_{k=1}^{K} \rho_{n,k} \qquad (3)$$

The required transmit power can be expressed as

$$p = \sum_{n=1}^{N} \sum_{k=1}^{K} \frac{f_k(r_{n,k})}{h_{n,k}^2} \rho_{n,k} \qquad (4)$$

Data rates $\{R_1, R_2, \ldots, R_K\}$ are predetermined parameters for each user. The bit error rate must be ensured at a certain level to meet the service quality. The subcarrier, bit, and power allocation problem for the minimization of total transmit power is formulated as

$$\min_{r_{n,k}, \rho_{n,k}} \sum_{n=1}^{N} \sum_{k=1}^{K} \frac{f_k(r_{n,k})}{h_{n,k}^2} \rho_{n,k}$$

$$\text{Subject to } \sum_{k=1}^{K} \rho_{n,k} = 1, \text{for } n = 1, 2 \ldots N$$

$$\sum_{n=1}^{N} r_{n,k} = 1, \text{for } \; k = 1, 2 \ldots K \qquad (5)$$

This nonlinear optimization problem can be solved by employing integer programming (IP). Therefore, the formulation to achieve the optimal solution for the performance comparison is briefly summarized as follows

If $r_{n,k} \in \{0, 1, \ldots, M\}$, then

$$f_k(r_{n,k}) \in \{0, f_k(1), \ldots, f_k(M)\} \qquad (6)$$

A new indicator variable $\gamma_{n,k,r}$ is defined as

$$\gamma_{n,k,r} = \begin{cases} 1, \; if \quad \rho_{n,k} = 1 \; \text{ and } \; r_{n,k} = r \\ 0, \qquad \text{otherwise} \end{cases} \qquad (7)$$

Where $r \in \{0, 1, \ldots, M\}$ It follows that (6) is rewritten as

$$f_k(r_{n,k}) = \sum_{r=0}^{M} \gamma_{n,k,r} f_k(r) \qquad (8)$$

The required transmit power in (4) can be re-expressed as

$$P = \sum_{n=1}^{N} \sum_{k=1}^{K} \left\{ \sum_{r=0}^{M} \gamma_{n,k,r} \frac{f_k(r)}{h_{n,k}^2} \right\} \rho_{n,k} \qquad (9)$$

The indicators $\gamma_{n,k,r}$ and $\rho_{n,k}$ are related as

$$\rho_{n,k} = \sum_{r=0}^{M} \gamma_{n,k,r} \qquad (10)$$

Then the equation (9) is rewritten as a linear function:

$$P = \sum_{n=1}^{N} \sum_{k=1}^{K} \sum_{r=0}^{M} \gamma_{n,k,r} \frac{f_k(r)}{h_{n,k}^2} \qquad (11)$$

The linear integer programming-based branch-and-bound algorithm can be employed to solve this problem.

3. TWO-STAGE SUBCARRIER, BIT AND POWER ALLOCATION ALGORITHMS

The two-stage allocation algorithms consist of the initial subcarrier assignment and the iterative improvement two steps. In the first step subcarriers are assigned to users by an initial subcarrier assignment scheme [4-5]. After that the initial subcarrier assignment with the iterative improvement schemes used to enhance the performance. The two stages in the allocation process are described as follows.

STAGE 1: Initial Subcarrier Assignment (ISA)

Subcarrier Allocation Algorithm: In Zhang's algorithm [6] each single user is initially supposed to be able to use all subcarriers. The optimal bit allocation is obtained by the water-filling method. In this algorithm there is no need to be pre-determined number of subcarriers for each user.

The step by step procedure of this algorithm is as follows:

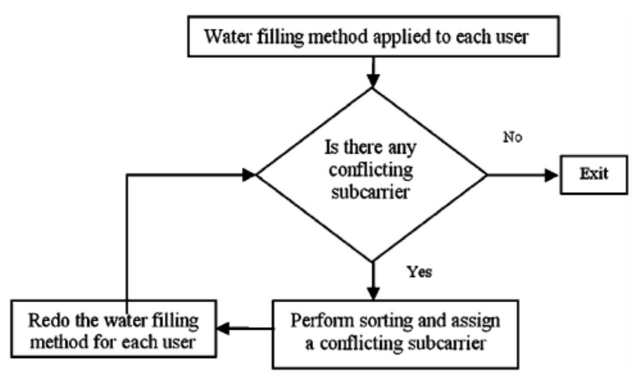

Fig.2: Subcarrier Allocation Algorithm

Step 1: For each user, apply the single user subcarrier and bit allocation algorithm (i.e. the greedy water-filing algorithm) to allocate subcarriers and bits to the user. The transmit power of each user on each subcarrier is computed. If a subcarrier that is in the list of desired subcarriers of several users, then this subcarrier is called a conflicting subcarrier.

Step 2: If there is no conflicting subcarrier, then the optimal allocation solution for multiuser OFDM systems is found. Otherwise, the conflict of desired subcarriers needs to be resolved. Suppose a conflicting subcarrier *k* is in the desired list of M users ($n_1, n_2 \ldots n_M$). Define the total transmit power on subcarrier k as the sum of each user's transmit power on this conflicting subcarrier. Arrange the conflicting subcarriers in the order of decreasing total transmit power of the subcarrier.

Step 3: The conflicting subcarrier with the largest power is chosen to start. The conflicting subcarriers are assigned to users in turn. Once a conflicting subcarrier is assigned to a user, other users are required to reallocate the bits which are allocated to this subcarrier currently. The required total transmit power after re-assigning of bits is re-computed.

Step *4*: The user providing the minimum total transmit power increase of the bit reassignment is selected to use the conflicting subcarrier. Then, the subcarriers and the bits are reallocated according the water-filling method. New conflicting subcarriers may be generated during the process. The procedure is performed iteratively until there is no conflicting subcarrier.

We combine the Zhang et al. algorithm with the iterative improvement schemes to provide better performance.

STAGE 2: Iterative Improvement Schemes (IIS)

A. IIS_1 : Subcarrier Swapping Scheme: After the initial subcarrier assignment in the first phase, it swaps subcarriers between users iteratively to improve the performance. All swapping cases between paired users are listed to form the power reduction list $\{p_{i,j}\}$

The power reduction factor *Pi,j* is defined as

$$p_{i,j} = \Delta p_{i,j} + \Delta p_{j,i} \tag{12}$$

Where Δ*Pi,j* is the amount of power reduction for the paired user (*i, j*) when a subcarrier assigned to user *i* is reallocated to user *j* and a subcarrier assigned to user *j* is reallocated to user *i*. Note that we may have a few possible values of $\{\Delta p_{i,j} + \Delta p_{j,i}\}$ for the paired-user (*i, j*). After constructing all the best swapping cases between paired users to form the power reduction list, we select the case with respect to the maximum of {*Pi,j*} to do the associated subcarrier swapping. If *Pi,j* is positive, it means that the new total transmit power after the subcarrier swapping is reduced. After the swapping, the power reduction factors *{Pi, j}* are updated, and we proceed to the next iteration. We terminate the iteration when the entire updated power reduction factors are negative, which implies that the total transmit power cannot be further reduced by swapping subcarriers between two users.

B. IIS_2 : Enhanced Subcarrier Allocation Algorithm: The enhanced subcarrier allocation algorithm performs either the swapping or the reallocation operation. It is believed that the required total transmit power can be further reduced if the number of subcarriers for each user could be adaptively adjusted.

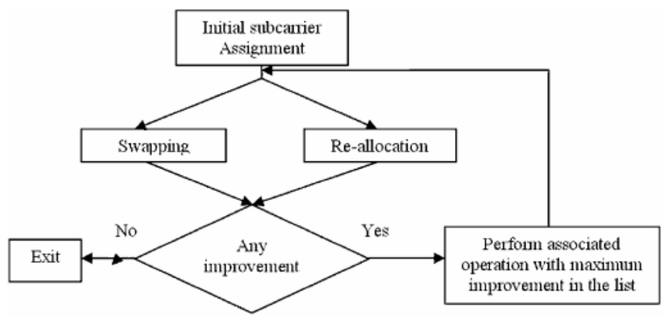

Fig.3: Enhanced Subcarrier Allocation Algorithm

The reallocation operation is to assign a subcarrier which is owned by one user to another user. Similar to swapping operation, only one case related to the maximum power reduction would be selected to reallocate subcarriers between paired users. The new extended power reduction list is explained as follows:

If $P(S_k)$ is the transmit power for user *k* with the required data rate R_k while the number of subcarriers assigned to user *k* is S_k, we define a new power reduction factor of the subcarrier relocation for the paired-user (*i, j*), i.e.,

$$p'_{i,j} = \Delta p'_{i,j} + \Delta p'_{j,i} \tag{13}$$

Where

$$\Delta p'_{i,j} = p(s_i) - p(s_i - 1) \tag{14}$$

$$\Delta p'_{j,i} = p(s_j) - p(s_j + 1) \tag{15}$$

the new power reduction list becomes $P_r = P \cup P'$

$$= p_{1,2}, p_{1,3}, \ldots\ldots p_{2,1\ldots\ldots}, p_{i,j\ldots\ldots\ldots} \cup$$

$$p'_{1,2}, p'_{1,3}, \ldots\ldots p'_{2,1}\ldots\ldots, p'_{i,j}\ldots\ldots\}$$

Where $P = p_{1,2}, p_{1,3}, \ldots\ldots p_{2,1\ldots\ldots}, p_{i,j\ldots\ldots\ldots}$ and

$$P' = p'_{1,2}, p'_{1,3}, \ldots\ldots p'_{2,1}\ldots\ldots, p'_{i,j}\ldots\ldots$$

4. SIMULATION RESULTS

The proposed algorithms are applied to an adaptive multiuser OFDM system. The modulation employed is no transmit, QPSK, 16QAM and 64QAM. The total allowed data rate is 36 Mbits/s, and the symbol rate per subcarrier is 250 Ksymbols/sec. 48 subcarriers are used in simulations, the center frequency is 5 Ghz and the frame duration is 10ms. Figs. 4 and 5 shows the relative transmit power compared with the number of users with different target BERs and channel power differences. The proposed heuristic algorithms are ISA + IIS_1 and ISA + IIS_2.

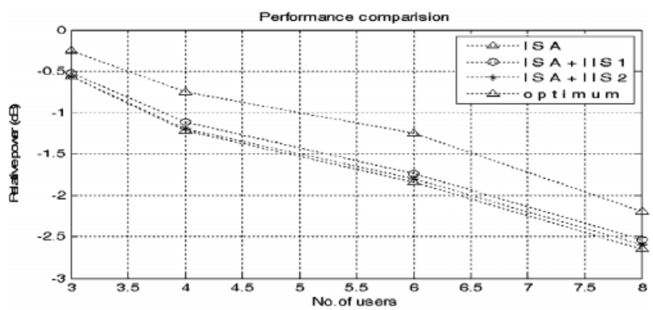

Fig.4: **Performance Comparison in Terms of Required Transmit Power Among Schemes the Largest Channel Power Difference Among Users=15dB, Target BER=10^{-2}**

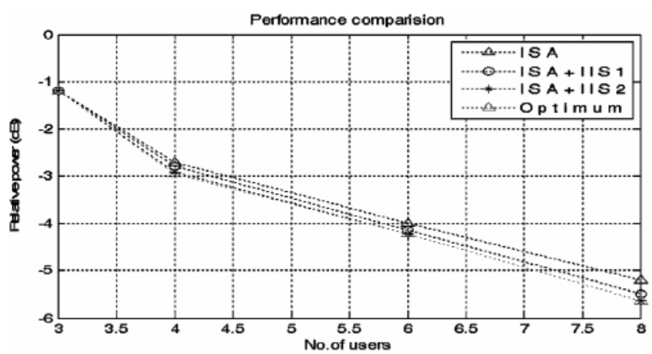

Fig.5: Performance Comparison in Terms of Required Transmit Power Among Three Schemes, the Largest Channel Power difference Among Users = 30dB, Target BER=10^{-4}

The performance of newly proposed heuristic algorithm ISA+IIS_2 is much close to that of optimal solution obtained from branch and bound algorithm, it reveals that the initial subcarrier assignments followed by enhanced subcarrier allocation (IIS_2) achieve better performance.

5. CONCLUSIONS

This paper proposes new heuristic algorithms to solve the subcarrier, bit, and, power allocation problem in polynomial computational complexity. The numbers of subcarriers for each user should be set adaptively according to mobile channel variations and transmit data rate requirements. The proposed schemes outperform the heuristic algorithms proposed by Wong et al.and chen et.al. initial subcarrier assignment combined with better iterative improvement schemes achieves better performance. Simulation results show that the performance of the proposed heuristic algorithm is close to that of the optimum solution. Some additional initial allocation schemes with lower complexity in the first phase for the two-phase allocation schemes will be developed in the future.

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