Adaptive Resource Allocation with Proportional Rate Constraints for OFDMA Based Next Generation Networks

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ABSTRACT
The primary objective of the Next Generation Networks, which are based on Multiuser Orthogonal frequency division multiplexing (MU-OFDM) is to increase the network efficiency by maximizing the total throughput of the system and minimizing the overall transmit power for a give quality of service (QOS). MU-OFDM is one of the promising techniques for achieving high downlink capacities in future cellular and wireless networks. The sum capacity of MU-OFDM is maximized when each subchannel is assigned to the user with the best channel-to-noise ratio for that subchannel, with power subsequently distributed. Ever increasing demand for high throughput, low delay and low Outage probability can be met by using Adaptive Resource Allocation in OFDM Technology. Optimal solution to the constrained fairness problem of Adaptive Resource Allocation is extremely computationally complex to obtain, a low-complexity suboptimal algorithm that separates subchannel allocation and power allocation is proposed. In the proposed algorithm, subchannel allocation is first performed by assuming an equal power distribution. Power allocation is done later to maximizes the sum capacity.

Keywords
OFDM; Adaptive Resource Allocation; sum capacity.

1. INTRODUCTION
Orthogonal frequency division multiplexing (OFDM) is a promising technique for the next generation of wireless communication systems [1], [2]. OFDM is based on the concept of multicarrier transmission. The idea is to divide the broadband channel into N narrowband subchannels each with a bandwidth much smaller than the coherence bandwidth of the channel. The high rate data stream is then split into N sub streams of lower rate data which are modulated into N OFDM symbols and transmitted simultaneously on N orthogonal subcarriers. Besides the improved immunity to fast fading [3] brought by the multicarrier property of OFDM systems, multiple access is also possible, because the subchannels are orthogonal to each other. There are two classes of resource allocation schemes namely: 1) fixed resource allocation [4]; and 2) Adaptive or dynamic resource allocation [5]–[8]. Fixed resource allocation schemes, such as time division multiple access (TDMA) and frequency division multiple access (FDMA), assign an independent dimension, e.g., time slot or subchannel, to each user. A fixed resource allocation scheme is not optimal, since the scheme is fixed regardless of the current channel conditions. On the other hand, dynamic resource allocation allocates a dimension adaptively to the users based on their channel gains. Due to the time-varying nature of the wireless channel, dynamic resource allocation makes full use of multiuser diversity to achieve higher performance. In fixed resource allocation schemes, an independent dimension is allocated to each user without considering the channel status. In such systems, the optimization problem of maximizing the total throughput of the system reduces to only power allocation or bit loading on the subcarriers. On the other hand, since the fading parameters for different users are mutually independent, the probability that a subcarrier is in deep fade for all users is very low. In other words, each subcarrier is likely to be in good condition for some users in the system. This is the principle of Orthogonal Frequency Division Multiple Access (OFDMA) scheme with adaptive resource allocation in which subcarrier allocation itself plays a very significant role in maximizing the total throughput by using multiuser diversity.

There are two classes of optimization techniques proposed in the literature, namely: 1) margin adaptive (MA) [5]; and 2) rate adaptive (RA) [6], [7]. The MA objective is to achieve the minimum overall transmit power given the constraints on the users' data rates or bit error rates (BER). The RA objective is to maximize each user's error free capacity with a total transmits power constraint. These optimization problems are nonlinear and, hence, computationally intensive to solve. In [8], the nonlinear optimization problems were transformed into a linear optimization problem with integer variables. The optimal solution can be achieved by integer programming. However, even with integer programming, the complexity increases exponentially with the number of constraints and variables.

Adaptive Resource Allocation algorithm in Multiuser OFDM systems with Proportional Rate Constraints has been proposed in [9]. In [9] subcarrier and power allocation has been done separately. Subcarrier allocation algorithm in [9] initially allocates one subarrier to each user irrespective of their data rate requirement and subsequently more subcarriers are allocated to the same user depending on the proportional rate constraints of the user. After subcarrier allocation to different users, the authors in [9] have also given algorithms to optimally allocate power to each user depending on their proportional rate constraints and then to allocate power to individual subcarriers for a single user using Water Filling Algorithm.

In this paper we have proposed an algorithm, wherein the initial subcarrier allocation itself is based on the data rate requirement of the users, i.e. user who has more data rate requirement is allocated subcarrier first. Then subsequent subcarriers are allocated according to [9].

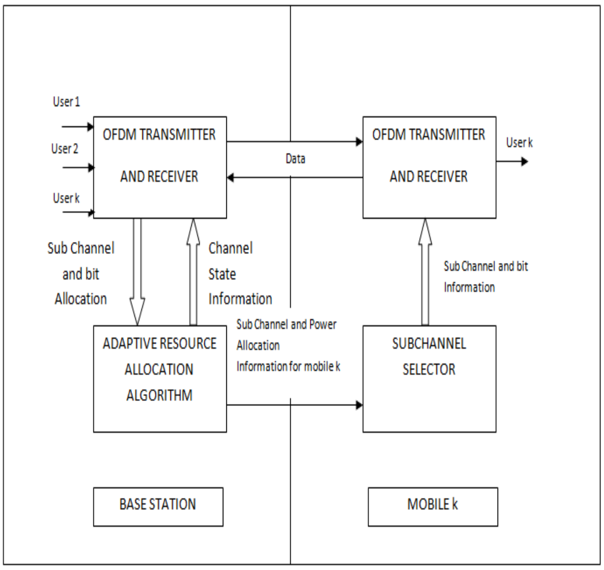

Fig. 1 Multiuser OFDM Block Diagram.

This increases the sum data rate and Maximum User's achievable data rate compared to [9]. Moreover, the power allocation to the users and to the subcarriers of a single user can also be done according to [9].

The paper is organized as follows; Section 2 introduces the multiuser OFDM system model and presents the optimization objective function. In Section3, the sub-optimal multiuser subcarrier and power allocation algorithms are developed and discussed. In section 4, simulation results are presented.

2. SYSTEM MODEL

A multiuser OFDM system is shown in fig 1. In the base station, all channel information is sent to the subchannel and power allocation algorithm through feedback channels from all mobile users. The resource allocation scheme made by the algorithm at the base station is forwarded to the OFDM transmitter. The transmitter then selects different numbers of bits from different users to form an OFDM symbol. The resource allocation scheme is updated as fast as the channel information is collected. In this paper, perfect instantaneous channel information is assumed to be available at the base station, and only the broadcast scenario is studied. It is also assumed that the subchannel and bit allocation information is sent to each user by a separate channel

In this paper, we assume a total of K users in the system sharing N subchannels, with total transmit power constraint . Our objective is to optimize the subchannel and power allocation in order to achieve the highest sum error free capacity under the total power constraint. We use the equally weighted sum capacity as the objective function, but we introduce the idea of proportional fairness into the system by adding a set of nonlinear constraints. The benefit of introducing proportional fairness into the system is that we can explicitly control the capacity ratios among users, and generally ensure that each user is able to meet his target data rate, given sufficient total available transmit power.

Mathematically, the optimization problem considered in this paper is formulated as:

$$\max_{p_{k,n},\rho_{k,n}} \sum_{k=1}^{K}\sum_{N=1}^{N}\frac{\rho_{k,n}}{N}\log_2\left(1+\frac{p_{k,n}h_{k,n}^2}{N_o\frac{B}{N}}\right)$$

$$\text{subject to } \sum_{k=1}^{K}\sum_{n=1}^{N}p_{k,n}\le P_{total}$$

$$p_{k,n}\ge 0 \text{ for all k, n}$$

$$\rho_{k,n}=\{0,1\} \text{ for all k, n}$$

$$\sum_{k=1}^{K}\rho_{k,n}=1 \text{ for all n}$$

$$R_1:R_2:\ldots:R_k=\gamma_1:\gamma_2:\ldots:\gamma_K \qquad (1)$$

where K is the total number of users, N is the total number of subchannels, is the power spectral density of AWGN, B and are the total available bandwidth and power, respectively, is the power allocated for user k in the subchannel n, is the channel gain for user k in subchannel n, and can only be either 1 or 0, indicating whether subchannel n is used by user k or not. The fourth constraint shows that each subchannel can only be used by one user.

The capacity for user k, denoted as:

$$R_k=\sum_{n=1}^{N}\frac{\rho_{k,n}}{N}\log_2\left(1+\frac{p_{k,n}h_{k,n}^2}{N_0\frac{B}{N}}\right) \qquad (2)$$

Finally $\{\gamma_i\}_{i=1}^{K}$ is a set of predetermined values that are used to ensure proportional fairness among users.

The fairness index (F) can be defined as below:

$$F=\frac{\left(\sum_{k=1}^{K}\gamma_k\right)^2}{K\sum_{k=1}^{K}\gamma_k^2}$$

with the maximum value of 1 to be the greatest fairness case in which all users would achieve the same data rate. When all terms are equal, the objective function in (1) is similar to the objective function of the max–min problem [7], since maximizing the sum capacity while making all terms equal is equivalent to maximizing the worst user's capacity3].

3. SUBOPTIMAL SUBCHANNEL ALLOCATION AND POWER DISTRIBUTION

Ideally for optimal solution of (1) subchannnel and power should be allocated jointly. However it poses a prohibitive computional burden at the base station for obtaining the optimal solution. Furthermore, the base station has to rapidly compute the optimal subchannel and power allocation as the wireless channel changes. Hence, for cost-effective and delay-sensitive implementations, low-complexity suboptimal algorithms are preferred. Sections 3.1 discuss a subchannel allocation scheme and Section 3.2 presents the power distribution scheme.

3.1 Suboptimal Subchannel Allocation

In this section, we are proposing a suboptimal subchannel allocation algorithm. This algorithm is based on [9] but the proposed modifications have been found to show considerable improvement in the results. In the suboptimal subchannel allocation algorithm, equal power distribution is assumed across all subchannels.

Let $H_{k,n} = \left(h_{k,n}^2 / N_0 (B/N)\right)$ as the channel-to-noise ratio for user k in subchannel n and is the set of subchannel assigned to user k. The algorithm is described as follows:

1) Initialization
   a) Set $R_k = 0$, $\Omega_k = \phi$, loop = 1 for k = 1,2,.....,K and A = {1,2,.....,N}.
2) For loop=1 to K
   a) Find k satisfying $\gamma_k \geq \gamma_i$ for all i, $1 \leq i \leq K$;
   b) For the found k, find n satisfying $|H_{k,n}| \geq |H_{k,j}|$ for all j $\in$ A;
   c) Let $\Omega_k = \Omega_k \cup \{n\}$, A = A-{n} and update R_k according to (2).
   d) Set loop = loop+1.
3) While $A \neq \phi$
   a) Find k satisfying $R_k/\gamma_k \leq R_i/\gamma_i$ for all i, $1 \leq i \leq K$;
   b) For found k, $|H_{k,n}| \geq |H_{k,j}|$ find n satisfying for all j $\in$ A;
   c) For the found k and n, let $\Omega_k = \Omega_k \cup \{n\}$, A = A-{n} and update according to (2).

The principle of the suboptimal subchannel algorithm is for each user to use the subchannels with high channel-to-noise ratio as much as possible. The subchannel allocation algorithm is suboptimal, because equal power distribution in all subchannels is assumed.

3.2 Power Distribution for a Fixed Subchannel Allocation

A. Power distribution among users:

Defining $P_{k,tot}$ as the total power allocated for user k, thus $P_{k,tot}$ can be expressed as:

$$P_{k,tot} = \left(\frac{\gamma_k}{\sum_{i=1}^{K} \gamma_i} \right) P_{total} \quad \text{where ;} \qquad (4)$$

subject to $\sum_{k=1}^{K} P_{k,tot} = P_{total}$

Where γ_k is data rate requirement of user k and P_{total} is the total power available at the base station.

B. Power distribution for a single user:

We assume that $H_{k,1} \leq H_{k,2} \leq \ldots \leq H_{k,N_k}$ for k=1, 2,..,K and N_k is number of subchannel in Ω_k Thus for a fixed subcarriers assignment and power assignment among users, power can be distributed among the subcarriers of a single user as:

$$P_{k,n} = \left(\frac{H_{k,n}}{\sum_{i=1}^{N_k} H_{k,i}} \right) P_{k,tot} \qquad (5)$$

Thus the proposed Resource allocation algorithm can be described in the following three steps:

1) Subcarrier allocation among different users
2) Power distribution among different users
3) Power distribution among different subcarriers of a single user

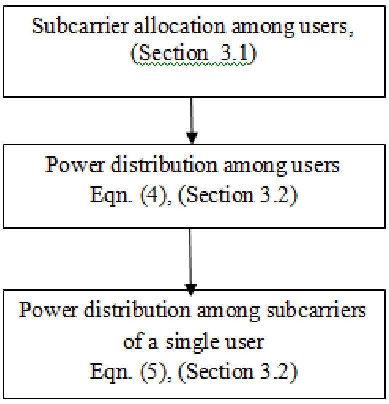

Fig. 2: Proposed resource Allocation Algorithm

All these steps should be executed sequentially for the proposed adaptive resource allocation scheme as shown in Fig.2.

4. SIMULATION RESULTS

In this section, we present simulation results to show the performance of the proposed resource allocation algorithm. In all simulations presented in this section, the wireless channel is modeled as a frequency-selective channel Simulation has been done in Matlab and following parameters have been considered for simulation purpose

Table1: Simulation Parameters

Total Power Available at the Base Station	1W
AWGN power spectral density	-30 dBW/Hz
Overall Bandwidth	1MHz
Number of OFDMA subchannels	64
Number of Simulations	500

We have two parts of our simulation results. The first part shows sum data rate performance comparison between the proposed method and the method in [9]. The second part shows maximum user's achievable data rate performance comparison of the proposed method with the method in [9]. The simulation result in first part has been shown in fig 3. It is shown that sum data rate increases with the number of users. Fig 3 also shows considerable improvement in sum data rate with proposed method over method in [9]. The result for the second part has been shown in fig 4. It is shown that maximum user's achievable data rate decreases with the number of users. Fig 4 also shows considerable improvement in maximum user's achievable data rate with the proposed method over method in [9].

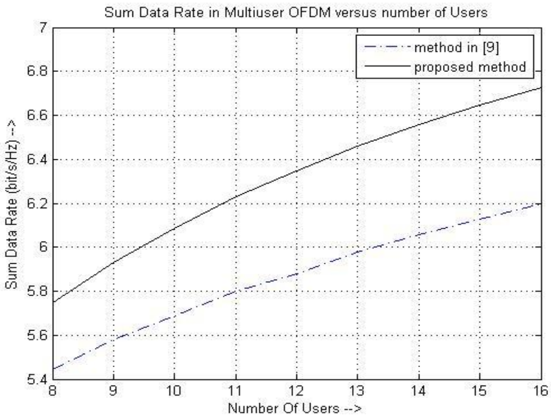

Fig 3: Comparison of sum data rate v/s number of user for method in [9] and proposed method.

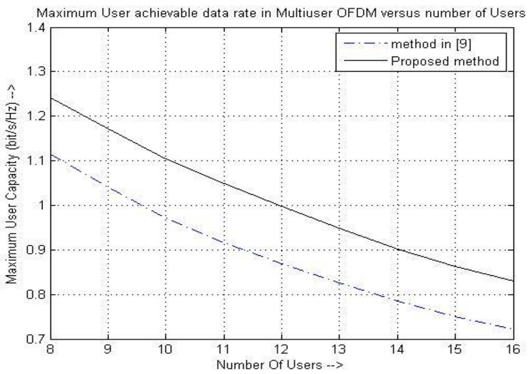

Fig 4:Comparison of maximum user's achievable data rate v/s number of user for method in [9] and proposed method.

5. CONCLUSION

This paper described suboptimal subchannel allocation and power allocation algorithms for the downlink of a multi-user OFDM system. Simulation results indicated that the proposed method provides a considerable improvement for sum data rate over the method in [9]; because in [9] the first subcarrier is allocated to a user irrespective of their data rate requirement and a user with less data rate requirement may get allocated a channel with good condition. But in our proposed method first subcarrier is allocated to a user who has the highest data rate requirement. Thus it is more likely that good channels are [10] allocated to users who have more capacity requirements. Also the sum data rate increases with the number of users which can be explained by the multiuser diversity.

This means as the number of users in the system increases it lowers the probability that a given subchannel is in a deep fade for all users. The proposed method also provides a considerable improvement for maximum user's achievable data rate over method in [9]. This can be explained from the fact that the proposed method provides more priority to the user whose data rate requirement is more.

6. REFERENCES

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