Adaptive Resource Allocation in OFDMA System: A Review

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ABSTRACT
The need for high capacity downlink in wireless mobile network in future is very much essential and efforts are being made to identify appropriate techniques to attain high capacity downlink. Latest approaches indicated that the orthogonal frequency division multiple access (OFDMA) technique is emerging as a potential technique. While the other techniques result inter-carrier interference, OFDMA technique over comes this problem due to orthogonal location of sub-carriers. This gives advantage by obviating the need for inter-carrier guard band. The issues of efficient utilization of bandwidth, minimizing power consumption and fair distribution of resources among users are central to determine the appropriate technique to be used for resource allocation. This paper discusses various techniques suggested by the researchers for resource allocation and concludes that adaptive algorithm is more efficient compared to static TDMA/FDMA system.

Keywords
wireless mobile network, OFDMA, resource allocation, fairness.

1. INTRODUCTION
In the wireless networks, many resource allocation schemes have been proposed that are categorized in static scheme, and dynamic scheme. The static schemes are fixed regardless of the current channel condition i.e. TDMA, FDMA. The dynamic schemes on the other hand that allocates the resources to the users adaptively. The OFDMA system is a dynamic system and provides the high data transmission rate with quality of services that are required by applications including multimedia and on demand services in mobile communication. The OFDMA divides the entire transmission bandwidth into N orthogonal subchannels [1] [2] [3]. The orthogonal channels eliminate intersymbol interference (ISI) in wideband transmission. Lets K denotes the number of users in the system that share N subchannels with total transmit power constraint P_{total} and bandwidth B [4] [5]. The transmitter at base station assign power $p_{k,n}$ to the subcarrier n ($1 \leq n \leq N$) of user k ($1 \leq k \leq K$). The bits of users modulated into NM- level quadrature amplitude modulated (QAM) symbols and generate the OFDMA symbol using the inverse fast Fourier transform (IFFT) [6]. The fading and channel gain is a major issues in wireless networks and it can be represented by $g_{k,n}$ of user k in subcarrier n. The additive white gaussian noise (AWGN) is defined as $\sigma^2 = N_0 B/N$ where N_0 is the noise power spectral density [7] [8]. The corresponding subchannel-to-noise ratio $h_{k,n} = g^2_{k,n}/\sigma^2$ and the k^{th} user's received signal-to-noise ratio (SNR) on subcarrier n is $\gamma_{k,n} = p_{k,n} h_{k,n}$.

2. ADAPTIVE RESOURCE ALOCATION ALGORITHM
There are different adaptive algorithms for OFDMA systems to allocate the resources. The key algorithms are given as follows.

2.1 Suboptimal Sub-Carrier Allocation
In [1], author Wonjong Rhee and John M. Cioffi developed an algorithm that allocates sub channels dynamically and increase the capacity of multiuser OFDMA system. In the FDMA and TDMA system, the non-adaptively methods are used to allocate the subcarriers and water filling method is used for power allocation. Since the sub channel allocation among users is not optimized, the author developed a low complexity adaptive sub channel allocation algorithm that is as follow.

The channel allocation algorithm can be described as [1]:

[1] Initialization

- $R_k = 0$ for all k=1…K and A= {1, 2, …, K}

[2] For k=1 to K

- Find sub channel n with highest channel gain
- update A=A- {n} and

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

[3] while A $\neq$ Ø

- Find the user k with lowest data-rate
- Find sub channel n with highest channel gain
- update A=A- {n} and

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

The objective of this method is to maximize the minimum user's capacity by equally normalized proportionality constraints for each user.

2.2 Optimal Power Allocation

Optimal power allocation method was proposed in [2] by Shen, Andrews, and Evans for multiuser OFDM system. It allocates power to the users proportionally. Also, the power and sub-carrier allocation are carried out sequentially to reduce the complexity of the method.

The optimal power allocation method for a single user is derived as

$$\frac{H_{k,m}}{1+H_{k,m}p_{k,m}}=\frac{H_{k,n}}{1+H_{k,n}p_{k,n}}$$

Where $H_{k,n}=\dfrac{h_{k,n}{}^{2}}{N_0\dfrac{B}{N}}$ is channel-to-noise gain for user k in sub-carrier n.

m, n $\in \Omega_k$ (Ω_k is a set of sub-carriers assigned to user k) and k=1,2,3,…K.

$p_{k,n}\geq 0$ for all k and n.

The total power allocation for user k defined as

$$p_{k,total}=\sum_{n=1}^{N_k}p_{k,n}=N_k p_{k,1}+\sum_{n=2}^{N_k}\frac{H_{k,n}-H_{k,1}}{H_{k,n}H_{k,1}}$$

Where N_k is number of sub-carriers in Ω_k.

The power distribution among users can be determined if set $\left(p_{k,total}\right)_{k=1}^{K}$ is known [2]. The total power constraints and capacity ratio constraints $R_1:R_2:...:R_K=N_1:N_2:...:N_K$ are used to obtain $\left(p_{k,total}\right)_{k=1}^{K}$. The capacity ratio constraints can be expressed as

$$\frac{1}{\lambda_1}.\frac{N_1}{N}\left(\log_2\left(1+H_{1,1}\frac{p_{1,total}-V_1}{N_1}\right)+\log_2 W_1\right)$$

$$=\frac{1}{\lambda_k}.\frac{N_k}{N}\left(\log_2\left(1+H_{k,1}\frac{p_{k,total}-V_k}{N_k}\right)+\log_2 W_k\right)$$

Where k=2,3,…,K,

$$V_k=\sum_{n=1}^{N_k}\frac{H_{k,n}-H_{k,1}}{H_{k,n}H_{k,1}}\quad\text{and}\quad W_k=\left(\prod_{n=2}^{N_k}\frac{H_{k,n}}{H_{k,1}}\right)^{\frac{1}{N_k}}$$

The set of above equations can be transformed into a set of simultaneous linear equations [7] as follow

$$\begin{bmatrix}1 & 1 & \cdots & 1\\ 1 & a_{2,2} & \cdots & 0\\ \vdots & \vdots & \ddots & \vdots\\ 1 & 0 & \cdots & a_{K,K}\end{bmatrix}\begin{bmatrix}p_{1,total}\\ p_{2,total}\\ \vdots\\ p_{K,total}\end{bmatrix}=\begin{bmatrix}p_{total}\\ b_2\\ \vdots\\ b_K\end{bmatrix}$$

Where

$$a_{k,k}=-\frac{N_1}{N_2}\frac{H_{k,1}W_k}{H_{1,1}W_1}\quad\text{and}$$

$$b_k=\frac{N_1}{H_{1,1}W_1}\left(W_k-W_1\frac{H_{1,1}V_1W_1}{N_1}-\frac{H_{k,1}V_kW_k}{N_k}\right)$$

The solution of simultaneous linear equation is as follow.

$$\begin{bmatrix}a_{K,K} & 0 & \cdots & 1\\ 0 & a_{K-1,K-1} & \cdots & 1\\ \vdots & \vdots & \ddots & \vdots\\ 1 & 1 & \cdots & 1\end{bmatrix}\begin{bmatrix}p_{K,total}\\ p_{K-1,total}\\ \vdots\\ p_{1,total}\end{bmatrix}=\begin{bmatrix}b_K\\ b_{K-1}\\ \vdots\\ p_{total}\end{bmatrix}$$

Perform LU factorization on the coefficient matrix to obtain

$$L=\begin{bmatrix}1 & 0 & \cdots & 0\\ 0 & 1 & \cdots & 0\\ \vdots & \vdots & \ddots & \vdots\\ \dfrac{1}{a_{k,K}} & \dfrac{1}{a_{K-1,K-1}} & \cdots & 1\end{bmatrix}$$

and

$$U=\begin{bmatrix}a_{K,K} & 0 & \cdots & 1\\ 0 & a_{K-1,K-1} & \cdots & 1\\ \vdots & \vdots & \ddots & \vdots\\ 0 & 0 & \cdots & 1-\sum_{k=2}^{K}\dfrac{1}{a_{k,k}}\end{bmatrix}$$

After solving matrix, the individual powers are given by

$$p_{1,total}=\left(p_{total}-\sum_{k=2}^{K}\frac{b_k}{a_{k,k}}\right)/\left(1-\sum_{k=2}^{K}\frac{1}{a_{k,k}}\right)$$

and

$$p_{k,total}=\left(b_k-p_{1,total}\right)/a_{k,k}\quad\text{for k=2,3,…,K.}$$

2.3 Sub-Carrier Allocation with Proportional Rate Constraints

Shen, Andrew and Evan also proposed a sub-carrier allocation algorithm with proportional rate constraints [3] where proportion rates $\phi_1 : \phi_2 : \phi_3 : ... : \phi_K$ are not equal. The method proposed in [1] is to maximize the minimum user's capacity by $\phi_1 : \phi_2 : \phi_3 : ... : \phi_K = 1 : 1 : 1 : ... : 1$ where assumed sub-carriers and power allocation to each user is equal. In [3] , a low complexity algorithm was proposed that handle sub-carrier and power allocation separately. For power allocation, the greedy water-filling algorithm was adopted to maximize the capacity.

2.4 Resource Allocation based on Decode-and-Forward Relaying Networks

Author Pan, Nix, and Beach utilized a decode-and-forward cooperation strategy [9] to maximize the total capacity. This strategy is based on the individual transmission power constraint and provides QoS to a user. It is provides proportional fairness to the users according to their data requirements. The authors proposed an efficient greedy resource allocation algorithm for both centralized and distributed based upon their analysis.

2.5 Other Resource Allocation Methods

In [10], a fast optimal algorithm is proposed for solving radio resource allocation problem in OFDMA system based on branch and bound approach. The branch-and-bound is a generic optimal searching approach that has two procedures. Fist procedure is branching which is based on divide and conquers method where the feasible region of a problem is divided into subregions to create smaller size of subproblems. The second procedure is bounding which finds upper and lower bounds for the solution within a feasible subregion. This proposed algorithm reduced computational complexity and its performance is same as some other existing algorithm.

In [11], author introduced relay nodes into cellular networks that gain the system capacity, and extend the coverage area. They also handle challenges of resource allocation in this new architecture. In this paper, the resource allocation problem is divided into two parts. The first part is a proposed heuristic algorithm that assigns the sub-carriers to each link. In the second part, an iterative power allocation algorithm was proposed that balance the two-hop links for each relay node. With the help of experimental results, the authors found that the proposed algorithm improved the performance of the system with low computational complexity.

Based on the genetic algorithm, an adaptive resource allocation algorithm [12] was proposed by Lin, Jinang, and Yuan. The purpose of an algorithm was considered the resource allocation problem and formulated to maximize the sum capacity with power constraint. For fairness some proportional constraints are also added to ensure that the each user can achieve a required data rate. The results demonstrate that the proposed method is more efficient than conventional method, and it can improve the system performance. In paper [13], the authors developed a sequential linear resource assignment algorithm for OFDMA system consist of M users and N resources (where N is greater than M) which can achieve near optimal energy consumption with polynomial complexity. In linear assignment, a single resource is assigned to a single user. The objective of this algorithm is to minimize the total cost of system.

The complexity is a major issue in many algorithms. The author [3] took this problem in account and proposed an adaptive resource allocation algorithm for OFDM system that reduces computational complexity. The problem is divided into two sub-problems: a combinational optimization sub-problem for sub-carrier assignment and relay selection, and a convex optimization sub-problem for power allocation in base station and relay stations. The first iterative algorithm was proposed for combinational optimization sub-problem to exploit multiuser diversity and second iterative algorithm for convex optimization sub-problem to exploit available power efficiently. A proportional resource allocation with low complexity algorithm was proposed by authors in [7]. In this paper, allocation of sub-carrier and power is proportional to user data rates that maximize the sum capacity of the system. It is a non-iterative method and has a low complexity. In [14], authors develop a genetic algorithm for adaptive sub-carrier and power allocation in OFDMA system. The steps of GA are following.

- **Encoding:** The encoding represents the individual genes. It can be bits, numbers, trees, arrays, lists or any other objects.
- **Selection:** Selection chooses two best chromosomes from population for crossover. The chromosomes are selected from the population to be parents of reproduction.
- **Crossover:** Crossover operates on two chromosomes at a time and generates new offspring of batter fitness.

3. CONCLUSION

The performance of OFDMA system can be enhanced with the effective resource allocation algorithms. In this paper, various algorithms related to resource allocation have been described. The purpose of these algorithms is improvements in the system. Some algorithms keep the system fair with proportional resource allocation in the system. Others are emphasized on the power allocation to the sub-carriers and designed an optimal power allocation method. Also, the complexity of algorithm is an important issue and it can be reduced by allocation of sub-carrier and power subsequently.

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