Adaptive Modulation Technique with Partial CQI for Multiuser OFDMA Systems

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Abstract — **In this paper, we present a new scheme for sub-band allocation in multiuser downlink orthogonal frequency division multiple access (OFDMA) systems with partial channel quality information (CQI). Our objective is to maximize the total throughput of the system under the constraints of transmit power. In previous methods, each user in a cell transmits CQI of its all sub-bands to the base station, which requires extremely high feedback overhead. Thus, we propose an efficient sub-band allocation algorithm in which each user transmits partial CQI and one additional information to reduce the amount of feedback. Simulation results show that we can greatly reduce the amount of feedback than full feedback system.**

Keywords — **multiuser downlink OFDMA, sub-band allocation, partial CQI, reduced feedback**

1. Introduction

Recently, demands for new multimedia service have been increased in wireless communication systems. To serve multimedia services efficiently and to satisfy the demand for higher data rate, advanced technologies should be applied to adaptive modulation and multiple access schemes. Among various multiple access schemes, OFDMA is considered as an attractive solution for the next generation multiple access scheme since it can allocate each frequency band to the user with the largest channel gain at each frequency band in frequency selective fading channels [1]-[3]. In previous papers, some suboptimal sub-band and power allocation methods with whole sub-band CQI have been proposed: the total power minimization method under a given throughput [1][2] and the throughput maximization method under a given total amount of power [3]. However, in practice, the previous methods are not applicable for mobile communication systems, which should support both high mobility and high frequency selectivity, because of their high computational complexity and extremely high feedback overhead. To solve this problem, a sub-band allocation method has been proposed, which uses the partial sub-band CQI of the selected sub-bands and additional channel information, the average channel gain of all sub-bands [4]. In this scheme, the average channel gain is used for the CQI of the null-bands (sub-bands without CQI at the base-station). Thus, the target bit error rate (BER) is not satisfied when the true channel gain of a null-band is lower than the average channel gain, which results in a packet loss.

In this paper, we consider a multiuser OFDMA system with the following two constraints: the first one is that a base station can use fixed amount of power and the second one is that the number of sub-bands allocated to each active user is fixed. The second constraint is introduced to take a practical physical layer frame structure, such as in [6], into account. As indicated earlier, the performance degradation is occurred when we overestimate the channel gain of a null-band. To solve this problem, we proposed a new sub-band allocation method, in which the CQI of a null-band is not overestimated. In addition, the proposed method requires the same amount of feedback bits to that used in [4].

This paper is organized as follows. The system model is introduced in Section II and the proposed allocation algorithm is presented in Section III. In Section IV, the performance of the proposed system is shown by computer simulation. Finally, conclusions are given in Section V.

2. System Model

Figure 1 depicts an OFDMA wireless communication system with K users and N sub-bands in a frequency selective fading channel. We assume that each sub-band consists of M sub-carriers. Thus, the total number of sub-carriers is given by MN over the whole system band B. Each sub-band can be assigned to only one user at each time slot. Each user is assumed to experience independent fading and the complex channel gain of the kth user in the nth sub-band is denoted as $h_{k,n}$, which is defined as the minimum channel gain among the constituent sub-carriers. Received signal to noise ratio (SNR) of kth user in the nth sub-band is represented as

$$\gamma_{k,n} = p_{k,n} \left| H_{k,n} \right| / N_o \ , \qquad (1)$$

where $p_{k,n}$ is the transmitted power of the kth user in the nth sub-band, N_o is the one-sided power spectral density of additive white Gaussian noise. If the target BER of the system is decided, it can be represented as a function of SNR of the kth user in the nth sub-band, $\gamma_{k,n}$, as [5]

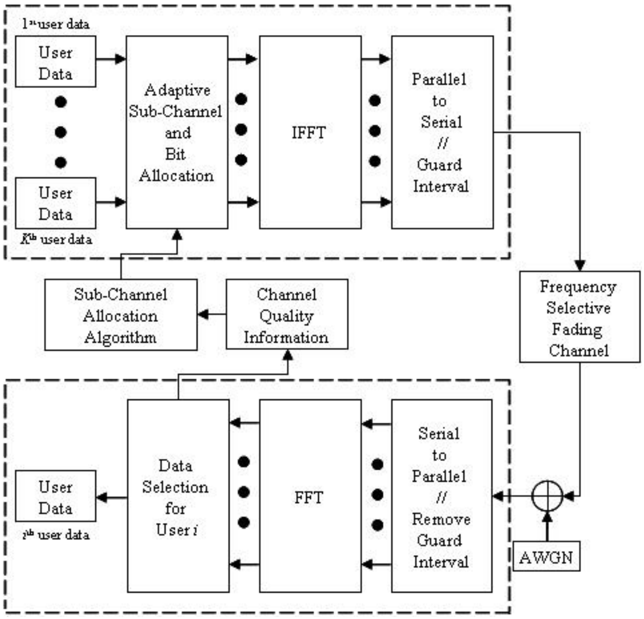

Figure 1. Schematic of The Proposed Multiuser OFDMA System

$$BER\left(\gamma_{k,n}\right) \le \frac{1}{5}\exp\left(\frac{-1.5\gamma_{k,n}}{2^{q_{k,n}}-1}\right), \qquad (2)$$

where $q_{k,n}$ is the number of bits allocated to each sub-carrier in the nth sub-band. Then, we have

$$q_{k,n} = \log_2\left(1+\frac{\gamma_{k,n}}{\Gamma}\right), \qquad (3)$$

where $\Gamma = -\ln\left(5BER\right)/1.5$ and the total system throughput is given as

$$Q=\sum_{k=1}^{K}\sum_{n=1}^{N}c_{k,n}\frac{Mq_{k,n}}{T}=\frac{\rho B}{N}\sum_{k=1}^{K}\sum_{n=1}^{N}c_{k,n}\log_2\left(1+\frac{\gamma_{k,n}}{\Gamma}\right), \quad (4)$$

where $c_{k,n} \in \{0, 1\}$ is the sub-band allocation indicator (i.e., $c_{k,n}$=1 when the nth sub-band is assigned to the kth user and $c_{k,n}$=0 otherwise), T is the OFDM symbol interval and $\rho = \frac{MN}{TB}$ indicates the ratio of the effective OFDM symbol length (without cyclic prefix (CP)) to T (including CP). Here, the maximization of the total throughput Q is done under the following constraints:

$$\text{i)}\ \sum_{k=1}^{K}\sum_{n=1}^{N}p_{k,n} \le P, \qquad p_{k,n} > 0,$$

$$\text{ii)}\ \sum_{k=1}^{K}c_{k,n} = 1, \qquad \forall n,$$

$$\text{iii)}\ \sum_{n=1}^{N}c_{k,n} = c = \frac{N}{S}, \qquad \forall k,$$

where P is the total transmit power allowed for the traffic channel in a base station and S is the number of active users in each slot.

3. The Proposed Sub-band Allocation Method

In downlink OFDMA systems, all users report all or partial CSI to their base station and the base station allocate sub-bands to users, determine the power, the modulation order of each sub-band, and the code rate of each user by using the CQI and transmit the traffic data to each user (See Figure 2). In case that a base station knows CSI of partial bands for each user, null-bands are occurred and the system throughput is decreased. To solve this problem in [4], a base station allocates null-bands to the user who has the best average channel gain (the additional information). However, if the true channel gain of a null-band is lower than the average channel gain, the system cannot satisfy the target BER. To remedy this problem, the proposed method is as follows. Each user reports the channel gains of N_{par} best sub-bands and the maximum value of the difference between adjacent two sub-bands, given by

$$D_k = \max\left(\left|H_{k,1}-H_{k,2}\right|,\left|H_{k,2}-H_{k,3}\right|,\cdots,\left|H_{k,N-1}-H_{k,N}\right|\right), \quad (5)$$

as additional information. In the base station, the channel gains of null-bands are estimated by using the reported channel gains and the additional information. Finally, each null-band is allocated to the user whose estimated channel gain is the maximum.

Figure 3 shows the initial sub-band allocation algorithm. In Figure 3, $ChAl_i$ and C_k represent the maximum channel gain in ith sub-band among the all user and the allocated set of sub-bands to kth user, respectively. After the initial sub-band allocation, the base station assigns null-bands to users not satisfying the constraint iii). To assign the null-bands to users, we propose a null-band allocation algorithm as shown in Figure 4 based on the null-band channel gain estimation using (5). In Figure 4, $|C_k|$ represents the number of allocated sub-bands and $CH_k(i)$ is the ith element in the set of

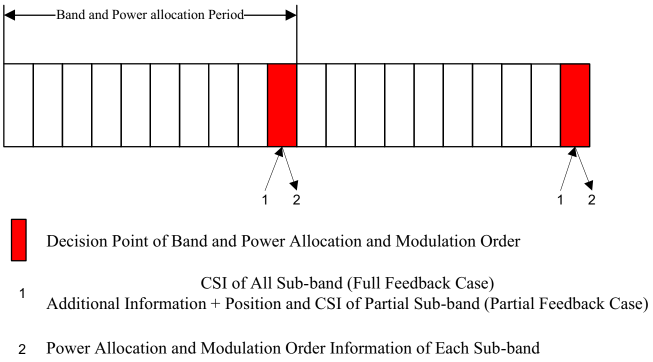

Figure 2. Adaptive Transmission Scheme

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Iteration:
    for  $i$=1:$N$
        $ChAl_i = \max_k \left(H_{k,i}\right)$
        $k' = \arg\max_k \left(H_{k,i}\right)$
        $C_{k'} = C_{k'} \cup \{i\}$
    end
end
```

Figure 3. The Initial Sub-band Allocation Algorithm

```
Iteration:
    for $i$=1:$N$
        if  $ChAl_i = 0$
            for $k$ =1; $K$
                $E_{k,i} = \max_j \left(CH_k(j) - \alpha_{k,i}(j) D_k\right)$
            end
        $ChAl_i = \max_{k,\, |C_k|<c} \left(E_{k,i}\right)$
        $k' = \arg\max_{k,\, |C_k|<c} \left(E_{k,i}\right)$
        $C_{k'} = C_{k'} \cup \{i\}$
    end
end
```

Figure 4. The Proposed Null-band Allocation Algorithm

the selected channel gains, which the *k*th user reported to base station. $E_{k,i}$ is the estimated channel gain of the *i*th sub-band (a null-band) in the *k*th user using the additional information D_k, which is the maximum value of the difference between adjacent two sub-bands. Also, $\alpha_{k,i}(j)$ represents the number of bands between the *j*th reported sub-band and the *i*th sub-band.

As the mentioned above, if all user report the CSI of all sub-band, the feedback overhead is extremely large and the computational complexity is very high. Here, we compare the amounts of feedback bits of the full-band channel information feedback system (FCIF), the partial bands and the average channel information feedback system (PAIF) proposed in [4], and the proposed partial bands and the distance channel information feedback system (PDIF), which are denoted as N_{full}, N_{conv},,and N_{prop}, respectively. Then, we obtain

$$N_{full} = N_{ch} N K \tag{6}$$

and

$$N_{prop} = N_{conv} = \left(\lceil \log_2 N \rceil \times N_{par} + \left(N_{par} + 1\right) N_{ch}\right) K\ , \tag{7}$$

where N_{par} is the number of bits to represent the channel gain information. When N_{par}=8, N=96, K=12, and N_{ch}=5, the numbers of bits of the FCIF, PAIF [4], and the proposed PDIF systems are 5760 bits, 1212 bits, and 1212 bits, respectively. Thus, we can reduce 79% of the feedback overhead compared to the full band feedback system.

4. Simulation Result

In the following simulations, we use the ITU Vehicular Channel A as summarized in Table I. Also, the modulation schemes considered in the simulations are no transmission, BPSK, QPSK, 16QAM, and 64QAM.

Table 1. ITU Vehicular Channel A Model

Relative Delay (ns)	Average Power (dB)
0	0.0
310	-1.0
710	-9.0
1090	-10.0
1730	-15.0
2510	-20.0

We assume that the fading channel for each user is independent and identically distributed. Also, each user can be assigned to any 8 sub-bands (c=8) out of 96 sub-bands (N=96). Then, the number of simultaneously active users in a cell is 12 users (S=12). In the simulation, we compare the performance of proposed system (PDIF), FCIF, PAIF, and the fixed sub-bands channel information feedback system (FiCIF). In the PAIF system proposed in [4], when the true channel gain is lower than average channel gain, the corresponding packet is assumed to be lost.

In Figure 4, the FCIF system shows the best performance and the FiCIF system shows the worst performance among the systems. The proposed system (PDIF) is about 3dB lower than the FCIF system, and about 6dB better than the FiCIF system. The PDIF and PAIF systems show similar performance trend, but PDIF system is slightly better than the PAIF system, except at very high SNR, at the same amount of feedback rate.

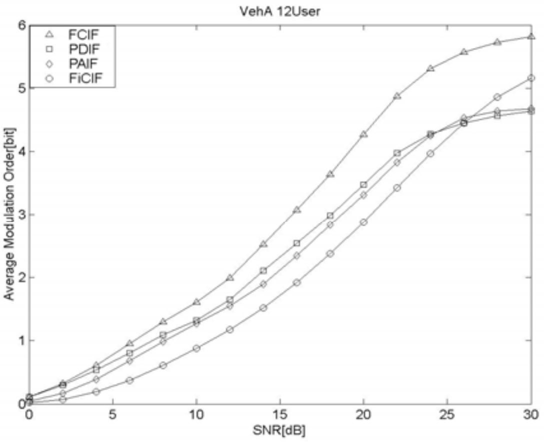

Figure 5. The Average Modulation Order of Various Adaptive Transmission Schemes When The Numer of User is 12

5. Conclusion

In this paper, we proposed a new sub-band allocation method using partial CSI and the maximum value of the difference between adjacent two sub-bands. Comparing the full feedback system, the proposed system uses only 21% of the feedback bits at the cost of 3dB performance degradation. In addition, the proposed system shows better performance compared to the PAIF system at the same feedback rate.

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