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LETTER

Efficient Adaptive Transmission Technique for Coded Multiuser OFDMA Systems

Duho RHEE[†], **Joong Hyung KWON**[†], **Ilmu BYUN**[†], ***Nonmembers, and*** **Kwang Soon KIM**[†*a)], ***Member***

SUMMARY In previous literature on adaptive transmission in multiuser OFDMA systems, only uncoded case or capacity (coded with infinite length of codeword) has been considered. In this paper, an adaptive transmission algorithm for coded OFDMA systems with practical codeword lengths is investigated. Also, in order to keep the feedback overhead within a practical range, a two-step partial CQI scheme is adopted, which has both better performance and reduced feedback overhead compared to conventional partial CQI schemes. By allowing a long codeword block across all allocated sub-bands with appropriate power and modulation order allocation rather than using short codeword blocks to each sub-band, high coding gain can be obtained, which leads to performance improvement.

key words: *adaptive transmission, OFDMA, partial CQI*

1. Introduction

In order to offer a high-rate data communication service, adaptive transmission is essential in the next generation wireless systems. For an adaptive transmission in orthogonal frequency division multiple access (OFDMA) system, user selection, sub-band allocation, power allocation, and modulation and coding set (MCS) selection are required. In previous literature, adaptive modulation schemes in uncoded OFDMA systems with full channel-quality-information (CQI) [1], [2], or capacity of coded OFDMA systems with an infinite codeword length and full CQI were considered [3]. In a practical system, however, the codeword length should be limited due to the delay constraint. Also, the full CQI assumption is no more valid in FDD systems. A partial CQI feedback scheme was proposed in [4], and a two-step partial CQI feedback scheme in uncoded systems was proposed by the authors in [5] for better performance and further reduction of feedback overhead.

Although it is well known that coding across frequency in frequency selective fading channels is useless in the context of capacity, performance of a practical system can be improved due to the finite codeword length. In this paper, an efficient adaptive transmission scheme is proposed for coded multiuser OFDMA systems using the two-step CQI scheme with a slight modification for the user selection and sub-band allocation and the proposed power allocation and MCS selection algorithm, which can be considered as an extension of the bit-loading algorithm to coded environments.

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[†]The authors are with the Department of Electrical and Electronic Engineering, Yonsei University, 134 Shinchon-dong, Seodaemun-gu, Seoul, 120-749, Korea.

[*]Corresponding author.

a) E-mail: ks.kim@yonsei.ac.kr

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2. System Model

A downlink OFDMA system in a single cell environment is assumed and there are K users and N sub-bands. A frame comprises many time slots and there are S sub-channels in each slot. Each sub-channel has $c = N/S$ sub-bands and each sub-band is composed of M consecutive subcarriers (i.e., the total number of subcarriers is MN). Here, we assume that each user goes through independent and identically distributed (i.i.d.) fading channel and the channel gain of the nth sub-band of the kth user is denoted as $h_{k,n}$, which is defined as the lowest absolute channel gain among the subcarriers of the nth sub-band. The received signal-to-noise ratio (SNR) of the nth sub-band of the kth user is given as

$$\gamma_{k,n} = p_{k,n}|h_{k,n}|^2/N_0, \tag{1}$$

where $p_{k,n}$ is the transmission power of the nth sub-band of the kth user and N_0 is the single-sided power spectral density of additive white Gaussian noise. The transmitter has a predefined MCS and selects one of them and allocates appropriate power. Let $q_{k,n}$ and $r_{k,n}$ be the number of bits per a coded symbol and the code-rate of the nth sub-band of the kth user, respectively. Then the system throughput, Q, can be represented as

$$Q = \frac{M}{T}\sum_{k=1}^{K}\sum_{n=1}^{N} c_{k,n}r_{k,n}q_{k,n} = \frac{\rho B}{N}\sum_{k=1}^{K}\sum_{n=1}^{N} c_{k,n}r_{k,n}q_{k,n}, \tag{2}$$

where $c_{k,n} \in \{0, 1\}$ is the indicator of the sub-band allocation, T is the OFDM symbol period including the cyclic prefix, $\rho = MN/TB$, and B is the system bandwidth. Here, the following constraints are considered for maximizing Q:

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

$$\text{(ii)} \sum_{k=1}^{K} c_{k,n} = 1, \quad n = 1, \ldots, N,$$

$$\text{(iii)} \sum_{n=1}^{N} c_{k,n} = c \text{ or } 0, \quad k = 1, \ldots, K, \tag{3}$$

where P denotes the maximum instantaneous transmission power. Note that the third constraint is included to take a practical sub-channel structure, such as IEEE 802.16e, into account. Note that an active user may take several sub-channels. However, the case where only one sub-channel is allowed to an active user is treated in this paper for simplicity.

3. Adaptive Transmission Schemes

3.1 Two-Step Partial CQI

The two-step partial CQI scheme is illustrated in Fig. 1. In the first step, all K users report the indices of partial sub-bands which have good channel gains and the average channel gain of the selected sub-bands to the base station (BS). The BS selects active users and allocates sub-bands to the selected users based on the CQI and broadcasts the information to users. The selected users transmit the channel gain of the allocated sub-bands to the BS as the second CQI. Using the second CQI, the BS performs power allocation and MCS selection. With the two-step partial CQI scheme, the null-band (sub-bands not selected by any active user) problem does not occur, which mainly degrades the performance of the conventional partial CQI scheme [5]. In addition, it can further reduce the amount of feedback compared to [4] since only selected users send the second CQI.

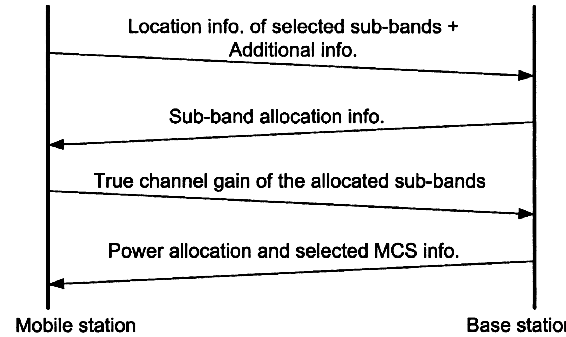

Fig. 1 The two-step partial CQI feedback scheme.

User Selection: $V = \emptyset$, $U_{UE} = \emptyset$

Do the following while $|U_{UE}| < S$

$Cost_k = \left(|V_k - V| + \beta\left(c - |V_k - V|\right)\right) \times AVE_k$, $k \in \{1, \cdots, K\} - U_{UE}$

$U_{UE} = U_{UE} \cup \{\arg\max_k \ (Cost_k)\}$, $V = V \cup V_{\arg\max_k \ (Cost_k)}$

Initial Sub-band Allocation: $V = \emptyset$

Do the following for the active users in descending order of AVE_k

$C_k = V_k - V$; Select c elements randomly if $|C_k| > c$

$V = V \cup C_k$

Null-band Allocation:

for $\forall n$ s.t. $n \in \{1, \cdots, N\} - V$

$i^* = \min_{q_{i,k}=1}(i)$ s.t. $q_{i,k} = 1$ if $(n-i)$ or $(n+i) \in V_k$ & $|C_k| < c$, 0 otherwise

$k^* = \arg\max_{k,\ q_{i^*,k}=1}(AVE_k)$; $C_{k^*} = C_{k^*} \cup \{n\}$

Fig. 2 The user selection and sub-band allocation algorithm.

3.2 User Selection and Sub-Band Allocation [5]

By using the first CQI of each user, the BS selects active users and allocates sub-bands with the algorithm as shown in Fig. 2. Here, V_k and AVE_k denote the set containing the indices of the selected sub-bands and the average channel gain of the selected sub-bands of the kth user, respectively. Also, U_{UE}, $|\cdot|$, and C_k denote the set of selected users, the cardinality of a set, and the set of sub-bands allocated to the kth user, respectively. The cost function, $Cost_k$, is introduced in the user selection algorithm in order to consider the number of overlapped sub-bands as well as the average channel gain, where β is a weighting factor ($0 \leq \beta \leq 1$). Note that $c - |V_k - V|$ indicates the number of the overlapped sub-bands of the kth user. Although not shown explicitly, the proposed user selection criterion has slightly better performance than the conventional criterion which uses the average channel gain only. The initial sub-band allocation follows the user selection, in which the selected S users take the sub-bands selected by themselves in the descending order of the average channel gain. Subsequently, the null-band allocation follows, in which each null-band is allocated to the user who selected the nearest sub-band from the null-band and does not occupy c sub-bands yet. Although not shown explicitly, the proposed null-band allocation has better performance than the random null-band allocation. More detailed discussion can be found in [5].

3.3 Power Allocation and MCS Selection

The BS allocates power and one of the MCS to each sub-channel (or sub-band) in order to maximize the throughput under the total power constraint. In a conventional scheme, which will be referred to as Conv1 later, each codeword block size fits to one sub-band and thus different power and different MCS option is allocated to each sub-band. This scheme suffers from the performance degradation due to the short codeword length. In a typical frequency selective fading channel in a mobile environment such as the ITU-R vehicular A channel model, the number of sub-carriers in a sub-band cannot exceed a few tens (Here, the sub-carrier spacing is around 10 kHz, which is commonly considered in practical mobile wireless communication systems). Also, the number of OFDM symbols in a slot is typically chosen to be several to few tens. Thus, the codeword length is typically limited to a few hundreds in this scheme. In another conventional scheme (referred to as Conv2 later), a long codeword block is allocated throughout all c sub-bands of a user and simply the same modulation order is used with power control. Although it can overcome the short codeword length problem, power is wasted in deep-faded sub-bands. To resolve these problems, the proposed scheme uses one long codeword block for a user and allocates different modulation order with different power to each sub-band as shown in Fig. 3. Here, i_k, $m_{k,n}$, and P_{sum} denote the index of the information bit length of the kth user, the modulation order of the nth sub-band of the kth user, and the total allocated power, respectively. Also, $L_{min}(i_k)(L_{max}(i_k))$, $d_{k,n,l}$, M_l, N_{sym}, and $P_{k,n}(d, l, i)$ denote the minimum (maximum) index

Let $i_k = MCS(0)$, $m_{k,n} = 0\ \forall k$ s.t. $k = 1,\ldots,K$, $\forall n \in C_k$; $P_{sum}=0$

Do the following until TERMINATE is confronted

for $k = 1:K$

for $l = L_{\min}(i_k) : L_{\max}(i_k)$

$M = 0$; $P_{sum,k,l} = 0$; $d_{k,n,l} = 0 \quad \forall n \in C_k$

while $M <= M_l / N_{sym}$

$\Delta P_{k,n,l} = P_{k,n}\left(d_{k,n,l}+2,l,i_k\right) - P_{k,n}\left(d_{k,n,l},l,i_k\right) \quad \forall n \in C_k$

$n^* = \arg\min_{n \in C_k} \Delta P_{k,n,l}$; $P_{sum,k,l} = P_{sum,k,l} + \Delta P_{k,n^*,l}$

$d_{k,n^*,l} = d_{k,n^*,l} + 2$; $M = M + 2$

end

$l^*_k = \arg\min_l P_{sum,k,l}$; $e_{k,n^*} = d_{k,n^*,l^*_k}$

$k^* = \arg\min_k P_{sum,k,l^*_k}$; $\bar{P}_{sum} = P_{sum} + P_{sum,k^*,l^*_k}$

if $\bar{P}_{sum} < P$

$P_{sum} = \bar{P}_{sum}$; $i_{k^*} = i_{k^*} + 1$; $m_{k^*,n} = e_{k^*,n}\ \forall n \in C_{k^*}$

else

TERMINATE

Fig. 3 The proposed power allocation and MCS selection algorithm.

of codeword length among the MCS options with information length of i_k, the modulation order of the nth sub-band of the kth user with the lth codeword length, the codeword length of index l, the number of symbols within a time slot, and the required power to meet the target packet error rate of the nth sub-band of the kth user when the modulation order is d, the codeword length index is l, and the information bit length index is i, respectively. Note that $P_{k,n}(1,l,i)$ is obtained from computer simulation of the channel code with information length i and codeword length l using BPSK in AWGN channel and $P_{k,n}(d,l,i)$ is determined to keep the minimum distance of the 2^d-QAM constellation to that in the BPSK case. For example, $P_{k,n}(2,l,i) = 2P_{k,n}(1,l,i)$ and $P_{k,n}(4,l,i) = 10P_{k,n}(1,l,i)$.

4. Simulation Results

To evaluate the proposed algorithms, the throughput performance is obtained by simulation. The ITU-R vehicular A delay profile is used in the simulation. Here, M=16, N=96, T=0.1 ms, B=20 MHz, and c=8. Also, it is assumed that a time slot is composed of eight OFDM symbols. The MCS tables used for Conv1, Conv2, and the proposed scheme in the simulation are shown in Tables 1 and 2, respectively, where n, k, r, and REq. SNR denote the codeword length, the information length, the code rate, and the required SNR in dB (SNR when using BPSK in Table 2). Note that in Table 2, any of 4QAM, 16QAM, and 64QAM can be selected in each sub-band as long as the total number of coded bits in a sub-channel is the given codeword length.

Figure 4 compares the performance of the proposed scheme to those in conventional schemes. Here, FCIF (Full Channel Information Feedback) and PAIF (Partial and Average Information Feedback) denote the sub-band allocation scheme with full CQI feedback and the proposed sub-band allocation scheme with the two-step partial CQI, respectively. Also, Prop. denotes the proposed power allocation and MCS selection. For the FCIF case, the proposed scheme shows the best performance but there is only slight enhancement from the others. For the PAIF case, the proposed scheme also shows the best performance and the Conv1 scheme and the Conv2 scheme follow. In contrast to the FCIF case, clear differences among the three schemes appear. Since the Conv1 scheme cannot achieve good coding gain due to the short codeword length, the performance is

Table 1 MCS table of Conv1 and Conv2 (Conv1/Conv2).

MCS No.	Mod.	n	k	r	Req. $\frac{E_s}{N_0}$ (dB)
0	No Tx.	-	-	-	-
1	4 QAM	256/2048	48/384	0.19	−1.2 / −2.6
2	4 QAM	256/2048	92/736	0.36	1.3 / −0.2
3	4 QAM	256/2048	180/1440	0.70	4.8 / 3.9
4	16 QAM	512/4096	268/2144	0.52	9.4 / 8.6
5	16 QAM	512/4066	356/2848	0.70	11.5 / 10.5
6	16 QAM	512/4096	444/3552	0.87	13.9 / 13.1
7	64 QAM	768/6144	532/4256	0.69	17.4 / 16.7
8	64 QAM	768/6144	620/4960	0.81	18.8 / 18.2

Table 2 MCS table of the proposed scheme.

MCS No.	n	k	r	Req. $\frac{E_s}{N_0}$ (BPSK)
0	No Tx.	-	-	-
1	2048	736	0.36	−3.2 dB
2	3072	736	0.24	−5.0 dB
3	2048	1440	0.70	0.9 dB
4	3072	1440	0.47	−2.0 dB
5	3072	2144	0.70	0.7 dB
6	4096	2144	0.70	−2.6 dB
7	4096	2848	0.70	0.55 dB
8	5120	2848	0.56	−1.0 dB
9	4096	3552	0.87	3.1 dB
10	5120	3552	0.69	0.5 dB
11	5120	4256	0.83	2.4 dB
12	6144	4256	0.69	0.5 dB
13	6144	4960	0.81	2.0 dB

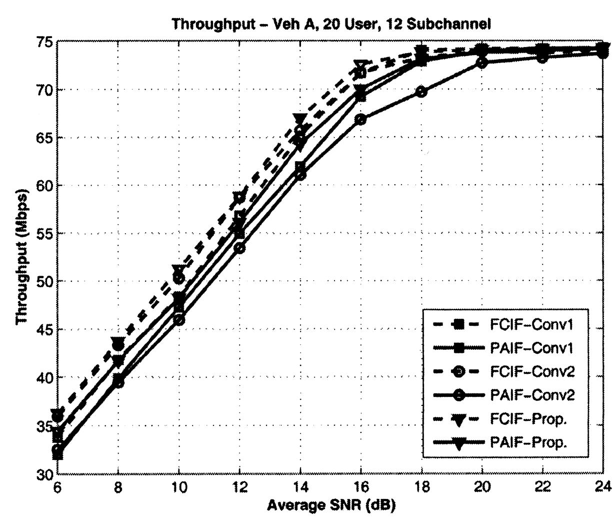

Fig. 4 The performance of the proposed system.

degraded. Although the Conv2 scheme acquires good coding gain, sub-bands in deep fades waste power and severely degrade the performance. The proposed scheme not only achieves the coding gain but also fully utilizes the frequency selective fading channel by allocating appropriate modulation order and power for each sub-band. Also, the performance difference of the proposed scheme in the FCIF and the PAIF cases is within 1 dB.

5. Conclusion

In this paper, a new efficient adaptive transmission technique for downlink multiuser coded OFDMA systems was proposed and evaluated. We can efficiently select users and allocate sub-bands by the two-step partial CQI concept. Also, we can achieve good performance by allocating one long codeword block across all sub-bands of a user with appropriate modulation order and power allocation for each sub-band. Thus, the proposed scheme can be used to improve the performance of practical OFDMA systems, such as IEEE 802.16e.

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