LETTER

Adaptive Transmission with Mixed Band-AMC and Diversity Modes for Multiuser OFDMA

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SUMMARY In this letter, we propose an adaptive transmission method for an OFDMA system supporting both band-AMC and diversity modes in a frame, simultaneously. In the proposed method, users are classified into the two groups preferring the band-AMC mode or the diversity mode based on their channel parameters. Then the BS performs resource allocation to maximize the throughput. It is observed that the proposed adaptive transmission method can reduce the feedback overhead with negligible performance loss.

key words: *OFDMA, band-AMC, diversity, resource allocation*

1. Introduction

Recently, orthogonal frequency division multiple access (OFDMA) has drawn much attention due to its capability in exploiting frequency and multiuser diversity [1]–[3]. Although the subcarrier-wise user selection and bit loading is optimal for link adaptation in OFDMA systems, its feedback overhead is unacceptable in wireless environments. To reduce the feedback overhead, practical systems instead adopt a band adaptive modulation and coding (AMC) mode with contiguous subcarriers and a diversity mode with distributed subcarriers, as in [2]. It is shown in [3] that the band-AMC mode improves the throughput compared with the diversity mode, but the former typically requires several times larger feedback bits than the latter. To compromise their tradeoffs, IEEE 802.16e proposes to construct a frame by multiplexing subchannels (SCHs) for the two modes in a time division multiplexing (TDM) manner [2]. However, there is no concrete work on how to operate the two modes in the same frame. In addition, IEEE 802.16e does not consider another possible frame structure using frequency division multiplexing (FDM). In this letter, we propose a preferred mode selection method and an adaptive user, rate, and transmit power (TP) allocation method when the system supports the two modes either in the TDM or FDM manner.

2. System Model

Figure 1 illustrates two possible mixed frame structures supporting both the band-AMC and diversity modes. The downlink (DL) frame, comprised of N_t OFDM symbols, is divided into the pilot channel and S_t data SCHs. There exist two types of data SCHs, B-type for the band-AMC mode and D-type for the diversity mode, of which the numbers are given by $S_B = \alpha S_t$ and $S_D = (1-\alpha)S_t$, respectively. The ratio α of the B-type in the data SCHs is chosen from a set of predetermined values according to the cell environments. In the frequency domain, the frame is divided into N_B subbands each with F_b subcarriers per OFDM symbol. Then, a B-type SCH is constructed by the subcarriers in the same subband while a D-type SCH is constructed by the subcarriers selected from different subbands. The TDM-based mixed frame separates the D-type and B-type SCHs in the first $(1-\alpha)N_t$ and the second αN_t OFDM symbols, respectively, as in Fig. 1(a) while the FDM-based one allows the two types of SCHs in an OFDM symbol as in Fig. 1(b). Also, note that the frame structures shown in Fig. 1 have the same feedback overhead and the same link quality for each SCH type if the time variation of a channel is negligible in a frame.

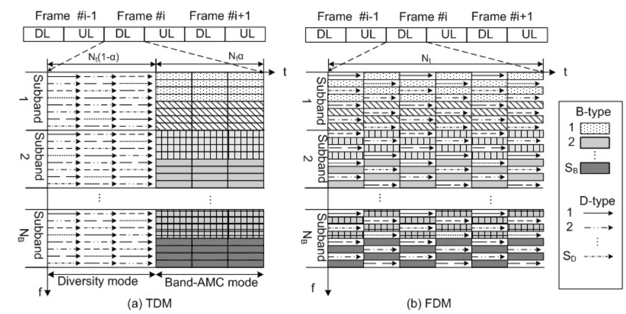

Fig. 1 The mixed frame structure: (a) TDM (b) FDM.

The adaptive transmission model is shown in Fig. 2 when there are K users in a cell. Each user determines its preferred mode to be reported to the base station (BS). With the mode information, the BS classifies the users into groups $\mathcal{U}_B = \{u\}_{u=1}^{K_B}$ and $\mathcal{U}_D = \{u\}_{u=K_B+1}^{K}$, where $\mathcal{U}_B$ ($\mathcal{U}_D$) is the group of users to be assigned with the B-type (D-type) SCHs and K_B (K_D) denotes the number of users in $\mathcal{U}_B$ ($\mathcal{U}_D$). The BS requests the users in $\mathcal{U}_B$ to feedback the mean SNRs $\{m_{k,b}\}_{b=1}^{N_B}$ of all subbands while the users in $\mathcal{U}_D$ to feedback the mean SNR m_k averaged over the entire band for the channel quality information (CQI). Then each user reports its CQI estimated with the pilot of the TP P_{pi}. With the CQI, the packet scheduler (PS) at the BS selects S_B and S_D active users for the B-type SCHs $\{s\}_{s=1}^{S_B}$ and the

Manuscript received January 24, 2008.
Manuscript revised May 24, 2008.
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DOI: 10.1093/ietcom/e91–b.9.3021

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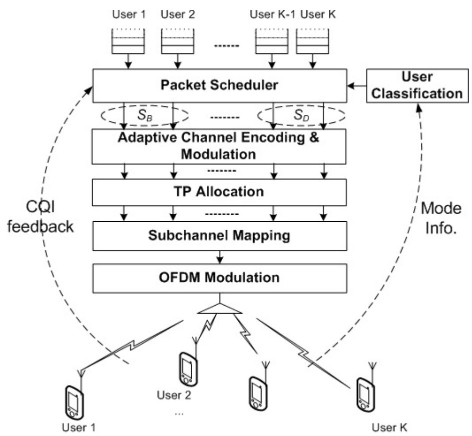

Fig. 2 The adaptive transmission model.

D-type ones $\{s\}_{s=S_B+1}^{S_t}$ from $\mathcal{U}_B$ and $\mathcal{U}_D$, respectively. The PS also determines the AMC options and TPs of the active users as well as the SCHs for the B-type users. The data streams of the active users are then channel encoded, modulated, and amplified according to their AMC options and TPs for OFDM modulation.

3. Adaptive Transmission Algorithm

3.1 User Classification

In this letter, a user selects its preferred mode using its channel parameters. If the time variation of a channel is negligible in a frame, the channel impulse response of a user can be expressed as $h(\tau) = \sum_{m=0}^{M-1} h_m \delta(\tau - \tau_m)$, where M is the number of resolvable paths and h_m is the complex fading gain at the delay τ_m with $E\{|h_m|^2\} = \sigma_m^2$. The channel frequency response is then given by $H(f) = \sum_{m=0}^{M-1} h_m e^{-j2\pi f \tau_m}$. The diversity order d_t determined by M and $\{\sigma_m^2\}_{m=0}^{M-1}$ [4] makes $|H(f)|^2$ fluctuate as f varies. On the other hand, the SNR variation over the subbands decreases with the frequency selectivity in a subband defined as $X_{sb} = B_{sb}\tau_{rms}$, where B_{sb} is the subband width and τ_{rms} is the rms delay spread determined by not only $\{\sigma_m^2\}_{m=0}^{M-1}$ but also $\{\tau_m\}_{m=0}^{M-1}$ [4]. Thus, the performance gain G of the band-AMC mode over the diversity mode i) would increase with d_t since d_t increases the peak to average power of $|H(f)|^2$ and thereby improves the SNR after subband selection in the band-AMC mode, but ii) would decrease with X_{sb} at the given d_t since a higher X_{sb} would decrease the peak value of the subband SNRs due to the averaging effect. By incorporating i) and ii), we define $\nu = X_{sb}/d_t$ to estimate the gain G. We can expect that G would be insignificant when ν is near zero (flat fading) or ν is too large. The proper region of ν for mode selection will be investigated later in Sect. 4. It should be also noted that the selected mode information can be updated in a long-term basis since τ_{rms} and d_t change slowly.

3.2 Adaptive Resource Allocation

After user classification, the BS performs resource allocation using the CQI to achieve the maximum throughput when a total TP of the N_d data subcarriers in an OFDM symbol is limited by P_t for the given target packet error rate (PER). Here, a user can be assigned with at most one SCH. Let $k(s)$, $j(s)$, and $P_{j(s)}(s)$ be the user, the AMC option, and the TP per subcarrier, respectively, for the sth SCH. Then the optimal resource allocation problem with the FDM-based mixed frame can be formulated as follows.

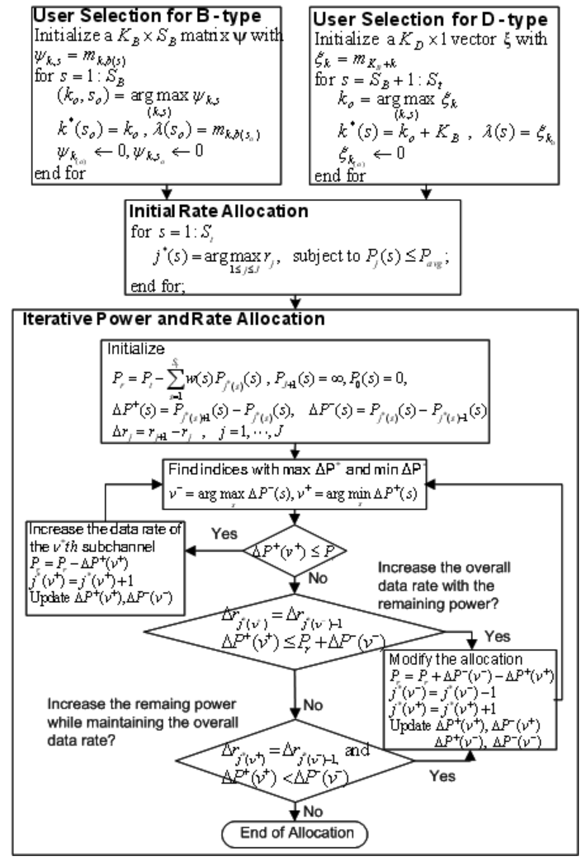

Fig. 3 The proposed resource allocation algorithm.

$$\{k^*(s), j^*(s), P_{j^*(s)}(s)\} = \arg \max_{k(s), j(s), P_{j(s)}(s)} \sum_{s=1}^{S_t} r_{j(s)} \qquad (1)$$

subject to

i) $\sum_{s=1}^{S_t} w(s) P_{j(s)}(s) \le P_t$,

ii) $P_{j(s)}(s) \ge P_{pi} - m_{k(s),b(s)} + \Lambda_{j(s)}$ for the B-type,
$P_{j(s)}(s) \ge P_{pi} - m_{k(s)} + \Lambda_{j(s)}$ for the D-type, and

iii) $\sum_{k=1}^{K} I(k, s) = 1$.

Here, r_j is the transmission rate of the jth AMC option, $w(s)$ is the number of subcarriers belonging to the sth SCH in an OFDM symbol subject to $\sum_{s=1}^{S_t} w(s) = N_d$, $b(s)$ denotes the index of the subband to which the sth SCH belongs, Λ_j is the SNR required for the jth AMC option to meet the target PER, and $I(k, s)$ is the indicator function which is one if the kth user is allocated to the sth SCH and is zero otherwise.

Due to the complexity in solving (1), we apply a suboptimal algorithm separating active user selection from the resource allocation as in Fig. 3: the active users are selected independently for each SCH type under the equal TP assumption and then iterative power and rate allocation (PRA) over all the SCHs is followed. For the B-type user selection, a $K_B \times S_B$ CQI matrix $\mathbf{\Psi}$ is constructed with the (k, s)th entry $\psi_{k,s} = m_{k,b(s)}$. Then the user and SCH index pair having the maximum CQI is selected as

$$(k_o, s_o) = \arg\max_{k,s} \psi_{k,s} \tag{2}$$

to assign the user and SNR of the s_oth SCH with $k^*(s_o) = k_o$ and $\lambda(s_o) = \psi_{k_o,s_o}$, respectively. Then, the row and the column corresponding to the user k_o and the subband s_o, respectively, are deleted from $\mathbf{\Psi}$. The selection process continues until all the B-type SCHs are assigned. For the D-type, a $K_D \times 1$ CQI vector ξ is constructed with the kth entry $\xi_k = m_{k+K_B}$. Then the user and SNR for the sth SCH $(s \geq S_B + 1)$ are given by $k^*(s) = k_o + K_B$ and $\lambda(s) = \xi_{k_o}$, respectively, where $k_o = \arg\max_k \xi_k$. After removing the CQI of the k_oth user from ξ, the selection process continues until all the D-type SCHs are assigned.

With the selected users, the AMC option is initially chosen from the J options as

$$j(s) = \arg\max_j r_j, \text{ subject to } P_j(s) \leq P_{avg} \tag{3}$$

assuming the equal TP $P_{avg} = P_t/N_d$ per subcarrier. Then the iterative PRA algorithm proposed in [5] is followed with the remaining power

$$P_r = P_t - \sum_{s=1}^{S_t} w(s) P_{j(s)}(s). \tag{4}$$

The algorithm in [5] calculates the required amount $P^+(s)$ of the additional power (the required amount $P^-(s)$ of the saved power) for increasing (decreasing) AMC option $j(s)$ of the sth SCH at each iteration. Then the remaining power is allocated to the users increasing the data rate at the smallest amount of the additional power. A similar approach can be applied to the TDM case except that the remaining power is allocated independently for the two SCH types in the iterative PRA.

4. Simulation Results

We consider a single cell using 2048-FFT over the 6 MHz bandwidth using the sampling time T_s=0.15 μs. The frame is constructed with $N_t = 12$, $N_B = 30$, $F_b = 56$, $S_t = 60$, and $N_d = 1440$. The data rates r_j of the 8 AMC options using the convolutional codes and QAM are 0, 1.0, 1.5, 2.0, 2.6, 3, 4, and 4.5 bps/Hz, respectively, and the required SNRs Λ_j corresponding to r_j are obtained as $-\infty$, 3.8, 5.5, 10, 12, 14, 17 and 18.5 dB in the AWGN channel to meet the PER of 10^{-2}. The performance is evaluated with the average spectral efficiency η when $K = 60$ and the uniform multipath intensity profile (MIP) with $\sigma_m^2 = 1/M$ or the exponential MIP with $\sigma_m^2 = \frac{1-e^{-\rho}}{1-e^{-\rho M}} e^{-\rho m}$ is used for the channel model. For the given MIP, a different rms delay spread is obtained by varying Δ in the delay time $\tau_m = m\Delta T_s$.

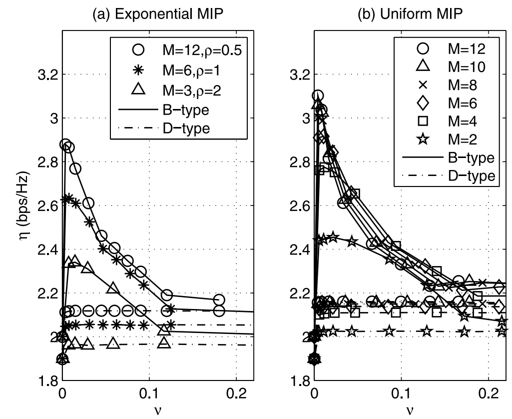

Fig. 4 The performance of the B-type or D-type SCHs only in different channel models when $K = 60$ and $SNR = 10$ dB.

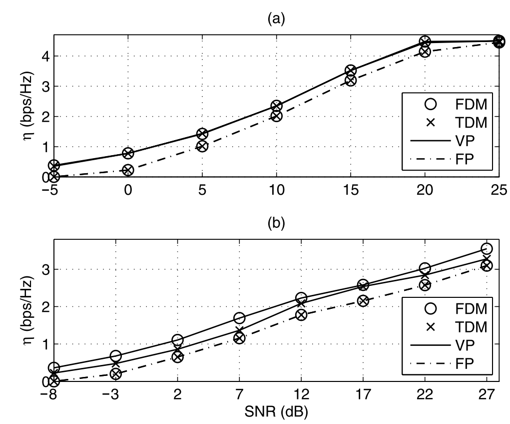

Fig. 5 The performance of the TDM- and FDM-based mixed frames when $K_B = 30$, $K_D = 30$, and $\alpha = 1/2$: (a) The equal average SNR (b) The unequal average SNR.

To obtain a proper region of ν for each mode, we compare the performance of the B-type only and the D-type only cases in Fig. 4. All users have the same MIP at the same average received SNR of 10 dB in evaluating each point. For the exponential MIPs with (M, ρ) = (3,2), (6,1), and (12,0.5) in Fig. 4(a), the diversity order d_t is obtained as 2, 3, and 5, respectively, ignoring the paths with power less than the strongest path by 10 dB. For the uniform MIPs in Fig. 4(b), $d_t = M$ since each path has the same power. It is observed that the gain G increases with d_t while it becomes trivial when $\nu \cong 0$ or $\nu > 0.13$ for most of the channel models employed. Since the event $\{\nu \simeq 0\}$, i.e., flat fading, seldom occurs in the broadband systems, we select the diversity mode if $\nu > \nu_T$ with $\nu_T = 0.13$ and the band-AMC mode otherwise.

Figures 5, 6 show the performance when all users experience the exponential MIP with $(M, \rho) = (6, 1)$, but a half of them have $\nu = 0.02$ with $\tau_{rms} = 0.33$ μs and the others have $\nu = 0.15$ with $\tau_{rms} = 2.5$ μs. Thus, α is chosen as 1/2 with $K_B = K_D = 30$. Here, 'FP' and 'VP' denote the fixed power and variable power cases, respectively, without or with iterative PRA in the proposed method. Figure 5 compares η

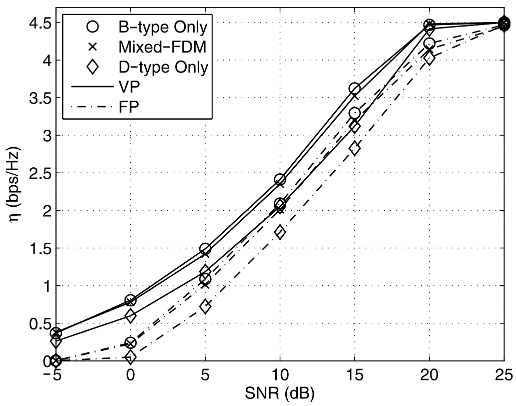

Fig. 6 The performance of the mixed mode when $K = 60$.

of the TDM- and FDM-based mixed frames for the received SNR averaged over all users. All users have the same average SNR in Fig. 5(a) while the average SNR of $\mathcal{U}_B$ is larger than that of $\mathcal{U}_D$ by 20 dB in Fig. 5(b). If the average SNR is the same for all users, the TDM and FDM exhibit the same performance either with 'FP' or 'VP,' where 'VP' provides 2–5 dB SNR gain over 'FP.' In case of the unequal SNRs for the two user groups, the FDM performs better than the TDM with 'VP' since the remaining power of one SCH type can be used to increase the data rate of the other type in the FDM case. In Fig. 6, the performance of the mixed frame with $\alpha = 1/2$ is compared with that of the single SCH frames when the average SNR is the same for all users. By using the mixed frame, we can obtain the performance close to the system using the B-type only while reducing the feedback overhead by about 50% of the B-type only case. In addition, we can expect that the proposed user classification will provide about 1 to 1.5 dB SNR gain over the random user classification of which the performance is given by the average of the B-type and the D-type performance.

In [6], it was shown that the rms delay spread of a user increases with the distance of the user from the BS. It implies that the average received SNR of $\mathcal{U}_D$ tends to be lower than that of $\mathcal{U}_B$. Thus, the FDM-based mixed frame will be more adequate for the proposed method. In addition, if the users experiencing the exponential MIP with $M = 6$ and $\rho = 1$ are uniformly distributed in a cell, the probability that $\{\nu < \nu_T\}$ is obtained as 1/2, 2/3 and 4/5 for the three channel models developed in 4 US cities, Manhattan, and Toronto provided in [6]. In such a cell environment, we can apply the proposed method with a proper α to reduce the feedback overhead incurred by the band-AMC mode.

5. Conclusions

In this letter, we proposed an adaptive transmission method using the mixed band-AMC and diversity modes for multiuser OFDMA, where the preferred mode is determined by the diversity order available in the channel and the frequency selectivity in a subband. It is observed that the proposed method with the mixed frame can reduce the feedback overhead with negligible performance loss when compared with the B-type only case. It is also observed that the FDM-based mixed frame has some benefit over the TDM-based one.

Acknowledgement

This work was partly supported by the IT R&D program of MIC/IITA [2005-S-002-03, Development of cognitive radio technology for efficient spectrum utilization] and the ITRC support program of MKE/ITTA [IITA-C1090-0804-0007].

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