LETTER

A Pragmatic Adaptive Transmission Scheme with Low-Rate Feedback Using Two-Step Partial CQI for Multiuser OFDMA Systems

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SUMMARY In this paper, we investigate an efficient user selection and sub-band allocation algorithm in which each user transmits two-step partial CQI to reduce the amount of feedback in multi-user downlink OFDMA systems. Simulation results show that we can greatly reduce the feedback rate at the expense of negligible performance degradation compared to the full CQI feedback schemes or that we can greatly improve the performance with slightly reduced feedback rate compared to conventional partial CQI feedback schemes.

key words: *OFDMA, Multiuser AMC, partial CQI*

1. Introduction

Orthogonal frequency division multiple access (OFDMA) has been considered as the most promising candidate for the multiple access scheme of the next generation wireless systems since it can allocate each band to the user with the largest channel gain in frequency selective fading channels, when a base station knows the channel quality information (CQI) of all sub-bands for all users [1]–[3]. However, due to the significant overhead of full CQI feedback schemes, they are not practical for mobile communication systems, which should support both high mobility and high frequency selectivity. To remedy this problem, a partial CQI feedback scheme has been proposed to reduce the feedback rate at the expense of some performance degradation [4]. Such performance degradation of the partial CQI feedback scheme comes from the fact that the power and modulation order of some sub-bands should be allocated without CQI (such a sub-band will be referred to a null-band). To solve this null-band problem, we separate CQI for each user into two parts: i) the indices and the average channel gain of the selected sub-bands (by a mobile station as a candidate for allocation) and ii) the channel gain of the allocated sub-bands (by a base station). Note that the proposed scheme requires less feedback rate than that in [4] since only selected users transmit the second CQI. Thus, it is expected that we can improve the performance with reduced feedback rate compared to the conventional partial CQI scheme.

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2. System Model

We consider a downlink OFDMA system with K users and N sub-bands in a frequency selective channel as shown in Fig. 1. Each sub-band consists of M sub-carriers. The received signal to noise ratio (SNR) of the kth user in the nth sub-band, $\gamma(k, n)$, is given by

$$\gamma(k, n) = p(k, n)|h(k, n)|^2/N_o, \tag{1}$$

where $h(k, n)$ and $p(k, n)$ are the complex channel gain and the transmit power of the kth user in the nth sub-band, respectively, and N_o is the one-sided noise spectral density. In [5], the bit error rate (BER) of the the nth sub-band of the kth user is represented as

$$BER(k, n) \leq 0.2 \exp(-1.5\gamma(k, n)/(2^{q(k,n)} - 1), \tag{2}$$

where $q(k, n)$ is the number of bits assigned to the nth sub-band of the kth user. Then, we obtain $q(k, n) = \log_2(1 + \gamma(k, n)/\Gamma)$, where $\Gamma = -\ln(5BER)/1.5$ and the total system throughput, Q, is given as

$$Q = \frac{M}{T} \sum_{k=1}^{K} \sum_{n=1}^{N} c(k, n)q(k, n), \tag{3}$$

where $c(k, n)$ is the sub-band allocation indicator ($c(k, n) = 1$

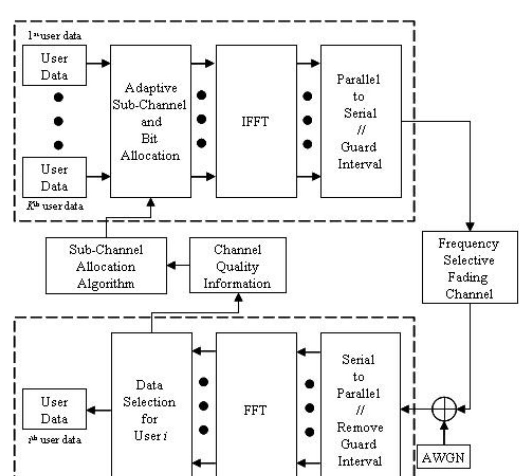

Fig. 1 The system model.

if the nth sub-band is assigned to the kth user and $c(k, n) = 0$, otherwise) and T is the OFDM symbol interval. In this paper, the maximization of the total throughput Q is done under the following three constraints:

1. $\sum_{k=1}^{K} \sum_{n=1}^{N} p(k, n) \leq P$, where P is the maximum transmit power of a base station.
2. $\sum_{k=1}^{K} c(k, n) = 1$.
3. $\sum_{n=1}^{N} c(k, n) = c$ or 0, where S is the number of simultaneous active users in a slot and $c = N/S$.

Note that the third constraint is introduced to take a realistic frame structure, such as in IEEE 802.16e, into account.

3. Proposed Method

In Fig. 2, the proposed adaptive transmission scheme with two-step partial CQI feedback is shown. All K users first report the indices and the average channel gain of the selected sub-bands to the base station. Based on the first CQI, the base station selects the active users, to which the base station will transmit data during the next allocation period, and allocates sub-bands to the selected users. After each active user receives the allocated sub-band information, it transmits the channel gain of the allocated sub-bands as the second CQI to the base station. Since the null-band problem does not exist in the proposed scheme, we can expect significant performance gain compared to the conventional partial CQI feedback scheme. In Fig. 3, the proposed user selection and sub-band allocation algorithm is shown. Here, μ_k and P_k denote the average channel gain of the selected sub-bands of the kth user and the $1 \times N$ column vector whose nth element, $P_k(n)$, is either 0 or 1, indicating whether the nth sub-band is selected by the kth user or not, respectively. Also, U_{UE}, $\bigoplus$, C_k, and $|C_k|$ denote the set of selected users, the logical or operation, the set of sub-bands assigned to the kth user, and the cardinality of the set C_k, respectively. As shown in Fig. 3, the user selection criterion includes the average channel gain as well as the number of overlapped sub-bands selected by previous users by the cost function, $Cost_k$, as

$$Cost_k = (A(P_k - P) + \beta(c - A(P_k - P))) \times \mu_k, \tag{4}$$

where $A(Z)$ denotes the number of positive elements in vector Z and β is an weighting factor ($0 \leq \beta \leq 1$). Note that $A(P_k - P)$ indicates the number of sub-bands selected by the kth user and not taken by the users in U_{UE}. Although it is not shown explicitly in this paper, the proposed user selection criterion shows slightly better performance than that using the average channel gain only. After the user selection, the base station performs initial sub-band allocation, in which every active user, in the order of the average channel gain, takes sub-bands that are both available and selected by the user. After the initial sub-band allocation, the base station assigns each null-band (not selected by any active user) to whom has the nearest selected sub-band to that null-band among those who do not satisfy the constraint iii). As will be shown later in Fig. 5, the proposed null-band allo-

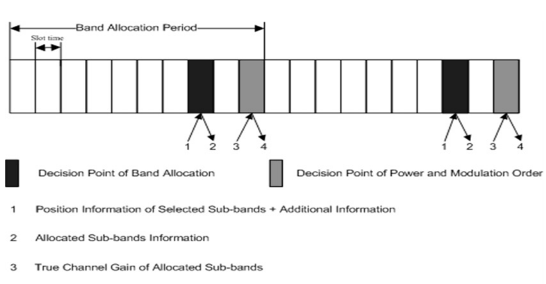

Fig. 2 The proposed adaptive transmission technique.

User Selection:
  Select S users iteratively in descending order of cost where
  $Cost_k = \left(A\left(P_k - P\right) + \beta\left(c - A\left(P_k - P\right)\right)\right) \times \mu_k$
  Update $U_{N_{UE}}$
Initial Subband Allocation:
  $P = 1 \times N$ zero vector, $U = \varnothing$
  for $l = 1:S$
    $k = \arg\max_{m \in M}\left(\mu_m\right)$
    for $n = 1:N$
      if $P_k\left(n\right) = 1$ and $P\left(n\right) = 0$ and $\left|C_k\right| < c$
        $C_k = C_k \cup \left\{n\right\}$, $P\left(n\right) = 1$
      end
      $U = U \cup \left\{k\right\}$
    end
  end
Null-band Allocation:
  for $\forall n$ s.t. $1 \leq n \leq N$ and $P\left(n\right) = 0$
    $i = 1$
    dowhile $\left(Q_n \neq \varnothing\right)$
      $Q_n = \left\{k \mid P_k\left(n - i\right) = 1 \text{ or } P_k\left(n + i\right) = 1 \text{ and } \left|C_k\right| < c\right\}$
      $i{+}{+}$
    end
    $k' = \arg\max_{k \in Q_n}\left(\mu_k\right)$, $C_{k'} = C_{k'} \cup \left\{n\right\}$
  end

Fig. 3 The proposed user selection and sub-band allocation algorithm.

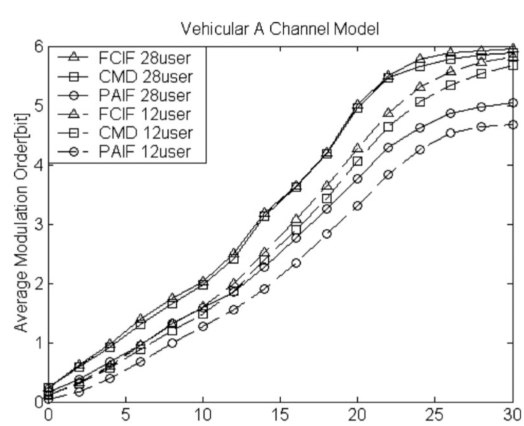

Fig. 4 The performance of the proposed scheme.

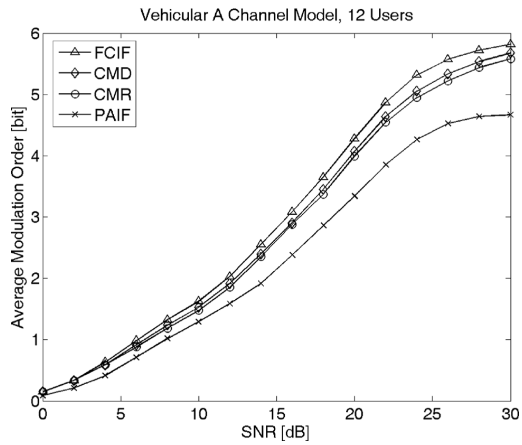

Fig. 5 The impacts of the proposed CQI scheme and sub-bands allocation scheme on the performance of the proposed scheme.

cation shows better performance than the conventional random null-band allocation. Let N_{full}, N_{conv}, and N_{prop} denote the numbers of the feedback bits in the full CQI feedback scheme, the partial CQI feedback scheme [4], and the proposed scheme, respectively. Then, it is easily seen as

$$N_{full} = N_{ch}NK, \quad (5)$$

$$N_{conv} = (N_p\lceil\log_2 N\rceil + (N_p + 1)N_{ch})K, \quad (6)$$

and

$$N_{prop} = (N_p\lceil\log_2 N\rceil + N_{ch})K + N_pN_{ch}S, \quad (7)$$

where N_p and N_{ch} are the number of sub-bands that each user selects and the number of bits required to represent channel gain of each selected sub-band, respectively, and $\lceil\cdot\rceil$ denotes the integer ceiling operation. For an example, when $N_p = 8$, $N = 96$, $K = 28$, $S = 12$, and $N_{ch} = 5$, we obtain $N_{full} = 13440$, $N_{conv} = 2828$, and $N_{prop} = 2188$. Thus, the proposed scheme reduces the feedback rate by 84% and 23% compared to the full CQI feedback scheme and the partial CQI feedback scheme in [4], respectively.

4. Simulation Results

In the following simulations, an OFDMA system with bandwidth 20 MHz is used under the ITU Vehicular-A channel. Here, the sampling rate is 25 MHz (12.2 KHz spacing) and 1536 among 2048 sub-carriers are used with the following modulation schemes: no Tx, BPSK, QPSK, 16-QAM, and 64-QAM. Also, we assume that $N = 96$, $c = 8$, and $S = 12$. In Fig. 4, the performance of the proposed scheme (denoted as CMD) is shown with the performance of the full CQI feedback scheme (denoted as FCIF) and the conventional partial CQI feedback scheme in [4] (denoted as PAIF) for comparison. From the result, it is seen that the proposed scheme can greatly reduce the feedback rate at the expense of only negligible performance loss compared to full CQI feedback scheme. Also, the proposed scheme shows not only much better performance but also reduced feedback rate compared to the conventional partial CQI feedback scheme in [4]. Note that the performance improvement of the proposed system compared to that in [4] comes from both the proposed partial CQI scheme and the proposed sub-band allocation scheme. In Fig. 5, the performance of the scheme using the proposed partial CQI and the conventional random null-band allocation (denoted as CMR) are compared with the proposed scheme, the full CQI feedback scheme, and the conventional partial CQI feedback scheme. From the result, it is seen that the performance improvement of the proposed scheme over the conventional one mainly comes from the proposed CQI scheme and that the proposed sub-bands allocation scheme can also improve the performance.

5. Conclusion

In this paper, we proposed an efficient user selection and sub-band allocation algorithm using the two-step partial CQI feedback scheme for multi-user downlink OFDMA systems. The proposed scheme eliminates the null-band problem and shows much better performance than the conventional partial CQI feedback scheme. Furthermore, the proposed scheme even shows comparable performance to the full CQI feedback scheme.

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