LETTER

Adaptive Modulation and Power Allocation Technique for LDPC-Coded MIMO-OFDMA Cellular Systems

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SUMMARY An adaptive transmission scheme, in which the work in [3] is extended to multiuser environment, is proposed for LDPC-coded MIMO-OFDMA cellular systems that employ FDD by considering active user selection and sub-channel power allocation. The performance of the proposed scheme is obtained from simulation and compared with that of the conventional scheme using mean SNR only. It is shown that the proposed scheme can provide up to 5.5 dB gain over the conventional scheme at the expense of only 6 more bits in feedback information.
key words: *adaptive transmission, MIMO, OFDMA*

1. Introduction

Recently, sub-carrier and power allocation algorithms for orthogonal frequency division multiple access (OFDMA) systems have been proposed, such as in [1], [2]. Although these algorithms can exploit frequency selectivity as well as multiuser diversity, they are not suitable for cellular systems due to their computational complexity and large amount of feedback information. In [3], a novel adaptive modulation and coding technique based on log-likelihood ratio (LLR) distribution was proposed for a multiple input multiple output (MIMO) OFDMA cellular systems that employ quadrature amplitude modulation (QAM) and low density parity check (LDPC) code. The LLR distribution was modeled as a Gaussian distribution so that its mean and standard deviation were used as the channel state information (CSI). The amount of feedback information required for this algorithm is comparable to those used in currently deployed cellular systems, such as cdma2000 1xEV-DO. Also, the computational complexity is greatly reduced since it does not require the sub-carrier (or band) allocation process. Although the frequency selectivity is not fully exploited, it was shown in [3] that 2–3 dB performance gain is obtained over the conventional system using the mean SNR only in single user case. In this letter, the work in [3] is extended to the multiuser case by considering active user selection and power allocation to multiple users.

2. System Model

A physical layer frame is comprised of a number of consecutive data slots, in which pilot symbols of each transmit antenna are well distributed over both the frequency- and the time-domain. Also, the number of sub-channels in a data slot is S and they are also well-distributed over a data slot. Figure 1 shows the system model considered in this letter. In the transmitter side, pilot symbols are transmitted with fixed power, P_{pilot}. The channel is estimated from the received pilot symbols by the channel estimator at the receiver that employs N_R receiving antennas. With the estimated channel, the channel state information (CSI) of each user is generated and sent to the transmitter. Based on each user's predetermined quality of service (QoS), the reported CSI, and the pre-determined required SNR table, active users are selected with corresponding MCS and transmit power (TP) by the MCS and TP selector. At the receiver side, the adaptively transmitted signal is demodulated by calculating the LLR from the received symbols and the estimated channel. Finally, the LDPC decoder extracts the transmitted information.

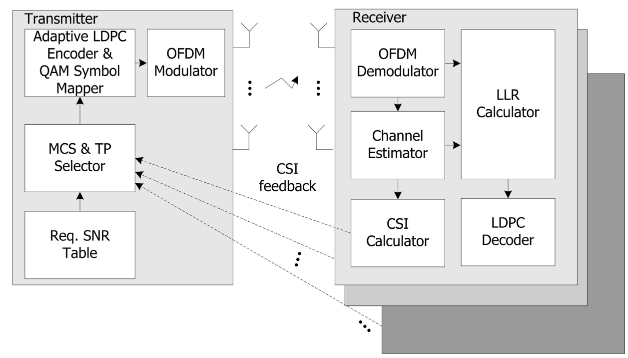

Fig. 1 The system model for the proposed adaptive transmission.

Among the MCS options, there are two types of transmit antenna schemes: the transmit diversity (TD), such as the space time block code, and the spatial multiplexing (SM). To support them simultaneously, the CSI of the kth user is comprised of the mean and the normalized standard deviation (NSD) of the received SNRs in the TD scheme, and the NSD of the received SNRs in the SM scheme, i.e., $CSI_k = [m_{k,TD}, \sigma_{k,TD}, \sigma_{k,SM}]$, where

$$m_{k,TD} = \frac{1}{L}\sum_{l=0}^{L-1}\mu_{k,l}, \tag{1}$$

$$\sigma^2_{k,TD} = \frac{1}{m^2_{k,TD}L}\sum_{l=0}^{L-1}\mu^2_{k,l} - 1, \tag{2}$$

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and

$$\sigma^2_{k,SM} = \frac{N_T}{m^2_{k,TD}L}\sum_{l=0}^{L-1}\sum_{i=0}^{N_T-1}\nu^2_{k,l,i} - 1. \tag{3}$$

Here, L is the number of symbols in a data slot, $\mu_{k,l}$ is the SNR of the decision variable of the kth user for the TD scheme at the lth symbol location in a data slot, and $\nu_{k,l,i}$ is the SNR of the ith spatial channel of the kth user for the SM scheme at the lth symbol location [3]. Note that we do not have to send the mean SNR of the SM scheme since it is given as $m_{k,TD}/N_T$.

3. The Proposed Adaptive Transmission Scheme

The CSI indicates the LLR distributions of the received symbols for the TD and the SM schemes when the TP is P_{Pilot}. Let $SNR_{n,TD}$ and $\Delta_{n,TD}(\alpha)$ ($SNR_{n,SM}$ and $\Delta_{n,SM}(\alpha)$) be the required mean SNR and the required additional power when the NSD is α for the nth MCS option of the TD (SM) scheme, respectively. Then, the required TP of the kth user when the nth MCS option of the TD (SM) scheme is used, $P_{k,n,TD}$ ($P_{k,n,SM}$), is obtained as

$$P_{k,n,i} = P_{Pilot} + SNR_{n,i} - m_{k,i} + \Delta_{k,i}(\sigma_{k,i}) \quad \text{(dB)}, \tag{4}$$

where i is either TD or SM. Note that, in the conventional scheme using the mean SNR only, we instead use

$$P^c_{k,n,i} = P_{Pilot} + SNR^c_{n,i} - m_{k,i} \quad \text{(dB)}, \tag{5}$$

where $SNR^c_{n,i}$ denotes the required SNR for the nth MCS option in the conventional scheme. For each user, the antenna scheme for each MCS option is selected to minimize the required TP and the required TP of the kth user for the nth MCS option, $P_{k,n}$, is given by

$$P_{k,n} = min(P_{k,n,TD}, P_{k,n,SM}). \tag{6}$$

Note that the additional gain achieved from the proposed adaptive antenna scheme selection is larger than that of the conventional scheme because the additional CSI, NSD, provides us with better understanding about a given channel. In [3], it was reported that the proposed adaptive antenna scheme selection is beneficial while it is useless in the conventional scheme.

Now, the optimal way to select active users and to allocate power to them for achieving maximum throughput at given total TP can be described as

$$\{k^*(s), n(k^*(s))\} = \arg\max_{\{k(s),n(k(s))\}}\sum_{s=1}^{S} r(n(k(s)))$$
$$subject\ to \sum_{s=1}^{S} P_{k(s),n(k(s))} \le P_A. \tag{7}$$

Since it is not easy to solve (7), we adopt a separate active user selection and an iterative power allocation algorithm to find a sub-optimal solution of (7) as follows. Firstly, the total TP, P_A, allowed to data channels is equally divided into all sub-channels. Then, the highest MCS option for each user with TP $P_S = P_A/S$ is obtained as

$$n(k) = \arg\max_n r(n) \quad subject\ to\ P_{k,n} \le P_S, \tag{8}$$

where $r(n)$ is the transmission rate of the nth MCS option. Then, the active user set $\{k^*(s), s = 1, \cdots, S\}$ is selected as

$$\begin{aligned} &for\ s = 1 : S \\ &\quad k^*(s) = \arg\max_k n(k); \quad n(k^*(s)) \leftarrow 0; \\ &end\ for. \end{aligned} \tag{9}$$

Finally, the power allocation and MCS selection among the selected users is performed as shown in Fig. 2. The initial allocation is done with (8) and (9). At each iteration, the required amount of the additional power, $P^+(s)$, (amount of saved power, $P^-(s)$) for increasing (decreasing) MCS option number of the user assigned to the sth sub-channel is calculated for all active users and the remaining power, P_r, is calculated as

$$P_r = P_A - \sum_{s=1}^{S} P_{k(s),n(k(s))}. \tag{10}$$

Then, the power allocation and MCS selection is modified if i) we can increase the total transmission rate with additional power smaller than the remaining power P_r or ii) we can increase the remaining power while maintaining the total transmission rate. Note that the proposed algorithm is a modified version of the well known bit-loading algorithm in

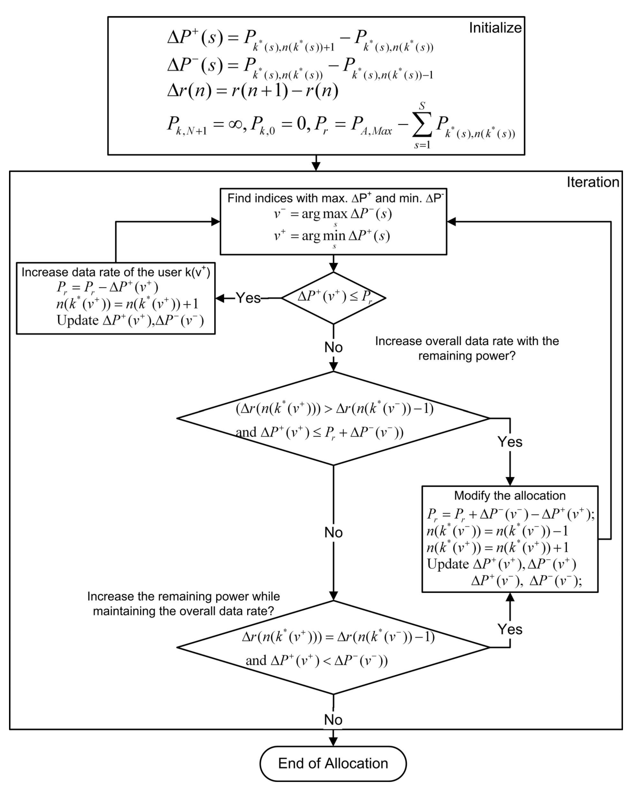

Fig. 2 The proposed power allocation and MCS selection algorithm.

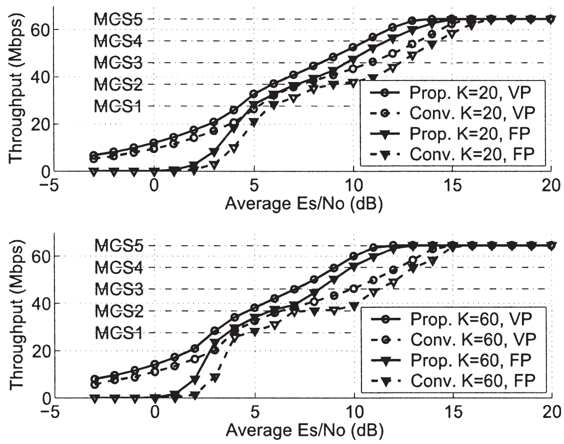

Fig. 3 The performance of the proposed scheme.

the following points: i) it can be applied to practical situations where the allowed transmission rates are not limited to equally spaced integers and ii) the initial allocation can reduce the number of iterations, especially for high SNR regime.

4. Numerical Results

The MCS options used in the simulation are the same to those in [3]. The transmission rate, $r(n)$, is given as 0, 2.304, 3.072, 3.84, 4.608, and 5.376 Mbps for n=0,1,2,3,4 and 5, respectively. Figure 3 shows the performance of the proposed adaptive transmission scheme (denoted as Prop.) for $N_T = 2$, $N_R = 2$, and $S = 12$ when the total number of users, K, is 20 and 60, respectively. Here, the ITU-R pedestrian A channel is used and all users' average channel gains are assumed to be identical. The average E_s/N_0 is the statistical average of the mean SNR when the TP is P_S and the target packet error rate (PER) is set at 0.01. Also, 'VP' and 'FP' denote the proposed algorithm using the iterative algorithm in Fig. 2 and the fixed power allocation using (8) and (9) only, respectively. In addition, the performance of the conventional scheme using mean SNR only (denoted as Conv.) is provided for comparison. From the results, it is observed that i) performance is improved in all cases as the number of users increases due to the multiuser diversity as expected, ii) the proposed adaptive power allocation can improve the performance in all cases, especially for low SNR regime, and iii) the performance gain of the proposed scheme over the conventional scheme is 2.5–4.7 dB, 2.5–5.5 dB, 1.2–4.4 dB, and 0.8–5.0 dB for the cases of (K = 20, 'FP'), (K = 60, 'FP'), (K = 20, 'VP'), and (K = 60, 'VP'), respectively, at the expense of only 6 more bits in the feedback CSI.

5. Conclusion

In this letter, an efficient adaptive transmission scheme using QAM and LDPC code was proposed for multiuser MIMO-OFDMA systems that employ FDD. In the proposed scheme, the antenna scheme (TD or SM) for each MCS option is first selected and then active user set is determined assuming equally divided TP. Finally, the TP and the corresponding MCS option for the active users are selected by using the proposed iterative algorithm. The simulation results showed that the proposed scheme has performance gain over the conventional scheme using mean SNR only up to 5.5 dB. Also, the proposed adaptive power allocation can improve the performance, especially for low SNR regime. The additional CSI of the proposed scheme over currently deployed cellular systems such as cdma2000 1xEV-DO is only 6 more bits. Also, the computational complexity of the proposed scheme is not a burden because the antenna selection and the user selection are simple and the power allocation and MCS selection can be done within several iterations for most cases. In more realistic cellular environments with different path-loss and shadowing among users, we can modify the user selection criterion in (8) by replacing $n(k)$ with $n(k)/n_a(k)$, where $n_a(k)$ is the average transmission rate of the kth user, as in the proportional fair algorithm [4]. Therefore, the proposed scheme is quite pragmatic and can be easily adopted to improve OFDMA cellular systems, such as IEEE802.16 [5].

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References

[1] C.Y. Wong, R.S. Cheng, K.B. Letaief, and R.D. Murch, "Multiuser OFDM with adaptive subcarrier, bit and power allocation," IEEE J. Sel. Areas Commun., vol.17, no.10, pp.1747–1757, Oct. 1999.
[2] D. Kivanc, G. Li, and H. Liu, "Computationally efficient bandwidth allocation and power control for OFDMA," IEEE Trans. Wirel. Commun., vol.2, no.6, pp.1150–1158, Oct. 2003.
[3] K.S. Kim, Y.H. Kim, and J.Y. Ahn, "An efficient adaptive transmission technique for LDPC coded OFDM cellular systems using multiple antennas," Electron. Lett., vol.40, pp.396–397, March 2004.
[4] P. Viswanath, D.N.C. Tse, and R. Laroia, "Opportunistic beamforming using dumb antennas," IEEE Trans. Inf. Theory, vol.48, no.6, pp.1277–1294, June 2002.
[5] IEEE P802.16-REVd/D5, "Air interface for fixed broadband wireless access systems," IEEE, May 2004.