Efficient adaptive transmission technique for LDPC coded OFDM cellular systems using multiple antennas

K.S. Kim, Y.H. Kim and J.Y. Ahn

An adaptive MIMO transmission scheme using QAM and LDPC code is proposed for an OFDM cellular system employing FDD. It is shown that the proposed scheme can provide up to 2–3 dB gain over the conventional scheme at the expense of only six more bits in feedback information.

Introduction: Recently, orthogonal frequency division multiplexing (OFDM) has been widely accepted as the most promising radio transmission technology for next generation wireless communication systems [1]. In addition, the use of multiple antennas and adaptive modulation and coding have been considered as key technologies to enhance the cell throughput [2, 3]. For an adaptive transmission, the transmitter should know the channel state information (CSI). In cellular systems employing frequency division duplexing (FDD), however, even the reduced amount of the feedback information required for the block-wise adaptive transmission schemes [3] is far from that which can be supported in practical situations. Thus, an efficient adaptive transmission scheme is required with a low feedback rate comparable to that in currently employed cellular systems. In this Letter, an adaptive transmission scheme based on the received log-likelihood ratio (LLR) distribution is proposed for an OFDM cellular system employing quadrature amplitude modulation (QAM) and low-density parity check (LDPC) code.

System model: A physical layer frame comprises 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, all sub-channels in a data slot are well distributed over a data slot. On the transmitter side, the pilot symbols of all N_T transmit antennas are transmitted with fixed power, P_{Pilot}. The channel is then estimated by the channel estimator at the receiver employing N_R receiving antennas. With the estimated channel, the CSI is generated and sent back to the transmitter. With the received CSI and the predetermined values of the required signal-to-noise power ratio (SNR), the modulation and coding set (MCS) and the transmit power (TP) are determined by the transmitter. Among the MCS options, there are two types of transmit antenna schemes: the transmit diversity (TD), such as the space time block code [4], and the spatial multiplexing (SM). Finally, the LLR calculator and the LDPC decoder at the receiver extract the transmitted information.

Proposed adaptive transmission scheme: For a given LDPC code, the performance is determined by the received likelihood distribution [5]. Thus, the transmitter can anticipate the performance of each MCS option if the LLR distribution at the receiver is known in advance. In this Letter, we use only two parameters to specify an LLR distribution: the mean and the normalised standard deviation (NSD). Firstly, we consider the case in which the TD is used. As is shown in [4], the SNR of the decision variable at the lth symbol location in a data slot can be written as $\mu_l = A^2\hat{h}_l^2/2\sigma^2$, where A^2 is the TP of the lth symbol and $2\sigma^2$ is the variance of the complex additive white Gaussian noise (AWGN). $\hat{h}_l$ is defined as

$$\hat{h}_l = \sqrt{\frac{1}{N_T}\sum_{i=0}^{N_T-1}\sum_{j=0}^{N_R-1}|h_{l,i,j}|^2} \tag{1}$$

where $h_{l,i,j}$ denotes the complex channel gain from the ith transmit antenna to the jth receiving antenna at the lth symbol location in a data slot. The mean, $m_{SNR,TD}$, and the NSD, $\sigma_{SNR,TD}$, of the LLR distribution over a code block with the length of L symbols are given as follows:

$$m_{SNR,TD} = \frac{1}{L}\sum_{l=0}^{L-1}\mu_l,$$
$$\sigma_{SNR,TD} = \sqrt{\frac{1}{m_{SNR,TD}^2 L}\sum_{l=0}^{L-1}\mu_l^2 - 1} \tag{2}$$

Now consider the case in which the SM is used. Let $\boldsymbol{H}_l$ be the $N_R \times N_T$ complex channel gain matrix whose (i,j)th element is $h_{l,i,j}$. Then, by applying singular value decomposition, we obtain $\boldsymbol{H}_l = \boldsymbol{U}_l\boldsymbol{D}_l\boldsymbol{V}_l^H$, where $\boldsymbol{U}_l$ and $\boldsymbol{V}_l$ are unitary matrices, and $\boldsymbol{D}_l$ is the diagonal matrix whose diagonal elements are the singular values of $\boldsymbol{H}_l$, $\lambda_{l,i}^{1/2}$, $i = 0, \ldots, N_T - 1$. Let $\boldsymbol{x}_l$, $\boldsymbol{y}_l$, and $\boldsymbol{n}_l$ be the normalised transmitted symbol vector, the received symbol vector, and the AWGN vector at the lth symbol location in a data slot, respectively. Then, we obtain $\boldsymbol{y}_l' = A'\boldsymbol{D}_l\boldsymbol{x}_l' + \boldsymbol{n}_l'$, where $\boldsymbol{y}_l' = \boldsymbol{U}_l^H\,\boldsymbol{y}_l$, $A'^2 = A^2/N_{Tx}$, $\boldsymbol{x}_l' = \boldsymbol{V}_l^H\,\boldsymbol{x}_l$, and $\boldsymbol{n}_l' = \boldsymbol{U}_l^H\,\boldsymbol{n}_l$. Thus, the multiple input, multiple output (MIMO) channel is equivalent to N_T parallel channels with channel gains of $\lambda_{l,i}^{1/2}$, $i = 0, \ldots, N_T - 1$. Also, since $\boldsymbol{U}_l$ and $\boldsymbol{V}_l$ are unitary, the Euclidean distance between any two constellation vectors or noise vectors is invariant under the transformation defined by the matrix $\boldsymbol{U}_l$ or $\boldsymbol{V}_l$. Thus, the SNR of the ith spatial channel at the lth symbol location, $\nu_{l,i}$, is defined as $\nu_{l,i} = A^2\lambda_{l,i}/2\sigma^2 N_{Tx}$. Then, the mean, $m_{SNR,SM}$, and the NSD, $\sigma_{SNR,SM}$, of the LLR distribution over a code block with the length of L symbols are given as follows:

$$m_{SNR,SM} = \frac{1}{LN_T}\sum_{l=0}^{L-1}\sum_{i=0}^{N_T-1}\nu_{l,i},$$
$$\sigma_{SNR,SM} = \sqrt{\frac{1}{m_{SNR,SM}^2 LN_T}\sum_{l=0}^{L-1}\sum_{i=0}^{N_T-1}\nu_{l,i}^2 - 1} \tag{3}$$

Since $\lambda_{l,i}$, $i = 0, \ldots, N_T - 1$, are the eivenvalues of $\boldsymbol{H}_l^H\boldsymbol{H}_l$, we obtain

$$tr\left[\boldsymbol{H}_l^H\boldsymbol{H}_l\right] = \sum_{i=0}^{N_T-1}\lambda_{l,i} = \sum_{i=0}^{N_T-1}\sum_{j=0}^{N_R-1}|h_{l,i,j}|^2 = N_T\hat{h}^2 \tag{4}$$

where $tr[\bullet]$ is the trace operator. Thus, we obtain $m_{SNR,SM} = m_{SNR,TD}/N_T$. Therefore, the CSI can be defined as the values of $m_{SNR,TD}$, $\sigma_{SNR,TD}$ and $\sigma_{SNR,SM}$, which are measured with the received pilot symbols. Note that the CSI indicates the expected LLR distribution at the receiver when the TP is $N_T P_{Pilot}$. Let SNR_n and $\Delta_{n,\alpha}$ be the required mean SNR and the required additional power when the NSD is α for the nth MCS option, respectively. The required TP when the nth MCS option is used, $P_{Tx,n}$, is then obtained as

$$P_{Tx,n} = N_T P_{Pilot} + SNR_n - m_{SNR} + \Delta_{n,\sigma_{SNR}}(dB) \tag{5}$$

where m_{SNR} and σ_{SNR} denote $m_{SNR,TD}$ and $\sigma_{SNR,TD}$, respectively, when the nth MCS option uses the TD, and denote $m_{SNR,SM}$ and $\sigma_{SNR,SM}$, respectively, when the nth MCS option uses the SM. Here, SNR_n and $\Delta_{n,\alpha}$ can be predetermined via computer simulations or field tests. The transmitter can then evaluate how much power is required for each user and each MCS option, and any optimisation process can be adopted to determine active user set and MCS option with corresponding TP for each user.

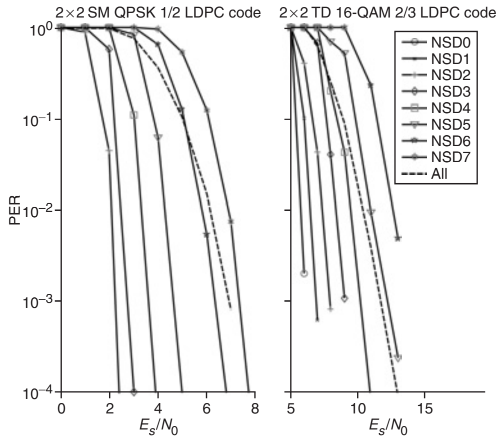

Fig. 1 *Packet error rates of MCS options*

Simulation results: In Fig. 1, the packet error rates (PERs) of the MCS option using SM, 4-QAM, and 1/3-rate LDPC code and that using TD, 16-QAM, and 2/3-rate LDPC code are shown. Here, the ITU-R pedestrian A fading channel is used and the TP is controlled to keep the mean of the received SNR in a packet constant. The PERs of the conventional scheme, in which the CSI is the mean of the received

SNR only, are also plotted for comparison (denoted as All). In the Figure, the NSD is quantised into three bits (denoted as NSD0–NSD7). From the results, it is observed that the PER increases as the NSD increases. In addition, when the NSD is small, the two MCS options of the proposed scheme require approximately 4.5 and 6 dB less TP compared to those of the conventional scheme at the target PER of 10^{-3}, respectively. Although it is not shown explicitly, the higher the modulation order or the code rate is, the more additional power is required at a given value of the NSD.

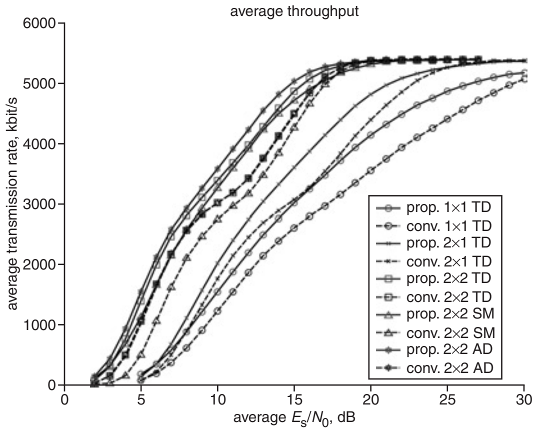

Fig. 2 *Performance of proposed adaptive transmission scheme*

Table 1: Summary of the MCS options used in the simulation

MCS option (Ant.,Mod.,CR)	Rate, Mbit/s	MCS option (Ant.,Mod.,CR)	Rate, Mbit/s
TD,16-QAM,1/2	2.304	SM,16-QAM,5/12	3.840
SM,4-QAM,1/2		TD,64-QAM,2/3	4.608
TD,16-QAM,2/3	3.072	SM,16-QAM,1/2	
SM, 4-QAM,2/3		TD,64-QAM,7/9	5.376
TD,16-QAM,5/6	3.840	SM,16-QAM,7/12	

In Fig. 2, the performance of the proposed adaptive transmission scheme (denoted as 'prop.') is shown for the TD only, the SM only, and the adaptive TD and SM (denoted as 'AD') cases for various values of N_T and N_R. The MCS options used in the simulations are summarised in Table 1. Here, the transmitter selects an MCS option in order to maximise the throughput under the constraint on the TP, and the target PER is set at 10^{-2}. For comparison, the performance of the conventional scheme (denoted as 'conv.') in each case is also provided. From the results, it is observed that the performance of the proposed scheme is up to 2–3 dB better than that of the conventional scheme, depending on the antenna configuration, at the expense of only three and six more bits in the feedback CSI for the TD (SM) only case and the adaptive TD and SM case, respectively. In addition, it is shown that the proposed adaptive TD and SM scheme improves the system performance, while the conventional one is useless.

Conclusion: An efficient adaptive transmission scheme using QAM and LDPC code is proposed for OFDM-based cellular systems employing multiple antennas. The TD scheme and the SM scheme are used adaptively as well as the modulation order and the code rate. The CSI comprises only three parameters and requires only six more bits when three-bit quantisation is used for the NSD. The MCS option and the TP can be determined with the predetermined values of the required mean SNR and the additional power corresponding to the NSD for each MCS option. From the simulation results, it is shown that, for various antenna configurations, the proposed adaptive transmission scheme can provide up to 2–3 dB gain over the conventional scheme.

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