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Research Article

Adaptive Cooperative Food Communication System Transmission in MIMO Channels

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Abstract: In this study, we propose a cooperative transmission framework based on Adaptive Modulation and Coding (AMC) cooperative food communication system in Multiple-Input Multiple-Output (MIMO) fading channels. We consider the scenario that consists of one source node, one relay node and one destination node, they all equipped with multiple antennas and employed the adaptive modulation and coding schemes. The relay node follows the decode-and-forward strategy, forwarding the information received from the source to the destination in case of correct decoding. Through computer simulation, we got the effective capacity of the adaptive cooperative transmission cooperative food communication system according to different Qos requirement.

Keywords: Adaptive Modulation and Coding (AMC), cooperative transmission, food communication system, MIMO channels

INTRODUCTION

The increasing development of wireless applications, especially real-time media traffic with stringent QoS constraints requires a high efficient utilization of the scarce radio resources. Many techniques are proposed to improve the throughput of time-varying fading channels while maintaining a satisfied QoS, such as link adaptation based on Adaptive Modulation and Coding (AMC) and Automatic Repeat Request (ARQ) (Liu *et al*., 2004) multiple-input and multiple-output cooperative food communication systems and cooperative transmission through node cooperation (Zhang *et al*., 2008).

There are many literature about the adaptive cooperative transmission, Jalil Seifali investigates the effective capacity for multi-rate relay channels with delay constraint exploiting adaptive cooperative diversity (Harsini and Zorzi, 2012) and authors in Wu and Negi (2003) design a decision-making algorithm on cooperative transmission by using a partially observable Markov decision process framework. Chu *et al*. (2013) exploits the use of cooperative relay transmission in a MIMO-based ad hoc network to cope with harsh channel condition. In this study, we propose a framework of adaptive cooperative transmission based on adaptive modulation and Low-Density Parity-Check (LDPC) codes in multi-antenna cooperative food communication systems.

MATERIALS AND METHODS

Cooperative food communication system model: The cooperative food communication system model of cooperative transmission based on LDPC codes in MIMO channels is shown in Fig. 1. The cooperative food communication system consists of source node S, destination node D and relay node R. Assuming that there are N_T transmit antennas, N_R relay antennas and N_D receive antennas.

Transmission principle: The adaptive transmission is achieved by two means, at the physical layer, there are multiple Modulation and Coding Schemes (MCSs) available, not only in source node but also in delay node. Coded symbols are transmitted to the relay node and the destination node simultaneously on a frame-by-frame basis through MIMO fading channels after space-time block coding. The CSI is estimated at the receiver and then sent back through a feedback channel to the AMC controller for both the source node and delay node, which chooses the appropriate MCS in the next transmission accordingly.

At the data link layer, adaptive cooperative retransmission is employed to improve the throughput performance, especially for the the food communication of delay-sensitive packet traffic. The packet and frame structures used in this study are similar to those. The difference is that no Cyclic Redundancy Check (CRC) codes are used in our cooperative food communication system. This is due to the fact that LDPC codes are employed here, whose strong error detection ability enables them to act as error detection codes as well. Source information are transmitted frame by frame, each frame is divided into two time-slots, during the first time-slot, node S selects an AMC mode based on the S-D channel condition, meanwhile node R and node D listen. When an error is detected in a packet at node

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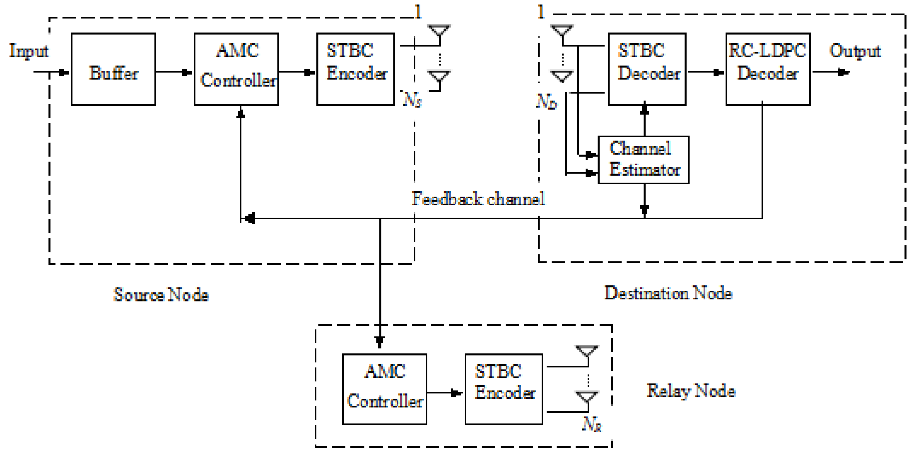

Fig. 1: Cooperative food communication system model

D, a retransmission request is generated and sent back to node S and node R via a feed back channel. Then at the second time-slot, node R forwards the packet received from node S to node D when it is able to decode the source packet correctly, otherwise, node S will deliver the packet again. For simplicity, we assume that the feed back channel is error free and has zero delay.

Channel model: A block fading channel model is adopted for all S-D, S-R and S-D links. Here we take the S-D link for an example, S-R and S-D links can be analyzed in a similar way. The MIMO fading channel between S and R can be expressed as a matrix, $\mathbf{H}_{SR} = [h_{ij}]_{i,j=1}^{N_S,N_R}$, where h_{ij} is the channel coefficient between the jth transmit antenna and the ith relay antenna. Under the assumption of independent Rayleigh fading, the channel coefficients h_{ij} are modeled as independent and identically distributed (i.i.d.) complex circular Gaussian random variables with zero mean and unit variance. The received signal at relay node can be expressed as:

$$\mathrm{Y_R = H_{SR}X + V} \tag{1}$$

where, Y_R is a $N_R \times T$ matrix of received symbols with T representing the number of symbols per antenna, X is a $N_T \times T$ matrix of transmitted symbols and V is a $N_R \times T$ noise matrix with elements modeled as i.i.d. complex circular Gaussian random variables having zero mean and unit variance.

Figure 1, the STBC encoder maps $R \leq T$ complex modulated symbols into N_T orthogonal complex symbol sequences of length T and then transmits them by N_T transmit antennas simultaneously. The coding rate of a STBC is therefore $R_c = R/T$. Let us define the average transmit power per stream/antenna as P_s. According to the effective SISO channel model for STBCs described in Lee *et al*. (2013), the received symbol y before the Maximum Likelihood (ML) detection can be expressed as:

$$y_R = \|\mathbf{H}_{SR}\|_{\mathrm{F}}^2 s + v \tag{2}$$

where, s is the real or imaginary part of the transmitted complex symbol, v is the noise symbol with mean power σ^2 after STBC decoding, $\|\cdot\|_{\mathrm{F}}^2$ denotes the squared matrix Frobenius norm and $\|\mathbf{H}_{SR}\|_{\mathrm{F}}^2 = \sum_{i,j} h_{ij}^2$. At the receiver, the SNR is given by:

$$\gamma_1 = \frac{P_s d_1^{-\alpha}}{\sigma^2}\|\mathbf{H}_{SR}\|_{\mathrm{F}}^2 = \frac{P_T d_1^{-\alpha}}{\sigma^2 N_T R_c}\|\mathbf{H}_{SR}\|_{\mathrm{F}}^2 = \frac{\overline{\gamma_1}}{N_T R_c}\|\mathbf{H}_{SR}\|_{\mathrm{F}}^2 \tag{3}$$

where, P_T is the total transmit power transmitted on N_T antennas per symbol duration and $\overline{\gamma_1} = P_T d_1^{-\alpha} / \sigma^2$ is defined to be the average pseudo SNR, in which d_1 is the Euclidean distances between noses S and D, α is the path loss exponent. Since $\|\mathbf{H}_{SR}\|_{\mathrm{F}}^2$ is the sum of $2K$ i.i.d. χ^2 random variables, we can get the probability density function (PDF) of γ_1 as follows:

$$p_{\gamma_1}(\gamma_1) = \frac{\gamma_1^{K-1}}{\Gamma(K)}\left(\frac{N_T R_c}{\overline{\gamma_1}}\right)^K \exp\left(-\frac{N_T R_c}{\overline{\gamma_1}}\gamma_1\right), \quad \gamma_1 \geq 0 \tag{4}$$

where, Γ (.) is the Gamma function.

In the same way, we let γ_2 and γ_3 denote the received SNR on the R-D and S-R channels the Euclidean distances between noses R and D and noses S and R are d_2 and d_3 respectively, accordingly, the average SNRs are given by $\overline{\gamma_2} = P_r d_2^{-\alpha} / \sigma^2$ and $\overline{\gamma_3} = P_T d_3^{-\alpha} / \sigma^2$.

Adaptive modulation and coding schemes: The AMC schemes adopted at node S and node R can be illustrated as follows: Packets received incorrectly after N_r retransmissions will be dropped. In order to meet the cooperative food communication system delay constraint, for a given packet loss probability PER_{link} at the data link layer, the Packet Error Rate (PER) P_{target} at the physical layer should be:

$$P_{\text{target}} = PER_{\text{link}}^{1/(N_r+1)} \tag{5}$$

The AMC is implemented at the physical layer according to the target PER. Suppose that there are N MCSs at the physical layer with increasing rates R_n (n = 1, 2, …, N) in terms of information bits per symbol. We will consider the modulation method with the MQAM signal constellation, where M denotes the number of points in each signal constellation. If the coding rate of a MCS is R_L, we have $Rn = R_L$. ($\log_2 M$), we assume constant power transmission and adopt the equivalent SISO channel model to describe the instantaneous channel SNR. The whole range of the SNRs γ_1, γ_2 are divided into N+1 and M+1 non-overlapping consecutive intervals, denoted by $[\gamma_{n,1}, \gamma_{n+1,1})$, n = 0, 1, … N and $[\gamma_{m,2}, \gamma_{m+1,2})$, m = 0, 1, … M. When γ_1 falls into the interval $[\gamma_{n,2}, \gamma_{n+1,1})$, $n \geq 1$, node S selects the AMC mode n and sends data with transmission rate $R_{n,1}$ (bits/symbol). In a similar way, when $\gamma_2 \in [\gamma_{m,2}, \gamma_{m+1,2})$, m ≥ 1, node R selects mode m and sends data to node D with rate $R_{m,2}$ (bits/symbol). When $\gamma_2 \in$, $[\gamma_{0,2}, \gamma_{1,2}]$ no data is sent by node R. But when $\gamma_1 \in$, $[\gamma_{0,1}, \gamma_{1,1}]$, nodes S still transmits packets from its buffer with the first AMC mode (n = 1).

It is an important issue to find the thresholds $\gamma_{n,1}$ and $\gamma_{m,2}$. We take $\gamma_{n,1}$ for an example, for LDPC codes, the relationship between the PER and γ_1 is given by:

$$\text{PER}_n(\gamma_1) = \begin{cases} 1, & if \quad 0 < \gamma_1 < \gamma_{cf} \\ \left(\dfrac{1}{1+\exp\{c_n(\gamma_1 - b_n)\}}\right)^{a_n}, & if \ \gamma_1 \geq \gamma_{cf} \end{cases} \tag{6}$$

where, n is the MCS index, $\gamma_{c,f}$ is the SNR cut-off value indicating that no information will be transmitted when the instantaneous SNR falls below it, α_n, b_n, c_n and $\gamma_{c,f}$ are parameters obtained by fitting (6) to the simulation results.

For a given target PER, The thresholds can be obtained from (6) as follows:

$$\gamma_{n,1} = \frac{\ln\{(1/P_{\text{target}})^{1/a_n} - 1\}}{c_n} + b_n, \quad n = 0, 1, ..., N, \\ \gamma_{N+1,1} = +\infty. \tag{7}$$

According to the AMC rule, each MCS n will be chosen with the following probability:

$$p_{n,1} = \int_{\gamma_{n,1}}^{\gamma_{n+1,1}} p_{\gamma_1}(\gamma_1) d\gamma = \frac{\Gamma(K, \lambda\gamma_{n,1}) - \Gamma(K, \lambda\gamma_{n+1,1})}{\Gamma(K)} \tag{8}$$

It can be shown that the average PER for MCS n is given by:

$$\overline{\text{PER}}_{n,1} = \int_{\gamma_{n,1}}^{\gamma_{n+1,1}} PER_n(\gamma_1) p_{\gamma_1}(\gamma_1) d\gamma_1 \tag{9}$$

Then, the total average PER can be written as follows:

$$\overline{P}_{n,1} = \frac{\sum_{n=1}^{N} R_{n,1} \overline{\text{PER}}_{n,1}}{\sum_{n=1}^{N} R_{n,1} p_{n,1}}. \tag{10}$$

RESULTS AND DISCUSSION

In real time multimedia services such as video transmission, time delay is an important QoS parameter. Effective Capacity (EC) is proposed to describe the maximum throughput of the cooperative food communication system under delay constraint and widely used to analyze the QoS performance of wireless multimedia networks.

In Rayleigh fading channel, let the binary random variable Xi indicate the number of packets serviced by the queue service process at node S in frame i. If the packet in the ith frame is decoded correctly by node D then X_i = 1, otherwise X_i = 0 (packet error). The EC function can be upper-bounded as follows:

$$\begin{aligned} EC(\theta) &\leq \frac{-1}{\theta \overline{T}_f} \log\left[E_{X_i}\left\{\exp\left(-\theta N_b X_i\right)\right\}\right] \\ &= \frac{-1}{\theta \overline{T}_f} \log\left[\exp(-\theta N_b) + (1 - \exp(-\theta N_b)) \Pr(X_i = 0)\right] \end{aligned} \tag{11}$$

where, $\theta \geq 0$ reflects the quality requirement of the transmission. A smaller θ represents a looser QoS constraint, when θ tends to 0, an arbitrarily long delay can be tolerated, the EC converges to the maximum throughput (ergodic capacity) of the cooperative food communication system.

In an AMC-based transmission cooperative food communication system with a fixed symbol rate, the duration of each time slot in a frame depends on the employed AMC mode. If in the first time-slot, node S transmits with mode n, the duration of this time-slot is denoted by:

$$T_{s,1}^{(n)} = \frac{N_b}{R_{n,1} R_s}, \quad \forall n \geq 1$$

where, N_b is the packet length in bits and R_S is the channel symbol rate per second. Similarly, the retransmission time duration in the second time-slot for node R can be expressed as:

$$T_{s,2}^{(m)} = \frac{N_b}{R_{m,2} R_s}, \quad \forall m \geq 1$$

$$\Pr(X_i = 0) =$$
$$p_{0,1} I_1 \overline{PER}_{0,1} + \sum_{n=1}^{N} p_{n,1} I_n \overline{PER}_{n,1}$$
$$+\left(p_{0,1}(1-I_1)\overline{PER}_{0,1} + \sum_{n=1}^{N} p_{n,1}(1-I_n)\overline{PER}_{n,1} \right)\left(p_{0,2} + \sum_{m=1}^{M} p_{m,2}\overline{PER}_{m,2} \right) \quad (12)$$

$$p_{m,2} = \int_{\gamma_{m,2}}^{\gamma_{m+1,2}} p_{\gamma_2}(\gamma_2) d\gamma = \frac{\Gamma(K, \lambda\gamma_{m,2}) - \Gamma(K, \lambda\gamma_{m+1,2})}{\Gamma(K)} \quad (13)$$

$$I_n = \int_0^{\infty} PER_n(\gamma_3) p_{\gamma_3}(\gamma_3) d\gamma_3 \quad (14)$$

For the relay-assisted transmission cooperative food communication system, the expected value of the frame length $\overline{T}_f$ is given by:

$$\overline{T}_f = E\left(T_f^{(i)}\right) = \sum_{n=0}^{N} T_{s,1}^{(n)} \overline{P}_{n,1} + \left(\sum_{m=1}^{N} T_{s,2}^{(m)} p_{m,2} \right) \times \left(p_{0,1}(1-I_1)\overline{PER}_{0,1} + \sum_{n=1}^{N} p_{n,1}(1-I_n)\overline{PER}_{n,1} \right) \quad (15)$$

NUMERICAL RESULTS

In this section, numerical results showing the effects of different parameters on the EC of our cooperative transmission framework are provided. Firstly, the cooperative food communication system parameters are set as follows: The S-D distance d_1 is normalized to one, the relay position is controlled by changing the R-D distance d_2, path loss exponent $\alpha = 4$, the packet length is $N_b = 1008$ bits. The frame time duration in the AMC mode 1, $T_{s,1}^{(1)} = 2ms$, relay position $d_2 = d_3 = d_1/2$, equal transmit powers for nodes S and R. Nodes S and R use the same AMC mode set, adopting from the IEEE 802.11a standard, which is shown in Table 1, we use RC-LDPC codes instead of convolutional codes. The variable node degree distribution of irregular LDPC codes is as follows:

$$\lambda(x) = \sum_i \lambda_i x^i = 0.47532x^2 + 0.27953x^3 + 0.03486x^4 + 0.10889x^5 + 0.10138x^{15}. \quad (16)$$

Assume that the performance constraint at the data link layer is $PER_{\text{link}} = 0.01$. Let us consider three values

Table 1: Parameters of MCSs at the physical layer

	MCS1	MCS2	MCS3	MCS4	MCS5	MCS6
Modulation	BPSK	QPSK	QPSK	16QAM	16QAM	64QAM
Coding rate	1/2	1/2	3/4	9/16	3/4	3/4
R_n (bits/sym)	0.50	1.00	1.50	2.25	3.00	4.50
a_n	2.0711	2.4654	1.3988	1.5948	1.2032	1.2086
b_n	-1.9453	1.1845	4.3105	7.2495	10.334	15.551
c_n	3.9263	3.0263	2.9004	3.4256	3.0533	2.6082
γ_{cf} (dB)	-3.3017	-0.63305	2.61	5.7713	8.7682	13.716

Table 2: Thresholds γ_n (dB) for $N_r = 0, 1, 2$

N_r	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6	γ_7
0	-1.4082	1.7463	5.4325	8.0757	11.58	17.003	∞
1	-1.7638	1.3282	4.8042	7.5924	10.908	16.22	∞
2	-1.9214	1.1361	4.5489	7.39	10.645	15.912	∞

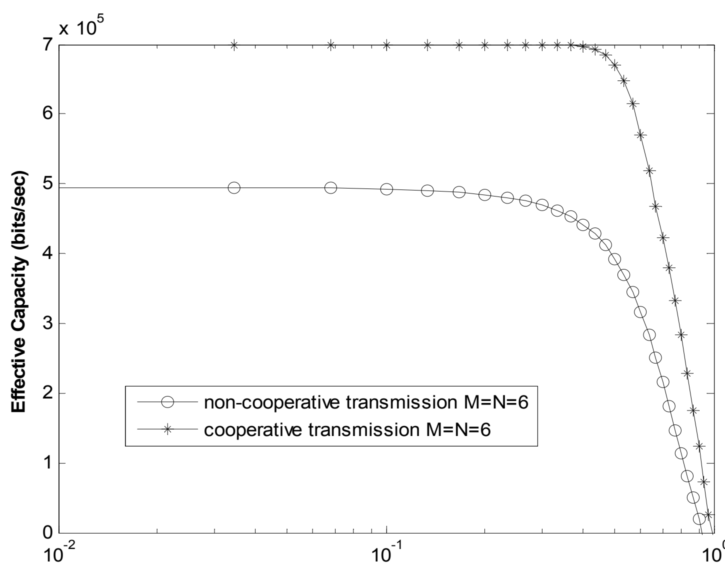

Fig. 2: EC for different θ

for the maximum numbers of retransmissions, i.e., N_r = 0, 1, 2. We can get the value of P_{target}. Then, the thresholds are shown in Table 2.

The EC for both cooperative and direct transmission cooperative food communication systems under several channel scenarios is given in Fig. 2. In noncooperative transmission scheme, node S directly transmit its packets to node D without the assistance of the relay node. We can see in Fig. 2, compared with the no cooperative transmission, the cooperative protocol dramatically improves the EC.

CONCLUSION

In this study, we proposed an adaptive transmission frame in cooperative food communication systems under MIMO channel. The AMC at the physical layer and the adaptive cooperative transmission at the data link layer are combined to achieve a better EC. At the source node and the relay node, relevant MCS is chosen based on the SNR thresholds calculated according to the LDPC PER-SNR relationship. Numerical results show that the cooperative cooperative food communication system can provide better EC than the non-cooperative cooperative food communication system.

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