LDPC Coded MIMO Communication System With Relay Selection

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Abstract— This paper presents a low-density parity check(LDPC) coded multiple-input multiple-output(MIMO) cooperative communication system with relay selection strategy. In the proposed cooperative network with multiple potential relays, we present selection cooperation to choose the best relay. We also present the outage probability analysis of this system. Furthermore, in the proposed architecture relays firstly perform sphere detection, then send extrinsic messages to the terminal node by using space time block codes. By this architecture the terminal node only needs to perform LDPC decoding so the power consumption of the terminal node can be reduced.

I. Introduction

Low density parity check(LDPC) code was firstly introduced by Gallager [1] in 1962. However, it was soon forgotten due to limited computational resources at that time which made the corresponding iterative decoding algorithms look impractical. Until the 1990s LDPC code was rediscovered by D.J.C Mackay in [2], which proves that LDPC code is a very powerful error correction technique which allows data transmission in wireless networks at rates near the channel capacity with arbitrarily low probability of error. For these reasons, LDPC code has been used in many broadband broadcasting systems. In our proposed system, LDPC code is employed as the channel code in order to improve the system performance.

It is well known that multiple-input multiple-output (MIMO) communication systems can provide a lot of benefits such as diversity gain and robustness against fading. The application of LDPC codes to spectrally efficient MIMO signaling has been proposed in Wireless Local Area Network within the IEEE 802.11 and 802.3 standards bodies [3]. It is certain that the combination of MIMO and LDPC will be used in an increasing number of communication environments in coming years. MIMO signal detector is a key part in this communication system. Although Maximum-likelihood(ML) MIMO detector can provide optimal performance, exhaustive search in ML incurs prohibitive computational complexities. So suboptimal detector which can provide good performance with a low computational complexity attracts a lot of attentions. One method is to use minimum mean square error(MMSE) detection, which is quite efficient in computation, however, it suffers from significant performance degradation. Another suboptimal approach to achieve optimal performance is sphere detection, which can offer significant performance advantages over MMSE at the cost of increasing computational complexity. In the proposed system, a modified sphere detector based on the iterative sphere decoding algorithm in [4] is employed, which efficiently obtains soft information for the transmitted signals.

High data-rate coverage is required in wireless communication systems. Relay nodes which help relaying the source signals to the destination can provide cooperative diversity. So cooperative communication system with relay nodes is a major candidate in various standard proposals. This system architecture promises significant improvements in coverage and spectral efficiency.

In our proposed system we use multi relays to improve the outage probability and BER performance. We add four additional bits to perform channel estimation, then select the best relay according to the channel information. Furthermore, different from previous relay systems which use amplify-and-forward or decode-and-forward strategies, in the proposed architecture relay receives messages sent by the base station, performs sphere detection to compute the extrinsic information of each bit. Then relay node sends the extrinsic information to the terminal node by using space time block codes(STBC) and BPSK modulation. By this architecture, the terminal node only needs to perform the LDPC decoding. So the power and complexity of the terminal node can be reduced.

II. System Model

Figure 1 shows the block diagram of LDPC coded MIMO communication system with multi relays. In the transmitter side, the information bits are encoded using an LDPC encoder. Then the LDPC coded bits are modulated using QPSK or other modulation schemes. The MIMO symbol vector mapper maps these symbols to multiple transmit antennas. A number of potential relaying nodes are willing to cooperate and relay signals to the destination. The relays satisfy a half-duplex constraint. The channel coefficient $\alpha_{i,j}$ between nodes i and j is flat and slowly-fading Rayleigh with variance $1/\lambda_{i,j}$,which means, $| \alpha_{i,j} |^2 \sim \lambda_{i,j} \mathtt{exp}[-\lambda_{i,j} | \alpha_{i,j} |^2]$. The relay node forms

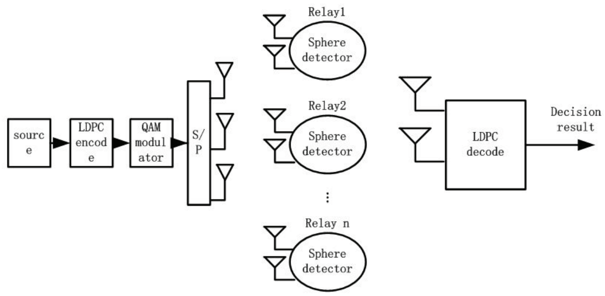

Fig. 1. LDPC coded MIMO communication system with multi relays.

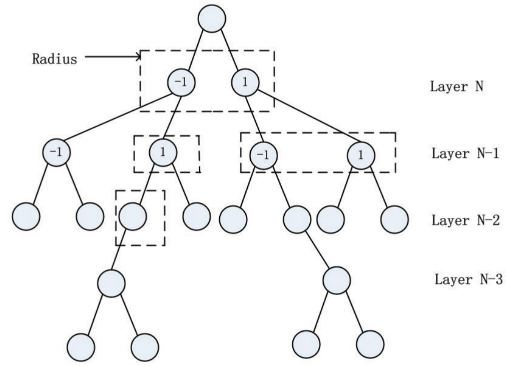

Fig. 2. Tree Search.

soft extrinsic information of each code based on the received symbols by using MIMO sphere detector. Then relay node sends these extrinsic information which is served as the priori information for the LDPC decoder to destination by using STBC. Destination selects the best relay according to the estimated channel information and outputs the decoding results of LDPC decoder.

The extrinsic LLR value of the estimated bit is computed as

$$\begin{aligned} L_D(x_i) &= \log \frac{P(x_i = +1|y,H)}{P(x_i = -1|y,H)} \\ &= \log \frac{\sum_{x\in\mathcal{X}_{i,+1}} P(y|x_j = +1)P(x_j = +1)}{\sum_{x\in\mathcal{X}_{i,-1}} P(y|x_j = -1)P(x_j = -1)} \\ &= \log \frac{\sum_{x\in\mathcal{X}_{i,+1}} \exp\left(-\frac{1}{\sigma^2}\|\mathbf{y}-\mathbf{Hs}\|^2 + \mathbf{x}^T\cdot\mathbf{L}_A\right)}{\sum_{x\in\mathcal{X}_{i,-1}} \exp\left(-\frac{1}{\sigma^2}\|\mathbf{y}-\mathbf{Hs}\|^2 + \mathbf{x}^T\cdot\mathbf{L}_A\right)} \end{aligned} \quad (1)$$

By using the max-log approximation, the extrinsic LLR of the ith bit in x can be approximated as

$$\begin{aligned} L_D(x_i) \approx& \frac{1}{2}\max_{x\in\mathcal{X}_{i,+1}}\{-\frac{1}{\sigma^2}\|\mathbf{y}-\mathbf{Hs}\|^2 + \mathbf{x}^T\cdot\mathbf{L}_A\} \\ &-\frac{1}{2}\max_{x\in\mathcal{X}_{i,-1}}\{-\frac{1}{\sigma^2}\|\mathbf{y}-\mathbf{Hs}\|^2 + \mathbf{x}^T\cdot\mathbf{L}_A\} \end{aligned} \quad (2)$$

Then the extrinsic information $L_D(x_i)$ is used in the variable node update step.

The basic idea of the sphere decoding algorithm [4] is that rather than search over the entire lattice, one should search only over lattice points in a hypersphere of radius around. The algorithm constructs a tree, whose nodes at the kth level correspond to the lattice points lying inside the sphere of radius r and dimension k as figure 2 shows. The algorithm performs a depth-first tree search over all lattice points of radius and dimensions to find the points inside a sphere of radius and dimension. Given a radius r, we search for the point s that belongs to the geometric body described by

$$\begin{aligned} r^2 &\ge \|\mathbf{y}-\mathbf{Hs}\|^2 \\ &\ge \|\hat{s}-Rs\|^2 \end{aligned} \quad (3)$$

where $\hat{s}$ is the unconstrained maximum likelihood estimate of y, and defined as $\hat{s} = Q^*y$. R is the upper triangle matrix by QR decomposition of H. As the property of upper triangle matrix, we start from the last layer which defined as m. We can get

$$(\hat{s_m} - r_{m,m}s_m)^2 \le r^2 \quad (4)$$

so we have

$$\frac{\hat{s_m} - r}{r_{m,m}} \le s_m \le \frac{\hat{s_m} + r}{r_{m,m}} \quad (5)$$

for the iterative search, we define

$$r_{m-1}^2 = r^2 - (\hat{s_m} - r_{m,m}s_m)^2 \quad (6)$$

a new condition can be written as

$$r_{m-1}^2 \ge (\underbrace{\hat{s}_{m-1} - r_{m-1,m}s_m}_{\hat{s}_{m-1|m}} - r_{m-1,m-1}s_{m-1})^2 \quad (7)$$

so we can get the candidates of s_{m-1} by

$$\frac{\hat{s}_{m-1,m} - r_{m-1}}{r_{m-1,m-1}} \le s_{m-1} \le \frac{\hat{s}_{m-1} + r_{m-1}}{r_{m-1,m-1}} \quad (8)$$

One can continue in a similar way and so on, thereby obtaining all lattice points.

For simplicity we assume time division multiplexing scheme, in the first time slot the source transmits its preamble to relay nodes for channel estimation. Relay nodes whose channel condition is sufficiently good to allow for successful decoding are selected into the decoding set(C). In the second time slot, relay nodes from the decoding set C(s) send preamble to the destination, then destination performs channel estimation and selects the best relay according to the channel condition. Because channel is slow fading, so it is reasonable to assume that channels nearly keep the same within a frame. In the following time slots, a frame is forwarded through the link from source to destination by the best relay. So for every frame, we need 2 time slots to select the best relay.

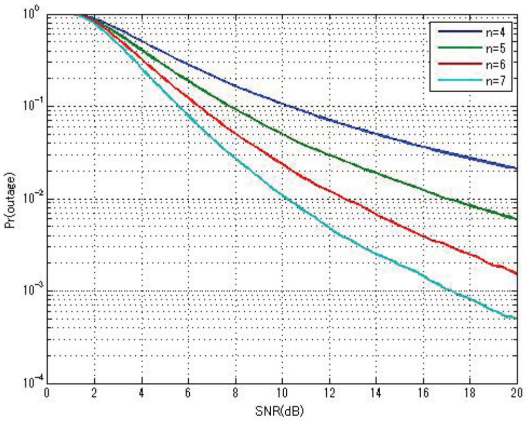

Fig. 3. LDOC coded MIMO communication system with multi relays. Relay number n=4,5,6,7.

III. Proposed System Architecture Analysis

In this section, we will analysis this system from outage probability, terminal power reduction and best relay selection these three points. We also present simulation results to show that the proposed system can provide advantages in these points.

A. *Outage Performance Analysis and Simulation Results*

Then we will discuss the method to decide whether a node $r_k \in C(s)$ or not. If the source-relay channel has a capacity above the required rate R:

$$\begin{aligned} &\frac{1}{2}\log(1+ \mid \alpha_{s,r_k} \mid^2 \frac{P}{N_0}) \\ &= \frac{1}{2}\log(1+ \mid \alpha_{s,r_k} \mid^2 SNR) \geq R \end{aligned} \tag{9}$$

This means channel capacity is above the required rate R. Then the source relay channel has the potential to support zero error transmission. So it is selected into the decoding set C(s). Here N_0 is the noise power spectral density and $SNR = \frac{P}{N_0}$ is the signal-to-noise ratio.

One advantage of this multi relay communication system is that it can increase the reliability of communication. The probability of outage which is an important characterization of cooperation system will decrease with the relay nodes increasing. So the communication is more stable and reliable. If node r_k is chosen as the relay, the system outage probability can be given by

$$\begin{aligned} P_{out} = \{ &(\frac{1}{2}\log(1+ \mid \alpha_{s,r_k} \mid^2 SNR) \leq R) \\ &\|(\frac{1}{2}\log(1+ \mid \alpha_{r_k,d} \mid^2 SNR) \leq R)\} \end{aligned} \tag{10}$$

In Fig.3, we use MATLAB to simulate the outage probability of this multi relay system. We assume that required rate R=1 b/s/Hz, Rayleigh channel variance $1/\lambda_{i,j} = 1$, relay number n=4,5,6,7. From Fig.3 we can see that outage probability falls off quickly with relay number increasing, so the system performance becomes better.

B. *Terminal Power Reduction Strategy*

Then we will present the advantage of terminal power reduction in this LDPC coded MIMO communication multi relay system. Fixed relays are low-cost and fixed radio infrastructures without wired connections. They receive signals from base station and retransmit these signals to terminals. Generally, fixed relays can increase throughput, extend coverage of cellular networks, enhance the capacity of a specific region with high traffic demands, improve signal reception. Previous relay systems always use amplify-and-forward(AF) or decode-and-forward(DF) strategies. However no matter which strategy is employed, the terminal needs to perform sphere detection and LDPC decoding. In some situations, for example, terminals are mobile phones, low power consumption in terminal is more precious than low power in fixed relays. So in our proposed relay system the relay performs sphere detection to detect the received signals, detection result is the extrinsic message of each bit. Then the relay quantizes these messages by 6 bits and transmits these information to terminal using space time block codes, which is low complexity for decoding. So the terminal only needs to perform LDPC decoding. By this architecture, the computational complexity and power consumption in terminal can be reduced.

C. *Optimal Relay Selection Method*

The basic idea of the proposed LDPC coded MIMO cooperative communication system with multi relays depends on selecting one relay among the decoding set to cooperate with the source. So we need to solve the question that how to determine the optimal relay for cooperation. In our system, before transmitting one frame, we first send preamble to the destination for channel estimation in the first two time slots. The cooperation ability of relay depends on the channel information of source-relay channel and relay-destination channel. The relay with larger channel gains and less noise variance has more potential to cooperate with the source. In order to achieve full diversity N, where N is the number of relays, we have to choose the best relay at each time instant. So instantaneous channel gains $\mid h_{s,r} \mid^2$ and $\mid h_{r,d} \mid^2$ are employed for optimal relay selection. Therefore, we propose the relay's

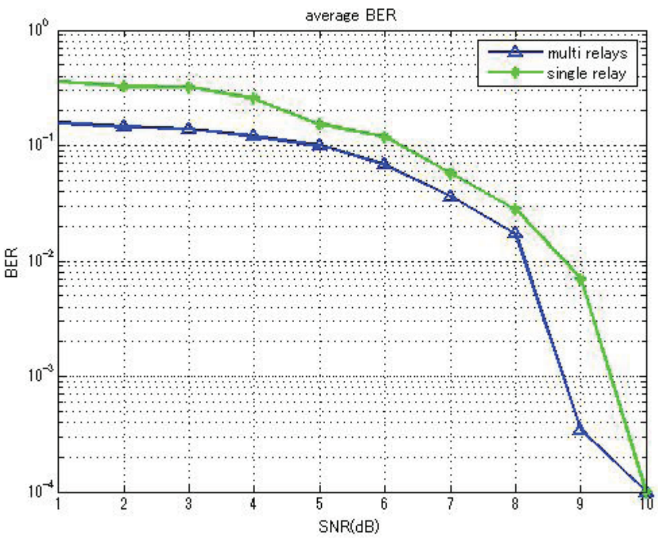

Fig. 4. Average BER comparison of multi relays and single relay.

metric μ,which is given by

$$\mu = \frac{\frac{1}{N_1 M_1}\sum_{j=1}^{M_1}\sum_{i=1}^{N_1} \mid h_{sr_{i,j}} \mid^2 + \frac{1}{N_2 M_2}\sum_{j=1}^{M_2}\sum_{i=1}^{N_2} \mid h_{rd_{i,j}} \mid^2}{\eta_1 + \eta_2} \quad (11)$$

where N_1 denotes transmitter antenna number in the source, M_1 denotes receiver antenna number in the relay, N_2 denotes transmitter antenna number in the relay, M_2 denotes receiver antenna number in the destination, η_1 denotes noise in the source relay channel, η_2 denotes noise in the relay destination channel. For each relay belonging to the decoding set, we compute the relay's metric μ according to equation (11), then select the relay with the largest relay's metric μ as the optimal relay for cooperation.

D. System BER Simulation Results

In this section, we will present performance of LDPC coded MIMO cooperative communication system with multi relays. We consider the multiantenna system with $N_t = 4$ transmit antennas in the source and $N_r = 4$ receive antennas in relays for sphere detection. Relatively, 2×1 space time block coding system is used in relay terminal transmission. An information bit sequence with 261 information bits is encoded by a rate $R = \frac{1}{2}$ QC-LDPC code. The coded sequence is modulated by 4-QAM modulation scheme. The LDPC encoder output is a code whose length is 522. We assume that a frame length is equal to the code length 522. Here the potential relay number is 5. Fig.4 shows the average BER comparison of multi relay system and single relay system. The blue line stands for our LDPC coded MIMO communication system with multi relays, green line stands for the same system but with only a single relay.

IV. Summary and Conclusions

In this paper we mainly talk about the LDPC coded MIMO cooperative communication system with relay selection. Firstly, we introduce the trend of combining LDPC and MIMO communication together. Then we describe the system model in detail. Through analysis and simulation, we have shown that system with multi relays have the advantage in outage probability. Furthermore, we have presented the partial decoding architecture in the relay. By this architecture, the terminal only needs to perform LDPC decoding so terminal power reduction can be realized. We also define the method to choose the optimal relay which has the maximum channel metric among all relays. The schedule of this system is that in the first two time slots, we do the channel estimation and select the optimal relay according to the relay metric. In the following time slots, we send the information to destination through the cooperation of optimal relay. The system performance is simulated by using matlab, which shows that multi relay system can provide better average BER and lower outage probability.

V. Acknowledgements

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