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Adaptive Space-Time Receiver for Cooperative Relay Networks Based on Signed Regressor Algorithm

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Abstract : The paper provides a rigorous analysis of the behavior of adaptive space-time receiver for cooperative relay networks is proposed. Using cooperative amplify-and-forward relay nodes, it is possible to increasing the rank of the multiple-input multiple-output (MIMO) channel. The proposed receiver is based on a joint adaptive iterative detection and decoding algorithm, adaptively cancels co-channel interference and eliminates the multiple access interference. The considered algorithm is signed regressor algorithm (SRA). Simulation results show that the proposed scheme achieves better bit error rate (BER) performance compared with the traditional MIMO scheme.

Keywords : Adaptive receiver, MIMO, LMS, SRA.

1. Introduction

Cooperative communication for wireless networks, such as cellular networks, sensor networks, and wireless ad-hoc networks, has recently attracted great attention The cooperative communication is a new communication method promising significant capacity and multiplexing gain increase in wireless networks where users and nodes in a wireless network share resources and create collaboration through distributed transmission [1].

MIMO systems have recently emerged as one of the most significant technical advances in modern communications. This technology promises to solve the capacity bottleneck in wireless communication systems[2]. It was shown in [3] that a diagonal bell laboratories layered space-time (DBLAST) MIMO system using a combination of forward error control (FEC) codes can exploit spatial diversity to asymptotically achieve outage capacity. In [4] proposed a threaded layered space-time code (TLSTC) structure, which has an improved bandwidth efficiency compared to the DBLAST structure.

The layered space-time coded(LSTC) systems, co-channel interference from adjacent layers limits the system performance. To reduce co-channel interference, two iterative receivers with combined detection and decoding are proposed in [4] and [5], based on the turbo principle.

In [6] it is shown that by node cooperation at the physical layer (PHY), e.g. cooperative relaying, it is possible to increase the rank of MIMO channels. The main idea of cooperative relaying is to have multiple idle nodes (or special relays) assisting the communication of active nodes. In this work we consider a 2-hop relay network using linear amplify-and-forward relay nodes; this way of relaying allows lower power consumption at the relaying nodes because there is no need of signal processing power for decoding (idle nodes in a low power mode are an example for amplify and forward relays). Improving the rank of the channel matrix leads to a higher information rate of the communication channel, therefore the application of MIMO techniques, in particular spatial multiplexing, is possible. Beyond the rank improvement there are further advantages of cooperative relaying: it is well known that multi-hop communication increases the coverage and reduces the total transmit power of a network.

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This paper is organized as follows: In Section 2 describes the LSTC systems and channel model as well as the proposed adaptive iterative receiver structure [7] and cooperative signaling scheme using amplify-and-forward relays based on signed regressor algorithm to enable MIMO techniques. The simulation results are discussed in Section 3 and followed by the conclusion in Section 4.

2. System model and adaptive algorithm

2.1 Transmitter scheme

A threaded layered space-time coded transmitter structure for a single user is shown in Fig. 1.

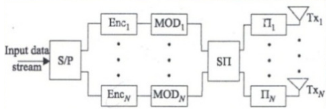

Fig. 1 Layered space-time transmitter scheme.

A structure consists of N_{TX} transmitters and M_{RX} receivers antennas. The binary information stream is converted by a serial to parallel converter and encoded by a convolutional encoder to produce a coded data steam for each layer corresponding to each of the N_{TX} transmit antennas. The layered coded data streams are then modulated and fed into a spatial interleaver to distribute a coded stream for all layers among N_{TX} transmit antennas. After time interleaving, the coded symbols of each layer are simultaneously and synchronously transmitted from the N transmit antennas through the MIMO channel.

2.2 Relaying scheme [6]

Fig. 2 shows the proposed cooperative MIMO system. The source has N_{TX} and the destination N_{RX} antennas. In contrast the relays do not necessarily feature multiple antennas. In this example the transmission of a data packet from the source to the destination occupies two time slots.

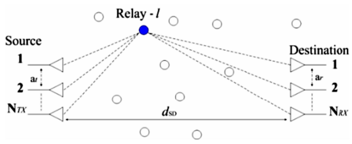

Fig. 2 2-hop relay network with antenna arrays at source and destination.

The first time slot is allocated to the source exclusively. The relays receive during the first time slot and retransmit an amplified version of the received analog signal during the second time slot. The goal of the node cooperation is to increase the rank of the compound (two time slots) channel matrix and to shape the eigenvalue distribution such that the achievable rate of the MIMO link improves.

Note, that the relay nodes in Fig. 2 can be viewed as "active" omni-directional scatters which establish a sort of multipath channel. A major difference to passive scattering is that the relay nodes add noise to the forwarded signal.

A source with N_{TX} transmit antennas sends information to a destination with N_{RX} receive antennas. N_R relay nodes assist the communication in order to increase the channel rank and the achievable information rate. In this paper we consider only single-antenna relay nodes. The extension to the multi-antenna case is straight forward.

In time slot k the source sends the baseband equivalent discrete-time(N_{TX} x 1) vector $\mathbf{s}_k$. The signals received by the relays and the destination in time slot k are given by

$$\mathbf{y}_k = \mathbf{H}_1 \mathbf{s}_k + \mathbf{w}_{k,R} \quad (1)$$

$$\mathbf{r}_k = \mathbf{H}_0 \mathbf{s}_k + \mathbf{w}_k \quad (2)$$

where the (N_R x 1) vector y_k contains the receive signals at the relays, the (N_{RX} x 1) vector r_k the receive signals at the destination, $\mathbf{w}_{k,R}$ and $\mathbf{w}_k$ the AWGN contributions at the relays and the destination receiver, respectively. $\mathbf{H}_0 \in \mathbb{C}^{N_{RX} \times N_{TX}}$ contains the channel coefficients of the direct link between source and destination and $\mathbf{H}_1 \in \mathbb{C}^{N_R \times N_{TX}}$ the channel coefficients between source and relays(first hop).

In the next time slot k+1, the relays send $\mathbf{G}\mathbf{y}_k$ to the destination and the source is quiet. The diagonal (N_R x N_R) matrix $\mathbf{G}$ contains the analog gain factors of the relays. Note that the relays are not able to receive in time slot k+1, since they are already forwarding the signals from the previous time slot and practical considerations (antennal coupling) prevent the relay nodes from transmitting and receiving concurrently at the same physical channel.

Thus, in time slot k+1 the receives signal at the destination can be expressed as

$$\mathbf{r}_{k+1} = \mathbf{H}_2\mathbf{G}\mathbf{y}_R + \mathbf{w}_{k+1} \tag{3}$$

The matrix $\mathbf{H}_2 \in \mathbb{C}^{N_{RX} \times N_R}$ contains the channel coefficients between the relays and the destination (second-hop). By inserting Eq.(1) into Eq.(3) and separating signal and noise terms we obtain

$$\mathbf{r}_{k+1} = \mathbf{H}_2\mathbf{G}\mathbf{H}_1\mathbf{s}_k + \mathbf{H}_2\mathbf{G}\mathbf{w}_{R,R} + \mathbf{w}_{k+1} \tag{4}$$

due to the gain matrix **G** and the channel matrix $\mathbf{H}_2$ the resulting noise at the destination in time slot k+1 is in general colored. Let $\mathbf{n}_{k+1} = \mathbf{H}_2\mathbf{G}\mathbf{w}_{R,R} + \mathbf{w}_{k+1}$ denote this noise component. Defining the two-hop relay channel as $\tilde{\mathbf{H}}_{12} = \mathbf{H}_2\mathbf{G}\mathbf{H}_1$ and describing both time slots jointly in a stacked vector

$$\mathbf{r}_{k,k+1} = \begin{bmatrix}\mathbf{r}_k \\ \mathbf{r}_{k+1}\end{bmatrix} = \underbrace{\begin{bmatrix}\mathbf{H}_0 \\ \tilde{\mathbf{H}}_{12}\end{bmatrix}}_{\tilde{\mathbf{H}}}\mathbf{s}_k + \begin{bmatrix}\mathbf{w}_k \\ \mathbf{n}_{k+1}\end{bmatrix} \tag{5}$$

leads to an channel matrix $\tilde{\mathbf{H}}$ describing a (N_{TX}x2N_{RX}) MIMO channel with spatially colored additive Gaussian noise.

2.3 Receiver Scheme

The iterative LSTC receiver structure is shown in Fig. 3. It consists of two stages: first a soft-input soft-output (SISO) detector and followed by N parallel SISO channel decoders. Time and, spatial deinteleavers and spatial and time interleavers separate the two stages. The SISO detector employs an iterative MMSE interference canceller consisting of a feed-forward filter and a feedback filter.

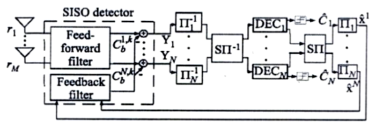

Fig. 3 Block diagram of iterative LST receiver.

In the first iteration, the feed-forward filter performs interference suppression without the interference cancellation process because there are no estimated symbols from the output of the MAP decoder. After the first iteration, the feedback filter is included into the detection process. The estimated symbols from the output of the decoder are fed back for the feedback filter to cancel the interference from other antennas in the detection process. The detected symbol obtained at the output of the MMSE detector in the kth iteration at time t, for layer i, denoted by $y_t^{i,k}$ is given by

$$y_t^{i,k} = \mathbf{w}_f^{i,k^T}\mathbf{r} + \mathbf{w}_b^{i,k^T}\underline{\hat{\mathbf{x}}}^{i,k}, \tag{6}$$

where $\mathbf{w}_f^{i,k}$ is an M x 1 feed-forward coefficient vector represented as $\mathbf{w}_f = [w_{f,0}, w_{f,1},\ldots,w_{f,M\text{-}1}]^T$ and $\mathbf{w}_b^{i,k}$ is an (N-1)x1 feedback coefficient vector, that can be written in the form $\mathbf{w}_b = [w_{b,0}, w_{b,1}, w_{b,i\text{-}1}, w_{b,j+1},\ldots,w_{b,N\text{-}1}]^T$ and $\underline{\hat{\mathbf{x}}}^{i,k}$ is an (N-1) x 1 vector of the estimated symbols from the output of the SISO MAP decoders at the kth iteration for other antennas, given as

$$\underline{\hat{\mathbf{x}}}^{i,k} = \left(\hat{x}_t^{1,k}, \hat{x}_t^{2,k}, \ldots, \hat{x}_t^{i-1,k}, \hat{x}_t^{i+1,k}, \ldots, \hat{x}_t^{N,k}\right), \tag{7}$$

The second term in Eq. (6) represents the cancelled interference, denoted by a scalar feedback coefficient $c_b^{i,k} = \mathbf{w}_b^{i,k^T}\underline{\hat{\mathbf{x}}}^{i,k}$. The values of $w_f^{i,k}$ and $c_b^{i,k}$ are calculated by minimizing the mean square error between the transmitted symbol and its estimate, given by

$$e = E\left[\left|y_t^{i,k} - x_t^{i,k}\right|^2\right], \tag{8}$$

The feed-forward coefficient vector $\mathbf{w}_f^{i,k}$ and feedback coefficient vector $\mathbf{w}_b^{i,k}$ defined in Eq.(6) are determined recursively by an adaptive signed regressor algorithm(SRA). By using Eq.(6) to calculated the coefficients $\mathbf{w}_f^{i,k}(t)$ and $\mathbf{w}_b^{i,k}(t)$ adaptively for a particular time instant t, the mean squared error in Eq.(8) is given by

$$e(t) = E\left[\left\|w_f^{i,k^T}(t)r + w_b^{i,k^T}\hat{\mathbf{x}}^{i,k} - x_t^{i,k}\right\|^2\right], \tag{9}$$

where

$$\mathbf{w}_f^{i,k}(t+1) = \mathbf{w}_f^{i,k}(t) + \mu_f sgn\, e(t)\mathbf{r}(t), \tag{10}$$

$$\mathbf{w}_b^{i,k}(t+1) = \mathbf{w}_b^{i,k}(t) + \mu_b sgn\, e(t)\hat{\mathbf{x}}(t), \tag{11}$$

μ_f and μ_b are the step sizes for the feed-forward and feedback adaptations, respectively.

The likelihood functions for the transmitted modulated symbols 1 and -1 can be written as

$$P\left(\left(y_t^{i,k}\right)\middle| x_t^{i,k} = \pm 1\right) = \frac{1}{\sqrt{2\pi\sigma^2}}exp\frac{-\left(y_t^{i,k} \mp 1\right)^2}{2\sigma^2}, \tag{12}$$

The log-likelihood ratios(LLR) determined in the *k*th iteration for the *i*th transmit layer, denoted by $y_t^{i,k}$, are given by

$$\lambda_t^{i,k} = \log\left(\frac{P\left(\left(x_t^{i,k} = 1\right) \middle| y_t^{i,k}\right)}{P\left(\left(x_t^{i,k} = -1\right) \middle| y_t^{i,k}\right)}\right), \tag{13}$$

The symbol a posteriori probabilities(APP) $P\left(x_t^{i,k} = q \middle| y_t^{i,k}\right.$, q=1, -1) conditioned on the output variable $y_t^{i,k}$ can then be obtained as

$$P\left(\left(x_t^{i,k} = 1\right) \middle| y_t^{i,k}\right) = \frac{e^{\lambda_t^{i,k}}}{e^{\lambda_t^{i,k}}+1}, \tag{14}$$

$$P\left(\left(x_t^{i,k} = -1\right) \middle| y_t^{i,k}\right) = \frac{1}{e^{\lambda_t^{i,k}}+1}, \tag{15}$$

Finally, the soft-output symbols estimate in the *i*th layer and *k*th iteration can be determined as

$$x_t^{i,k} = \frac{e^{\lambda_t^{i,k}} - 1}{e^{\lambda_t^{i,k}} + 1}, \tag{16}$$

3. Performance Results

This section presents the simulation results for the LSTC adaptive iterative receivers for cooperative relay networks with BPSK modulation in both slow and fast Rayleigh fading channels and signed regressor algorithm. The slow fading channel is modeled as a quasi-static fading channel, where each fading coefficient is constant within a frame, but changes from one frame to another and for each sub-channel. The system operation the training mode until the mean square error (MSE) approaches the minimum mean square error and then it switches to the decision directed mode. The constituent codes are nonsystematic convolutional codes with the code rate *R* of 1/2, memory order of 3, and the generating polynomial g = [1 1 0 1;1 1 1 1]. The proposed system is simulated with 2 transmit and 2 receive antennas, i.e., a 2 x 2 MIMO system, with 260 information bits in each frame. After serial to parallel conversion, each layer of the LSTC system consists of 130 information bits, followed by 266 encoded symbols per layer. The data rate is 1 Mb/s at the carrier frequency, f_c, of 2 GHz. The simulation results are represented in terms of the average bit error rate (BER) versus the ratio of the averaged energy per bit, denoted by E_b, to the power spectral density of the AWGN, denoted by N_0.

Outgoing from the system model in section 2.2 two different scenarios can be derived. In the first scenario the direct link between source and destination is obstructed, caused e.g. by shadowing effects (scenario: direct link blocked). Therefore the destination receives only from the relays in the even timeslots. In the second scenario there is a direct link component available at the destination and thus H_0 is unequal to zero (scenario: direct link available).

3.1 Scenario : direct link blocked

Applying the described relaying scheme it is possible to trade data rate and link reliability in a very flexible way. Fig. 4 shows the average BER of the adaptive iterative receiver for various numbers of iterations. A system with $N_{TX} = N_{RX} = 2$ antennas at the source and destination and $N_R = 2, 3$, respectively, number of relay is considered. The system performance is significantly improved for the second iteration compared to the first iteration and gradually increases for higher iterations.

It can be seen that in the data packet was transmitted by the source to destination occupies in the two time slots may increase noise. Fig. 5 compares the gain of relay for G = 1, 2 respectively. The system performance is significantly improved for the second iteration compared to the first iteration, but we found that the average BER of the adaptive iterative receiver decreased when the gain of relay is increased, which is increate noise.

3.2 Scenario : direct link available

In this line of sight (LoS) scenario the destination receives the transmitted signal over a rank one channel in the first timeslot. Therefore the destination is not able to decode the signal until receiving the signals from the relays.

From Fig. 6, the result show that in the case of LoS and time slot two scenario(H_0 and H_{12}), the average BER has a good in the case of the receive signal from the LoS and time slot two and three(H_0, H_{12} and H_{34}). The system performance is significantly improved for the second iteration compared to the first iteration and gradually increases for higher iterations.

From Fig. 7, the result show that the gain of relay for various gain. The system performance is significantly improved for the second iteration compared to the first iteration and higher iterations, but we found that the average BER of the adaptive iterative receiver decreased when $G_1 = 2$ compare to $G_1 = 1$. There is increate noise.

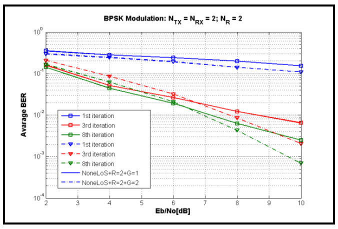

Fig. 4 Comparison BER versus Eb/No[dB] : adaptive iterative algorithm only H_{12} and H_{34} with various number of relay ($N_R = 2$ and 3).

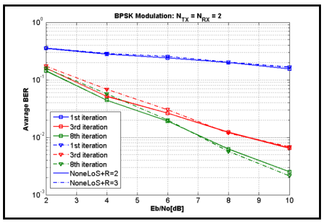

Fig. 5 Comparison BER versus Eb/No[dB] : adaptive iterative algorithm only H_{12} with $N_R = 2$, and various number of gain (G = 1 and 2).

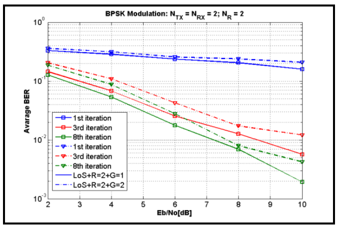

Fig. 6 Comparison BER versus Eb/No[dB] : adaptive iterative algorithm of H_0, H_{12} and H_{34} with various number of relay ($N_R = 2$ and 3).

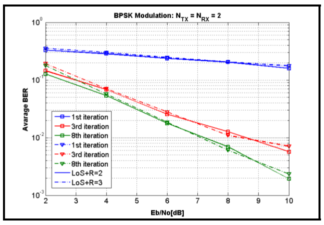

Fig.7 Comparison BER versus Eb/No[dB] : adaptive iterative algorithm of H_0 and H_{12} with $N_R = 2$, and various number of gain (G = 1 and 2).

4. Conclusion

In this paper, we are studied a cooperative signaling scheme using amplify-and-forward relays employing an adaptive iterative receiver for MIMO systems has been developed, based on a joint adaptive iterative detection and decoding structure (LSTC) and signed regressor algorithm (SRA). The adaptive iterative receiver can effectively mitigate the co-channel interference and multiple access interference by using interference suppression and cancellation techniques. More relay antenna can increase the diversity gain and improve the performance of the system further.

5. References

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