Performance evaluation of STBC based cooperative systems over slow Rayleigh fading channel

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\textbf{A B S T R A C T}

In this paper, we study the transmit diversity of the cooperative relay system employing multiple-input multiple-output (MIMO) technology, especially for the Alamouti space-time block codes (STBC), over slow Rayleigh fading channel. The transmit diversity gain is achieved by STBC and cooperative technology. Maximum ratio combining (MRC) and maximum likelihood detection (MLD) are applied in the destination node. Two typical relay protocols, generation relay and non-generation relay with two cooperative implementation schemes are studied in this paper. Our attention is paid to the realization and signal processing algorithms of different STBC coded cooperative systems. System bit error probabilities of these cooperative systems are provided in the simulation. Compared with the conventional non-cooperative system and Alamouti STBC scheme, the STBC coded cooperative system obtains two inherent benefits, achieving the spatial diversity offered by the relay channel and also the ability to exert the characteristics of STBC into the relay system.

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1. Introduction

Nowadays, there is a growing demand for providing high data rates and transmission quality in the condition of limited spectral resource and power consumption. With these requirements, several new technologies emerge, such as multiple-input multiple-output (MIMO) technology\textsuperscript{[1,2]}, cooperative communication\textsuperscript{[3–5]}, ultra wideband (UWB)\textsuperscript{[6]} and cognitive radio\textsuperscript{[7]}.

Space-time coding as a primary MIMO technique\textsuperscript{[13]} which uses multiple antennas at both the transmitter and receiver sides are well known for its ability to resist the influence of wireless fading channel and provide higher capacity and better system performance than single link systems in wireless communications. Recently, it has been demonstrated that user-cooperation represents an effective way to introduce spatial diversity in wireless scenarios where we can not take the full benefit of the uncorrelated channels from the multi-antenna systems. Cooperative diversity gains can be achieved through creating distributed virtual antennas across different terminals in the network. Taking advantage of the rich wireless propagation environment across multiple protocol layers in network architecture, we can obtain numerous opportunities to dramatically improve network performance. The theoretical analysis of such cooperative systems has attracted significant interests and the study of practical architectures is a fertile area of research.

Cooperative communication system is shown in Fig. 1. Each relay can play as a virtual antenna of the source. Laneman gave the basic algorithm and architecture of cooperative communication in his thesis\textsuperscript{[5]}. Different relay protocols can be classified according to their forwarding strategies. There exist three basic cooperative schemes:

(i) Amplify-and-Forward (AF): Relays act as analog repeaters by retransmitting an amplified version of their received signals, which makes the noise floor increased.

(ii) Decode-and-Forward (DF): Relays attempt to decode, regenerate and retransmit an exact copy of the original signals, which potentially propagates decoding errors.

(iii) Decode-and-Re-encode (DR): Relays attempt to decode and construct codewords that are different from the received codewords, which thereby provides incremental redundancy to a receiver that assesses the original and the re-encoded signals. Again, there exists the problem of error propagation.

Among the various cooperative protocols, there is an efficient way to design the channel codes which leads to the coded cooperation based on the rate compatible punctured convolutional (RCPC) codes proposed in\textsuperscript{[8–10]}. The space-time coded cooperative communication system is introduced in\textsuperscript{[11,12]}. Coded cooperation works by sending different portions of each user’s codeword via
independent fading channels. Each user can transmit incremental redundancy for its partner. Whenever that is impossible, the users automatically revert to non-cooperative mode. The key to the efficiency of coded cooperative communication is the code design without feedback between the users. Besides the RCPC codes and space-time codes, Turbo codes and LDPC codes have also been considered in cooperative systems. In this paper, our attention is paid to the multiple implementations and signal processing schemes of the STBC based cooperative virtual multi-antenna communication system.

The organization of this paper is as follows. In Section 2, an overview of the AF cooperative communication, especially, the coded cooperation is introduced. Section 3 presents the different implementation schemes of the STBC based cooperative relay system. According to the different STBC based cooperative schemes, the corresponding signal processing algorithms are provided. Section 4 presents the simulation results and interpretations. Finally, conclusions are drawn in Section 5.

2. AF cooperation and coded cooperation

In this section, we first give a brief overview and simple analysis of the AF cooperative system. Single relay cooperative system is considered in this section and we also assume that the channels between the source node and relay nodes, the relay nodes and the destination node are orthogonal to each other. In the second part of this section, we introduce the coded cooperation system.

When the relay nodes act as an amplifier and retransmitter, it becomes the conventional AF cooperative system as shown in Fig. 1. In wireless communication, we often consider the slow Rayleigh fading channels. In this case, the propagation from a network node to node j can be determined by a single channel coefficient $h_{ij}$. This coefficient keeps constant during one time block. The instantaneous channel attenuation is the multiplication of a deterministic distorted copies of the original signal between the source, relay and destination nodes, respectively. The receiver gathers these two noise-distorted copies with a maximum ratio combining [14] algorithm. With this combining scheme, we can form a decision variable by weighting the combining copies with different powers respectively. The signal to noise ratio (SNR) of the decision variable can be obtained as

$$\gamma_y = \frac{|h_{r,i}|^2 P_0}{\sigma_s^2 + |A h_{s,i} h_t|^2 P_0 / \sigma_d^2},$$  

(3)

where $P_0$ is the transmitted signal power at source node, $\sigma_s^2$, $\sigma_d^2$ are the variance of $n_s$ and $n_d$, respectively.

With the assumption of the slow fading channel, the symbol error probability of the binary phase shift keying modulation conditioned on the instantaneous SNR $\gamma_y$ is given by [14]

$$P_e = \text{Q}(\sqrt{2\gamma_y}),$$

(4)

where $\text{Q}(x) = \int_x^\infty e^{-u^2/2} du$.

In the coded scheme, cooperative signaling is based on the channel coding scheme and each user tries to transmit incremental redundancy for its partner.

Transmission diagram of the single relay coded cooperative system is shown in Fig. 2. The idea of coded cooperation is to use the same overall rate for coding and transmission. The coded symbols are rearranged between the cooperative users such that better spatial diversity can be obtained. In the coded cooperation, we assume that there are K original information bits and the forward error control (FEC) code has the code rate $R_c$ so N coded bits can be generated. The N coded bits are divided into two frames, frame I with the last $N_2$ bits and frame II with the last $N_2$ bits. In the first frame, each user transmits codeword at a rate $R_1 > R$ with $R_1 = K/N_1$ bits. This part itself is a valid codeword which can be decoded to obtain the original information. Each user also receives and decodes the signals from its partner.

There exist four cases in the coded cooperation as shown in Fig. 3.

Case 1: If the user successfully decodes the partner’s codeword at rate $R_1$, which is determined by checking the cyclic redundancy check (CRC) bits, the user computes and transmits $N_2$ additional parity bits of its partner in the second frame. These additional parity bits are selected such that they can be combined with the first frame codeword to produce a more powerful rate R codeword.

Case 2: If the source does not successfully decode the bits from the relay in frame II, $N_2$ additional parity bits for the source’s own data are transmitted.

Case 3: If the relay does not successfully decode the bits in the source in frame II, $N_2$ additional parity bits for the relay’s own data are transmitted.

Case 4: If the user does not successfully decode the partner’s rate $R_c$ code word, the user transmits $N_2$ additional parity bits of its data in the second frame. In this case, the cooperative communication returns to be a non-cooperative system.
In these four cases, each user always transmits a total number of \( N \) bits per source block over the two frames, and the users only transmit in their own multiple access channels. We also make a definition to describe the level of cooperation. It can be expressed as \( N_2/N \), the percentage of the total bits per each source block that the user transmits for its partner. A smaller percentage implies a more powerful code for the first frame and increased probability that a user successfully decodes the partner. However, this also means a smaller \( N_2 \), thus reducing the diversity gain.

3. STBC based cooperative communication system

Alamouti STBC proposed in [1] employs two transmit antennas and one receive antenna. With the application of maximum ratio combining scheme and maximum likelihood detection, full transmit diversity can be achieved in Alamouti scheme.

In Alamouti STBC system, two signals, \( s_1 \) and \( s_2 \), modulated by BPSK are transmitted simultaneously by the two antennas in the first symbol period. In the second symbol period, the two signals, \( -s_2 \) and \( s_1^* \), originated from \( s_1 \) and \( s_2 \) are sent. With the assumption of slow Rayleigh fading channel, the channel attenuation amplitudes, \( h_1 \) and \( h_2 \), keep constant in the two symbol periods. In the single-antenna terminal cooperation, the two received signals can be expressed as,

\[
r_1 = h_1 s_1 + h_2 s_2 + n_1 \quad \text{and} \quad r_2 = -h_1 s_2^* + h_2 s_1^* + n_2,
\]

where \( n_1 \) and \( n_2 \) are complex independent identity distributed (IID) additive white Gaussian noise with \( N(0, N_0) \).

With MRC in the receiver end, we have the combined signals as,

\[
\hat{s}_1 = h_1^* r_1 + h_2^* r_2 = (|h_1|^2 + |h_2|^2) s_1 + h_1^* n_1 + h_2^* n_2, \quad \text{and} \quad
\hat{s}_2 = h_2^* r_1 - h_1^* r_2 = (|h_1|^2 + |h_2|^2) s_2 - h_1^* n_2 + h_2^* n_1.
\]

The combined detection signals, \( \hat{s}_1 \) and \( \hat{s}_2 \), just depend on their corresponding signals. In this way, dual diversity can be obtained. And also, the receiver just needs to make the MLD \( s'_i \) (\( i = 1, 2 \)) to recover \( s_1 \) and \( s_2 \) for each of the transmitted signal. That is,

\[
s'_i = \min\{\hat{s}_i - (|h_1|^2 + |h_2|^2)s_i\}.
\]

For the limitation of the size and complexity of the wireless terminal, it is always difficult to make multiple antennas on it. In order to utilize the advantages of MIMO system, cooperative virtual MIMO technology is proposed. In this paper, we will consider two scenarios of the STBC based cooperative communication systems as shown in Figs. 4 and 5, respectively. And also in the relay nodes, two relay functions, generation relay and non-generation relay, are also taken into account. In the following, we will describe these two scenarios in detail.

3.1. Scenario 1: STBC based cooperative downlink CDMA system

This system consists of the base station with two transmit antennas, two relay single-antenna terminals (Relay A and Relay B) and one destination single-antenna terminal. We also call this scenario as Alamouti cooperative system. In the first two time slots, the source base station transmits signals to the relay terminals and destination node with the same function of Alamouti scheme. For destination code, the received signals can be given as,

\[
r_1 = h_1 s_1 + h_2 s_2 + n_1 \quad \text{and} \quad r_2 = -h_1 s_2^* + h_2 s_1^* + n_2,
\]

for Relay A:

\[
r_3 = h_3 s_1 + h_4 s_2 + n_3 \quad \text{and} \quad r_4 = -h_3 s_2^* + h_4 s_1^* + n_4,
\]

for Relay B:

\[
r_5 = h_5 s_1 + h_6 s_2 + n_5 \quad \text{and} \quad r_6 = -h_5 s_2^* + h_6 s_1^* + n_6,
\]

where \( r_1, r_3 \) and \( r_5 \) are received signals in the first time slot, \( r_2, r_4 \) and \( r_6 \) are received signals in the second time slot. \( h_1, h_2, h_3, h_4, h_5 \) and \( h_6 \) are the channel attenuation amplitudes from the base station to the relay and destination terminals, respectively, which follow the distribution of slow Rayleigh fading. \( n_1, n_2, n_3, n_4, n_5 \) and \( n_6 \)
are the receiver additive white Gaussian noise in two time slots of the destination and relay nodes, respectively.

(1) Function 1: Non-generation relay.

In this case, the relay nodes just receive and amplify the received signals, then forward the amplified signals to the destination. In this paper, we just consider the amplification factor to be one for the simplification. In the last two time slots, the third and fourth time slots, the destination receives the signals as,

\[ r_7 = h_7 r_7 + h_7 r_7 + n_7 \text{ and } r_8 = h_8 r_8 + n_8, \]

where \( h_7 \) and \( h_8 \) are the channel attenuation amplitudes from the relay nodes to the destination node in these two time slots, respectively. \( n_7 \) and \( n_8 \) are the receiver additive white Gaussian noise of these two time slots, respectively.

With the maximum ratio combining of the received signals from both the base station and relay nodes, the destination node obtains the detected signals \( \hat{s}_1 \) and \( \hat{s}_2 \), as

\[
\hat{s}_1 = \hat{s}_{1,d} + \hat{s}_{1,r} \quad \text{and} \quad \hat{s}_2 = \hat{s}_{2,d} + \hat{s}_{2,r},
\]

where

\[
\hat{s}_{1,d} = h_1 r_1 + h_2 r_2 = (|h_1|^2 + |h_2|^2)s_1 + h_1 n_1 + h_2 n_2, \quad \hat{s}_{2,d} = h_2 r_1 - h_1 r_2 = (|h_1|^2 + |h_2|^2)s_2 + h_1 n_2 - h_2 n_1, \quad \hat{s}_{1,r} = h_1 r_7 + h_2 r_8 = (|h_1|^2 + |h_2|^2)s_1 + h_1 n_7 + h_2 n_8, \quad \hat{s}_{2,r} = h_2 r_7 - h_1 r_8 = (|h_1|^2 + |h_2|^2)s_2 + h_1 n_8 - h_2 n_7, \quad H_1 = h_1 h_7 + h_2 h_8, \quad H_2 = h_7 h_7 + h_8 h_8, \quad N_1 = h_1 n_7 + h_2 n_8 \text{ and } N_2 = h_7 n_1 + h_8 n_2.
\]

(2) Function 2: Generation relay.

In the relay generation scheme, the relay nodes will recover the received signals and then transmit the recovered signals to the destination node. We assume the relay nodes A and B recover the received signals as \( (\hat{s}_1, \hat{s}_2) \) and \( (\hat{s}_1', \hat{s}_2') \), respectively. Following the same function of non-generation scheme, the destination node gets the signals during the third and fourth time slots as,

\[ r_7 = h_7 s_1' + h_8 s_2' + n_7 \text{ and } r_8 = -h_7 s_2' + h_8 s_1' + n_8. \]

With the same way, we can give the expressions of the decision signals after MRC as,

\[
\hat{s}_1 = \hat{s}_{1,d} + \hat{s}_{1,r} \quad \text{and} \quad \hat{s}_2 = \hat{s}_{2,d} + \hat{s}_{2,r},
\]

where

\[
\hat{s}_{1,d} = h_1 r_1 + h_2 r_2 = (|h_1|^2 + |h_2|^2)s_1 + h_1 n_1 + h_2 n_2, \quad \hat{s}_{2,d} = h_2 r_1 - h_1 r_2 = (|h_1|^2 + |h_2|^2)s_2 + h_1 n_2 - h_2 n_1, \quad \hat{s}_{1,r} = h_1 r_7 + h_2 r_8 = (|h_1|^2 + |h_2|^2)s_1 + h_1 n_7 + h_2 n_8, \quad \hat{s}_{2,r} = h_2 r_7 - h_1 r_8 = (|h_1|^2 + |h_2|^2)s_2 + h_1 n_8 - h_2 n_7, \quad \text{under the assumption of} \ (s_1, s_2) = (s_1', s_2') \text{ we have}\]

\[
\hat{s}_{1,r} = (|h_1|^2 + |h_2|^2)s_1' + h_1 n_7 + h_2 n_8 \quad \text{and} \quad \hat{s}_{2,r} = (|h_1|^2 + |h_2|^2)s_2' + h_1 n_8 - h_2 n_7. \]

In the simulation, the ideal relay generation is assumed.

3.2 Scenario 2: STBC based cooperative single-antenna terminal system

In this scenario, the cooperative system is composed of three single-antenna terminals, the source, relay and destination terminal. This scenario is also called virtual Alamouti cooperative system. The assumption of the channel condition is the same with scenario 1. Considering the transmission scheme of this scenario, there are two conditions.

1. The source terminal sends symbol block \( (s_1, s_2) \) to the relay node in the first time slot, but makes no transmission to the destination node. In the second time slot, the source and relay node transmit each of their symbol blocks to the destination node. The source transmits \( (-s_2, s_1) \) and the relay sends the signal \( (s_1', s_2) \) with generation or non-generation function, respectively. This transmission process is similar with the virtual multiple-input single-output (MISO) scheme. If the destination node also receives the symbol block \( (s_1, s_2) \) from the source node in the first time slot, then this process can be called as virtual MIMO scheme.

In the first time slot, the received signals can be expressed as, for destination node:

\[ r_{11,d} = h_1 s_1 + n_{11,d} \quad \text{and} \quad r_{12,d} = h_2 s_2 + n_{12,d}, \]

for relay node:

\[ r_{11,r} = h_3 s_1 + n_{11,r} \quad \text{and} \quad r_{22,r} = h_3 s_2 + n_{22,r}, \]

where \( n_{11,d} \) and \( r_{11,r} \) are the received signals of the destination and relay node in the first half of time slot 1, respectively. \( r_{12,d} \) and \( r_{22,r} \) are the received signals of the destination and relay node in the last half of time slot 1, respectively.

In the second time slot, we will consider two relay generation functions, non-generation relay and generation relay.

(1) Function 1: Non-generation relay

In this case, the received signals of the destination node in time slot 2 can be given as,

\[ r_{21,d} = -h_1 s_2 + h_3 r_{21,r} + n_{21,d} \quad \text{and} \quad r_{22,d} = h_1 s_1 + h_3 r_{22,r} + n_{22,d}, \]

where \( r_{21,d} \) and \( r_{22,d} \) are the received signals of the destination in the first and last half of time slot 2, respectively. Substituting Eqs. (16) to (17), we can calculate the detected signals after MRC as,

\[ \hat{s}_1 = h_1^* h_3^* r_{21,d} + h_2^* r_{22,d} = (|h_1|^2 + |h_2|^2)s_1 + (h_1^* h_3^*) (h_1 n_{11,d} + h_3 n_{21,d}), \]

\[ \hat{s}_2 = -h_1^* r_{21,d} + h_2^* r_{22,d} = (|h_1|^2 + |h_2|^2)s_2 + (h_1^* h_3^*) (h_1 n_{12,d} + h_3 n_{22,d}). \]

(2) Function 2: Generation relay

In the relay generation scheme, the regenerated signals at the relay node are denoted as \( (s'_1, s'_2) \). With the assumption of the linear relationship between the recovered signals and the transmitted signals, that is \( s'_1 = a s_1 \) and \( s'_2 = b s_2 \) where \( a \) and \( b \) are the constants, the received signals at the destination node during time slot 2 can be expressed as,

\[ r_{21,d} = -h_1 s'_2 + h_1 s'_1 + n_{21,d} \quad \text{and} \quad r_{22,d} = h_1 s'_2 + h_1 s'_1 + n_{22,d}. \]

With MRC, the decision signals can be obtained as,

\[ \hat{s}_1 = \hat{s}_{1,d} + \hat{s}_{1,r} \quad \text{and} \quad \hat{s}_2 = \hat{s}_{2,d} + \hat{s}_{2,r}, \]

where

\[ \hat{s}_{1,d} = h_1^* r_{21,d} + h_1^* r_{22,d} = (|h_1|^2 + a |h_2|^2)s_1 + h_1^* h_3^* n_{21,d} + h_1^* n_{22,d}, \]

\[ \hat{s}_2 = -h_1^* r_{21,d} + a h_1^* r_{22,d} = (|h_1|^2 + a |h_2|^2)s_2 + a h_1^* h_3^* n_{22,d} - h_1^* n_{21,d}. \]

2. The source node first transmits signal \( s_1 \) to the relay node in the first half slot of time slot 1, then transmits signal \( s_2 \) to the destination node in the last half slot of time slot 1. In the same way, the source node sends signal \( -s'_2 \) to the relay node in the first half slot of time slot 2. In the last half slot of time slot 2, the destination terminal receives signal \( s'_1 \) from the source node and also the estimated signal \( -s'_2 \) from the relay node. In this situation, both the virtual MISO and MIMO scheme can be implemented like the above cases. The two relay generation functions are provided as below.

(1) Function 1: Non-generation relay

In the first half slot of time slot 1, the received signals at the destination node and the relay node can be expressed respectively as,

\[ r_{11,d} = h_1 s_1 + n_{11,d} \quad \text{and} \quad r_{11,r} = h_3 s_1 + n_{11,r}. \]
In the last half slot of time slot 1, the received signals at the destination node is written as,
\[ r_{12,d} = h_1 s_2 + h_3 r_{12,r} + n_{12,d}. \] (23)

In the first half slot of time slot 2, the received signals at the destination and relay node is obtained as,
\[ r_{21,d} = -h_1 s_2 + n_{21,d} \] and \[ r_{21,r} = -h_3 s_2 + n_{21,r}. \] (24)

In the last half slot of time slot 2, the received signals at the destination node is,
\[ r_{22,d} = h_1 s_1 + h_3 r_{22,r} + n_{22,d}. \] (25)

With the maximum ratio combining of the received signals from both the source and relay nodes, the decision signals \( \hat{s}_1 \) and \( \hat{s}_2 \) can be obtained as,
\[ \hat{s}_1 = h_1^* r_{12,d} + h_2 r_{22,d} \] and \[ \hat{s}_2 = h_1^* r_{12,d} - h_3 h_3 r_{22,d}. \] (26)

(2) Function 2: Generation relay

In the generation scheme, we also assume the linear relationship between the regenerated signals at the relay node and the transmitted signals at the source node. The signals in the first half slot of time slot 1 and time slot 2 keep unchanged compared with the non-generation scheme. The signals in the last half slot of time slot 1 and time slot 2 can be expressed respectively as,
\[ r_{12,d} = h_1 s_2 + h_3 s_1 + n_{12,d} \] and \[ r_{22,d} = h_1 s_1 - h_3 s_2 + n_{22,d}. \] (27)

With MRC, the decision signals in the destination node can be written as,
\[ \hat{s}_1 = bh_1^* r_{12,d} + h_1 r_{22,d} \] and \[ \hat{s}_2 = h_1^* r_{12,d} - ah_3 r_{22,d}. \] (28)

4. Numerical results

In this section, we present the computer simulation results about the STBC based cooperative communication systems. Virtual Alamouti STBC theory is employed in all these different cases. Slow Rayleigh fading channel and ideal channel estimation are assumed in the simulation. BPSK modulation and MRC/MLD receiver are applied.

Since there are two schemes in scenario 2, we present the bit error probability (BEP) performance of scenario 1 and compare it with each scheme in scenario 2, as shown in Figs. 6 and 7, respectively. Simulation results of no cooperation scheme and conventional Alamouti scheme are also provided. Alamouti cooperation and Virtual Alamouti scheme correspond to scenario 1 and 2, respectively. As mentioned in Section 3, both MISO and MIMO realization schemes are evaluated for scenario 2. For scenario 1, \( 2 \times 2 \times 1 \) means the system consists of one base station with two transmit antennas, two single antenna relay nodes and one destination node with single-antenna.

As seen from the simulation results in Figs. 6 and 7, we find that almost all the Alamouti STBC based cooperative systems have better performance than the non-cooperative system and conventional Alamouti scheme. The cooperative Alamouti schemes with non-generation relay have approximately the same BEP performance with Alamouti scheme and the relay generation schemes outperform the non-generation systems in both Virtual Alamouti and Alamouti cooperation scenario. Virtual Alamouti MIMO systems also obtain advantages from the doubly transmitted signals and get better performance than the virtual MISO schemes. Alamouti cooperative scheme with generation relay can achieve the best performance. Numerically, when BER is about \( 10^{-3} \) in Fig. 6, Alamouti cooperative scheme with generation relay obtains about 2.2, 2.3, 4.0, 6.2, 7.0 and 6.2 dB gains compared with Alamouti cooperation with non-generation relay, virtual Alamouti scheme with generation relay and virtual MIMO, virtual Alamouti scheme with generation relay and virtual MISO, conventional Alamouti scheme and virtual Alamouti scheme with non-generation relay and virtual MISO, respectively. Similar trend and conclusions can be obtained in Fig. 7. With the achievement of lower BER, Alamouti cooperative schemes (generation and non-generation) outperform the other schemes for the applications of multiple transmit antennas and two relay nodes.

5. Conclusions

In this paper, we investigate the STBC based multi-antenna cooperative systems and provide the corresponding simulated
performance under slow Rayleigh fading channel. According to the realization of different scenarios, the corresponding signal processing algorithms are given in this paper. From the simulation results, the conclusions are obtained that the Alamouti cooperative schemes \((2 \times 2)\) have advantages in system performance and cooperative diversity compared to other cooperative schemes and conventional Alamouti STBC systems with feasible increase in the system complexity. Through the optimal design of the cooperative scheme, improved system performance can be achieved. Our future work will focus on this aspect and other complex channel conditions.

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References


Fig. 7. Performance of STBC based cooperative system in slow Rayleigh fading channel (scheme 2).