A Study on Cooperative Communication using Space-Time Codes

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ABSTRACT

In cooperative communication systems, the source terminal transmits signal to the destination terminal with the aid of partner terminals. Therefore, the source terminal obtains extra spatial diversity gain. As a result, its performance is enhanced in term of higher achievable transmission rate, the larger coverage range, and the lower bit-error-rate (BER). Space-time codes (STCs) have been applied to cooperative communication systems in distributed fashion, in which the signal is spatially time exploited to obtain gains analogous to those provided by STCs. In this work, we consider the application of orthogonal Space-time Block Codes (OSTBCs) to the cooperative communication systems to further achieve higher diversity gain. The advances of the proposed approach are verified via computer simulations.

Keywords

Cooperative communication, diversity gain, Space-Time Block Codes (STBC), Wireless Commuication, MIMO

I. Introduction

The recent developed multiple antenna techniques [7] have considerable potential to meet the challenges of the next generation wireless systems, which can not only provide higher data date, better quality of service, but also be effective approach to mitigate fading channels and overcome bandwidth limitations. These techniques, obtained by deploying antenna arrays at both transmitter and receiver, enable communication systems to exploit either high performance provided by spatial diversity available or high data-rate provided by the capacity available in multi-input multi-output (MIMO) channels, or both. Unfortunately, a wireless device may not always be able to support multiple antennas due to the constraint of size, cost and hardware implementations. Especially, this is the case for most handsets in current cellular networks or for nodes of wireless sensor networks and mobile ad-hoc wireless networks.

STCs have been proposed to exploit the diversity gain of MIMO systems [7]. Among STCs, orthogonal space-time codes is the most favored schemes due to its full diversity gain and simplicity of decoding implementation. Similar to other STCs, OSTBCs have been designed for allocated antenna array. Therefore, due to the constraint of size and complexity, the impractical implementation of multiple antennas at the mobile user/sensor node, OSTBCs can not be directly applicable to those devices.

Cooperative relaying (or cooperative communications) is a solution to overcome the above limitations [1]-[6]. It allows single-antenna devices to gain some benefits of spatial diversity without the need for physical antenna arrays or allocated antennas. The principle of cooperative communication is that in a multi-user network, two or more users share their information and transmit jointly as a virtual antenna array. As a result, redundant messages are generated and delivered over multiple independent paths in the network. This redundancy enables the receiver to essentially average channel fluctuations, thus gains diversity gain improving the communications performance or saving transmission energy at a target BER.

A variety of cooperative schemes have been studied and analyzed. They are mainly classified into the following three groups [1]: amplify-and-forward, decoded-and-forward and coded cooperation. In the amplify-and-forward scheme, each cooperating user receives a noisy version of the signal transmitted by the source terminal. Then, it simply amplifies and retransmits the received noisy version. Unlike amplify-and-forward cooperating terminal, decoded-and-forward terminal attempts to detect partner's bits and then retransmits the detected bits. The coded cooperation is a method that integrates cooperation into channel coding. Coded cooperation works by sending different portions of each user's code word via multiple independent fading paths. The basic idea is that each user tries to transmit incremental redundancy to its partners. The key to the efficiency of coded cooperation is that all this managed automatically through code design, with no feedback between users. The application of space-time codes to cooperative protocol, so called distributed space-time coded cooperative protocol, has been considered in [2]-[6]. In this paper, we study a new application of orthogonal space time code to the coded cooperative protocol called multiple-node distributed space-time coded cooperative protocol. By combining signal of both partners to transmit in the second stage in orthogonal space-time coding fashion, the system can achieve not only maximum diversity gain but also coding gain.

The remain of paper is organized as follows. The brief induction of system model is presented in section II. The considered multiple-node distributed space-time cooperative protocol is illustrated in section III. The computer simulations for verifying the considered protocol is shown in section IV. Finally, conclusion of our work is given in section V.

II. System model

The system under the consideration is the multi-user network consisting of a source terminal, a destination terminal and R cooperating terminals which aid the source in communicating to the destination depicted in Fig.1. The layout of terminals are constructed randomly and independently according to some distribution. We assume that each terminal including the source and destination is equipped with one antenna. In addition, the system is subject to a half-duplex constraint, i.e., a terminal cannot transmit and receive simultaneously. The channel path gains from the source to the j^{th} cooperating terminal, f_j, and from the j^{th} cooperating terminal to the destination, g_j, are all independently and identically distributed complex Gaussian variables with zero-mean and variance of 0.5 per dimension. Furthermore, we assume that the terminals are synchronized at the symbol level.

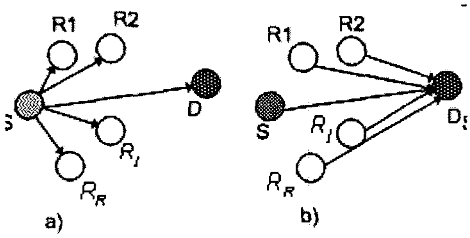

Fig. 1 Diagram of the considered network: a) network at the stage I, b) network at the stage II.

By applying similar transmission cycle of [2]-[6], every transmission cycle from source to destination comprises of two stages. In the first stage, the source transmits a T length vector s to the cooperating terminals and destination. The signal vector s is drawn from a codebook consisting of $s=[s_1\, s_2 \ldots s_L]$ information vectors, with $E\{s^H s\}=1$, so that the average transmit power is T. The received vector at the j^{th} cooperating terminals and destination is given as:

$$y_j = h_j s + n_i \qquad (1)$$

In the second half of the cycle, all the cooperating terminals and the source are schedule to transmit together. The j^{th} terminal transmits a T length vector t_j which is a function of the received vector y_j. To be precise, the j cooperating terminal is equipped with a fixed OSTBC TxT unitary matrix Aj and it is jointly scheduled with the source and each others to transmit to destination in OSTBC fashion. The received vector at the destination is given as follows.

$$y_d = \sum_{i=0}^{R+1} g_j t_j + n_d \qquad (2)$$

The received signal will be used to detect transmitted signal under the assumption of the availability of channel information state at the destination.

III. Proposed approach

In this section, we will present the proposed distributed orthogonal space-time protocol for cooperative communication. For sake of simplicity, we illustrate the considered protocol in system of three terminal: a source, a cooperating terminal and a destination. The signal transmitted by the source terminal during the first time slot are $s_1(n)$ and $s_2(n)$, respectively. In the following, we consider symbol-by-symbol transmission so that the time index can be dropped and we simply write s_1 and s_2 for symbol transmitted in the first time slots, respectively. We assume that $E[s_i]=0$ and $E\{|s_i|^2\}=1$. The data symbols may be chosen from a complex-valued finite constellation such as M-ary quadrature amplitude modulation (M-QAM) or from M-ary phase shift keying (M-PSK). The signal received at the destination terminal in the first time slot is given by

$$y_{d,1} = \sum_{i=1}^{2} h_{sd} s_i + n_{d,1} \qquad (3)$$

where E_{sd} is the average signal energy received at the destination terminal over one symbol period through the S->D link, h_{sd} is the random complex-valued unit-power channel gain between source and destination and nsd is additive white noise $n_{d,1} \sim CN(0,\sigma^2)$. The signal received at the cooperative terminal during the first time slot is given by

$$y_{r,1} = \sum_{i=1}^{2} h_{sr} s_i + n_{r,1} \qquad (4)$$

where E_{sr} is the average signal energy over one symbol period received at the relay terminal, h_{sr} is the random complex-valued unit-power channel gain between the source and the cooperating terminal and $n_{r,1} \sim CN(0,\sigma^2)$ is additive white noise.

The cooperating terminal normalizes the received signal by a factor of γ and retransmits the signal during the second time slot in orthogonal STBC fashion as cooperating with the source. The destination now receives a superposition of the cooperating terminals and the source transmission during the third and fourth time slots according to

$$y_{d,2} = \sum_{i=1}^{2} h_{sr} s_i + \sum_{i=1}^{2} h_{rd} \hat{s}_i + n_{d,2} \qquad (5)$$

As can be seen from (5), and from the signal formation given in Table 1, our protocol is different from [4]-[6]. The signal transmission is compressed in only two time slot and fully applies the distributed space-time cooperative protocol as [6]. Fig. 2 visualizes the proposed cooperative protocol.

At the destination, the combination of $y_{d,1}$ and $y_{d,2}$ is used to detect the transmitted signal.

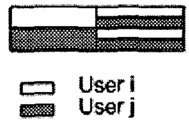

Fig. 2 Diagram of the proposed distributed orthogonal space time cooperative protocol

Table I. Summary of distributed STC cooperative communication protocol.

Stage	Time slot I		Time slot II	
	i	i+1	i+2	i+3
S->R,D	s(n)	s(n+1)	s(n+1)	$-s^*(n)$
S,R->D			s(n)	$s^*(n+1)$

IV. Computer Simulation Results

In order to verify the considered cooperative protocol, we implement the computer simulation. The setup for simulation is as follows. Without loss of generality, the system given in the section III is used. The modulation scheme is QPSK. The result is evaluated via 1000 Monte-Carlo runs.

Fig. 3 illustrates the BER performance of the considered distributed space-time coded cooperative protocol and the conventional Alamouti with 2 transmit and 1 receive antenna. As we can see from the Fig. 1, the distribuded space-time coded cooperative protocol provides coding gain leading better

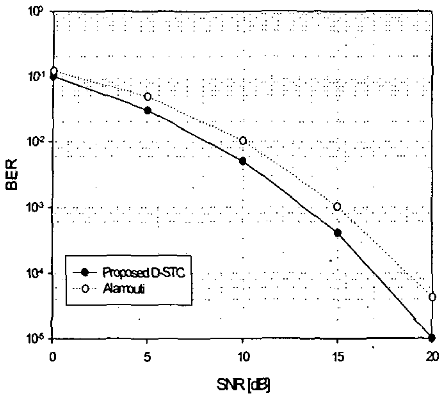

Fig. 3 BER performance evaluation of the proposed scheme.

BER performance in comparison with that of Alamouti scheme. In addition, thanks to the aid of cooperating terminals in data transmission, the distributed space-time coded cooperative protocol enables to achieve maximum diversity gain which is the same of Alamouti scheme.

V. Conclusion

In this work, a new multiple-node distributed space-time cooperative protocol, which exploits the cooperation of other users in the network under OSTBC fashion, has been presented. The simulation result shows that the considered protocol can provide not only maximum diversity gain but also coding gain.

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References

[1] Aria Nosratinia et al., "*Cooperative Communication in Wireless Newworks*", IEEE Com. Mag., Oct. 2004, pp.74-80.

[2] Andrew Sendonaris et al., "*User Cooperation Diversity - Part I: System Description*", IEEE Trans. Com., Vol.51, No.11, Nov.2003, pp.1927-1938.

[3] Andrew Sendonaris et al., "*User Cooperation Diversity - Part II: Implementation Aspects and Performance Analysis*", IEEE Trans. Com., Vol.51, No.11, Nov.2003, pp.1939-1948.

[4] J. Nocholas Laneman et al., "*Distributed Space-Time Coded Protocols for Esploiting Cooperative Diversity in Wireless Networks*", IEEE Trans. Infor. Theory, Vol.49, No.10, Oct.2003, pp.2415-2425.

[5] Gesualdo Scutari et al., "*Distributed Space-Time Coding for Regenerative Relay Networks*", IEEE Trans. Wire. Com., Vol.4, No.5, Sep.2005, pp.2387-2399.

[6] Mohammad Janani et al., "*Coded Cooperation in Wireless Communications: Space-Time Transmission and Iterative Decoding*", IEEE Trans. Sig. Proc., Vol.52, No.2, Feb.2004, pp.362-370.

[7] Branka Vucetic et al., *Space-Time Coding*, Wiley 2003.