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Green multi-hop cooperative wireless communication with signal space diversity

Saima Zaheer, Sarmad Sohaib *

University of Engineering and Technology, Taxila, Pakistan

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ABSTRACT

The cooperative communication in wireless multi-hop networks is a reliable energy efficient mechanism that mitigates the effects of channel fading and improves the performance and throughput of the systems. In this paper, green cooperative multi-hop scheme is proposed by employing signal space diversity (SSD). The proposed scheme offers a significant improvement in performance of the regenerative multi-hop networks without the requirement of extra bandwidth or power. The expressions for the average end to end bit error probability of the multi-hop networks employing the SSD scheme is derived. The optimal relay location for a better performance and the total energy consumption of the scheme is also probed. The simulation results show that the proposed scheme provides better quality of service and is more energy efficient compared to the conventional decode and forward scheme in single-hop as well as multi-hop situations.

1. Introduction

Cooperative communication has acquired much attention in the recent years due to its capabilities to provide good quality of service (QoS) even in the presence of multipath fading. It exploits the broadcast nature of wireless channel. The source node broadcasts the data to relays. The selected relays then forward the data to the destination. In general, there are two types of relaying techniques: *amplify and forward* (AF), where the relay simply amplifies the noisy version of the signal transmitted by source, and *decode and forward* (DF), where relay decodes, re-encodes and re-transmits the signals [1].

Multi-hop cooperative networks are effective in the areas that are heavily shadowed and where classical single hop cannot efficiently convey information. These networks are a chain of short point to point links which utilize less transmitting power and can improve the coverage, and throughput [2].

The use of cooperative diversity in multi-hop networks had been an active research area. A new protocol was designed for network wide broadcasting of such networks in [3]. Space time block coding was employed, and the benefits of increased coverage, reduced latency and reduced cost were obtained.

For the multi-relay cooperative MIMO systems employing both DF and AF protocol, combined transmit diversity selection and relay selection algorithms were proposed in [4]. Different versatile linear minimum mean square error based reception techniques were used. Mutual information of the cooperative system was formulated. The technique was found to be stable, computationally efficient with increased diversity and improved interference suppression.

The cross layer design and optimization of multi-hop wireless using cooperative diversity is quite challenging. The optimization of such networks with AF protocol with joint power allocation and linear interference algorithms significantly increase the coverage, capacity and reliability [5]. For DF protocol a systematic approach considering joint routing, relay selection and power allocation result in significant improvement in power consumption and source rates [6].

Signal space diversity (SSD) or the modulation diversity is another protocol to mitigate the effects of fading in a wireless communication system. The concept of SSD was pioneered by Belfiore and Boulle [7] and was afterward proposed in [8] as coordinate interleaving scheme for performance improvement in fading channels. The scheme acquired its name and was generalized in [9] as a SSD scheme. The great interest in SSD is due to the fact that the scheme does not require additional bandwidth and power expansion, and results in significant QoS improvement over conventional wireless communication systems [9]. In SSD, the information carried by each signal point is spread among all components of that

* Corresponding author. Tel.: +92 (0) 51 9047 558.
E-mail address: sarmad.sohaib@uettaxila.edu.pk (S. Sohaib).

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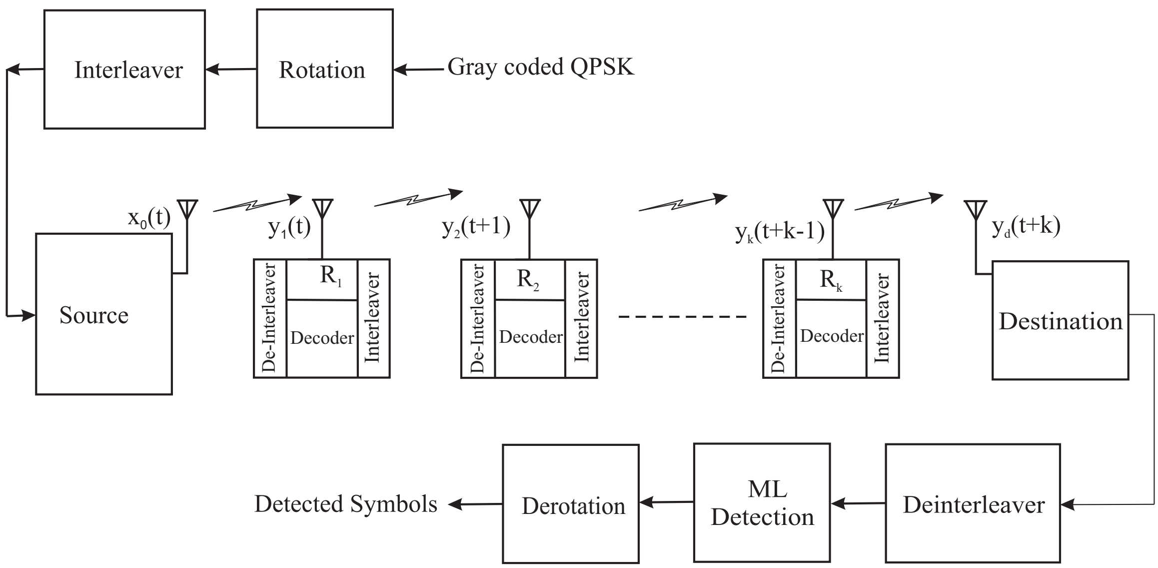

Fig. 1. System model of the proposed GMSSC scheme.

particular signal point by rotating the signal constellations. These signal constellation points are then sent through an independent realization of the channel [9]. The independence of fading channels is achieved by the use of a component interleaver/deinterleaver pair.

In [10,11] Ahmadzadeh et al. presented the single relay cooperative model called signal space cooperative (SSC) scheme based on SSD. The direct link between the source and destination was present and DF strategy was employed for relaying information. To the best of authors' knowledge the SSD technique has yet not been employed on a multi-hop network. This paper presents the SSD scheme employed on a single antenna regenerative multi-hop network without a direct link between the source and the destination. The resulting system shows an improved performance compared to the traditional multi-hop systems and in addition is bandwidth and energy efficient. The diversity order is also improved.

The rest of the paper is organized as follows. Section 2 describes the proposed green multi-hop SSC (GMSSC) scheme. The performance of the GMSSC is analyzed in Section 3. The energy analysis of the GMSSC system is done in Section 4. The simulation results are discussed in Section 5 and finally Section 6 concludes the paper.

2. Proposed green multi-hop signal space cooperative scheme

Consider a network with a source, destination and K relays as shown in Fig. 1 where each node is equipped with a single antenna and the relays are assumed to operate in half duplex mode. There is no direct communication link between the source and the destination. $K+1$ orthogonal channels (time slots or frequency bands) are required to complete the transmission. In the first time slot, the information is transmitted from the source to the first relay which is retransmitted to the second relay in the next channel till it reaches the destination. This simple technique improves the range of the communication link between the source and the destination.

The channel $\bar{h}_i$ between any transmit and ith receive antenna is

$$\bar{h}_i = \frac{h_i}{\sqrt{(d_i)^{\alpha}}}, \tag{1}$$

where h_i is the normalized channel gain, which is an independent and identically distributed (i.i.d.) complex Gaussian random variable with zero mean and unit variance. This describes the random fading effect of multipath channels, and is assumed to be Rayleigh flat fading. d_i represent the distance between any transmitter and ith receiver, and α is the path loss exponent depending on the propagation environment which is assumed to be the same over all links.

Signal rotation and interleaving is incorporated at the source. The classical $\pi/4$ gray coded QPSK signal constellation is rotated anticlockwise by applying the transformation

$$T = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}, \tag{2}$$

where θ is the optimum angle that maximizes the minimum squared product distance between the constellation points [8]. Each signal point in the rotated constellation has distinct in-phase (I) and quadrature (Q) components as shown in Fig. 2. The rotated constellation offer more protection against the effects of noise as no two points collapse together if a deep fade hits only one of the components, and has the same performance as the unrotated constellation over additive white Gaussian noise (AWGN) [9].

For the independent fading of the I and Q components of the symbols a component interleaver is employed. The component interleaver breaks the correlation between the I and Q components. To avoid the problem of large delays caused by interleaving only the Q components are interleaved. For example the symbol sequence $[x_1+jy_1 \quad x_2+jy_2 \quad x_3+jy_3 \quad x_4+jy_4]$ after interleaving becomes $[x_1+jy_2 \quad x_2+jy_1 \quad x_3+jy_4 \quad x_4+jy_3]$, where $j=\sqrt{-1}$.

In the kth time slot, the kth relay node will receive

$$y_k(t+(k-1)T) = \sqrt{E_{k-1}}\bar{h}_k x_{k-1}(t+(k-1)T) + n_k(t+(k-1)T), \tag{3}$$

where $k \in (1, 2, \ldots, K)$, T is the time slot or frame duration, $x_{k-1}(t+(k-1)T)$ represents the decoded and transmitted signal of the previous node with energy E_{k-1}, and $n_k(t+(k-1)T)$ captures the effect of AWGN at the kth node. The received signal at each relay is de-interleaved and then decoded. The de-interleaving is required to get back the original constellation with four signal points rather then the expanded constellation for decoding. Decoding is performed by means of a maximum-likelihood (ML) detector. After decoding the signal is interleaved again and transmitted to