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Optimal power distribution in non-binary LDPC code-based cooperative wireless networks

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ABSTRACT

This work analyzes the optimal power allocation in coded cooperative communication systems with a single relay and using the amplify-and-forward protocol. Non-binary low-density parity-check (LDPC) codes are used at the source and a fast Fourier transform (FFT)-based decoding algorithm is employed at the destination. We study the power distribution between the source and the relay based on the minimization of the LDPC bit error rate (BER) performance at the destination as well as on the information theoretic measures such as the channel capacity and outage probabilities. The optimal power allocation estimated by the LDPC performance simulation corresponds to the capacity/outage probability results. In addition, BER comparisons of the coded systems (cooperative and noncooperative) are carried out for some typical cooperative scenarios.

1. Introduction

Internet of Things is an emerging paradigm where various objects (or things) are able to connect to the Internet using technologies as wireless sensor networks [1], radio frequency identification [2], Wi-Fi [3] and cellular networks [4]. In a wireless sensor network, many sensor nodes are used to monitor physical or environmental conditions and utilize wireless communications to transmit information to each other [5]. An efficient strategy to cope with the impairments offered by the wireless communication channel is to employ a cooperative protocol between spatially distributed nodes. Several protocols, including amplify-and-forward (AF), decode-and-forward (DF), estimate-and-forward (EF) are widely used [6]. Since the sensor nodes have limited energy supply, energy efficiency is a crucial issue in the design of cooperative communication protocols.

Optimal power allocation is an important question in performance enhancement of cooperative network protocols. In [7], the optimal power allocation and the associated symbol error rate performance were studied for AF and DF protocols under different modulation schemes. A similar investigation was done in [6] where the performance analysis and optimal power allocation for the EF protocol depend on the modulation scheme. Recently, optimal power allocation and adaptive modulation were used in AF cooperative protocols [8], where the objective was to find the signal-to-noise ratio (SNR) regions for adaptive modulation schemes considering a bit error rate (BER) constraint.

Binary low-density parity-check (LDPC) coding strategies have been used to improve the performance of cooperative communication protocols [9,10]. To perform close

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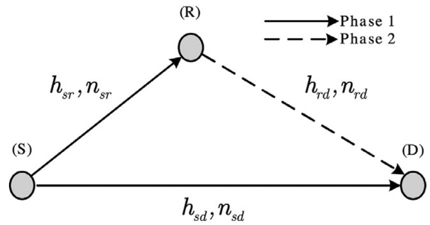

Fig. 1. Model of the cooperative communication system using a single relay.

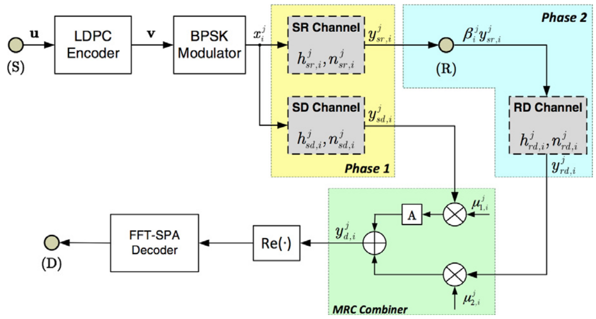

Fig. 2. Block diagram of the coded cooperative communication system from the modulator output to the MRC combiner output (the diagram highlights the binary components of the signals). (S), (R), and (D) represent, respectively, source, relay, and destination, while $Re(\cdot)$ indicates the real part of the signal $y^j_{d,i}$.

to the theoretical limit, binary LDPC codes require large blocklengths, leading to high transmission latency and complex decoding. Since it is not desirable in the real world communications, we consider the investigation of non-binary LDPC codes, motivated by their strong decoding performance for short-to-moderate blocklengths [11]. Short-to-moderate LDPC codes have been applied to enhance the performance of practical wireless communications systems [12].

Works at physical layer are significant to get efficient power allocation strategies, not only considering modulation but also including error control coding schemes. In this work, we present an analysis of the optimal power allocation in an AF coded cooperative network with a single relay. We consider both short-length binary and non-binary LDPC codes. The BER of the coded AF protocol as well as information theoretical measures (channel capacity and outage probability) are used as performance metrics to find the optimal power distribution between the source and the relay in two cooperative scenarios. These metrics are obtained from the conditional formula for the maximum average mutual information of the AF protocol. Then, we resort to a semi-analytical approach that simulates the fading effect through Monte Carlo integration. We compare the performance of optimal power allocation scheme with that of equal power allocation one. We also compare the power allocation and the system performance of the cooperative system to those of the point-to-point communication system.

The outline of the paper is as follows. In Section 2, we present the description of the cooperative system model and the decoding algorithm used at the destination. Numerical BER and channel capacity results of the optimal power allocation for fast fading are shown in Sections 3 and 4, respectively, while the outage probability is employed in Section 5 to study the optimal power allocation in block fading channels. Finally, conclusions are drawn in Section 6.

2. System description

2.1. Cooperative system model

Consider the cooperative communication system illustrated in Fig. 1, where a source (S) sends information directly and through a relay (R) to a destination (D) [6]. Assume that source and relay transmit their data through orthogonal channels and that time division multiple access (TDMA) is done. Solid lines in Fig. 1 represent the broadcast performed by the source in the first time slot (phase 1), while the dot line represents the routing from the relay to the destination in the second interval.

Fig. 2 shows a block diagram of the cooperative communication system adopted in this work. In the first stage, the source encodes a vector of k information symbols $\mathbf{u} = [u_1, \ldots, u_k]$ using a non-binary LDPC code $C(n, k)$ defined in $GF(q), q = 2^m$ and m a positive integer, in a vector of n coded symbols $\mathbf{v} = [v_1, \ldots, v_n]$. After that, the source transmits (broadcasts) the q-ary codeword $\mathbf{v}$ to the relay and the destination. For each coded symbol v_i, its corresponding binary vector of m bits $\mathbf{c}_i = [c_i^1, \ldots, c_i^j, \ldots, c_i^m]$ is mapped into an vector of antipodal signals $\mathbf{x}_i = [x_i^1, \ldots, x_i^j, \ldots, x_i^m]$ $(x_i^j \in \{-1, +1\})$ and sent through source-relay (SR) and source-destination (SD) channels. For the jth bit of the ith transmitted symbol, the received signals at the relay and at the destination, denoted by $y^j_{sr,i}$ and $y^j_{sd,i}$, are given by

$$y^j_{sr,i} = \sqrt{E_s} h^j_{sr,i} x^j_i + n^j_{sr,i} \quad (1)$$

and

$$y^j_{sd,i} = \sqrt{E_s} h^j_{sd,i} x^j_i + n^j_{sd,i}, \quad (2)$$

where E_s is the energy of the transmitted signal from the source, and $n^j_{sr,i}$ and $n^j_{sd,i}$ represent additive white Gaussian noise (AWGN). In (1) and (2), $h^j_{sr,i}$ and $h^j_{sd,i}$ represent multiplicative gains due to the flat fading of the SR and SD channels, respectively. Both gains are modeled by independent zero-mean complex Gaussian random variables with variances σ^2_{sr} and σ^2_{sd}, respectively. In addition, we assume that $h^j_{sr,i}$ and $h^j_{sd,i}$ vary independently bit to bit (recall that we are using a binary modulation) and that they are known at the receiver. Without loss of generality, we consider that $n^j_{sr,i}$ and $n^j_{sd,i}$ are modeled as zero-mean complex Gaussian random variables with variance N_0.

In the second stage, the relay only amplifies the received analog signal $y^j_{sr,i}$ and forwards it to the destination.