Computers and Electrical Engineering 000 (2017) 1–11

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Threshold-based selection combining for relay networks☆

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ARTICLE INFO

Article history:
Received 15 June 2016
Revised 8 February 2017
Accepted 9 February 2017
Available online xxx

Keywords:
Decode and forward
Relay networks
Selection combining
Wireless communication
SEP

ABSTRACT

A wireless system model which typically consists of a beginning node, multiple relays, and an ending node, has been considered. The conventional selection combining schemes are not suitable for cooperative diversity systems due to its inherent detection errors. The relays forward beginning node's information through a decode and forward protocol. The detection errors can be minimized by having a threshold at the relay. The relays participate in the cooperation process only if the instantaneous signal-to-noise ratio (SNR) of the beginning node to relay node is more than a fixed threshold. We derive the end-to-end symbol error probability of this scheme for *M*-ary phase-shift keying using paired error method for relay networks in the presence of flat Rayleigh fading. We numerically find the optimum value of relay-threshold. Numerical results show that the relay-threshold selection combining outperforms the conventional selection combining in terms of SNR gain.

1. Introduction

Diversity is a promising technique for improving the reliability of communication between the beginning node and the ending node. Spatial diversity is one of the methods through which several antennas are deployed in both source and destination nodes or at one of the place. But adopting spatial diversity concept onto the mobile unit leads to complex architecture. In order to get over this issue, 'Distributed Spatial Diversity' (DPS), where single antenna mobile units contribute their antenna to other mobile units for communication has been introduced. The implementation of this DPS needs some cooperative agreements among mobile units. The idea of relaying has been first introduced by Sendonaris et al. [1]. Two popular relay methods viz., amplify & forward (AF) and decode & forward (DF) to facilitate transmission from beginning node to ending node through relay are adopted in practice. In AF, the relays magnify the strength the beginning node's data and forward it to the ending node and in contrary, in DF, the relays regenerate the beginning node's data and forward it to the ending node [2].

In [3], a general framework for maximum likelihood (ML) and piecewise-linear combiner detectors for cooperative diversity systems has been introduced. The outage probability of selection combining DF receiver has been investigated in [4]. A high performance C-maximal ratio combining demodulator which performs close to ML demodulator has been proposed in [5]. In [6], expressions for outage and error rate for Nakagami fading environment have been obtained for cooperative DF relay networks. The exact error probability and channel capacity has been analyzed to select suitable relay for multi-relay

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. P. Nagaradjane.

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http://dx.doi.org/10.1016/j.compeleceng.2017.02.007

diversity network in [7]. For a joint multi user environment and AF relaying, several performance parameters have been studied in [8].

In [9], a simplified form of ML receiver for various modulation techniques has been investigated for cooperative diversity systems. A general framework is developed in [10] for studying the capacity and outage expressions for adaptive DF relaying systems. In [11], the performance investigation on various system modules/techniques is conducted when the beginning node forwards the data to the ending node.

In [12], performance of an adaptive DF protocol and its power allocation has been analyzed. The symbol error probability (SEP) of an opportunistic DF relaying for independent nonidentical Rayleigh fading with M-ary phase-shift keying (MPSK) has been derived in [13]. An adaptive modulation technique is proposed for relay system having only one beginning and ending node and also its performance has been analyzed in [14]. The application of the cooperative relay diversity to multi carrier- code division multiple access has been studied in [15].

The motivation behind this work is based on the literature survey. On the careful reading of the literature, an exact analytical framework to investigate the performance of a cooperative diversity network with multiple relays has been missing. The performance analysis of the multiple relay cooperative network in the presence of Rayleigh fading is very useful for the system designers to reduce the complexity and power requirements. Therefore, in this work, a specific problem related to placing an instantaneous signal to noise-ratio (iSNR) threshold at the relays has been studied and its performance has been analyzed.

The inherent problem with the relay networks is that whenever link quality between the beginning node and the relay node is poor, then the detection error increases at relay. To reduce the detection errors, a threshold can be fixed at the relay which decides whether to participate in cooperation or not. Relays participate in cooperation only if the iSNR of beginning node-to-relay node link under consideration is above a threshold (we call it as 'Relay-Threshold' denoted by Γ_T). Otherwise, relays do not participate in cooperation. The relays that participate in cooperation regenerate and then forward the beginning node's data to ending node, and finally at ending node, a link which has maximum iSNR is chosen. We find the exact error values of relay-threshold selection scheme in a flat Rayleigh fading environment for a DF relay network consisting of a beginning node, multiple relays and an ending node. The cumulative SEP is derived in terms of a simple expression for MPSK signaling. The theoretical results have been verified using Monte–carlo simulations.

The paper is organized as follows. The system model for the given network and notations adopted are given in Section 2. Section 3 presents error analysis for MPSK and BPSK signaling of relay-threshold selection combining in detail. The numerical results and conclusion are presented in Sections 4 and 5 respectively.

2. System model

Let us assume a relay network where N relays help the beginning node to transmit its data in orthogonal channels to an ending node. We consider single antenna mobile units which operates in half duplex mode and also assume symbol-by-symbol transmission.

The MPSK symbol S which is complex in nature possess energy $\sqrt{2E_s}$ and belong to the constellation $\mathcal{S}$ shown as

$$\mathcal{S} = \{s_1, s_2, \ldots, s_M\}, \tag{1}$$

where

$$s_m = \sqrt{2E_s}\exp\left(\frac{\jmath\, 2\pi(m-1)}{M}\right), \quad m = 1, \ldots, M, \tag{2}$$

and $\jmath = \sqrt{-1}$.

Note that the beginning node and ending node are denoted by the subscripts 's' and 'd' respectively in the mathematical expressions which implicitly refer the words 'source' and 'destination'.

The beginning node transmits its data to the ending node in two successive orthogonal time phases. In 1st orthogonal phase, the beginning node broadcasts the MPSK symbol to ending node and to the relays. The baseband symbol which is complex by nature collected at ending node and at relays are given by

$$r_{sd} = h_{sd}\, s + n_{sd}, \tag{3}$$

$$r_{sr_j} = h_{sr_j}\, s + n_{sr_j}, \quad j = 1 \ldots N, \tag{4}$$

respectively. We assume that all diversity links are statistically independent and subject to Rayleigh fading.

In second orthogonal phase, the relay forward the detected MPSK symbol $\hat{s}$ to the ending node. The baseband symbol, which is complex by nature is collected at ending node given by

$$r_{rd_j} = h_{rd_j}\hat{s} + n_{rd_j}, \quad j = 1 \ldots N, \tag{5}$$

respectively.

Note that the random variables h_{sd}, h_{sr}, h_{rd}, n_{sd}, n_{sr}, n_{rd} are statistically independent of each other. We assume that the ending node has full channel state information (CSI) of all links and relay has knowledge of h_{sr}.

Please cite this article as: V. Nagarajan, M. Balasaraswathi, Threshold-based selection combining for relay networks, Computers and Electrical Engineering (2017), http://dx.doi.org/10.1016/j.compeleceng.2017.02.007