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Cooperative diversity performance of selection relaying over correlated shadowing

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ABSTRACT

The study of relaying systems has found renewed interest in the context of cooperative diversity for communication channels suffering from fading. In particular, dual-hop relaying with diversity combining of the relayed and direct path at the receiver has practical importance and can be considered as a building block for forming larger communication systems. This paper presents novel analytical expressions and numerical results on cooperative diversity performance using selection relaying over correlated lognormal channels for both SC and MRC techniques at the receiver. In addition, an exact framework for comparing the performance and efficiency of the medium access protocol and relay capabilities (TDMA/half-duplex, SDMA/full-duplex) is proposed. Finally, based on the analysis and novel mathematical expressions for the outage probability, we investigate the impact of the lognormal parameters (including correlation) on the cooperative system performance and its efficiency.

1. Introduction

Cooperative diversity systems consist of multiple nodes that share their resources in order to create multiple diversity channels and thereby improve system performance, typically in terms of availability, range and throughput. This paper considers cooperative diversity in lognormal fading channels. Lognormal channel models can be used to model indoor, as well as outdoor propagation, e.g. shadowing (see [1–3], [4, section 4.2.1], [5] and references therein). Moreover, due to various propagation effects and geometrical parameters, the fading gains of differing propagations paths can be assumed to be correlated (see e.g. [6–8] and references therein) thus following a multi-variate lognormal distribution, as described in the next Section.

A fundamental building block for cooperative diversity systems is the relaying channel [9], which has been studied in the context of fading channels in recent years [10,11]. To the authors' knowledge, results on the performance of diversity combining as well as cooperative diversity techniques in correlated lognormal channels are very limited. The outage probability of maximum ratio combining (MRC) and selection combining (SC) are studied in [12–15], while multi-hop communications over independent lognormal fading channels have been studied in [16].

Results on cooperative lognormal systems are also very limited. In [17], several cooperative diversity systems with independent and identically distributed lognormal fading gains are studied and bounds on the pairwise error probability are provided. In [18], the impact of total power constraints are investigated through bounds of the outage probability and error probability of relaying with independent lognormal fading channel gains, while utilizing Fenton-Wilkinson's method [19] for approximating the combiner output at the destination node. Finally, in [20] a distributed diversity system with amplify and forward [11] relays is studied, under the assumption of independent diversity channels.

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In [21], the authors study a fixed relaying [11] system assuming MRC or SC at the destination. More specifically, an exact analytical expression of the outage probability is provided for both orthogonal relaying schemes utilizing time and frequency division multiple-access protocols and half-duplex relays and non-orthogonal schemes utilizing space division multiple access and full-duplex relays. In addition, the provided analytical framework is used to demonstrate the significant impact of fading correlation on the system performance and also show that the variance of the source-relay link has to be smaller than the variance of the source-destination link for cooperation to outperform non-cooperation.

In this paper, we provide exact integral expressions for the end-to-end outage probability of a cooperative diversity selection relaying [11] system. In the considered selection relaying system, a cooperative system is created whenever the signal-to-noise ratio between the source node and the relay node lies above a certain threshold; otherwise, the system falls back to direct link transmission. The two formed diversity branches are combined coherently by the destination node using either MRC or SC [4]. It should be noted that our analysis considers correlated lognormal channels, in contrast to prior art [16–18,20] that considers uncorrelated channels, and presents a thorough investigation of the impact of correlation on cooperative system performance. In addition, some novel insights are obtained on the efficiency of cooperation by studying the impact of the multiple-access protocol on cooperation and comparing it to the performance of non-cooperation. The choice of multiple-access protocol depends on the ability of the relay to perform half-duplex or full-duplex operation.

It should also be emphasized that the final outage probability formula derived in this paper is produced using a different methodology than [11] and consists an alternative representation of the outage event of a selection relaying system. More specifically, in this paper the dual-hop part of the cooperative system is replaced by an equivalent system described by the same outage event. This equivalent system is then combined with the direct link to produce the final outage probability expression for selection relaying. Preliminary results of this analysis have been presented in [22].

This paper is organized as follows. Section 2 presents the system model and the correlated lognormal channel model including a description of the possible multiple-access protocols utilized by the cooperative diversity system. Section 3 provides exact expressions for the outage probability of selection relay systems with a single relay and MRC or SC at the destination. Section 4 establishes the energy and spectral efficiency of the cooperative protocols under consideration and proposes an appropriate direct link system for comparison purposes. Finally, Section 5 utilizes the proposed formulas and efficiency framework to numerically assess the impact of the various system parameters on the cooperative diversity system's performance.

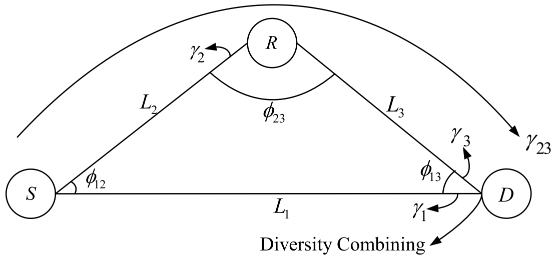

Fig. 1. Geometrical configuration of the cooperative diversity network.

2. Cooperative diversity system model

2.1. General considerations

The geometrical configuration of the considered cooperative wireless network is shown in Fig. 1. The source node S communicates with the destination node D through two different routes. The first signal is directly transmitted by the node S to the node D and the second signal is transmitted by the node S to the node D through the regenerative (decode-and-forward) relay node R (dual-hop transmission). These two signal paths form two diversity branches, which are combined by the node D using coherent combining [4] to form the final received signal. In Fig. 1, the length of the link j ($j = 1, 2, 3$) is denoted as $L_j(m)$, while the links i, j ($i, j = 1, 2, 3, i \neq j$) subtend an angle ϕ_{ij}(deg) where $\phi_{ij} = \phi_{ji}$.

The received signal-to-noise ratio (SNR) of link j is given by (in linear scale)

$$\gamma_j = \frac{1}{N_0} P_{Txj} w_j \tag{1}$$

where N_0 is the noise density in linear scale (assumed to be equal to 1 in this paper without loss of generality), P_{Txj} is the transmitted power for link j and w_j is the shadowing lognormal variable with parameters (in Neper):

$$(\mu_{w_j}, \sigma_j) = (-\ln(PL_j), \sigma_j) \tag{2}$$

where PL_j is the path-loss of link j expressed in linear scale and σ_j is the variance of the shadowing parameter that depends on the specific propagation environment (values for various propagation scenarios are given in [7]).

The received SNR of link j follows the lognormal distribution. The lognormal parameters can be produced by the appropriate random variable transformation which results in a linearly scaled mean and equal variance (in Neper):

$$(\mu_j, \sigma_j) = ((\ln(P_{Txj}) + \mu_{w_j}), \sigma_j) \tag{3}$$

where μ_{w_j} is given by (2). Parameters expressed in Neper can also be expressed in dB using $1Np = \xi$ dB $= 10/\ln(10)$ dB. Moreover, the lognormal random variables $\gamma_j (j = 1, 2, 3)$ are assumed to be correlated and follow the trivariate lognormal distribution $f_{\gamma_1\gamma_2\gamma_3}(\gamma_1, \gamma_2, \gamma_3)$ as described in Section 3. In addition, the dual-hop signal-to-noise ratio γ_{23} expresses the signal transmitted by the source and received by the destination through the Relay (links 2 and 3).