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Second-Order Statistics of MRC Reception With a Transparent Amplify-and-Forward Relay

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ABSTRACT

Achievable spatial diversity supported by a single transparent amplify-and-forward (AF) relay relies on disintegrated channel state information (CSI) that can be acquired at the destination. This paper studies the impact of the quantization of the source-relay (SR) CSI in terms of the first- and second-order statistics of maximal-ratio combining (MRC) reception with the incomplete SR CSI at the destination. Probability density functions (PDFs) of the upper and lower bounds of the signal-to-noise ratio (SNR) achieved at the destination are derived. Corresponding level-crossing rate (LCR) and average fade-duration (AFD), which are undoubtedly required to choose parameters of forward error correcting (FEC) mechanisms across the transparent AF relay network, are evaluated via Monte Carlo simulations. The simulations show that the SNR PDF, LCR and AFD highly depends not only on the accuracy of SR CSI at the destination but also on the location of the AF relay.

KEYWORDS

Amplify-and-Forward Relay, Maximal-Ratio Combining (MRC), Relay Network, Spatial Diversity

1. INTRODUCTION

Diversity combining and error-correction coding techniques are the two most important ways to overcome channel fading effects. Cooperative communication has become an effective means of achieving spatial diversity, especially when a direct link would frequently incur deep channel fades (Kim et al., 2011; Khan et al., 2012; Duong et al., 2011). A relay can create an additional link between the source and the destination to provide spatial diversity. The effectiveness of the spatial diversity provided by an amplify-and-forward (AF) relay network inevitably relies on the knowledge of the channel state information (CSI) of the disintegrated channels, which consist of (i) the direct link from source to destination (SD) and (ii) the indirect link from source to relay (SR) and from relay to destination (RD). On diversity reception, considerable research regarding the first- and second-order statistics has been undertaken. Signal-to-noise ratio (SNR) probability density function (PDF) is one of the commonly employed first-order statistics, meanwhile level-crossing rate (LCR) and average fade duration (AFD) are the commonly employed second-order statistics. The SNR PDF is

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often adopted to quantitatively describe the severity of channel fading and is therefore often used to evaluate the time-average bit-error rate (BER) (Dwivedi & Singh, 2011), the outage probability and the ergodic capacity of various time-varying channels (Simon & Alouini, 2005). LCR and AFD convey important insights for the choice of forward error correcting (FEC) block coding, determination of the interleaving depth, parameter selection of retransmission methods and analysis of achievable rates (Chan & Chuang, 1996; Alouini & Goldsmith, 2000; Anastasov et al., 2013).

A performance evaluation of an AF relay network with quantized SR CSI was conducted in a previous study using simulations (Amin et al., 2010). With the objective of SNR maximization, a brute-force approach was studied to optimize a quantizer at the relay (Abdallah & Papadopoulos, 2008). A previous study (Fang & Wang, 2009) studied the optimal relay selection problem for an AF network. In (Abdallah & Papadopoulos; 2008), a modified beamforming algorithm was developed with full knowledge of the RD CSI and a quantized description of the SR CSI for multi-relay AF and decode-and-forward (DF) networks. A previous study (Karamad et al., 2013) derived a tight bound on the sum-rate performance with quantization error for a dual-hop DF network, and efficient quantization and bit-allocation techniques were proposed. Although the impact of the channel quantization error in an AF relay network was investigated in a prior study (Lin et al., 2017), no prior study furthermore investigated LCR and AFD of maximal-ratio combining (MRC) reception supported by a transparent AF relay network. Especially, LCR and AFD are much important in an AF relay network because a transparent AF relay does not demodulate signals, perform any error correction decoding, then encode and finally remodulate the signals, which must be performed in DF or filter-and-forward (FF) (Chou et al., 2016) relay networks. A transparent AF relay passes the sector identification (SID) and cell identification (CID) from the serving basestation and the initial synchronization process (Lin, 2018; Lin et al., 2016) has never been conducted at the transparent AF relay. Therefore, an effective channel coding scheme used in a transparent AF network must take care of the overall channel impairment from the source to the destination both via indirect and direct links because the FEC decoder only works after the inner receiver, which consists of a diversity combiner, at the destination. As a result, LCR and AFD obtained using MRC reception supported by a transparent AF relay at the destination are, of course, required to choose parameters of an effective channel coding scheme and to determine interleaving depth.

In this paper, performance assessment of a transparent AF relay network that adopts the quantization-based signaling strategy is studied in the presence of channel quantization error (CQE) occurring with the SR CSI over Rayleigh fading channels. Closed-form expressions of the SNR PDF were derived by means of the moment-generating function (MGF) method to provide sufficient insight. LCR and AFD are then evaluated via computer simulations. The remainder of this paper is organized as follows. Signal models and problem formulations are briefly described in Section 2. Performance evaluations with impact of CQE are derived in Section 3. Simulation results are given in Section 4 and concluding remarks are given in Section 5.

2. SIGNAL MODELING

There is a source node denoted as S, a destination node denoted as D and a relay node denoted as R in the studied AF relay network. It is assumed that the relay network operates in a half-duplex mode according to the bi-phase transmission protocol. In the first phase, S transmits information-bearing signals to both R and D. In the second phase, R sends the signal received from S toward D after signal amplification, while S sends a blank slot to avoid inter-link interference. The complex-valued channel weights of the $S-D$, $S-R$ and $R-D$ links, h_{SD}, h_{SR} and h_{RD}, can be modeled as complex Gaussian RVs with zero mean and variances Ω_{SD}, Ω_{SR}, and Ω_{RD}, respectively. The signals received at R and D in the first phase can be written as:

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