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A simple approach for the suppression of Rician interference in a relay backhaul using limited feedback

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ABSTRACT

The benefits of Decode and Forward (DF) relaying span from deployment flexibility to coverage extension and improved capacity distribution in the network. Accordingly, relaying has become an integral part of the modern radio access network standards. Besides the evident benefits of DF relaying, the fact is that it uses part of the valuable radio access resources for the communication between network elements. Thus, the amount of radio resources allocated to the Relay Link (RL) between serving Donor Base Station (DBS) and the Relay Node (RN) should be minimised. This easily makes the RL a bottleneck in conventional two-hop infrastructure relaying. Furthermore, current mobile systems apply universal frequency reuse in macrocell deployments where macrocell BS's serve RN's as well. As a result, RL's may suffer from severe interference.

We propose a practical limited feedback approach that can be used to simultaneously improve the signal strength and to suppress the interference in the RL. To that end, we deduce analytical formulae for the distribution of the Signal to Interference and Noise Ratio (SINR) in the RL by assuming Rice and Rayleigh fading combinations in desired and interfering links. Furthermore, we compute two-hop end-to-end (e2e) outage probabilities for different interference and limited feedback scenarios. Results show that especially in Rice fading environment, large performance gains can be obtained with only few bits feedback in case where RL has scarce radio resources and suffers from dominant interferer. This makes the proposed method very feasible for the infrastructure relaying where RN's can be placed either in the rooftop level or other locations that provide a line of sight towards macro BS's.

1. Introduction

1.1. Background

Decode-and-Forward (DF) relaying is a well-known and extensively studied concept that has recently become an integral part of the modern radio access network standards. Notably, standards for DF relaying have been developed for 4G, that is 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) Release 10 and beyond [1] and discussion on the role of relaying is ongoing in the 5G development community. The motivations for using relaying as an enhancement technology to current radio access networks has been well elaborated in the literature, see e.g. [2–5]. The documented benefits of relaying range from deployment flexibility to coverage extension and more equitable capacity distribution in the network.

However, even in the most typical two-hop scenario of 4G the RL between the so-called Donor BS (DBS) and Relay Node (RN) easily becomes a bottleneck. If there is a number of relays connected to the same DBS, then it is limited in number of resources it can allocate per RN. On the other hand, all relays may apply the same radio resource pool in the Access Link (AL) between the RN and the User Equipment (UE). Then, the spatial radio reuse is much more effective for the AL resources than it is for the RL resources. This imbalance can be compensated by e.g. using the advanced antenna technologies, coordinated communication and by scarcely planning the relay locations, see e.g. [6–10]. Such methods are effective but may also increase the cost and implementation complexity of the relays and the network.

The crucial factor for the RL performance is the interference created by the neighbouring macro BS's. While universal frequency reuse is utilised in the macrocell deployment, the interference in RL's of adjacent macrocell macro BS's are difficult to avoid. In current 4G mobile system standards, it is presumed that relays have fixed locations. While the wireless nature of the RN enables some flexibility while choosing the location, planning should take into account the expected relay service area and the RL quality.

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Thus, fixed outdoor relays are preferably located above street level in e.g. building walls, lamp posts or even in the rooftop level. Then, RL is either having a Line of Sight (LoS) or a dominant signal direction towards the serving DBS. However, in these cases the interference from adjacent macro BS easily becomes a significant factor as well [11–13].

1.2. Contribution

In this section we first discuss the previous research that have led to this paper. Then we present the contribution of the paper and recall other research in the field that is closely related to this work.

Let us start by recalling that explicit and standard compliant feedback methods for multi-antenna transmission have not been extensively examined in the literature. More precisely, in 3GPP standards (for 3G and 4G) the receiver feedback for the transmitter in multi-antenna transmission methods is standardised incrementally making the mathematical analysis challenging. Yet, in case of single link two-antenna transmission simplest 3GPP methods can be mathematically analysed in terms of outage and average rates, see e.g. [14,15].

The same explicit feedback methods that are used to obtain antenna gain can also be used to suppress the interference by applying them in the interfering transmitter. This interference suppression technique was introduced in [16,17] and later analysed also in [18]. According to our best knowledge this method has not been introduced, analysed or applied elsewhere. We also recall that in [16–18] interference suppression is applied in the direct link between transmitter and receiver and only Rayleigh fading scenario is considered.

In this paper we introduce and analyse a two-hop DF relay system where method of [16–18] is applied in the RL. The contributions comprise analytical formulae for the distribution of SINR in the RL by assuming Rice and Rayleigh fading combinations for the dedicated and interfering links. Based on the obtained SINR distributions, we have deduced a two-hop e2e outage probabilities for different interference and limited feedback scenarios. Analysis is limited to two-antenna case due to inherent technical complexity of the computations when the number of antennas are higher. We recall that in current mobile systems two-antenna BS's is a default solution.

We emphasise that the analysis in this paper is a non-trivial extension of the analysis carried out in the previous papers [19,20]. Due to Rice channel assumption analysis becomes complicated even in the direct link case and the analysis of e2e performance over a two-hop relay link has been challenging. That is, we claim that the idea, analysis and results of this paper are new. Furthermore, the proposed method can be implemented with small changes to the current 4G systems. These changes are considered in more detail in Section 2. It is not claimed that the proposed method is optimal with respect to some general performance measure. Yet, we show how to obtain notable interference mitigation gains in the e2e link with just few bit feedback and small changes to the current 4G systems. We have verified analytical results via numerical simulations. Related performance results show that suppressing the dominant interferer in RL may provide large performance gains especially if RL is the bottleneck for the e2e performance and Rice fading with large K-factor takes place in either/both desired and interfering links. This makes the proposed method very feasible for the infrastructure relaying where RN's can be placed either on the rooftop level or on locations that provide LoS towards macro BS's.

Numerous excellent studies on DF relaying has been published in the literature. Let us recall some works that are relevant from the perspective of this paper. One of the most cited early works in the field is [19]. Therein, fundamental closed-form performance results have been shown for two-hop relaying over Rayleigh fading channels. In [21] the performance of spatial diversity methods in DF relaying has been studied in terms of outage probability and in [22] the performance have been investigated using the ergodic capacity as a performance measure. In [23] the authors have assumed covariance feedback in a MIMO relay system and investigated different transmission strategies. Capacity studies have been extended to general fading channels in [20] and to Rician channel in [24]. The outage probability of relaying in presence of interference has been considered in [25] and [26], with the latter article assuming a cooperative relaying framework. The cooperative relaying has been investigated in more depth in [27–31]. Therein, LTE-Advanced framework is assumed in [28] while [27,30] focus on MIMO scenario. Finally, in [29,31] authors consider space–time block coding and non-orthogonal multiple access in cooperative relaying system.

We note that femtocell interference models applied in [18,32,33] are similar with the model applied in the RL of this paper. In [32] eigen-beamforming is applied without feedback quantisation, while in [18,33] focus is merely on the impact of scheduling where a restricted precoding codebook is applied. All mentioned papers assume Rayleigh fading channel while we have assumed the Rician channel that is more feasible for RL with fixed endpoints. We emphasise that in general there is only a small number of DF relaying studies that assume antenna feedback. Furthermore, according to our best knowledge, there are no other studies considering the e2e relay performance analysis assuming standards-compliant, bit-wise defined feedback methods in the relay link with interference.

The rest of the paper is organised as follows. Section 2 presents the general system model and assumptions for the two-hop DF relaying scenario including e2e probability formulation, SINR model for the RL, limited feedback methods and definitions for the fading models. The analytical study of SINR and outage have been carried out in Section 3 and performance results are given in Section 4. Finally, conclusions are drawn in Section 5.

2. System model

We study relay enhanced cellular (REC) network downlink as shown in Fig. 1. That is, we focus on a two-hop system composed by RL and AL between DBS and RN, and RN and UE, respectively. Before building the mathematical model, we make few notes on the applied assumptions:

(1) Both RL and AL are carried over fast fading channels. There, we assume a block fading model such that channel is constant for a short time period (proportional to the transmission time for a symbol or a short data packet), and channel samples corresponding to different temporal blocks are uncorrelated. This is a conventional and widely accepted assumption that enables mathematical analysis of various transmission methods over fading channels.

(2) The instantaneous rates on the RL and the AL are described by using the classical AWGN channel capacity formula:

$$R_{\mathrm{r}} = W_{\mathrm{r}} \cdot \log_2(1+\Upsilon_{\mathrm{r}}), \qquad R_{\mathrm{a}} = W_{\mathrm{a}} \cdot \log_2(1+\Upsilon_{\mathrm{a}}), \tag{1}$$

where W_{r} and W_{a} are the transmission bandwidths and Υ_{r} and Υ_{a} are the Signal to Interference and Noise Ratios (SINRs) of the corresponding RL and AL, respectively. When computing the e2e performance measures, we will need distributions of Υ_{r} and Υ_{a}.

(3) In practical systems, bandwidths W_{r} and W_{a} can be fixed or system can dynamically schedule resources for RL and AL. The long-term balance between RL and AL data transfer can be obtained by e.g. choosing W_{r} and W_{a} such that expected rates are equal: $E\{R_{\mathrm{r}}\} = E\{R_{\mathrm{a}}\}$. This is not optimal resource approach since instantaneous rates on RL and AL may greatly vary due to fast fading. However, this approach is simple to implement and enables