Ergodic mutual information and its fluctuation in multi-level MIMO relay system

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Performance Analysis of Dual-hop Beamforming for Multiuser MIMO Relay Networks with Interference

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Cooperative multiple-input multiple-output (MIMO) relay networks have been extensively investigated for the last decade from both industry and academia since they are able to improve the throughput and broaden the coverage of wireless communication systems. In particular, multiuser relay networks (MRN) have been recently proposed and adopted in some relevant standards such as IEEE 802.16m and LTE-A.

In MRN a source is assisted by a relay for sending information to a set of users. At any time the user to be served is selected according to a scheduling strategy that aims at reaping the benefits of multiuser diversity. Among the most known scheduling strategies there is opportunistic scheduling (OS), which is a greedy algorithm able to maximize the system throughput [1–3]. Under OS, the relay node serves the user with the highest instantaneous SNR. However, OS is prone to problems related to user fairness. This issue is overcome by proportional fair scheduling (PFS) [4], which assigns each user a scheduling priority that is proportional to the user relative condition in terms of SNR. Both OS and PFS require users to feedback channel state information to the relay node. Since feedback by users with severely impaired channel represents a waste of bandwidth, a threshold-based limited feedback scheme, named selective multiuser diversity (SMUD), has been proposed [5]. According to SMUD, only users with instantaneous SNR higher than a given threshold, return their feedback to the relay. We remark that all works cited above assume that at least one node of the network is equipped with single antenna and that the effect of path loss can be neglected. The system performance of MIMO MRN has been discussed in [2], which however does not take into account path loss or co-channel interference (CCI).

In this work, we address a cellular MIMO network where a base station transmits data to with M users via a relay node. We assume that communications are subject to co-channel interference and all nodes (source, relay, interferers, and users) are equipped with multiple antennas and operate in half-duplex mode. Also, no direct link exists between the source and the users. Over both hops (base station-relay and relay-user), the received signal is degraded by out-of-cell interferers. Signal propagation is affected by both large-scale path loss and small-scale uncorrelated Rayleigh fading. In such dual-hop MIMO MRN, we provide a comprehensive analysis of the coupled effects of antenna diversity, path loss, multiuser diversity, CCI, as well as scheduling strategy. We investigate the distribution of the signal-to-interference-plus-noise-ratio (SINR) over each hop in presence of beamforming. Then we present a closed-form lower bound on the system outage probability, and closed-form upper and lower bounds on the system ergodic capacity. Furthermore, the high-SNR asymptotic performance is investigated and we analyze the above mentioned multiuser scheduling schemes in terms of fairness and feedback efficiency.

In order to analyse our system, we denote the product of the transmit power and the path-loss coefficient from transmitter i to receiver j by α_{ij}. According to the beamforming principle, we assume that the symbol x transmitted by the source is sent to the relay by exploiting the channel associated with the largest singular value of the source-relay channel matrix $\mathbf{H}_{sr}$. At the relay, the received signal is amplified with an adaptive gain $\mathbf{G}$ and forwarded to the user selected by the scheduling scheme. The latter transmission occurs over a channel characterized by matrix $\mathbf{H}_{ru}$. Given the served user u, the end-to-end (e2e) SINR γ_u^{eq} from the source to user u can be written as:

$$\gamma_u^{eq} = \frac{\gamma_1 \gamma_2}{\gamma_1 + \gamma_2 + 1}\,. \tag{1}$$

In the above expression, $\gamma_1 = \alpha_{s,r}\lambda_1/(\beta + 1)$ is the SINR at the relay node and $\gamma_2 = \alpha_{r,u}\lambda_{2,u}/(\mu_u + 1)$ is the SINR at the user's receiver, while λ_1 and $\lambda_{2,u}$ denote the largest eigenvalues of the source-relay and relay-user matrices, respectively. β and μ_u denote, respectively, the CCI power at the relay and at the served user, which are assumed to be subject to the distribution of the sum of multiple independent exponential random variables [6, 7]. In order to derive the aforementioned results, we analyse the cumulative density function (CDF) of γ_u^{eq}. Since a closed-form expression for the CDF of the e2e SINR is, unfortunately, hard to derive, we present an upper bound of the CDF of γ_u^{eq} and use this to obtain a closed-form expression for the lower bound of the system outage probability. Then we use the bounding technique adopted in [8] to get an analytical expression for the upper and lower bounds of the ergodic capacity. These results hold for arbitrary number of antennas, SNR, and node location. Moreover, the outage probability of the system can be asymptotically approximated in the high-SNR regime. The validity of the derived analytical results is confirmed through comparison with Monte Carlo simulations. It is observed that the proposed bounds are very tight and that the asymptotic expressions converge to the numerical results in the high-SNR scenario.

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