Design of Linear Pre-coders and Equalizers for the Uplink in Multiuser Distributed Antenna System

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In this paper a joint design of linear pre-coders and equalizers is investigated for the uplink in multiuser distributed antenna system (DAS) over uncorrelated channels with perfect channel state information (CSI) at both the transmitters and receivers. It is assumed that there are L users and K access points (APs) in the DAS. Each user is deployed with $M_i (i = 1, \cdots, L)$ antennas while each AP with $N_j (j = 1, \cdots, K)$ antennas. The multiple input multiple output(MIMO)channel of the i-th user, is modeled by an $N \times M_i$ matrix , where $N = N_1 + \cdots N_K$ and $(\cdot)^T$ denotes the transpose of a vector or matrix. The virtual MIMO channel between the L users and the K APs is denoted by an $N \times M$ matrix $\mathbf{G} = [\ \mathbf{G}_1 \quad \mathbf{G}_2 \quad \cdots \quad \mathbf{G}_L\ ]$, where $\mathbf{G}_i \in C^{N \times M_i}$ and $M = M_1 + \cdots + M_L$. The symbol of the i-th user $\mathbf{s}_i \in C^{M_i \times 1}$ is pre-coded by $\mathbf{F}_i \in C^{M_i \times M_i}$. $\mathbf{n} \in C^{N \times 1}$ is additive white Gaussian noise vector with zero mean and covariance $\mathbf{R_n} = E\{\mathbf{n}\mathbf{n}^H\} = \sigma_n^2 \mathbf{I}_N$.

By minimizing the sum mean square error of all users, under a total power P constraint, the linear transceiver design is modeled as an optimization problem. Based on research on MIMO centralized antenna system (CAS), the optimal linear equalizer is $\mathbf{T}_i = \mathbf{F}_i^H \mathbf{G}_i^H \sigma_n^2 \mathbf{I}_N + \sum_{j=1}^{L} \mathbf{G}_j \mathbf{F}_j \mathbf{F}_j^H \mathbf{G}_j^{H-1}$. $\tilde{\mathbf{F}} = diag\{\ \mathbf{F}_1\mathbf{F}_1^H \quad \cdots \quad \mathbf{F}_L\mathbf{F}_L^H\ \}$ is obtained based on the block diagonal elements of $\tilde{\mathbf{F}}^*$. $\tilde{\mathbf{F}}^* = \mathbf{V}_h \mathbf{\Lambda}_f \mathbf{V}_h^H$ where $\mathbf{V}_h$ and $\mathbf{\Lambda}_h$ are the unitary and diagonal matrix of the singular value decomposition of $\mathbf{G}^H \mathbf{R}_\mathbf{n}^{-1} \mathbf{G}$. $\mathbf{\Lambda}_f$ is a diagonal matrix and $[\mathbf{\Lambda}_f]_{i,i} = (\sqrt{1/(\lambda[\mathbf{\Lambda}_h]_{i,i})} - 1/[\mathbf{\Lambda}_h]_{i,i})_+$, where $(\cdot)_+$ denotes the fact that the negative elements of the matrix are replaced by zero and $\sqrt{\lambda} = \left(\sum_{i=1}^{M} (1\Big/[\mathbf{\Lambda}_h]_{i,i}^{1/2})\right)\Big/\left(P + \sum_{i=1}^{M} (1\Big/[\mathbf{\Lambda}_h]_{i,i})\right)$.

Through the simulation of the average symbol error rate (SER), it is concluded that the optimal design of pre-coders and equalizers in DAS outperforms that in CAS. The 5dB and 7dB gain in signal-to-noise ratio (SNR) is achieved in DAS when the path loss exponent is 3 and 3.7 as SER is 10^{-3}, respectively. The performance in DAS is more robust under the propogation environment with higher path loss. Taking advantage of pre-coders and equalizers, distinct data streams are transmitted through multiple antennas, thus the throughput of the system is increased. However, the SER becomes worse under the same SNR due to higher user data rate. The channels between users and APs are diagonalized by the joint design of pre-coders and equalizers with CSI known. With pre-coding, 4dB gain in SNR is achieved when SER is 10^{-3}. Since the pre-coders are designed in the central unit, fraction of the bandwidth is used to broadcast pre-coding matrices to users, the downlink throughput is decreased.