Revised System Model: Massive MIMO-OFDM with Rayleigh Fading

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1 System Model

We consider a single-cell massive MIMO-OFDM downlink system where the base station (BS) employs $N_t \gg 1$ transmit antennas, and the user equipment (UE) has a single receive antenna ($N_r = 1$). The system utilizes N_c orthogonal subcarriers with frequency-division duplexing (FDD).

1.1 Channel Model

The time-domain channel impulse response between the i-th transmit antenna and the UE follows a Rayleigh fading model with L multipath components:

$$h_i(\tau) = \sum_{l=1}^{L} \alpha_{i,l} \delta(\tau - \tau_l), \quad \alpha_{i,l} \sim \mathcal{CN}(0, \sigma_l^2), \tag{1}$$

where $\alpha_{i,l}$ is the complex path gain and τ_l is the delay of the l-th path.

The frequency-domain channel matrix for the n-th subcarrier is:

$$\mathbf{H}_n = [H_{1,n}, H_{2,n}, \ldots, H_{N_t,n}] \in \mathbb{C}^{1 \times N_t}, \tag{2}$$

where each element is derived from the DFT of the CIR:

$$H_{i,n} = \sum_{l=1}^{L} \alpha_{i,l} e^{-j2\pi n \tau_l / N_c}. \tag{3}$$

1.2 Pilot Transmission and LS Estimation

The BS transmits orthogonal pilot sequences $\mathbf{X}_{p,n} \in \mathbb{C}^{N_t \times T_p}$ ($T_p \geq N_t$) for each subcarrier. The received signal at the UE is:

$$\mathbf{Y}_{p,n} = \mathbf{H}_n \mathbf{X}_{p,n} + \mathbf{Z}_n, \quad \mathbf{Z}_n \sim \mathcal{CN}(0, \sigma^2 \mathbf{I}). \tag{4}$$

The least-squares (LS) channel estimate is:

$$\hat{\mathbf{H}}_n = \mathbf{Y}_{p,n} \mathbf{X}_{p,n}^{\dagger}, \quad \text{where } \mathbf{X}_{p,n}^{\dagger} = \mathbf{X}_{p,n}^H (\mathbf{X}_{p,n} \mathbf{X}_{p,n}^H)^{-1}. \tag{5}$$

1.3 CSI Feedback Compression

The full CSI matrix $\mathbf{H}_{\text{freq}} \in \mathbb{C}^{N_c \times N_t}$ is constructed as:

$$\mathbf{H}_{\text{freq}} = \left[\hat{\mathbf{H}}_1^T, \hat{\mathbf{H}}_2^T, \dots, \hat{\mathbf{H}}_{N_c}^T\right]^T. \tag{6}$$

To exploit sparsity, we transform $\mathbf{H}_{\text{freq}}$ to the angle-delay domain via 2D-DFT:

$$\tilde{\mathbf{H}} = \mathbf{F}_d \mathbf{H}_{\text{freq}} \mathbf{F}_a^H, \tag{7}$$

where $\mathbf{F}_d \in \mathbb{C}^{N_c \times N_c}$ (delay DFT) and $\mathbf{F}_a \in \mathbb{C}^{N_t \times N_t}$ (angular DFT) are unitary matrices. Only the first N_i delay bins are retained:

$$\tilde{\mathbf{H}}_f = \left[\tilde{\mathbf{H}}\right]_{1:N_i,:}. \tag{8}$$

1.4 Deep Learning-Based Compression

The UE compresses $\tilde{\mathbf{H}}_f$ into a codeword $\mathbf{s}$ using an encoder network f_{enc}:

$$\mathbf{s} = f_{\text{enc}}(\tilde{\mathbf{H}}_f), \quad \mathbf{s} \in \mathbb{R}^{N_s}. \tag{9}$$

The BS reconstructs the CSI using a decoder f_{dec}:

$$\hat{\tilde{\mathbf{H}}}_f = f_{\text{dec}}(\mathbf{s}). \tag{10}$$

The compression ratio is:

$$\gamma = \frac{N_s}{2N_i N_t}. \tag{11}$$

2 References

1. D. Tse and P. Viswanath, *Fundamentals of Wireless Communication.* Cambridge University Press, 2005.
2. R. W. Heath Jr. and A. Lozano, *Foundations of MIMO Communication.* Cambridge University Press, 2018.