

# Abstract

The demand for a higher data rate in wireless communications has motivated the study of the usage of multiple antennas both at the transmitter and the receiver side. Multiple-input multiple-output (MIMO) systems assure higher reliability and spectral efficiency than single-input single-output systems due to their diversity and spatial multiplexing gains. With increasing system capacity, massive MIMO and multi-user MIMO (MU-MIMO) have applications in networks beyond 5G and 6G. The existing communication technologies are based on coherent detection, which needs significant amounts of signaling specifically for massive MIMO. Therefore, alternative approaches to overcome the drawbacks of coherent massive MIMO systems are noncoherent detection and differential detection. In addition to that, machine learning algorithms can be one of the effective tools for enhancing the performance of multi-antenna systems. There are three main categories of machine learning techniques: supervised learning (SL), unsupervised learning, and reinforcement learning. SL trains models using labeled data, whereas unsupervised learning infers patterns from unlabeled data.

In this thesis, we study both single-user (SU) and MU-MIMO systems under a flat Rayleigh fading environment. Here, we focus on designing an optimal precoder analytically for SU-MIMO systems with the Kronecker product correlation model using noncoherent detection and differential detection. Firstly, for the case of noncoherent reception, we optimize precoder parameters considering a spatially multiplexed SU-MIMO system with constellations  $\{0, 1\}$  and  $\{1, -r\}$  (with  $0 \leq r < 1$ ). The saturation value of the symbol vector error probability at high signal-to-noise ratio (SNR) is minimized with respect to the precoder parameters and  $r$ . It is found from computation that the optimal precoder parameters are approximately in geometric progression,

which simplifies the optimization problem. Furthermore, computational results show that for a large number of transmit antennas, the optimal value of  $r$  in the constellation  $\{1, -r\}$  tends to 0. Secondly, we study deterministic precoding and combining for an SU-MIMO system where we use differential encoding at the transmitter and differential detection with a maximum likelihood decision rule at the receiver. The precoder is designed to maximize the bound on the average received SNR, whereas the combiner is structured to minimize the union bound on the symbol error probability.

We next extend our work by implementing machine learning algorithms in cellular and cell-free (CF) networks to obtain performance better than that of traditional systems. Specifically, we focus on an SL based method for symbol detection in an MU single-input multiple-output (MU-SIMO) system and an unsupervised learning based access point (AP) clustering technique in a CF massive MIMO (CFMM) system. For supervised learning, an extreme learning machine (ELM) is chosen as the equalizer at the receiver end due to its super-fast learning ability and minimum training error. The network is trained online with known pilot symbols and then used to detect unknown transmit symbols using the parameters learned during training. To reduce the pilot requirement of the proposed model, we discuss an alternative method where the channel is estimated using a small number of pilot symbols and the ELM network is trained using a separate training dataset along with the channel estimate. Furthermore, we demonstrate how the proposed ELM equalizer outperforms existing linear equalizers, nonlinear detection techniques, and deep learning based models in terms of error rate and computational complexity. For the case of unsupervised learning, we use the Gaussian mixture model to cluster the APs on the basis of large-scale fading coefficients. We present an optimization problem that optimizes both the upper bound on the average downlink rate per user and the number of clusters. The computation expense is much lower than the current techniques, since the existing methods require evaluations of network performance in multiple iterations to find the optimal number of clusters. Additionally, we study the statistics of the spectral efficiency (SE) per user of clustered CFMM, and the SE per user can be approximated by the logistic distribution.