Abstract

Classical control theory assumes that the communication links connecting plants, sensors and controllers are perfect. However, this is not true in practical applications. The imperfection of communication channels would introduce uncertainties into feedback control systems, which might impact the stability and performance of the corresponding control system. Different issues arise when different communication channels are used in control systems, such as the minimal data rate, tolerable time delay and minimal signal-to-noise ratio (SNR), etc. This thesis focuses on the fading phenomenon in wireless communications and study how the fading affects the stability of the feedback control system.

In the first part of this thesis, we consider the mean square stabilization problem of discrete-time linear time invariant (LTI) systems controlled over fading channels. Firstly, we consider the power constrained fading channel, which suffers from both SNR constraint and time-varying i.i.d. channel fading. We try to characterize the channel requirement for the existence of sensing and control policies that can mean square stabilize the linear system. We firstly show that there is a fundamental limitation on the mean square stabilizability obtained via information theoretic arguments. For scalar systems and two-dimensional systems, necessary and sufficient conditions for the mean square stabilizability are provided. Moreover, time division multiple access (TDMA) and adaptive TDMA communication schemes are designed for high-dimensional systems, which are proved to be optimal under certain situations. Then we proceed to study the mean square stabilization problem over Gaussian finite-state Markov channels, which suffer from both SNR

constraints and the correlated channel fading modeled by a Markov chain. Similarly, the existence of a fundamental limitation for mean square stabilization is proved. Sufficient stabilization conditions achieved with TDMA communication schemes are derived in terms of the stability of a Markov jump linear system (MJLS). Besides, for the networked control over power constrained Markov lossy channels, one special kind of Gaussian finite-state Markov channels, we present a necessary and sufficient condition for the mean square stabilization of two-dimensional systems. Moreover, improved sufficient stabilization conditions are derived based on an adaptive TDMA communication scheme for general high-dimensional systems, which achieves larger stabilization regions than the TDMA communication scheme.

In the second part of this thesis, we study the distributed consensus problem of linear multi-agent system (MAS) over fading networks with both undirected communication topology and directed communication topology. The agents in the MAS communicate with each other through fading channels. We try to derive conditions on the agent dynamics, the fading networks and the communication graphs to guarantee the existence of a distributed consensus controller. First of all, we study the consensus problem under an undirected graph setting. Sufficient conditions to guarantee mean square consensus are derived with both identical fading networks and non-identical fading networks. It is proved that the sufficient condition is also necessary for scalar systems. The results imply that the consensusability is closely related to the statistics of the fading networks, the eigenratio of the graph, and the instability degree of the dynamical system. Then, we consider the mean square consensus problem over fading networks with directed graphs. Sufficient conditions are firstly provided for mean square consensus over identical fading networks with directed graphs. For consensus over non-identical fading networks with directed graphs, compressed in-incidence matrix (CIIM), compressed incidence matrix (CIM) and compressed edge Laplacian (CEL) are proposed to facilitate the modeling and consensus analysis. It is shown that the mean square consensusability is solely determined by the edge state dynamics on a directed spanning tree. As a result, sufficient conditions are provided for mean square consensus over non-identical fading networks with directed graphs in terms of fading parameters, the network topology and the agent dynamics. Moreover, the role of network topology on the mean square consensusability is discussed.