Stability analysis of random networks of dynamical systems has been of interest in many disciplines such as biology and physics and chemistry with applications such as LASER cooling and plasma stability. These large networks are often modeled to have a completely random (Erdős-Rényi) or semi-random (Small-World) topologies. The former model is often used due to mathematical tractability while the latter has been shown to be a better model for most real life networks.

The recent emergence of cyber physical systems, and in particular the smart grid, has given rise to a number of engineering questions regarding the control and optimization of such networks. Some of the these questions are: How can the stability of a random network be characterized in probabilistic terms? Can the effects of network topology and node dynamics be separated? What does it take to control a large random network? Can decentralized (pinning) control be effective? If not how large does the control network needs to be? How can decentralized or distributed controllers be designed?

Motivated by these questions, we began by studying the probability of stability of synchronization in random networks of oscillators. We developed a stability condition separating the effects of topology and node dynamics and evaluated bounds on the probability of stability for both Erdős-Rényi (ER) and Small-World (SW) models. We then turned our attention to the more realistic scenario where the dynamics of the modes and couplings are mismatched. We utilized the concept of e-synchronization, we have studied the probability of synchronization and showed that the synchronization error can be arbitrarily reduced using linear controllers.

We have also considered the decentralized approach of pinning control to ensure stability in such complex networks. In the pinning method, decentralized controller are used to control a fraction of the nodes in the network instead of traditional decentralized approaches where all the nodes have their own controllers. While the problem of selecting the minimum number of pinning nodes is known to be NP-hard and grows exponentially with the number of nodes in the network we have devised a suboptimal algorithm to select the pinning nodes which converges linearly with network size. We have also analyzed the effectiveness of the pinning approach for the synchronization of oscillators in the networks with fast switching, where the network links disconnect and reconnect quickly relative to the node dynamics.

To look at the scaling questions in the design of distributed control networks, we have considered to use a random control network to stabilize a random plant network. Our results show that for ER plant the control network needs to grow linearly with the size of the plant network.

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