

Abstract

This work aims to explore input-output dynamic properties of a class of distributed system called complex networks. The complex network aims to achieve certain goals collectively. For example, multiple unmanned aerial vehicles can be deployed to achieve certain objectives like surveying and vigilance more effectively than what can be achieved through a single vehicle. Complex networks have been widely studied in the field of networked control systems. The study of distributed control systems is motivated from its applications in diverse domains of engineering and sciences which include control of complex networks, vehicle coordination control, distributed networked control, mobile sensor networks, synchronization of oscillators, robot formation, biological networks, social networks, and power networks. A network comprises of nodes and edges, where a node represents an entity. These entities can be linked to various systems from diverse fields such as genes in a biological network, sensors in a detection system, vehicles in a traffic system, buses in a power network and persons or individuals in a social network. The edges model connections or interactions between the nodes. The attribute of a node has a state and this state may represent position coordinates of a sensor or a robot, an opinion of a person, expression of the protein by a gene, and voltage or frequency of a bus. The nodes work together to form a system, by exchanging information through edges, and perform task collectively.

A node is said to be a driver node (or control node) if the network can be driven from an initial state to the desired final state using this node. The minimum number of driver nodes required to control a network is fixed and this number can be obtained through existing theories. The set of driver nodes through which a network can be controlled, may not be unique. It is important to characterize these sets of driver nodes, and select an optimal set of driver nodes when there are several options available to choose a set of driver nodes. Non-uniqueness of the set of driver nodes leads multiple possibilities to create such sets of driver nodes. All such sets may not use equal energy to achieve the same control objectives. Furthermore, it is also possible that some driver nodes are more sensitive towards disturbances and noise.

One of the problems related to control of the complex network is to find the right nodes (physical system) such that, controlling these nodes eventually lead controlling the entire network in a desired manner. The existing literature quantifies controllability properties of directed and undirected graphs, however, how network structure is related to control properties is not well understood. In particular, in many applications, it is important to understand how one node (or a set of nodes) influences the other node (or a set of nodes) and how the network structure plays a role in it.

This thesis establishes a relationship between the input-output dynamic properties and graph structure. The work presents, how the DC-Gain, Gain Factor and Sensitivity are related with the network properties such as the distance between the control node and the output node, the diameter of networks and the sum of the product of weights of all shortest paths of a particular length in the networks. These relationships provide an insight into structural properties and its influence on system dynamics. In this regards, the work shows that the sum of the product of weights of all shortest paths between the control and output nodes is equal to the Gain Factor of the pole-zero-gain transfer function of the complex network. In addition, the work also shows that DC-Gain for the peripheral nodes of the complex network depends on the distance between the control and output nodes in the network. The existence of non-minimum phase zeros for collocated control and output nodes are discussed. The Sensitivity for a given input-output pair depends on the Gain Factor as well as DC-Gain. Therefore, this work investigates the correlation between the

network properties and Sensitivity in the complex networks.

The minimum number of driver nodes required to control a network is unique. However, the set of driver node(s) is not unique and poses an important question of selection of driver nodes when multiple options exist. This work proposes algorithms on the selection of an optimal set of driver nodes in the complex networks based on maximization of Region of Attraction (ROA). In a complex network, dynamics is captured by Adjacency matrix and, generally, it has unstable eigenvalues. Furthermore, in any practical applications, the actuators cannot have an infinite capability. Therefore it is imperative to consider this limitation a priori. The limitations of actuators (driver nodes) pose severe challenges in control when the Adjacency matrix (system matrix) has unstable eigenvalues; even stability cannot be guaranteed in this situation. For unstable eigenvalues of the Adjacency matrix of the network, the region of guaranteed stability in state space is finite when limitations of actuators are considered. This region is known as Region of Attraction (ROA) and generally, described by ellipsoids in the n -dimensional state space. The proposed work is aimed to obtain ROA and to make this region sufficiently large by selecting optimal driver nodes. The proposed theories and algorithms are verified with the help of real-world network examples such as robotic network, IEEE-4 bus, and IEEE-14 bus systems using the numerical simulation.

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