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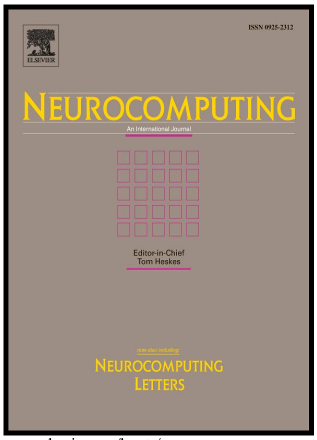

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Exponential Synchronization via Pinning Adaptive Control for Complex Networks of Networks with Time delays

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***Abstract*—This paper is concerned with the pinning adaptive synchronization control problem for a class of complex networks of networks. The complex networks of networks under consideration are composed of both leaders' network and followers' networks (also called "subnetworks"), where the leaders' network and subnetworks are regarded as the nodes of the networks of networks, each subnetwork can receive the information from leaders' network, but not the reverse. In order to achieve the synchronization for the networks of networks, pinning control strategy is adopted, and adaptive controllers are designed for the controlled nodes. By utilizing the stability theory of dynamical systems and some analysis techniques such as the Barbalat lemma, several sufficient criteria are obtained to ensure global exponential synchronization for the controlled complex networks of networks. Finally, a numerical simulation example is given to verify the theoretical results.**

Complex network; Network of networks; Exponential synchronization; Pinning adaptive control; Time delay.

I. Introduction

Over the last few years, complex networks have received increasing attention since they have extensive applications in both science and engineering such as Internet, world wide web, foods, electric power grids, cellular and metabolic networks, scientific citation networks, social network, ecosystems and biological neural networks. It is well known that there are a lot of interesting and important collective phenomena in complex networks, such as self-organization, synchronization, and spatiotemporal chaos [1], [2]. Among these phenomena, synchronization phenomenon has been intensively investigated in various different fields [3]–[8].

It is well known that time delays in the dynamical nodes inevitably exists, and have dramatic influence on the behavior of systems such as stability, oscillations, etc. There have been a large number of works on the investigation on the dynamics of delayed systems, especially on stability and synchronization, reported in literature [9]–[15]. For example, in [11] the adaptive feedback synchronization of complex dynamical networks with delayed nodes was investigated. In [14] the synchronization of continuous complex dynamical networks with discrete-time communications and delayed nodes was discussed. The exponential synchronization problem for an array of N linearly coupled complex networks with Markovian jump and mixed time-delays was presented in [15].

It should be noted that, in practice, only few networks could realize synchronization by themselves. In order to achieve synchronization, external force controllers usually need to be designed and applied to ensure the synchronization of networks. Recently, a variety of control strategies have been considered for network synchronization problem. However, for a network with a large number of nodes, it is literally impossible to add controllers to all nodes. To reduce the number of controlled nodes, some local feedback injections may be applied to only a fraction of nodes, which is known as pinning control. Since pinning control is economical and effective in large scale networks, it has widely investigated in complex networks [16]–[23]. For example, in [17] the global pinning controllability of complex networks was studied and some sufficient pinning conditions were established. In [18], the synchronization problem via pinning control was studied. Some low-dimensional pinning criteria for global synchronization of both directed and undirected complex networks were presented in [23]. Recently, the pinning adaptive control scheme was also considered in the synchronization problem of networks [24]–[27].

On the other hand, it is also noted that, in most practical systems, an individual network is only one component within a much larger complex multi-level network, and these individual networks are interdependent. For example, diverse infrastructures are coupled together, such as water and food supply, communications, fuel, financial transactions, and power stations [28]. For another example, in transportation networks, there are typically highway, bus, train and airplane networks covering the same areas but behaving differently, but each of

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