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Cluster synchronization between uncertain networks with different dynamics

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HIGHLIGHTS

- A new technique for the cluster synchronization between uncertain networks with different dynamics is proposed.
- The dynamics of nodes in different clusters can be different.
- There are not any limitations for the division of the clusters, the number of nodes in each cluster and the connections between nodes.

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ABSTRACT

We propose a new technique for the cluster synchronization between uncertain networks with different dynamics. Based on the Lyapunov theorem and Lipschitz condition, the network controllers and the identification laws of uncertain parameters are designed, and they are efficiently used to achieve the cluster synchronization and the identification of uncertain parameters. Particularly in our work, the dynamics of nodes in different clusters can be different. And there are not any limitations for the division of the clusters, the number of nodes in each cluster and the connections between nodes.

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1. Introduction

As it is well known, the research on network synchronization is very important due to its potential applications in many fields including secure communication, laser transmission, image identification, and information science, and so on [1–6]. In recent years, a large number of literatures reported the research results of network synchronization, and it has become a frontier issue [7–10]. As a result, different types of network synchronization have been put forward, for example, complete synchronization [11–13], phase synchronization [14,15], projective synchronization [16,17] and cluster synchronization [18,19], etc.

In the above synchronization types, the cluster synchronization of the network has gradually aroused people's wide attention. The cluster synchronization of the network means that all nodes in a complex network are divided into several clusters. The synchronization between nodes in each cluster or between the node and the synchronization target can be achieved, and the synchronization between the nodes in different clusters cannot be achieved. Obviously, cluster synchronization of the network in some application fields, such as secure communication, has stronger practicability and security. To this end, in view of the cluster synchronization of the network, some interesting researches have been done. Among them, typical works such as, Rakkiyappan and Sakthivel researched the cluster synchronization problem for T-S fuzzy complex networks with probabilistic time-varying delays, and proposed the pinning control strategy [20].

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Sorrentino et al. described a method to find and analyze all of the possible cluster synchronization patterns in a Laplacian-coupled network, by applying methods of computational group theory to dynamically equivalent networks. And they presented a general technique to evaluate the stability of each of the dynamically valid cluster synchronization patterns [21]. Nishikawa and Motter researched the network-complement transitions, symmetries, and cluster synchronization [22]. Glyzin et al. considered nonlinear systems of differential–difference equations with delays that provide mathematical models for artificial complete genetic networks. And they studied problems of the existence and stability of special periodic motions referred to as two-cluster synchronization modes in these systems [23]. Vahedi and Noorani investigated the cluster modified projective synchronization between two topologically distinct community networks [24].

It is worth noting that the cluster synchronization schemes of the network are relatively small, and there are some limitations. For example, in the reported literatures, the nodes in the all clusters have the same dynamics, that is, the dynamical systems of network nodes must be identical and the only difference is the initial conditions. Therefore, to realize synchronization of these identical dynamical systems is to restrain track separation caused by the sensitivity to the initial value rather than that caused by the different characteristics of bifurcation as well as the different domain of attraction. However, though the complex network nodes are often different, the research on it has not been reported.

In this paper, we propose a new technique for the cluster synchronization between uncertain networks with different dynamics. Based on the Lyapunov theorem and Lipschitz condition, the network controllers and the identification laws of uncertain parameters are designed, and they are efficiently used to achieve the cluster synchronization and the identification of uncertain parameters. Particularly in our work, the dynamics of nodes in different clusters can be different. And there are not any limitations for the division of the clusters, the number of nodes in each cluster and the connections between nodes.

This paper is organized as follows. Section 2 express the problem description. In Section 3, main results, including designs of network controllers and identification laws of uncertain parameters, are presented. Numerical results are given in Section 4. Finally, conclusions are derived in Section 5.

2. Problem description

Considering a complex network consisting of N nodes, it can be divided into m clusters. Then, the state equation of the network node can be expressed by

$$\begin{aligned}\dot{x}_i(t) &= F_i(x_i(t), \alpha_i) + \xi_i \sum_{j=1}^{N} c_{ij} x_j(t) \\ &= f_i(x_i(t)) + g_i(x_i(t))\alpha_i + \xi_i \sum_{j=1}^{N} c_{ij} x_j(t) \quad i \in \Omega \end{aligned} \tag{1}$$

where $x_i(t) = (x_{i1}(t), x_{i2}(t), \ldots, x_{in}(t)) \in R^n$ is the state variable of the ith node, α_i is the network parameter. k_l represents the number of nodes in the lth cluster, $\Omega = \{k_1 + k_2 + \cdots + k_{l-1} + 1, \ldots, k_1 + k_2 + \cdots + k_{l-1} + k_l\}$ represents the index set of all the nodes in the lth cluster, $l = 1, 2, \ldots, m$ and $k_1 + k_2 + \cdots + k_m = N$. ξ_i is the coupling strength between the network nodes, and c_{ij} is the coupling matrix element that represents the network topology structure. If the connection between node i and node j exists, then $c_{ij} \neq 0$, otherwise, $c_{ij} = 0$.

Remark 1. There are not any limitations for the division of the clusters, the number of nodes in each cluster and the connections between nodes.

Remark 2. All nodes within a cluster have the same dynamics, and the dynamics of nodes in different clusters can be different.

Assumption 1. If the function $F(x_i(t), \alpha_i)$ satisfies the Lipschitz condition, there exists the real number $\delta_i > 0$ such that for $\forall x_i(t), y_i(t) \in R^n$, we have

$$|F(y_i(t), \alpha_i) - F(x_i(t), \alpha_i)| \leq \delta_i \left| y_i(t) - x_i(t) \right| . \tag{2}$$

We construct a response network corresponding to the drive network (1)

$$\dot{y}_i(t) = f_i(y_i(t)) + g_i(y_i(t))\hat{\alpha}_i + \xi_i \sum_{j=1}^{N} c_{ij} y_j(t) + u_i(t) \quad i \in \Omega . \tag{3}$$

Here, we assume that the parameters in the response network are uncertain, and its identification is $\hat{\alpha}_i$. $u_i(t)$ is the network controller.

Definition 1. The cluster synchronization between uncertain networks with different dynamics is realized if $\lim_{t\to\infty} |y_i(t) - x_i(t)| = 0$.

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