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Design of synchronization technique for uncertain discrete network group with diverse structures

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HIGHLIGHTS

- Synchronization of network group constituted by uncertain discrete networks with diverse structures is researched.
- The identification laws of uncertain parameters in networks are determined.
- There are not any limitations for the network number, the number of network nodes and network connectivity.

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ABSTRACT

In this work, we design a novel synchronization technique to realize the synchronization of the network group which is constituted by some uncertain discrete networks with diverse structures. Based on Lyapunov theorem, the selection principle of the control inputs and identification law of uncertain parameters in networks are determined, and the synchronization conditions of network group are obtained. Finally, numerical simulations using one-dimensional convective equations with spatiotemporal chaos behaviors illustrate the performance of the synchronization scheme. The research results show that our synchronization technique can be suitable for the network connecting arbitrarily, and not only the network number but also node number in each network can also be chosen freely.

1. Introduction

There exists a mass of nonlinear systems in the nature which are associated with one another, and their collective behaviors can be described and investigated by using complex network. The synchronization problem of complex network constituted of nonlinear systems with chaos behaviors is a key and hot topic for the investigation of network dynamics and it is also one of the most focused directions, in which so many research fruits have been gotten [1–6]. The synchronization investigation of complex network exhibits unique application potential in many fields, such as control engineering, image identification, network communication, WWW and Internet network, and so on.

At present, some mature techniques for network synchronization have been reported, including the Master Stability Functions (MSF) method [7], connection graph method [8], adaptive control [9,10], pinning technique [11,12] and impulsive synchronization [13], etc. Originally, the research objects of network synchronization mainly focus on regular networks, however, the concerned targets become more and more extensive since Watts and Barabási proposed respectively the famous concepts of small-world network and scale-free network [14,15]. The synchronization of the irregular networks has been investigated deeply and many significant progresses have been made [16–19]. Especially, the synchronization of networks with delay effects or uncertain parameters has attracted widespread attention recently [20–22] because the delay

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effects are inevitable when the signals transmit among network nodes. At the same time, the parameters in networks may be uncertain due to the external disturbance or technology limitation.

In fact, the synchronization effects exist in not only among nodes within network but also among networks. Among them, the practical applications of the synchronization among networks are very extensive. For instance, the signal is transmitted synchronously and amplified among several laser networks; information is transmitted synchronously among several local networks; and infectious disease is spread in different countries or populations, and so on. Therefore, the investigation about the synchronization among networks, i.e. synchronization of network group, is quite necessary. So far, some typical works have been done: Al-Mahbashi et al. achieved the projective lag synchronization between chaotic systems in drive–response dynamical networks with nonidentical nodes [23]; Zhou et al. analyzed the outer synchronization between WS and NW small-world networks with different node numbers [24]; Lü et al. discussed outer synchronization between uncertain complex networks based on Backstepping design [25]; Ray and Roychowdhury investigated outer synchronization of networks with different node dynamics [26]; Wu et al. realized anti-synchronization between complex dynamical networks with non-delayed and delayed coupling based on pinning adaptive control theory [27]; Sakthivel et al. obtained anti-synchronization conditions for BAM memristive neural networks with different memductance functions [28]; Wu et al. proposed complex projective synchronization scheme for two stochastic networks with time delays [29].

Whereas, the synchronization techniques reported previously aim mainly at the designs for two complex networks, and they are often ineffective for the synchronization in the network group constituted by many complex networks. To the best of our knowledge, the synchronization technique about network group, especially about such network group constituted by many uncertain discrete networks with diverse structures, has not been reported yet. In this paper, our goal is to emphasize the synchronization investigation about such network group.

Q3 The rest of this paper is organized as follows: In Section 2, the problem statement is expressed. In Section 3, the main results of synchronization of network group are given. The simulation and discussion are completed in Section 4. Finally, some conclusions are summarized in Section 5.

2. Problem statement

Assuming there are l complex networks and N_k nodes in each network. Those nodes are discrete systems with spatiotemporal chaotic behaviors and every connection way between nodes is arbitrary and different from each other. Then the state equation of ith nodes in kth network can be described as follows

$$\begin{aligned} x_i^k(m, n+1) &= f(x_i^k(m,n)) + \varepsilon_i^k \sum_{j=1}^{N_k} c_{ij}^k x_j^k(m,n) + u_i^k(m,n) \\ &= F(x_i^k(m,n)) + Q(x_i^k(m,n))\rho_i^k + \varepsilon_i^k \sum_{j=1}^{N_k} c_{ij}^k x_j^k(m,n) + u_i^k(m,n) \end{aligned} \tag{1}$$

where m and n denote discrete space and time, respectively. ρ_i^k is parameter in spatiotemporal chaos system which is chosen as node of network and it is hypothesized as uncertain parameter in the synchronization process. $x_i^k(m,n) \in R^s$ represents state variable of chaos system and $f : R^s \to R^s$. ε_i^k is the coupling strength between nodes within kth network. c_{ij}^k expresses the matrix element of inner coupling matrix $C^k(c_{ij}^k)$ in kth network and its concrete expression depends on connection style of network, which can give the topology structure of network. $u_i^k(m,n)$ means the control input of network.

Remark 1. The inner coupling matrix $C^k(c_{ij}^k)$ in kth network not only satisfies the rules in which if there exists a connection between node i and node j in the network, then $c_{ij}^k = c_{ji}^k = 1$ $(i \neq j)$, but can also be bounded constants. And diagonal elements meet $c_{ii} = -\sum_{j=1, j\neq i}^{N} c_{ij}$.

Suppose synchronization target is

$$x_d(m, n+1) = f(x_d(m,n)) \tag{2}$$

then the error between the network and the synchronization target can be defined as

$$e_i^k(m,n) = x_i^k(m,n) - x_d(m,n) \quad (k = 1, 2, \ldots, l; i = 1, 2, \ldots, N_k) \tag{3}$$

and the error evolution equation can be further obtained as

$$\begin{aligned} e_i^k(m, n+1) &= x_i^k(m, n+1) - x_d(m, n+1) \\ &= F(x_i^k(m,n)) + Q(x_i^k(m,n))\rho_i^k + \varepsilon_i^k \sum_{j=1}^{N_k} c_{ij}^k x_j^k(m,n) + u_i^k(m,n) - f(x_d(m,n)). \end{aligned} \tag{4}$$

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