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Synchronization of multi-stochastic-link complex networks via aperiodically intermittent control with two different switched periods[☆]

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HIGHLIGHTS

- We model a general multi-stochastic-link complex networks with mixed time delays.
- Two aperiodically intermittent pinning control schemes are proposed.
- Control width and rates of control duration may be different in each switched period.
- Sufficient conditions are established based on Lyapunov stability theory.

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ABSTRACT

This paper investigates the exponential synchronization problem for a class of multi-stochastic-link complex networks via novel aperiodically intermittent control approaches with two different switched periods, i.e. the control width and rates of control duration are different in each switched period. Firstly, we consider a general multi-stochastic-link model, it means that there is more than one edge between two nodes and the links among the nodes are perturbed by stochastic noises. The delay terms comprise both discrete and distributed delays. Furthermore, the multi-stochastic-link complex networks can be thought of consisting of many stochastic sub-networks with different time delays. Two new aperiodically intermittent control schemes are developed by virtue of the Lyapunov stability theory and pinning intermittent control techniques. Several novel and useful synchronization criteria are obtained, which guarantee global exponential synchronization of multi-stochastic-link complex networks in the mean square. Finally, two numerical examples are given to illustrate the effectiveness of the proposed method.

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1. Introduction

Nowadays, complex networks may be found everywhere in daily life, many systems in science and technology can be modeled as complex networks [1,2]. Therefore, in the past few years, there has been a substantial growth of research interest in the study of complex networks in various fields, which include mathematics, biology, physics, sociology etc. [3,4]. In general, a complex network usually consists of many sets of coupled interconnected nodes, and each node is a basic unit with specific contents and exhibiting dynamical behavior. Hence, the complexity nature of complex networks raises a series of important research problems. In particular, the synchronization phenomenon in complex dynamical networks occurs when all nodes have the same dynamical behavior under local protocols between neighbors of each node, which has become a hot topic in various fields [5–8]. Based on the requirements of practical problems, many synchronization patterns have been analyzed, such as complete synchronization [9,10], cluster synchronization [11], finite-time synchronization [12], etc.; on the other hand, synchronization phenomena has attracted widely attention in many hot research fields such as secure communication [13], image processing [14], and chemical and biological systems [15]. However, to the best of our knowledge, the most of existing results about synchronization problem of complex networks are based on two assumptions: one is that the edge between two nodes is only one; other assumption is that the links between nodes are deterministic or fixed. Unfortunately, in real world, such as communication networks, social networks and transport networks, etc. are not single link complex networks but are multi-link networks [16–18]. Multi-link means that there are more than one link between two nodes and each of the link has its own property, meantime, compared with ones with single-link, networks with multi-link are of the advantages of higher communication speed, lower communication cost, etc. Therefore, the research on the synchronization of networks with multi-link has important practice value. Furthermore, due to various reasons such as sudden failures, abrupt environmental changes, sensor aging and dynamical changes of the working conditions, the connectivity may be stochastic and time-varying [19]. Obviously, deterministic single link complex networks are a special case of multi-stochastic-link complex networks. However, few researchers focus on the multi-stochastic-link complex networks, and the synchronous analysis of multi-stochastic-link complex networks cannot be dealt with along the lines of aforementioned references. Therefore, it is necessary to further research in complex dynamical networks with multi-stochastic-link.

It is well known that time delays in spreading information are ubiquitous in nature, technology, and society because of the finite speed of signal transmission over the links as well as network congestion [20,21]. The existence of time delays can make systems unstable and degrade performance [22,23]. Considerable attention has been devoted to time-varying delay systems due to their extensive application in practical problems containing circuit theory, complex dynamical networks, automatic control, etc. Generally speaking, there are two kinds of time delays: discrete time delays and distributed delays. While signal propagation is sometimes instantaneous and can be modeled with discrete delays, it may also be distributed during a certain time period so that distributed delays are incorporated into the model [24,25]. As a particular kind of time delays, the distributed delays have also received much research attention [26–28].

As is well known, in the case where the whole networks cannot synchronize by themselves, controllers should be designed and applied to force networks synchronization. Compared with continuous control strategies, discontinuous control strategies are more economical and can better simulate the real world, for example in impulsive control [29], sample-data control [30,31], edge snapping pinning control [32,33] and event-triggered scheduling algorithm [34,35]. Intermittent control is an important kind of discontinuous control in engineering fields, which has the advantage of reducing the amount of information required to be transmitted to achieve synchronization in complex networks. In this type of control strategy, each period usually contains two types of time, one being work time where the controller is activated, and the other one being rest time where the controller is off. Hence, intermittent control combined with pinning control can effectively reduce the control cost and have been extensively investigated by researchers in recent years. In [36], the author deals with the synchronization problem for a delayed complex network with hybrid-coupling via intermittent pinning control; in [37], the cluster synchronization problem of linearly coupled complex networks via aperiodically intermittent control is investigated; in [38], authors study the cluster synchronization of coupled genetic regulatory networks with time-varying delays via aperiodically adaptive intermittent control on some nodes, and two cases of delays are considered; in [39], authors investigate the exponential synchronization problem for linearly coupled networks with delay by pinning a simple aperiodically intermittent controller.

It should be noted that in traditional intermittent control schemes, each control interval includes only one switched period, and each switched period possesses the same time width [40] and same rates of control duration [41]. This may be unreasonable and unavoidably restricts its scope of practical applications. Hence, aperiodically intermittent control with two switched periods usually uses nonidentical control width and rates of control duration, it may eliminate the imposed restriction on different switched periods and gives more flexibility to the designer. Therefore, base on real application and theoretical analysis, it is necessary to consider the synchronization problem for multi-stochastic-link complex networks under aperiodically intermittent pinning control with two different switched periods. Unfortunately, to the best of our knowledge, the results about aperiodically intermittent pinning control with two switched periods for multi-stochastic-link complex networks, especially the case of completely aperiodically has not yet appeared.

Motivated by the above discussion, this paper aims to investigate the synchronization problem for a class of multi-stochastic-link complex networks via aperiodically intermittent pinning control with two different switched periods. The contribution of this paper can be summarized as follows: (1) The problem of synchronization for a class of generalized

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