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Synchronization of nonlinear singularly perturbed complex networks with uncertain inner coupling via event triggered control

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ABSTRACT

This study is concerned with the synchronization problem of nonlinear singularly perturbed complex networks with time-varying coupling delays. In an aim to shrink the treatment of network resources event triggered control strategy is proposed to achieve the synchronization criteria. By developing the novel Lyapunov–Krasovskii functional, some adequate conditions which ensure the asymptotic synchronization are obtained in the form of linear matrix inequalities. Besides that, synchronization problem of nonlinear singularly perturbed complex networks with uncertain inner coupling are also taken into account. The uncertain inner coupling is represented by making use of the interval matrix approach. Finally, simulation results are displayed to show the efficacy of the proposed theoretical results.

1. Introduction

A complex dynamical network (CDN) is a set of unified nodes, in which every node describes a fundamental unit with specific dynamics. Most of the real world systems such as telephone cell graphs, metabolic system, Internet, and disease transmission networks and so on can be specified as CDNs. Especially, the synchronization phenomena in CDNs have secured growing attention among the research community and many efficient methodologies to clarify the synchronization problem of CDNs have been developed [1–8]. For example, local exponential synchronization criteria for CDNs with time-varying delay and hybrid coupling has been addressed in [1]. Synchronization of CDNs with time-delay and discrete time information has been investigated in [2]. In [5], authors have considered the cluster synchronization problem for CDNs with distinct communities via random adaptive control.

In most existing literature, it is implicitly assumed that each node of the complex networks represents a regular system or a general non-linear system. But, in many practical applications such as electric power systems and biological systems, the dynamical system typically possesses two time-scale characteristics, namely, the ‘fast’ dynamics and the ‘slow’ dynamics, which makes the system ‘irregular’. Such systems are governed by both fast and slow dynamics, and customarily referred to as the singularly perturbed systems (SPSs). Feedback design for singularly perturbed systems (SPSs) often suffers from high

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dimensionality and ill-conditioning so that the design based on the whole system or some simplified models may result in the a closed-loop system far from its desired performances or even in unstable systems. To alleviate numerical stiffness, engineers usually separate states into two parts, and introduce a small parameter to determine the degree of separation between reduced (slow) and boundary layer (fast) models. In [9], authors took notice of the multi-time scale characteristic of power systems, and gave the time-scale separation procedure in the beginning of 1980s. In [10], authors have presented the order reduction method and reduced model of synchronous generator. The principle of the reduction of multi-time scale system and its application in alternating current or direct current (AC/DC) hybrid power systems has been shown in [11]. The corresponding analysis and design tasks for SPSs are more complicated than those for the ‘regular’ systems. Singular perturbation phenomenon is of common occurrence for systems subject to small parasitic parameters multiplied by time derivatives of certain system states. In this case, the original full system can be divided into two time-scale sub-networks, a reduced (slow) model and a boundary layer (fast) model, both of which can be further analyzed instead of the original system.

So far, the synchronization, state estimation and pinning control problems have gained an increasing research interest for various types of complex networks, where the nodes are dynamic systems subject to a variety of engineering oriented phenomena such as stochastic disturbances, incomplete measurements, parameter uncertainties and mixed (discrete and distributed) time-delays. It should be pointed out that, for certain complex networks such as power networks and neural networks, the singular perturbation phenomenon does occur on the corresponding nodes as dynamic systems. For example, in [12], a differential geometric control approach has been provided to deal with the dynamics of the nodes of a power network modelled from the singular perturbation of the power flow equations. The neural network-based control and observer design problems have been investigated in [13] for a class of singularly perturbed non-linear (SPN) systems with guaranteed H_∞ control performance. Unfortunately, despite its theoretical significance and engineering importance, the concept of singularly perturbed complex networks (SPCNs) has not attracted much research attention yet, not to mention the dynamics analysis issues on the SPCNs. Summarizing the discussions made so far, there is a practical need to introduce a new type of complex networks with singular perturbations.

In CDNs, when signals are transmitted among subsystems the propagation delays are unavoidable as a result of the finite speed of communication and limited bandwidth of the channels. Because of this cause, while designing mathematical models it is essential to think about propagation delay, which was denoted as coupling delay. Along with it should be noticed that, the coupling strength plays a positive role and at times negative role or even no effect in the network behaviors. In most of the existing literature the coupling strength is assumed to be known. By the virtue of the uncertainties appeared in network structures and coupling mechanisms it is not possible to assume the coupling strength to be precisely known. In recent times, problems with unknown coupling strength has increasing attention among the research community [14–16]. For example, H_∞ State estimation problem for complex networks with uncertain inner coupling and incomplete measurements has been discussed in [16].

Note that it is often the case that, for a complex network, all the behaviors of the dynamical nodes do not evolve synchronously. As such, it would be more interesting to study the condition that can guarantee the synchronization of all the nodes in complex networks and how to achieve synchronization for an asynchronous complex network. A natural idea is to introduce a set of controllers to adjust the behaviors of the network nodes and accordingly achieve the network synchronization. Besides with the rapid development of high-speed computers, modern control systems tend to be controlled by discrete time controllers. Time triggered controllers and event triggered controllers are the two main types of digital controllers. In the existing literature, time triggered controllers are widely investigated for the synchronization process of complex networks [17–21]. Nevertheless, the time triggered controller updating the control instants even after the goal is attained and this results control waste. In an event-triggered framework, controllers can be updated discretely, and keep constant by a zero-order-hold device if there is no event being triggered, which implies that the energy can be saved compared with the continuous updating. Furthermore, the event-triggered control is different from the traditional time-triggered control, since the main characteristic of the former scheme is that the instants for updating controllers are determined by the given event-triggered condition rather than timing equipment. Consequently, if there is little fluctuation of the controller between two successive instants, then unnecessary updating can be avoided in the event triggered strategy. In an aim to save the network resources the new control technique namely event-triggered control has been introduced and some remarkable results are available in the literature, see [22–28]. Event triggered synchronization problem for CDNs with the Markovian switching topologies has been investigated in [22]. Authors in [27], have been addressed the event-triggered networked control problem for discrete-time nonlinear singular systems. In [28], synchronization criteria for complex networks with uncertain inner coupling has been explained by making use of the event-triggered control strategy. However, as far as authors knowledge yet there has been no result announced in the literature that deals with the synchronization of SPCNs with event-triggered control strategy.

Inspired by the above revealed discussions, in this paper we have studied the synchronization problem of nonlinear SPCNs with coupling delays through event triggered control strategy. The main contribution of the work is described as follows:

- Different from the existing works, we deal with the synchronization control problem for SPCNs with coupling delays. In order to save the network resources, the event-triggered control is applied for the first time to SPCNs.