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Time-controllable combinatorial inner synchronization and outer synchronization of anti-star networks and its application in secure communication

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ABSTRACT

In this paper, a time-controllable combinatorial inner synchronization and outer synchronization of anti-star networks, each of which consists of four-wing hyper-chaotic system as node dynamics, is investigated. Based on the adaptive technique and the stability of Lyapunov function, some sufficient conditions, which can ensure the realization of not only combinatorial inner synchronization within an anti-star network with unknown parameters and external perturbations in the computable time, but also combinatorial outer synchronization between different sub-networks with external perturbations in the computable time, are obtained. Moreover, a simple secure communication scheme, which is based on the adaptive combinatorial outer synchronization between different sub-networks under the influence of stochastic noise and time-delay, is presented. Numerical simulation results show the feasibility and validity of the proposed method.

1. Introduction

Chaos is a very interesting nonlinear phenomenon and it has been widely studied in the past three decades. Since the concept for constructing synchronization of coupled chaotic systems was proposed by Pecora and Carroll in 1990 [1], the control and synchronization problems of chaotic systems have been intensively investigated due to their potential applications in various fields such as in secure communication, chemical reactions, biological systems and many other fields. Up to now, various types of control method such as active control [2], adaptive control [3], sliding mode control [4], back-stepping control [5], linear and nonlinear feedback control [6,7], impulse control [8], pinning control [9], etc. have been successfully used in the complete synchronization [10], phase synchronization [11], lag synchronization [12], generalized synchronization [13], projective synchronization [14], modified projective synchronization [15], Q–S synchronization [16], novel compound synchronization [17] and so on. However, most of the aforementioned works have focused on the synchronization of the one-to-one system, which limits the application range of synchronization in the reality to some extent. As the fact that the complex dynamical networks including neural networks, power grids, food webs, ecosystems, the World Wide Webs, etc. are ubiquitous in our daily lives, it seems that the study of the dynamical structure and the synchronization of complex networks may have great value to understand the functions of the real-world. In this regard, at present, more and more researchers begin to draw their attention to the synchronization of large and complex network with multiple nodes. Considering the complexity of the network structure, the synchronization of networks is still an open and challenging problem. In

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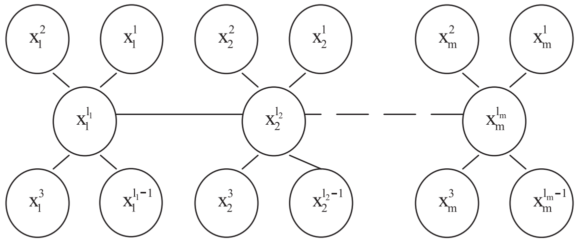

Fig. 1. The network structure diagram with m anti-star sub-networks.

general, the synchronization of networks can be roughly divided into two kinds: inner synchronization and outer synchronization. In the past decade, the majority of works in synchronization of the network has focused on the inner synchronization, which is concerned with the synchronization among the nodes within a network [18–20]. While in the real world, there are a variety of complex networks with the same or different topological structure, most of them need to realize the synchronization and control between different networks namely outer synchronization. Recently, Wu et al. have investigated the outer synchronization between drive-response networks with non-identical topological structure and unknown parameters [21]. In [22], the outer synchronization of uncertain complex delayed networks with adaptive coupling method has been studied. The generalized outer synchronization between two different delay-coupled complex dynamical networks with noise perturbation has been investigated in [23]. Moreover, the finite-time control techniques which have been demonstrated with better disturbance rejection and robustness against uncertainties [24], have become a research hotspot for its practical application value in engineering. In [25], He et al. have investigated the problem of finite-time mixed outer synchronization of complex networks with coupling time-varying delay, some novel stability criteria for the synchronization between drive and response complex networks with coupling time-varying delay are derived by using the Lyapunov stability theory and linear matrix inequalities. Sun et al. have proposed a finite-time stochastic outer synchronization between two different complex dynamical networks with noise perturbation based on the finite-time stability theory of stochastic differential equations [26]. In [27], a finite-time synchronization between two complex networks with non-delayed and delayed coupling has been proposed by using the impulsive control and the periodically intermittent control. However, most of the above works on the outer synchronization are limited to only two networks, and there are some difficulties to extend these methods to the synchronization between the three or more ones. As in the reality, there are still three or more sub-networks that need to synchronize with each other, such as in the secure communication, to improve the security level of the transmitted signal, the transmitted signal may be split into several parts, each part is loaded in different sub-networks respectively, these sub-networks need to achieve the recovery of the information signal in a synchronous way. Therefore, it has become more and more important and meaningful if we can put forward a more general method to deal with the synchronization of multiple sub-networks.

On the other hand, due to the fact that the chaotic system offers some advantages in communication systems such as broadband noise-like waveform, prediction difficulty, etc., the synchronization of chaotic systems as an effective encryption mechanism has been widely used in the secure communication, and the level of security is mostly dependent on the complexity level of the drive's dynamics and the formation of the driving signal as well as the modulation scheme used [28]. In the traditional chaotic secure communication scheme, the information signal to be transmitted is added to only one chaotic system, which has proved to be obtained easily by the attackers [29]. In order to improve the security level of the transmitter signal, similar to the serial packet transport, we can split the original signal into several parts, each part with different weighting is loaded in different complex dynamical systems with very complex dynamic behavior, such as hyper-chaotic systems. Knowing the weightings as secret keys, the receiver will recover the information signal accurately if all parts from different sub-networks arrive at the destination in the synchronous way. It is qualitative to say that the method may have much stronger anti-attack and anti-translated capability than the traditional transmission mode [28]. Furthermore, due to the finite information transmission and processing speed among the network nodes, the transmitted signal is still inevitably influenced by all kinds of random factors such as channel noise, time-delay, etc. Effectively reflecting these stochastic factors can help us recognize the real world more reasonably, therefore, it has more practical value to study the chaos synchronization of stochastic system.

In addition, how to realize the synchronization of large scale complex networks with only fewer controllers is extremely challenging and far-reaching significance. The star topological structure which is known for its simple structure has been studied in the synchronization of complex network [30–32], but it needs too many controllers in realizing the inner synchronization and the outer synchronization of complex networks. How to reduce the number of controllers for the synchronization of complex networks seems particularly important. The pinning control technique can yet be regarded as a kind of good way to decrease the number of controllers. Thus, a natural question may arise: can we propose a simple topological structure by making full use of the superiority of the star topological structure and pinning control scheme to reduce the number of controllers for the synchronization of large scale complex networks? If this is possible, the method will realize the synchronization of the nodes within a network or from different ones with only fewer controllers. We may as well name