

Delay effects on synchronization in networks of dynamical systems

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Synchronization is a fundamental nonlinear phenomenon observed in diverse natural systems. The underlying phenomenon is universal and can be understood within a common framework based on modern nonlinear dynamics. Investigations on synchronization of chaos have become an active area of research not only from theoretical perspectives but also in view of its potential applications in diverse areas of science and technology. Soon after understanding the concept of synchronization in two coupled chaotic systems, a flurry of research activities was provoked in understanding this phenomenon as an emergent behavior of an ensemble of dynamical systems with different topologies.

Deducing the conditions for stable synchronization is an important issue in the synchronization studies for its applications. In this regard, the framework of the master stability formalism has been largely employed in analyzing the stability of networks, which allows one to separate the local dynamics of the individual oscillators from the coupling matrix characterizing the topology of the underlying network. Similarly, time-delay is ubiquitous in many physical systems and investigations on the influence of connection delays in networks of nonlinear dynamical systems have been an active area of research in the domain of synchronization studies in recent times. Now, it has been understood the connection delays can actually be conducive to synchronization, so that it is possible for the delayed system to synchronize where the undelayed system does not.

In this thesis, we will explore the effect of delay coupling on networks of chaotic dynamical systems using the framework of master stability formalism. We will investigate the phenomenon of delay-enhanced and delay-induced stable synchronization in an arbitrary delay coupled network of time-continuous dynamical systems. We will demonstrate that there always exists an extended regime of stable synchronous state as a function of coupling strength for appropriate coupling delays, which cannot be observed without any delay in the coupling.

We will also propose a partial delay coupling as a combination of both the instantaneous and the completely delay coupling with certain weights determining their contributions. We will show that the partial delay coupling outperforms both limiting cases of the instantaneous and the completely delay coupling on the synchronizability of networks. The framework of master stability formalism is extended to a network of intrinsic time-delay systems, whose node dynamics are described by delay differential equations, for the first time in the literature and illustrated the generic behavior of the master stability function in networks of scalar time-delay systems based on the synchronization properties of the network. We also investigate the interplay of noise and delay in the phenomenon of noise-enhanced phase synchronization in both unidirectionally and bidirectionally coupled time-delay systems.