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CONTROLLING PARTIAL SYNCHRONIZATION PATTERNS: CHIMERA STATES

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Abstract

Synchronization phenomena in nonlinear dynamical networks [Haken, 1983; Pikovsky et al., 2001; Boccaletti et al., 2002; Mosekilde et al., 2002; Balanov et al., 2009; Schöll et al., 2016] are of great importance in many areas ranging from physics and chemistry to biology, neuroscience, socio-economic systems, and engineering. Chaos synchronization of lasers, for instance, may lead to new secure communication schemes. The synchronization of neurons is believed to play a crucial role in the brain under normal conditions, for instance in the context of cognition, learning, and sleep, and under pathological conditions such as epilepsies and tremor. Synchronization of power grids is essential for their operation.

Recent interest has focussed on more complex partial synchronization patterns like chimera states [Kuramoto and Battogtokh, 2002; Abrams and Strogatz, 2004], i.e., symmetry-breaking states of partially coherent and partially incoherent behavior, for recent reviews see [Panaggio and Abrams, 2015; Schöll, 2016]. Chimera states are intriguing spatio-temporal patterns made up of spatially separated domains of synchronized (spatially coherent) and desynchronized (spatially incoherent) behavior, although they arise in networks of completely identical units. In Greek mythology, the chimera is a fire-breathing monster composed of incongruous parts, i.e., a lion's, a goat's, and a snake's head. In real-world systems chimera states might play a role, e.g., in the unihemispheric sleep of birds and dolphins [Rattenborg et al., 2000; Rattenborg et al., 2016] or humans [Tamaki et al., 2016], in epileptic seizures [Rothkegel and Lehnertz, 2014; Andrzejak et al., 2016], in power grid blackouts [Motter et al., 2013], or in social networks [Gonzalez-Avella et al., 2014].

We show that a plethora of chimera patterns arise if one goes beyond the Kuramoto phase oscillator model, and considers coupled phase and amplitude dynamics, and more complex topologies than a simple one-dimensional ring network. For the FitzHugh-Nagumo system [Omelchenko et al., 2013; Omelchenko et al., 2015a; Isele et al., 2016; Semenova et al., 2016; Zakharova et al., 2017], the Van der Pol oscillator [Omelchenko et al., 2015b; Ulonska et al., 2016; Sawicki et al., 2017], and the Stuart-Landau oscillator with symmetry-breaking coupling [Zakharova et al., 2014; Zakharova et al., 2016; Schneider et al., 2015; Loos et al., 2016; Tumash et al., 2017; Gjurchinovski et al., 2017; Kalle et al., 2017] various multi-chimera patterns including amplitude chimeras and chimera death occur. It has been shown that the chimera lifetime [Sieber et al., 2014] as well as the chimera position [Bick and Martens, 2015] can be efficiently controlled by a feedback loop combining symmetric and asymmetric contributions from the coupling [Omelchenko et al., 2016]. We review the control of chimera patterns by a subtle interplay of dynamics, topology, feedback, and delay.

Key words

Synchronization, Networks, Chimera states, FitzHugh-Nagumo system, Van der Pol oscillator, Stuart-Landau oscillator

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