Excitation-Inhibition-based oscillations: from sparse synchrony to quasiperiodic partial synchrony in networks of pulse-coupled phase oscillators

Pau Pomés, Ernest Montbrió

Neuronal Dynamics Group, Department of Information and Communication Technologies, Universitat Pompeu Fabra, 08018 Barcelona, Spain

Networks of interacting excitatory (E) and inhibitory (I) neurons are known to robustly generate high-frequency oscillations (>40 Hz). Additionally, in vivo and in vitro studies indicate that during episodes of E-I-based oscillations, the spiking activity of individual E pyramidal cells is highly irregular and significantly slower than the global oscillation frequency, although their contribution is essential to sustain the fast network oscillation. Analytical and computational studies have revealed that these synchronous states, also referred to as "sparse synchronization", robustly arise in spiking neuron networks with sparse connectivity, stochastic inputs, and strong inhibitory coupling. In contrast, smaller amounts of noise disrupt the oscillation and synchronize neurons in a number of clusters, suggesting that this state can only be studied in neuronal networks with a restricted set of parameters. Here we implement a simple, pulse-coupled, phase oscillator model that generalizes the oscillatory properties (more specifically, the Phase Response Curve) of Quadratic Integrate and Fire (QIF) neurons. Such model readily displays sparse synchronization in conditions of strong noise and sparse network connectivity. However, as the amount of noise is decreased, the system does not fall into the cluster states described by previous work, but it smoothly transitions into a fully deterministic partially synchronous state where E neurons still fire at a slower frequency than the global oscillation, but they do so in a regular quasiperiodic manner. We use the so-called Ott-Antonsen theory to provide the full dynamical picture of these novel Quasiperiodic Partially Synchronized (QPS) states and show how, as stochastic inputs are gradually introduced, they continuously become the so-called sparsely synchronized states. In summary, our results offer a novel theoretical perspective on the origin, nature and properties of sparsely synchronized states.