A delicate balance: New study shows how networks keep themselves in synch

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(PhysOrg.com) -- Synchronization is all around us. Think of fireflies flashing together, crickets chirping in unison, neurons firing together and power plants generating electrical currents with the exact same frequency all across the power grid.

These important collective behaviors happen spontaneously in both natural and engineered networks composed of a large number of interacting parts, but how?

Two Northwestern University researchers examined how a network's structure governs its synchronization and found that different factors interact antagonistically for a network to optimize, or efficiently perform, its task. For example, using a smaller number of interactions, or even negative interactions, can -- contrary to expectations -- improve synchronization. They also discovered that very similar networks can behave very differently.

The findings, which are published by the journal Proceedings of the National Academy of Sciences (*PNAS*), contribute a new understanding of the interplay between the parts of networks and their synchronization.

The general mathematical framework developed by the researchers is very flexible and can be applied to a large variety of network systems, ranging from those with a few nodes to networks with millions of nodes of various types.

"The network we are very interested in is the power grid, especially considering the ongoing efforts to develop a Smart Grid," said Adilson E. Motter, an author of the paper and an assistant professor of physics and astronomy at the Weinberg College of Arts and Sciences. "A Smart Grid not only will increase harnessing of intermittent sources such as solar and wind but also may allow real-time pricing and give customers the option to choose their power supplier."

"While it can be argued that a new system will undergo new perturbations, it also offers the possibility of exploiting the network structure to prevent or recover from failures in real time, thus adding a new dimension to the concept of smart network," Motter said. "We want to know how such a system can be kept stable, and our research is helping us understand what parameters affect the stability of synchronous states."

Motter also is an assistant professor of engineering sciences and applied mathematics at the McCormick School of Engineering and Applied Science and a member of the executive committee of the Northwestern Institute on Complex Systems (NICO). He conducted the research with colleague Takashi Nishikawa, a sabbatical visitor from Clarkson University.

The results of the study are:

- Synchronization often can be enhanced not by reducing the size of the network or making it more densely connected, but instead by increasing the number of parts to synchronize and reducing the number of interactions between them. For example, even if it is not possible to synchronize 1,000 nodes it may be possible to synchronize 2,000 of them.

"A network out of synch also may be made to synchronize by taking out, or obstructing, some of the interactions," Nishikawa said. "This illustrates that ‘less can be more' in synchronization phenomena."

- Contrary to the prevailing paradigm, network structures that in isolation would inhibit synchronization can, in fact, facilitate synchronization when in the presence of other synchronization-inhibiting structures. For example, negative interactions cause the nodes to distance their activities from each other, thus inhibiting synchronization. But when the entire network is taken into account, negative interactions can cancel the effect of heterogeneities in the network and lead to synchronous behavior that would not be possible without them.

- The researchers identified for the first time the networks that can most easily lead to synchronous activity and found, surprisingly, that very similar networks can behave very differently. For example, sets of networks with only slightly different sizes or differing by only one or a few interactions can include very good and very bad "synchronizers."

"This sensitive dependence on the network structure is the network analogue of chaos," Motter said. "Small perturbations in the network can have far-reaching and counterintuitive consequences for synchronization." The fall of a tree on a power line in Canada could set off a blackout in Florida, but the twist is that it also may prevent one, he says.

Motter and Nishikawa's research opens up new possibilities on how to develop controllers for engineered systems. Consumers' daily needs depend on tightly controlled systems. In the power grid in the eastern U.S., for example, nearly 4,000 power generators must oscillate "up and down" in synch more than five million times a day to keep houses lighted.

More information: The paper is titled "Network Synchronization

Landscape Reveals Compensatory Structures, Quantization, and the Positive Effect of Negative Interactions." The full article is available on PNAS' website at www.pnas.org/ .

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