Adaptive control of self-organized synchronization in wireless sensor networks

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Along with the development of wireless communication technology, now wireless sensor networks (WSNs) are actively developed for practical deployment. WSNs consist of many small sensor devices which communicate with each other through wireless signals to collect sensing data. In WSNs, synchronization and scheduling are essential for analysis of data, duty cycling, and collision avoidance. To cope with instability and unreliability of wireless communication, self-organized synchronization and scheduling mechanisms using a pulse-coupled oscillator model (PCO) [1] are proposed in literature [2][3]. PCO is a mathematical model of biological synchronization observed in, for example, a group of flashing fireflies. In PCO, each oscillator has a timer which counts up from 0 to 1. When a timer reaches 1, an oscillator fires and a timer is initialized to 0. A firing oscillator stimulates coupled oscillators and advances their timers by a small amount. An oscillator whose timer reaches 1 by stimulus also fires. Although each oscillator only repeatedly flashes based on its timer, they eventually become synchronized through mutual stimulation and begin flash at the same time and the same frequency. In general, the flashing frequency of a group of oscillator is identical to the minimum intrinsic frequency of their timers. In PCO-based scheduling mechanisms, a sensor node and broadcasting correspond to an oscillator and flashing, respectively.

In this abstract, assuming PCO-based scheduling is adopted, we propose a mechanism to adjust the operational frequency of a WSN to the desired one by taking control over a single node. In realistic WSNs, it is required to control the operational frequency to wake up, sense, communicate, and sleep in accordance with changes in condition of targets and purposes of monitoring. For example, in environmental monitoring, the operational frequency should be low enough to save energy in normal operation. However, once an unusual event occurs, more frequent sensing and data gathering are required. Instead of introducing a deterministic and complicated adaptation algorithm to nodes or forcing all nodes to change their operational frequencies, we take a more moderate approach. We select a single node in a WSN and change its timer frequency to the target. Or, in case it is not possible to manipulate an operating node, we add a node whose timer is set at the target frequency to a WSN to stimulate the selected node. Then, all nodes become synchronized to the target frequency through mutual interaction.

In our approach, selection of a node to control, called control node, is apparently crucial to accomplish a desired result. To identify characteristics of an appropriate control node, we define eight indexes and evaluate their effectiveness from viewpoints of probability of synchronization and time to synchronize. Among eight, six indexes are taken from the field of network science. We consider to select a control node having the maximum or minimum centrality measures, i.e. degree centrality, closeness centrality, and betweenness centrality. It is well known that a node with high centrality plays a important role in information dissemination and influences other nodes [4]. Although such selection results in effective control, a high-centrality node is exposed to influence of many other nodes at the same time. Another index is taken from control theory, that is, controllability. In control theory, a system is called controllable if its internal state can be changed from an arbitrary initial state to a desired state by adding appropriate input to one or more system components called driver nodes [5]. Based on this theory, we consider to select a driver node as a control node. The last index is random selection, used as a benchmark.

We conducted simulation experiments using various parameters such as the number of nodes, PCO parameters, and topology. We revealed that selecting a node with the minimum centrality contributes to faster convergence with higher probability. It is because a control node with high centrality is easily affected by neighbor nodes and cannot maintain its operational frequency. Among centrality indexes, using the minimum degree centrality accomplishes faster and more reliable control than the others, but difference is not significant. In PCO-based self-organized synchronization, nodes are equivalent and there is no domination. Therefore, obtained results indicate that it is more important to reduce influence from other nodes than to increase influence to other nodes in order to control self-organization of homogeneous entities.

References

[1] R.E. Mirollo and S.H. Strogatz, “Synchronization of pulse-coupled biological oscillators,” SIAM Journal on Applied Mathematics, vol.50, no.6, pp.1645–1662, Nov. 1990.
[2] Y. Taniguchi, G. Hasegawa, and H. Nakano, “Self-organizing transmission scheduling mechanisms using a pulse-coupled oscillator model for wireless sensor networks,” In Proceedings of 2012 Second International Conference on Digital Information Processing and Communications, pp.84–89, July 2012.
[3] A. Tyrrell, G. Auer, and C. Bettstetter, “Fireflies as role models for synchronization in ad hoc networks,” In Proceedings of 2006 First Bio-Inspired Models of Network, Information and Computing Systems, pp.1–7, Dec. 2006.
[4] M.J. Newman, “A measure of betweenness centrality based on random walks,” Social Networks, vol.27, no.1, pp.39–54, Sept. 2005.
[5] Y.Y. Liu, J.J. Slotine, and A.L. Barabási, “Controllability of complex networks,” Nature, vol.473, no.7346, pp.167–173, May 2011.