Pulse-Coupled Oscillator Desynchronization (PCO-D) Based Resource Allocation for Multi-hop Networks

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Abstract. In recent years, because of the increasing number of network nodes and the rapidly changing network environment, several studies have attempted to extend biologically inspired algorithms to distributed resource-allocation schemes. In this paper, we present an algorithm representative of the class of bio-inspired resource allocation algorithm and propose a new distributed resource-allocation algorithm for fair sharing in multi-hop networks. Through simulation, we show that the proposed algorithm works well in a multi-hop network environment, with all nodes in the multi-hop network evenly sharing resources with their two-hop neighbors in a non-overlapping way.

Keywords: Bio-inspired · Multi-hop network · Pulse-coupled oscillator desynchronization · Distributed · Resource allocation

1 Introduction

In multi-hop network environments, nodes are needed to access the communication medium in a distributed way for stable, fair and efficient resource allocation. A number of studies have been conducted with the goal of applying biologically-inspired (bio-inspired) algorithms to a various resource allocation problems. Bio-inspired algorithms are modeled on the simple and distributed heuristic behavior of organisms on Earth without the aid of a central coordinator. Previous researches attempt at developing bio-inspired algorithms have shown that these algorithms have excellent characteristics such as convergence, scalability, adaptability, and stability [1]. A resource allocation algorithm based on bio-inspired algorithms can therefore be expected to be able to cope with multi-hop networks.

The PCO based desynchronization algorithm (PCO-D), that is proposed by Pagliari et al. in 2010 [2], is a representative of the class of bio-inspired resource allocation algorithms. PCO-D comprises elements that, when interconnected, pulse in sequential order, with constant intervals between each other; the interconnected oscillators are thus evenly spaced around a phase ring. Let us assume that, in a set of N nodes, each node pulses with period of T. Let $\phi_i(t) \in [0, 1]$ denote the phase of node i at time t, where phases 0 and 1 are identical and $0 \leq i \leq N - 1$. Upon reaching $\phi_i(t) = 1$, node i "pulses" to indicate the termination of its cycle to the other nodes. Upon pulsing, the

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node resets its phase to $\phi_i(t^+) = 0$. In the PCO-D, as show in Fig. 1(a), when node i pulses, node j whose phase is located within the range moves towards its desired phase position $1 - 1/N$ as follows:

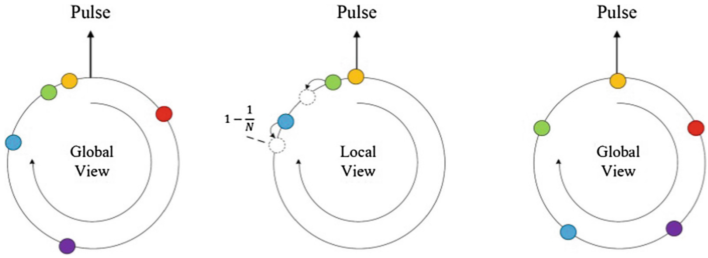

Fig. 1. Concept of PCO-Desynchronization.

$$\phi_j(t_i^+) = (1-\alpha)\phi_j(t_i) + \alpha\left(1 - \frac{1}{N}\right) \tag{1}$$

where $\alpha \in [0, 1]$ is a scaling parameter that determines how much the phase of node j moves from its current value toward $1 - 1/N$.

All the nodes observe their neighbor's pulsing phases, and use this information to change their phase according to (1). Therefore, all the oscillators are evenly spaced around the phase ring, as shown in Fig. 1(b). Node i occupies the time division multiple access (TDMA) slots beginning at its pulsing phase, and ending at its next-phase neighbor j pulsing phase. In this way, all the nodes occupy non-overlapping time slots, covering T evenly.

2 Design of a Multi-hop Pulse-Coupled Oscillator Based Desynchronization (MH-PCO-D)

We propose the MH-PCO-D algorithm to allocate resources fairly between two-hop neighbors contending for medium access. Let N_2^j be the number of two-hop neighbors of node j. In the proposed MH-PCO-D, and as shown in Fig. 2, when node i pulses, node j, the node with the highest phase among its two-hop neighbor nodes, moves toward its desired phase position, as follows:

$$\phi_j(t_i^+) = (1-\alpha)\phi_j(t_i) + \alpha\left(1 - \frac{1}{N_2^j}\right) \tag{2}$$

where $\alpha \in [0, 1]$ is a scaling parameter that determines how much the phase of node j moves from its current value toward $1 - 1/N_2^j$.

Node j occupies the TDMA slots beginning at the pulsing phase of its previous-phase neighbor i, and ending at its own pulsing phase.

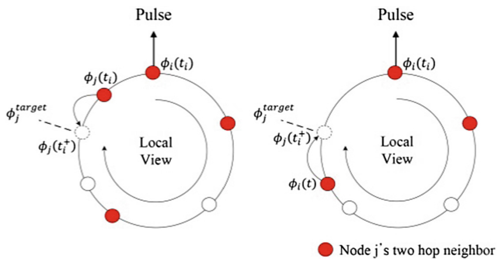

Fig. 2. Concept of MH-PCO-Desynchronization.

3 Simulation Results

To evaluate the performance of the proposed MH-PCO-D algorithm in multi-hop networks, a linear topology is used, as shown in Fig. 3. The period T is set to 1, and the scale parameter α is set to 0.5. We assume that all nodes observe their two-hop neighbor's pulsing phase, and use this information to change its phase forwards or backwards, according to (2).

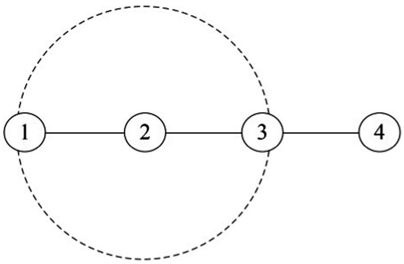

Fig. 3. A linear topology

Simulation results show that in this multi-hop environment there are two different desynchronized configurations, reachable from the various initial pulsing phase configurations, as shown in Fig. 4(a), (b). We define "node pair" as being a set of two nodes separated by more than two hops. In a multi-hop environment, two nodes forming a node pair (e.g., (1, 4) in our case) are not affected by the pulsing phases of each other. Thus, if the initial pulsing phases of two nodes are adjacent, the two pulsing phases will be coupled as in an oscillator, as shown in Fig. 4(b).

Figure 4(a) and (b) shows the pulsing phase of each node as the round progresses, when no node pair (a node pair) exist. Because the amount of requested resources exceeds (no exceeds) the amount of resources occupied by the nodes, when node i pulses, the phase of node j moves away from (toward to) the phase of node i according to (3), for all nodes i and j. As a result, the pulsing phase of each node does not converge. All the nodes will therefore occupy non-overlapping time slots that cover T, but not evenly at every round.

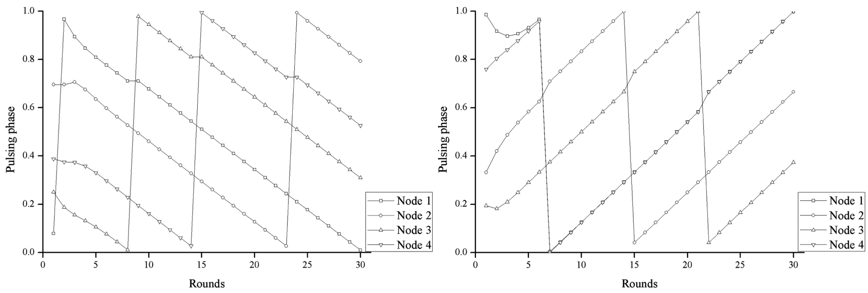

Fig. 4. Two desynchronization configurations

4 Conclusions

In this paper, we proposed the MH-PCO-D algorithm capable of solving the allocation problem in multi-hop networks, without collisions. Through simulation, we confirmed that, with this algorithm, all the nodes in a linear topology will occupy non-overlapping TDMA slots, even though not evenly. The results of our study will contribute to motivate research on distributed fair resource allocation algorithm in multi-hop network environments.

References

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