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An efficient scheduling method based on pulse-coupled oscillator model for heterogeneous large-scale wireless sensor networks

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Abstract

Wireless sensor networks (WSNs) have been common networking technologies for data gathering applications. In order to collect necessary data effectively, such applications require large-scale WSNs many sensor nodes are deployed widely. As its solution, IEEE 802.11ah is promising. However, it operates at sub 1 GHz band that is license-free, which may result in that different service providers deploy WSNs for different purposes. This incurs serious collisions due to hidden nodes. Unfortunately, they often refuse cooperation among the others due to their service policies. Therefore, self-organized scheduling methods are needed without proactive cooperation. To this end, in this paper, we propose a self-organized scheduling method for large-scale WSNs, which is based on the pulse-coupled oscillator model. To avoid collisions effectively, the proposed method utilizes a phase response function that has attractors corresponding to time slots and a random mechanism for slot selection. Through simulation-based evaluation, we demonstrate that the proposed method can collect about 90% of data in a situation sensor nodes have different cycles of data gathering while achieving a reasonable convergence time. We also show its good flexibility for environmental changes.

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Keywords: biologically-inspired approach; pulse-coupled oscillators; phase response function; scheduling; wireless sensor networks

1. Introduction

Wireless sensor networks (WSNs) have been common networking technologies to realize data gathering applications including smart grid[1,2] and environmental monitoring[3,4]. One of purposes for smart grid applications is to monitor and collect real-time status of lifeline for gas, water, and electric power and so on. On the other hand, environmental monitoring applications collect environmental information and protect natural environments from negative outcomes. Such applications require large-scale WSNs many sensor nodes are deployed in wide areas in order to collect necessary information. Therefore, how to control a lot of sensor nodes and how to collect data from sensor nodes widely deployed are important issues for such applications.

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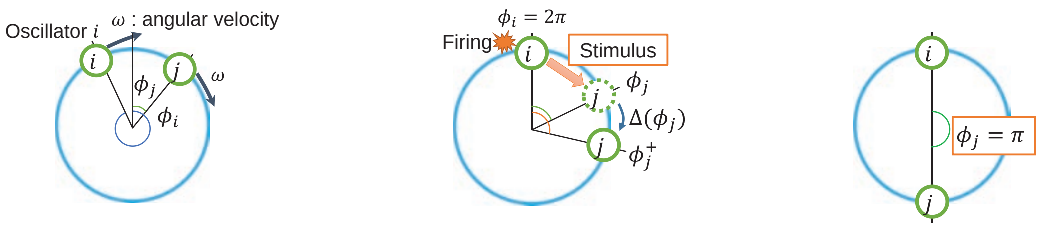

(a) Phase of oscillators i, j (b) Phase change of oscillator j (c) Phase after synchronization

Fig. 1: Behavior of PCO

As an promising solution, IEEE 802.11ah[5,6] has been defined as an IEEE 802.11-based standard for wireless sensor networks at sub 1 GHz band, which aims to handle up to 6000 nodes in a single access point or a sink node. It also provides large transmission range up to 1 km. These features enable us to handle many sensor nodes in wide areas by a sink node, which leads to reduce the deployment cost. As a result, multiple WSNs are deployed at an overlapped area and nodes coexist that belong to different WSNs in a service area. As the number of nodes increases in a service area, scheduling of transmissions of nodes becomes important due to serious interference caused by transmissions.

However, sub 1 GHz band at which IEEE 802.11ah operates is license free band. As a result, different service providers may deploy WSNs for different purposes at an overlapped area. This incurs serious collisions due to hidden nodes. Unfortunately, they often refuse cooperation among the other providers due to their service policy. Therefore, in order to achieve effective scheduling, self-organized scheduling methods without proactive cooperation are preferable.

One of approaches to achieve self-organized scheduling is biologically-inspired scheduling based on the pulse coupled oscillator (PCO) model[7]. The PCO model is a mathematical model that describes synchronization behavior such as firefly flashing, frog calling, and pacemaker cells in a heart. In the PCO model, the phase of the oscillator is shifted by stimulus from the other oscillators. The strength of stimulus is determined by the phase response function as a function of own current phase. Scheduling algorithms based on the PCO model have been proved that they achieve effective and adaptive scheduling for environmental changes such as traffic fluctuations and topology changes[8,9,10,11]. For instance, Degesys *et al.*[8] proposed DESYNC that can adjust automatically participating nodes based on behavior of the PCO model. However, DESYNC including in other methods in[9,10,11] cannot be applied to overlapped WSNs because they assume ideal situations all nodes can communicate with each other. Consequently, they significantly increase collisions, especially, in a situation the hidden node problem[12] is non-negligible, which is serious in the situation where multiple WSNs are deployed at an overlapped area and there are many nodes in a service area. Therefore, it is need to be alleviated for large-scale single-hop WSNs.

To this end, in this paper, we propose an effective scheduling algorithm for large-scale WSNs, which is based on the PCO model that introduces new phase response function. In order to address the hidden node problem, the phase response function is designed to have attractors corresponding to time slots in WSNs. The proposed method further improves the data gathering rate by stochastic slot selection mechanism after detecting data collisions. Through simulation-based evaluations, we demonstrate that the proposed method can achieve high rate of data gathering with a reasonable convergence time and it is adaptive for environmental changes in both homogeneous and heterogeneous situations.

2. Pulse-coupled oscillator model

2.1. Overview

The PCO model is a mathematical model that describes the synchronization behavior in biological systems. In the PCO model, the behavior of an oscillator is modeled by two variables: phase and stimulus. Figure 1 shows the behavior of two coupled oscillators. Let $\phi_i \in [0, 2\pi]$ denote a phase of oscillator i as a function of angular velocity ω. Phase ϕ_i grows according to ω as time passes (Fig. 1(a)). When ϕ_i reaches 2π, oscillator i fires, which is a stimulus