Demo Abstract: A Traveling Wave-based Self-Organizing Communication Mechanism for WSNs

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Abstract

We have proposed a simple and energy-efficient communication mechanism which can organize a variety of communication depending on dynamically changing application requirements. In this demonstration, we show that our mechanism can gather or diffuse information in accordance with application requirements in a dynamic wireless sensor network.

Categories and Subject Descriptors

C.2.1 [**Computer Communication Networks**]: Network Architecture and Design — Wireless Communications

General Terms

Algorithms, Design

Keywords

Wireless Sensor Networks, Traveling Wave

1 Introduction

In wireless sensor networks (WSNs), due to several restrictions including limited battery capacity, random deployment, and a large number of fragile sensor nodes, a communication mechanism should be energy efficient, adaptive, robust, fully distributed, and self-organizing. Furthermore, it should be able to handle various types of communication, i.e., diffusion and gathering, involving the whole network in accordance with application requirements. For example, a sensor node detecting an emergency would distribute the notification over the whole WSN to alert the other nodes and make them cooperatively react to the emergency. On the contrary, a sensor node detecting an uncertain condition would collect and aggregate sensor information of the other nodes to have a more precise view of the environment from collected information.

To accomplish the above-mentioned goal, we have proposed a simple and energy-efficient communication mechanism which can organize a variety of communication, i.e., diffusion and gathering, depending on dynamically changing application requirements [1]. The desired pattern of message propagation emerges through reactions of sensor nodes to surrounding conditions and local and mutual interactions among sensor nodes, that is, by self-organization. For this purpose, we adopt a pulse-coupled oscillator (PCO) model based on biological mutual synchronization such as that observed in flashing fireflies [2]. In a PCO model, oscillator i has a timer, whose phase is denoted as $\phi_i \in [0,1]$. When the phase reaches one, oscillator i fires. Oscillators coupled with the firing oscillator are stimulated and they shift their phase by small amount $\Delta(\phi_j)$, where j is an identifier of stimulated oscillator. The function $\Delta(\phi)$ is called Phase Response Curve (PRC). Through mutual interactions by stimuli among oscillators, the global synchronization where all oscillators fire synchronously, or a traveling wave, where oscillators behave synchronously keeping fixed phase difference, appears. In [1], we considered a PRC function generating a traveling wave from random initial condition to organize a preferred communication pattern on demand in WSNs.

In this demonstration, we show implementation of our traveling wave-based communication mechanism. We also demonstrate that our mechanism can gather or diffuse information in accordance with application requirements in a dynamic WSN.

2 A Traveling Wave-based Communication Mechanism

We now briefly introduce our communication mechanism for WSNs. In our mechanism, any of sensor nodes can become a point, called a core node, from which messages are disseminated or to which messages are gathered. When there is no session, sensor nodes emit messages at their own timing and independently from the others.

Sensor node i has a timer with phase $\phi_i \in [0,1]$, $d\phi_i/dt = 1/T$, where T is a cycle of data diffusion or gathering. It maintains PRC function $\Delta(\phi_i)$, level value l_i, session identifier s_i, direction δ_i, and offset τ_i ($\tau_{min} \leq \tau_i \leq \tau_{max} < 0.5$). A level value indicates the number of hops from a core node and it is used to define the relationship among sensor nodes. Direction δ_i is a parameter which controls the direction of information propagation, and it is set at 1 for diffusion and -1 for gathering. The offset defines the interval of message emission between a node of level $l-1$ and that of level l. The maximum offset τ_{max} is determined taking into account the density of sensor nodes in the whole WSN. Offset τ_i is chosen randomly to avoid synchronous message emissions among same hop sensor nodes. In this paper, we use the following PRC function for all sensor nodes.

$$\Delta(\phi_i) = a \sin \frac{\pi}{g_i} \phi_i + b(g_i - \phi_i), \qquad (1)$$

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Here, g_i is defined as $(1 + \delta_i \tau_i) \bmod 1$.

As time passes, phase ϕ_i shifts toward one and, after reaching it, sensor node i broadcasts a message and the phase jumps back to zero. A message that sensor node i emits contains level value l_i, session identifier s_i, direction δ_i, and its information aggregated with other sensor's information kept in its buffer. To initiate a new communication, a core node broadcasts a message containing a new session identifier set at the current value plus one, a level value of zero, the direction, and information to disseminate or gather.

Now, sensor node i receives a message from sensor node j. If session identifier s_j is larger than s_i, sensor node i considers that a new communication begins. Therefore, it sets its level value l_i at $l_j + 1$, session identifier s_i at s_j, and direction δ_i at δ_j. Then, it is stimulated to join a new traveling wave. This mechanism means that the current communication is terminated by a newly initiated communication. If session identifiers are the same but the level value l_j is smaller than l_i, sensor node i sets its level value l_i at $l_j + 1$, direction δ_i at δ_j, and it is stimulated. Stimulated sensor node i shifts its phase based on the PRC function. As in the PCO model, a sensor node is not stimulated by messages from sensor nodes with a smaller level value during the following duration of τ_{max} when it has already been stimulated, to avoid being stimulated by deferred messages. If the session identifier is the same and level value l_j is $l_i - \delta_i$, sensor node j is an upstream node of sensor node i. Therefore, to relay information of sensor node j to the next downstream node, sensor node i deposits the received information in its local buffer. If a message does not satisfy any of the above conditions, sensor node i ignores it.

Through mutual interactions among neighboring sensor nodes, they reach the state, called phase-lock, where the phase differences among sensor nodes are kept constant, and they emit sensor information alternately. After reaching the phase-lock, a sensor node starts a sleep schedule. It wakes up when its phase is at $1 - \tau_{max}$ to receive messages from upstream nodes. Upstream nodes are scheduled to emit their messages from $1 - \tau_{max}$ to 1. When its phase reaches one, a sensor node broadcasts a message. After that, it keeps awake for τ_{max} to receive messages from downstream nodes, and then goes to sleep. Therefore, a node is awake for the duration of $2\tau_{max}$ in one communication cycle. An example of timing of message emission where node i is a downstream node of nodes j and k is illustrated in Fig. 1.

Although further details are note given in the paper due to limitation of the space, our mechanism can adapt to additional deployment and removal of sensor nodes, multiple core nodes, and node failures [1].

3 Demonstration

We implemented our mechanism on MICAz Motes. To maintain the stable multi-hop network topology on a table, we introduce a filter with which a node ignores messages from non-neighboring nodes based on their identifiers. Each sensor node has a red LED and two push switches. The LED flashes when the sensor node broadcasts a message. A sensor node becomes a core node for information diffusion or gathering when its switch is pushed.

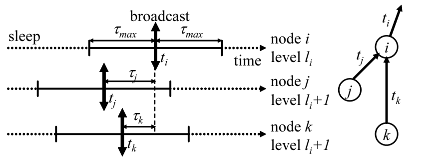

Figure 1. Timing of Message Emission

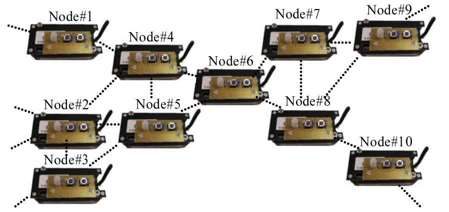

Figure 2. Prototype Network

We can choose any sensor node as a core node for information diffusion or gathering. For example, consider a WSN illustrated in Fig. 2, where dashed lines indicate neighbor relations. When node 6 becomes a core node for information diffusion, a communication pattern centered at node 6 eventually emerges. First node 6 broadcasts a message. At this time, nodes 4, 5, 7, and 8 are awake to receive the message. Then, they broadcast a message at slightly different timing based on their offset τ_i. The messages are received by their downstream nodes and then relayed further toward the edge of the WSN. If we next choose node 7 as a core node for information gathering, the previous diffusion pattern is first broken and a new pattern appears. In our preliminary experiments where 25 nodes are arranged in a grid layout, the average delivery ratio of 95% is accomplished.

The prototype can adapt to addition and removal of nodes. When node 5 is removed from gathering type of session to node 7 for example, node 3 does not receive any message of lower level value any more. Then, node 3 sets its session identifier to 0 and re-joins the session by receiving messages from remaining neighboring nodes. In this case, node 2 becomes a downstream node of node 3. Now node 5 returns. Since a level value of node 5 is 2 and that of node 2 is 3, a level value of node 3 is changed from 4 to 3. Then, the former traveling wave is established again.

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5 References

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