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A Density Control Scheme Based on Disjoint Wakeup Scheduling in Wireless Sensor Networks

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Abstract

Since sensor nodes have limited battery power, it is desirable to select a minimum set of working sensor nodes which should be involved in sensing and forwarding data to the sink. In this paper, we propose a disjoint scheduling for density control in wireless sensor network to achieve the desired robust coverage as well as satisfactory connectivity to the sink with a small set of working nodes. Simulations showed that our scheme works well in an energy efficient fashion by turning off too many redundant nodes.

Keywords: *density control, energy efficient, wireless sensor network*

1. Introduction

Advanced sensor and wireless communications technologies have enabled the development of wireless sensor networks which can be used for various applications such as earth-quake, forest fire, battlefield surveillance, machine failure diagnosis, biological detection, home security, smart spaces and inventory tracking [1, 2].

A wireless sensor network consists of various types of sensor nodes, which is capable of detecting some phenomena, and sink node. The sensor node has a variety of types of sensors, data processor and wireless communication interfaces, which enable it to gather environmental information. Also, the sensor node generates and delivers messages to sink node [3]. The sink node aggregates, analyzes received messages, decides whether there are abnormal event occurred in the monitored area. The sink node also disseminates query messages to whole sensing field or specified field to get its concerned data.

In a multi-hop ad hoc sensor network, each node plays as data originator and data router. The failure of few nodes can cause significant topological changes and might require packet re-routing and network re-organization. Hence, power management becomes more important and many researchers are currently focusing on the design of energy efficient protocols and algorithms for sensor networks.

Power consumption is not the primary consideration in case of wireless mobile networks because power resources can be recharged by the user. This network request better quality of service (QoS) than the power efficiency. However power efficiency is an important performance metric in sensor networks that directly influences the network lifetime [4-6]. Application specific protocols can be designed appropriately by trading off other performance metrics such as delay and throughput with power efficiency.

In a large-scale sensor network, we need to deploy many sensor nodes closely together in the sensing field and maintain them in a proper way. One of the most important issues in such dense sensor networks is density control [7], which keeps distribution density of the working sensors at certain level [8]. Density control schemes select a set of working nodes to satisfy

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the coverage as well as the connectivity. It can save energy by turning off redundant nodes and can prolong the system lifetime by replacing the failed nodes with some sleeping nodes.

Scheduling scheme at sensor node is a very important factor related to energy efficiency in topology control of wireless sensor networks. In this paper, we propose an energy efficient scheduling scheme to satisfy requirements for sensing coverage and network connectivity. We select a small subset of working nodes in the deployed nodes to provide full coverage and connectivity to the sink node by a hop-based disjoint wakeup scheduling.

The rest of this paper is organized as follows. In Section 2, we introduce related works such as GAF, OGDC, ASCENT and Joint Scheduling. In Section 3, we address the hop-based disjoint wakeup scheme and we evaluate the proposed algorithm through simulation in Section 4, and finally conclude this paper in Section 5.

2. Related Works

In a wireless sensor network, saving energy is a major design factor because it is difficult to recharge a battery. Many methods are proposed to minimize energy consumption and prolong the lifetime of sensor network. In this section, we give a summary of some related works.

H. Zhang and J. C. Hou focus only on the coverage problems since they prove that if the transmission radius is at least twice of the sensing radius, a complete coverage of a convex area implies connectivity among the working set of sensor nodes [8]. They propose a completely localized density control algorithm, called OGDC [8]. This algorithm selects sensor nodes, which are close to optimal locations, to be active.

Some protocols suggest scheduling scheme with accurate location information of sensor nodes. In GAF, total network is divided into a smaller virtual grid cell enough to communicate with its neighbors and one sensor node is selected as active node in a virtual grid cell [9]. This method provides full coverage and connectivity but it needs the accurate information of sensor nodes and its neighbor nodes.

OGDC proves that if transmission radius is greater than twice of sensing radius, the full coverage provides guaranteed connectivity automatically. Initially some sensor nodes are randomly waked up. Then, they choose their neighbors within a distance of $\sqrt{3}(sense\_radius)$, and the next active node are selected by the closest two nodes.

Since it is usually expensive to obtain and maintain the location information of each sensor node, some protocols do not use it. In ASCENT, sensor node decides whether or not to participate in configuration of the network topology based on some parameters such as the number of neighbors and packet loss ratio [10].

Joint scheduling offers a satisfactory coverage ratio by awaking sensor nodes at a random time slot. It wakes up at the other extra time slot which is allocated to its downstream hop neighbors to guarantee the connectivity to the sink node [8]. It was shown that this kind of random awake method is proper to solve the coverage problem [12-14]. To provide connection to the sink node certainly, every node checks if there is one more active upstream-hop nodes with the same time slot.

3. Hop-based Disjoint Wakeup Scheduling

3.1. Basic Concept

In this section, we introduce a hop-based disjoint wakeup scheduling to preserve network coverage and connectivity with a small number of sensor nodes in wireless sensor networks. In our method, we assume wireless sensor network has the following conditions;

- sensor nodes are homogeneous, energy constrained and stationary,
- sensing and radio transmission radius of a sensor node are the same,
- sensor nodes are arbitrarily located densely,
- sensor node knows its one-hop neighbor’s information using hello messages,
- sensor node does not have accurate position information, and
- sensor nodes are synchronized to the standard time.

Active sensor nodes keep to wake up continuously and relay data packet while other sensor nodes remain in power-saving mode and periodically check if they can wake up to become active. Our scheme aims at both a perfect coverage ratio and a full connectivity to the sink node with a small number of active nodes in densely deployed networks as depicted in Figure 1. To obtain a perfect coverage, a sensor node should wake up if there is no active neighbor within its transmission radius. To get a full connectivity, an active sensor node must have at least one active upstream neighbor. In our scheme, each active node selects one of its upstream neighbors when there is no active upstream neighbor (HDS-SU). This ensures that every sensor node can have at least one upstream neighbor.

neighbor node: a sensor node within its transmission radius.

upstream neighbor: a neighbor node with a smaller hop count by one than itself.

downstream neighbor: a neighbor node with a larger hop count by one than itself.

peer neighbor: a neighbor node with the same hop count.

adjacent node: a sensor node sharing its area within transmission radius.

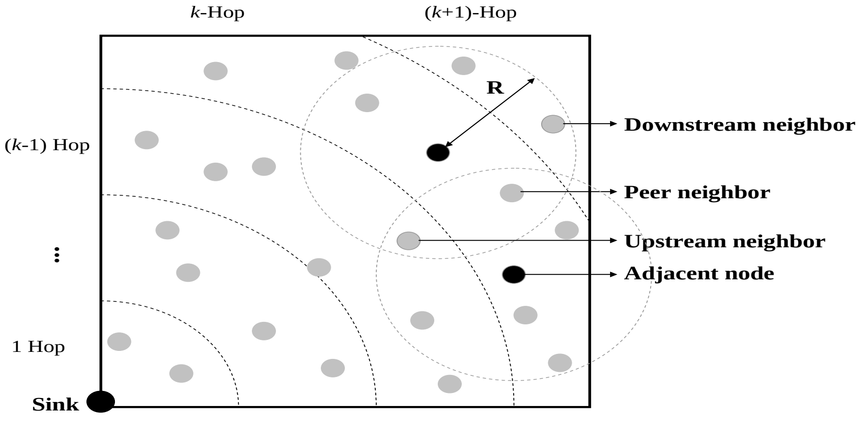


Figure 1. Types of Neighbors in Hop-based Sensor Networks

3.2. Detailed Operation

Every active sensor node periodically broadcasts a *HELLO_MSG*, by which each sensor node constructs a list of its neighbors. Based on this local information, each node determines its activation. Our scheduling scheme uses three qualifications and three announcements as follows.

> *active_qualification_1*: if none of its peer neighbors are active. If this condition is met, a sensor node should be active.
>
> *active_qualification_2*: if it receives a *SELECT_MSG*, which is sent by an active sensor node when it does not have active upstream neighbors. If this condition is met, a sensor node should be additionally active
>
> *sleep_qualification*: if one of its peer neighbors is active and it is not required as active upstream neighbor to all of its downstream neighbors. If this condition is met, a sensor node goes to sleep state.

Figure 2 shows an example, in which a sensor node satisfying *active_qualification_1* wakes up and other sensor nodes become active additionally by *active_qualification_2*.

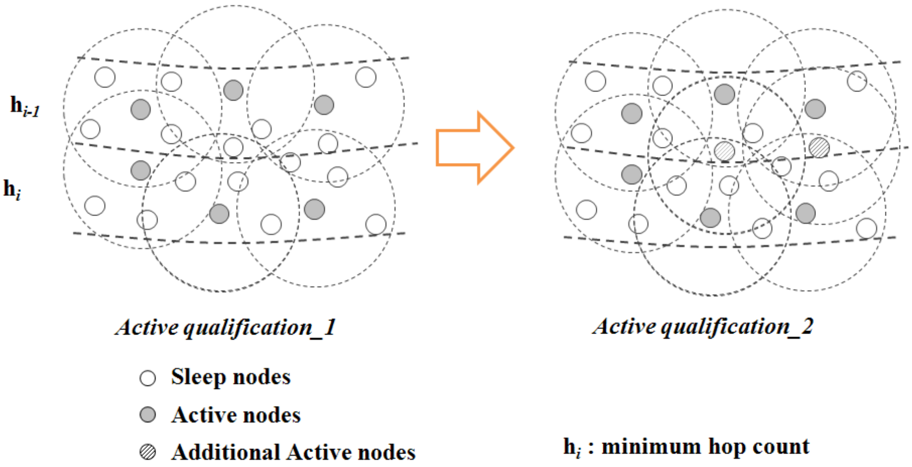


Figure 2. An Example Showing Activation of Sensor Nodes

Active Announcement_1

Periodically, a sleeping node switches its state to *LISTEN*, and it turns on its radio and checks if it should become active or not. At this time, a sensor node switches its state to *ACTIVE* if the following two conditions are met. First, a sensor node should become active if the *active_qualification_1* is satisfied. If several sensor nodes justify *active_qualification_1* at the same time, there happens an announcement contention. In this case, we resolve the contention by using a randomized back-off delay. At the end of the back-off time, it checks the *active_qualification_1* again, and it changes its state to *ACTIVE* if and only if the condition is satisfied. The back-off delay is given by

$$delay = ((1-\frac{E_r}{E_m})+(1-\frac{C_i}{N_i})+v)\times N_i \times T \qquad (1)$$

where the meaning of symbols are listed in Table 1.

Table 1. Symbols used in Calculation of the Backoff Time

Symbol	Description
N_i	the number of neighbor for sensor node i
C_i	the number of active upstream neighbors
E_m	the maximum energy available at a node
E_r	the remaining energy at a node
V	random variables uniformly selected from interval (0,1]
T	the round-trip delay over the wireless link

Second, a sensor node in *LISTEN* state switches to *ACTIVE* after t_L which means the maximum time allowed to stay at *LISTEN* state. To elect more active sensor nodes when a sensor node loses *HELLO_MSG*s, t_L is given by

$$t_L = 3 \times N_i \times T$$

which is the maximum value of back-off time determined by equation (1).

Unless a sensor node does not justify the *sleep_qualification*, it switches to *ACTIVE* state after this time period. Figure 3 shows the procedure of active announcement.

```
/* a sensor node i in LISTEN state
periodically calls this routine to see if it should
become an active node */

active_announcement(i){
IF( active_qualification(i))
wait delay
IF( active_qualification(i))
announce itself as an active node;
END IF
ELSE IF( sleep_qualification(i) )
change its state to SLEEP;
ELSE IF( active_qualification2(i))
change its state to ADDITIONAL ACTIVE
ELSE
change its state to ACTIVE;
END IF

active_qualification(i){
For each neighbor a {
IF ( a's hop count = i's hop count )
IF( a's state is ACTIVE )
    return false;
END IF
END IF  }
return true;  }

sleep_qualification(i){
IF (! active_qualification(i))
IF( downstream_check(i) )
return true;
END IF
END IF
return false; }

active_qualification2(i){
For each neighbor a {
IF (a's hop count > i's hop count )
IF ( a's active_upstream == i )
return true;
END IF
END IF  }
return false; }

downstream_check(i){
For each neighbor a {
IF ( a's hop count > i's hop count )
IF (a's state == ACTIVE && a's
active_upstream == i)
return false;
END IF
END IF  }
return true;  }
```

Figure 3. Procedure for Active Announcement

Active Announcement_2

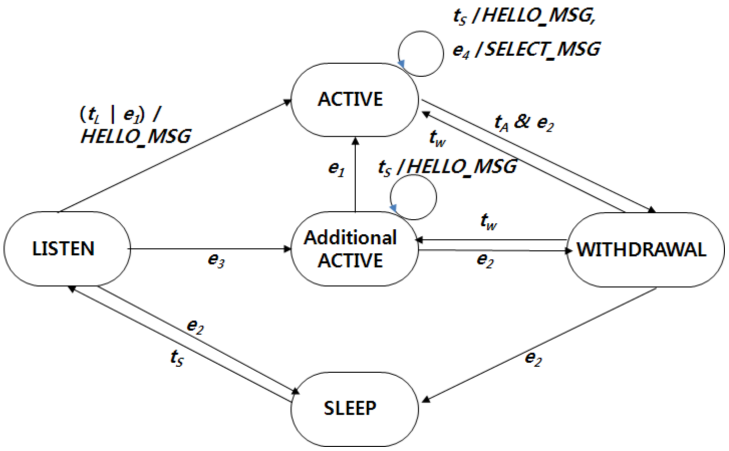
After switching to *ACTIVE* state, the sensor node checks if there are active upstream neighbors. If not, the active sensor node unicasts a *SELECT_MSG* to one of its upstream neighbors.

To select sensor nodes with much remaining energy, the sensor node stores the activation count of neighbors by *HELLO_MSG*. In *LISTEN* state, a sensor node receiving a *SELECT_MSG* switches its state to *ADDITIONAL_ACTIVE*.

If upstream neighbor fails due to some physical damage or environmental interference, the active sensor node broadcasts *HELLO_MSG* to make a peer neighbor take part as a relaying node. A peer neighbor that has active neighbors sends an *ACK_MSG*, and the active sensor node selects one of them, which has the most remaining energy, as a relaying node.

Withdrawal Announcement

To give each node a fair chance of being selected as active node, each node can stay in *ACTIVE* for a certain time period t_A at maximum. This time period t_A is determined depending on the remaining energy at each node. An active sensor node periodically checks its remaining energy, and it changes its state to *WITHDRAWAL* when its remaining energy reaches some threshold value. The withdrawing neighbor is treated as a sleeping node during the time period t_L. After t_L, the sensor node checks its *sleep_qualification* again. And, if *sleep_qualification* is satisfied, it goes to *SLEEP*. Otherwise, it changes back to its previous state. Figure 4 shows the state transition diagram for hop-based disjoint wakeup scheduling.



(a) Status transition diagram of sensor node

State	Description		
	Radio	**Communication**	**Characteristic**
LISTEN	On	Receive only	Receive broadcast msg.
ACTIVE	On	Receive/transmit	
Additional ACTIVE	On	Receive/transmit	Relaying node
WITHDRAWAL	On	Receive/transmit	For energy distribution
SLEEP	Off	X	Power saving state

(b) State table

Event	Description
e_1	is satisfied active qualification_1 after random back_off
e_2	is satisfied sleep qualification
e_3	is satisfied active qualification_2
e_4	no active upstream neighbors
t_L	the scheduled time period of *LISTEN* state
t_A	the scheduled time period of *ACTIVE* state
t_S	the scheduled time period of *SLEEP* state
t_W	the scheduled time period of *WITHDRAWAL* state

Action	Description
HELLO_MSG	Broadcast *HELLO_MSG*
SELECT_MSG	Unicast *SELECT_MSG* to a specific neighbor

(c) Event and action table

Figure 4. Status Transition Diagram of Sensor Node

4. Performance Evaluation

In this section, we report results from experiments to measure the ratio of coverage and connectivity of the network. Experiments are carried out on a simulator implemented in C/Java on the top of the 802.11 MAC ad hoc power-saving mode in SPAN [15].

4.1. Simulation Environments

To evaluate the proposed scheme, we deploy sensor nodes over a square region in a uniformly random fashion. The sink node is located at the corner of the sensing field. We assume that

- sensing field is flat region with a rectangular shape,
- each sensor node has a flat disk shape with sensing and transmission radius,
- there is a symmetric link between sensor nodes,
- the link is error free, and
- the traffic load is so light that link failure is mainly caused by network partition.

4.2. Simulation Results

The Ratio of Network Coverage

It is defined as the ratio of the area covered by active sensor nodes to the whole network area. A high ratio of network coverage means high sensing quality. We calculate the ratio of network coverage by counting the number of units detected by active sensor nodes over the total number of units within the sensing field.

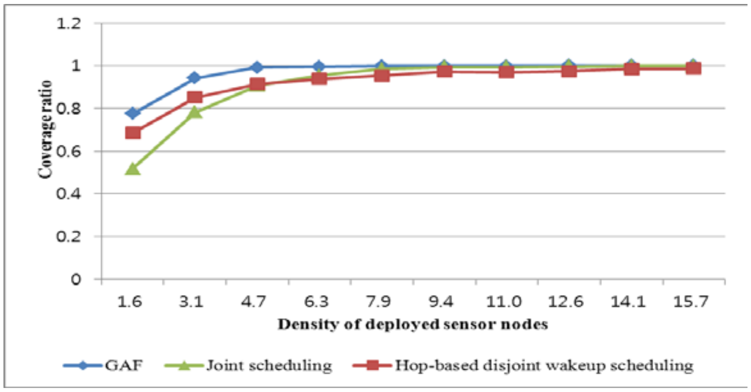
Figure 5(a) shows the coverage ratio of GAF, Joint Scheduling and HDS-SU as we vary the density of deployed nodes, denoted by

$$\rho = \frac{\#\ \text{of sensor nodes}}{\text{transmission radius}} = \frac{N * \pi * R^2}{A}$$

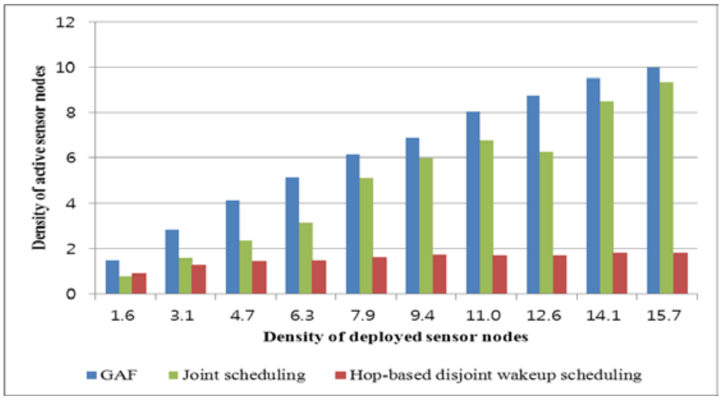
where *N*, *A*, and *R* denote the total number of deployed sensor nodes, the area of the whole sensing field, and the transmission radius of sensor node, respectively.

In Joint Scheduling, the number of random periods is critical parameter. We use a proper parameter calculated in [11].

Figure 5(a) indicates that three schemes can fully cover the whole network field when there are more than about 8 nodes deployed in the transmission range. Figure 5(b) shows that the disjoint wakeup scheduling uses a smaller number of active nodes than GAF and Joint Scheduling to obtain full coverage. This means that the disjoint wakeup scheduling offers a better coverage performance than the other two schemes with the same number of active nodes in a dense network.



(a) Coverage ratio



(b) Density of active sensor nodes

Figure 5. Coverage Ratio and Density of Active Sensor Nodes

The Ratio of Network Connectivity

It is defined as the ratio of the number of active nodes that have more than one active upstream neighbor, to the total number of active nodes. A higher ratio of network connectivity means that data can be delivered to the sink node with a higher possibility.

In Figure 6, we can see that all three schemes can guarantee connectivity in a dense network. However, GAF and Joint Scheduling produce more redundant active nodes than proposed method, as shown in Figure 5(b).

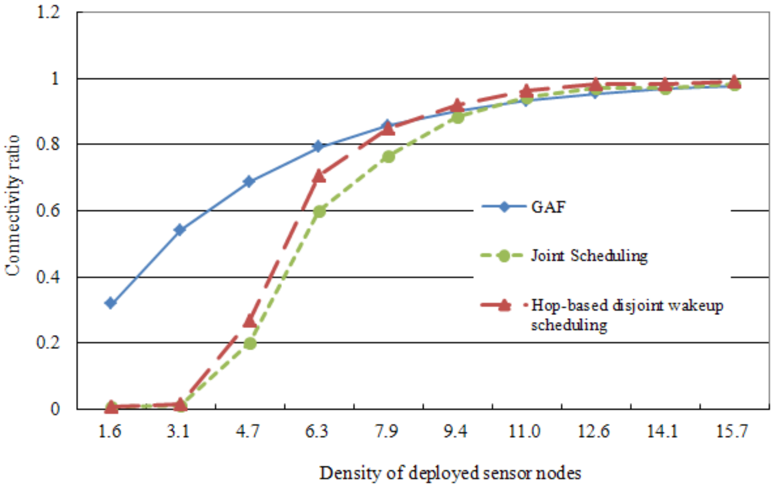


Figure 6. Ratio of Network Connectivity as the Density of Deployed Sensor Nodes

5. Conclusion

In this paper, we propose a density control scheme to avoid wasting excessive energy by turning off too many redundant nodes in wireless sensor network field. The proposed scheme can provide good network coverage and satisfactory network connectivity with a small set of active nodes by a hop-based disjoint wakeup scheduling. This scheme works in a distributed manner at each sensor node and automatically provides a routing path to the sink.

Simulation results show that the proposed scheme achieves the desired robust coverage as well as satisfactory connectivity to the sink node with a smaller number of active sensor nodes compared with GAF and Joint Scheduling. It is also shown that the proposed scheme works in a more energy-efficient fashion, so the network lifetime can be prolonged.

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