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NOVEL SLEEP SCHEDULING TO REDUCE BROADCASTING DELAY DURING CRITICAL EVENT MONITORING IN WIRELESS SENSOR NETWORKS

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ABSTRACT

In this paper, we focus on critical event monitoring in wireless sensor networks (WSNs), where only a small number of packets need to be transmitted most of the time. When a critical event occurs, an alarm message should be broadcast to the entire network as soon as possible. To prolong the network lifetime, some sleep scheduling methods are always employed in WSNs, resulting in significant broadcasting delay, especially in large scale WSNs. In this paper, we propose a novel sleep scheduling method to reduce the delay of alarm broadcasting from any sensor node in WSNs. Specifically, we design two determined traffic paths for the transmission of alarm message, and *level-by-level offset* based wake-up pattern according to the paths, respectively. When a critical event occurs, an alarm is quickly transmitted along one of the traffic paths to a center node, and then it is immediately broadcast by the center node along another path without collision. Therefore, two of the big contributions are that the broadcasting delay is independent of the density of nodes and its energy consumption is ultra low. Exactly, the upper bound of the broadcasting delay is only $3D+2L$, where D is the maximum hop of nodes to the center node, L is the length of sleeping duty cycle, and the unit is the size of time slot. Extensive simulations are conducted to evaluate these notable performances of the proposed method compared with existing works.

KEYWORDS: Broadcasting Delay, Critical Event Monitoring, Multi-Channels, Sleep Scheduling Wireless Sensor Network (WSN)

INTRODUCTION

Among wireless sensor networks applications, event monitoring is an application that has attracted a lot of attention in the recent years. As a physical event may be mobile, communication protocols should be designed to support mobility and allow the user to track the mobile event continuously, in energy-efficient way. As there may be no communication infrastructure, users are usually equipped with communicating devices to communicate with sensor nodes. When a critical event (e.g. gas leak or fire) occurs in the monitoring area and is detected by a sensor node, an alarm needs to be broadcast to the other nodes as soon as possible. Then, sensor nodes can warn users nearby to flee or take some response to the event. As sensor nodes for event monitoring are expected to work for a long time without recharging their batteries, sleep scheduling method is always used during the monitoring process. Obviously, sleep scheduling could cause transmission delay because sender nodes should wait until receiver nodes are active and ready to receive the message. The delay could be significant as the network scale increases. Therefore, a delay-efficient sleep scheduling method needs to be designed to ensure low broadcasting delay from any node in the WSN. Recently, many sleep schedules for event monitoring have been designed most of them focus on minimizing the energy consumption. Actually, in the critical event monitoring, only a small number of packets need to be transmitted during most of the time. When a critical event is detected, the alarm packet should be broadcast to the entire network as soon as possible. Therefore, broadcasting delay is an important issue for the application of the critical event monitoring.

RELATED WORK

Sleep scheduling is an usual way for power management to save energy. Recently, many sleep schedules for event monitoring have been designed [1]-[4]. However, most of them focus on minimizing the energy consumption. Actually, broadcasting delay is an important issue for the application of the critical event monitoring. To minimize the broadcasting delay, it is needed to minimize the time wasted for waiting during the broadcasting. The ideal scenario is the destination nodes wake up immediately when the source nodes obtain the broadcasting packets.

Here, the broadcasting delay is definitely minimum. Based on this idea, a level-by-level offset schedule was proposed in [5]. Hence, it is possible to achieve low transmission delay with the level-by-level offset schedule in multi-hop WSNs [6]-[9]. Energy management in sensor networks is crucial to prolong the network lifetime. Though existing sleep scheduling algorithms save energy, they lead to a large increase in end-to-end latency. A new sleep schedule (Q-MAC) for query based sensor networks that provides minimum end-to-end latency with energy efficient data transmission[10][12]. To eliminate the collision in broadcasting, a colored connected dominant set (CCDS) in the WSN via the IMC algorithm proposed in [12] is established.

Problem Description

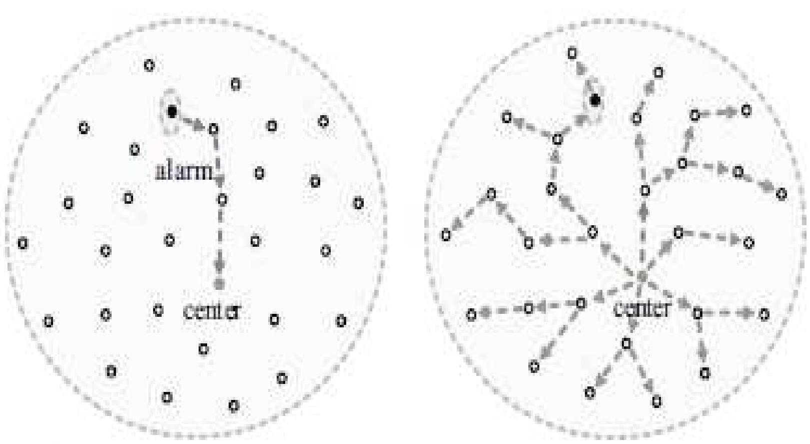
We assume that a certain node, called as center node, in the network has obtained the network topology in the initialization (e.g, sink node). The center node computes the sleep scheduling according to the proposed Scheduling scheme and broadcasts the scheduling to all the other nodes.

Event Detection: For the critical event monitoring in a WSN, sensor nodes are usually equipped with passive event detection capabilities that allow a node to detect an event even when its wireless communication module is in sleep mode. Upon the detection of an event by the sensor, the radio module of the sensor node is immediately woken up and is ready to send an alarm message.

Slot and Duty Cycle: Time is partitioned into time slots. The length of each slot is about the minimum time needed by sensor nodes to transmit or receive a packet, which is denoted as τ.

Network Topology: For the sake of simplicity, we assume the network topology is steady and denote it as a graph G.

Synchronization: Time of sensor in the proposed scheme is assumed to be locally synchronous, which can be implemented and maintained with periodical beacon broadcasting from the center node.



Phase 1: Send the alarm to center node Phase 2: Center node broadcasts the alarm

PROPOSED SCHEDULING METHOD

The proposed Algorithm is still based on the *level-by-level offset* schedule, to achieve low broadcasting delay in a large scale WSN. The proposed scheduling method includes two phases:

- Any node which detects a critical event sends an alarm packet to the center node along a predetermined path according to *level-by-level offset* schedule.
- The center node broadcasts the alarm packet to the entire network also according to *level-by-level offset* schedule.

The proposed scheduling scheme should contain two parts:

- Establish the two traffic paths in the WSN *uplink* (traffic paths from nodes to the center node) and *downlink* (traffic path from the center node to other nodes)
- Calculate the wake-up parameters (e.g., time slot and channel) for all nodes to handle all possible traffics.

To minimize the broadcast delay, we establish a *breadth first search* (BFS) tree for the uplink traffic and a *colored connected dominant set* (CCDS) for the downlink traffic, respectively. Characteristics of the proposed sleep scheduling scheme are as follows:

- The upper bound of the broadcasting delay is $3D+2L$, where D is the maximum hop of nodes to the center node, and L is the length of duty cycle, the unit is the size of time slot. As the delay is only a linear combination of hops and duty cycle, it could be very small even in large scale WSNs.
- The broadcasting delay is independent of the length of the duty cycle and density of nodes, but it increases linearly with the number of the hops.
- Energy consumption is also much lower when compared with existing system.

Traffic Paths

First of all, we choose a sensor node as the center node c. Then, we construct the BFS tree which divides all nodes into layers $H1$, $H2$, $H3$, ..., HD, where Hi is the node set ith minimum hop i to c in the WSN. With the BFS tree, the uplink paths for nodes can be easily obtained.

To establish the second traffic path, we establish the CCDS in G with three steps: 1) construct a maximum independent set (MIS) in G; 2) select *connector nodes* to form a connected dominated set (CDS), and partition *connector nodes* and *independent nodes* in each layer into 4 disjoint sets with IMC algorithm proposed in [12]; 3) color the CDS to be CCDS with no more than 12 channels. The details are described as follows, and the variables therein are defined below.

c - The center node in the networks

Hi - The nodes with minimal hop i to c in G

$H'i$ - The nodes with minimal hop i to c in CDS

Ii - The *independent nodes* with minimal hop i to c in CDS

Ci - The *connector nodes* with minimal hop i to c in CDS

Bi - The *dominated nodes* dominated by Ii

Algorithm 1 Construction of MIS

1: **Input:** BFS

2: $I \leftarrow \varphi$

3: **for** $i \leftarrow 0$ to D **do**

4: Find an MIS $I' \subset H_i$ also independent of I

5: $I \leftarrow I \cup I'$

6: **end for**

7: **return** I

Algorithm 2 Connector nodes selection

1: $C \leftarrow \varphi$

2: **for** $i \leftarrow 2$ to $D - 1$ **do**

3: $U \leftarrow I \cap H_i$

4: $W \leftarrow (H_{i-1} \cup H_{i-2}) \cap I$

5: **Input:** U and W

6: Applying IMC algotihm

7: **Output:** $U = U_{i,1} \cup U_{i,2} \cup U_{i,3} \cup U_{i,4}$

$W \supseteq W_{i-1,1} \cup W_{i-1,2} \cup W_{i-1,3} \cup W_{i-1,4}$

8: $C \leftarrow C \cup W_{i-1,1} \cup W_{i-1,2} \cup W_{i-1,3} \cup W_{i-1,4}$

9: **end for**

10: $B \leftarrow (V \setminus I) \setminus C$

11: **return** C, I, B and CDS

Algorithm 3 Colors assignment

1: **Input:** CDS

2: **Output:** CCDS

3: Divide I into I_0, I_2, I_4,….

4: Divide B into B_0, B_2, B_4,…..

5: Divide C into C_1, C_3, C_5,….

6: Coloring $G = (I, E')$ with cl_1, ….. , cl_{12}, and each node in I gets its *sending channel* according to the color

7: **for** $i \leftarrow 0$ to $2D - 1$ **do**

8: **for** each node $n_k \in C_{i+1} \cup B_i$ **do**

$chr(nk) \leftarrow ch(nt)$, nt is any parents of nk in Ii

end for

for $m \leftarrow 0$ to 3 **do**

Each node in Wi,m obtains color clm as its *sending color*

Each node in Ui,m obtains color clm as its *waking color*

end for

end for

Wake-Up Patterns

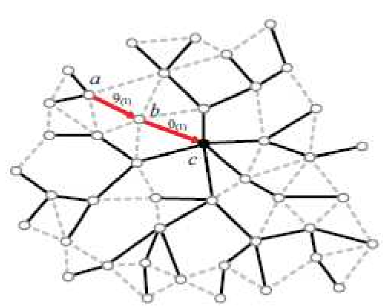
After all nodes get the traffic paths, *sending channels* and *receiving channels* with the BFS and CCDS, the proposed wake-up pattern is needed for sensor nodes to wake-up and receive alarm packet to achieve the minimum delay for both of the two traffic paths. As described above, there are two traffic paths for the alarm dissemination, and sensor nodes take two *level-by-level offset schedules* for the traffic paths. 1) sensor nodes on paths in the BFS wake up *level-by-level* according to their hop distances to the center node; 2) after the center node wakes up, the nodes in the CCDS will go on to wake up *level-by-level* according to their hop distances in the CCDS.

Since it is hard to predict when the alarm occurs, the two *level-by-level offset schedules* are taken periodically. Moreover, it is needed to effectively arrange time slots for sensor nodes at different positions in the topology, so that the two *level-by-level offset schedules* can periodically work without interfering with each other. The assignment of time slots is summarized in Table 1, which can be briefly described as follows: 1) all nodes in H obtain slots for uplink traffic according to their hops in H and the sequence number of duty cycles; 2) nodes in H' obtain slots for downlink traffic according to their hops in H' and the sequence number of duty cycle; 3) nodes in B_i obtain the same slot as c_{i+1} for downlink traffic.

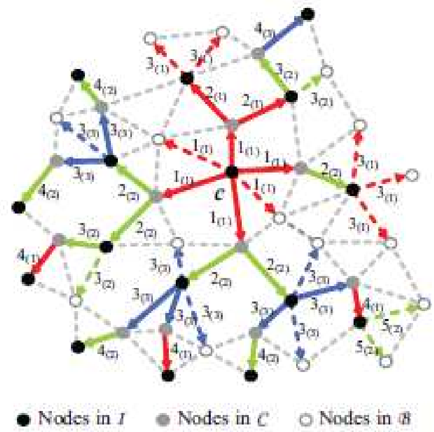
Table 1: Wake-Up Patterns

Node ($0 \le s \le L-1$)	Time Slot for Wake-Up	
	In 2kth Duty Cycle	In (2k+1)th Duty Cycle
n_j € $H_{(2m+1)L+s}$	f(nj) = L - s	
nj € H_{2mL+s}		f(nj) = L – s
nj € H^1_{2ml+s}	f(nj) = s	
nj € $H^1_{(2m+1)L+s}$		f (nj) = s
nj € $\mathbf{B_i}$	f(nj) = f(n_i), where n_i is any node in Ci+1	

Alarm Broadcast with Proposed Scheduling Method



Uplink Traffic in BFS



Downlink Traffic in CCDS

CONCLUSIONS

In this paper, we proposed a novel sleeping scheme for critical event monitoring in WSNs. The proposed sleeping scheme could essentially decrease the delay of alarm broadcasting from any node in WSN. The upper bound of the delay is $3D + 2L$, which is just a linear combination of hops and duty cycle. Moreover, the alarm broadcasting delay is independent of the density of nodes in WSN. The energy consumption of the proposed scheme is much lower than that of existing methods.

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