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SNOOZE SETTING UP FOR DANGEROUS INCIDENT 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 snooze setting up methods are always employed in WSNs, resulting in significant broadcasting delay, especially in large scale WSNs. In this paper, we propose a novel snooze setting up 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 and its energy consumption is ultra low.

Keywords—Wireless Sensor Network (WSN), critical event monitoring, snooze setting up, broadcasting delay, multichannels.

I. INTRODUCTION

In mission-critical applications, such as battlefield reconnaissance, fire detection in forests, and gas monitoring in coal mines, wireless sensor networks (WSNs) are deployed in a wide range of areas, with a large number of sensor nodes detecting and reporting some information of urgencies to the end-users. As there may be no communication infrastructure, users are usually equipped with communicating devices to communicate with sensor nodes.

Recently, many sleep schedules for event monitoring have been designed [1], [2], [3], [4], [5]. However, 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. 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 [8]. Based on this idea, a level-by-level offset schedule was proposed in [6]. As shown in Fig. 2, the packet can be delivered from node a to node c via node b with minimum delay. Hence, it is possible to achieve low transmission delay with the level-by-level offset schedule in multi-hop WSNs.

In the proposed snooze setting up method [9]. First, when a node detects a critical event, it originates an alarm message and quickly transmits it to a center node along a predetermined path with a level-by-level offset way.

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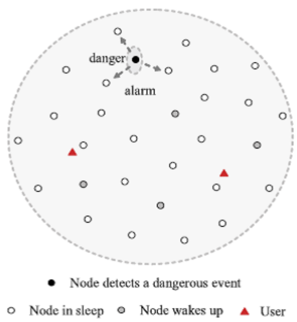

Fig. 1. Dangerous incident monitoring with a WSN

To eliminate the collision in broadcasting, a colored connected dominant set (CCDS) in the WSN via the IMC algorithm proposed in is established. Each node transmits or receives packets in a specific channel according to the color assigned. In summarization, characteristics of the proposed snooze setting up scheme are:

1. 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.
2. The broadcasting delay is independent of the length of the duty cycle, but it increases linearly with the number of the hops.
3. The broadcasting delay is independent of the density of nodes.
4. The energy consumption is very low as nodes wake up for only one slot in the duty cycle during the monitoring.

II.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 snooze setting up according to the proposed scheduling scheme and broadcasts the scheduling to all the other nodes [9].

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.

Slot and duty cycle: Time is partitioned into time slots.

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

We define $f(n_i)$ as the slot assignment function. If $f(n_i) = s$; $s \in \{0,...,L-1\}$, it means that node ni wakes up only at slot s to receive packets.

III. THE PROPOSED SCHEDULING METHOD

3.1 Basic Idea

It is known that the alarm could be originated by any node which detects a critical event in the WSN. To essentially reduce the broadcasting delay, the proposed scheduling method includes two phases

1. 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.
2. The center node broadcasts the alarm packet to the entire network also according to level-by-level offset schedule.

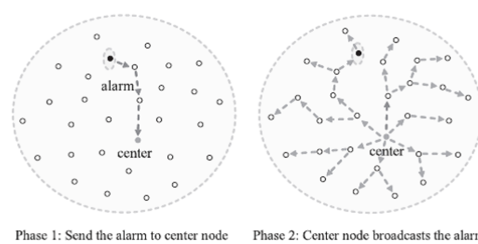

Fig. 3. Two phases of the alarm broadcasting in a WSN.

We define the traffic paths from nodes to the center node as uplink and define the traffic path from the center node to other nodes as downlink, respectively. The proposed scheduling scheme should contain two parts:

1. Establish the two traffic paths in the WSN
2. 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 for the downlink traffic, respectively.

3.2 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 with 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 four disjoint sets with IMC algorithm proposed in
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 in Table 1.

First, we construct a MIS I.As all nodes have been divided into H1, H2, H3; . . .;HD with the BFS tree, the MIS can be established layer by layer (i.e., hop by hop) in the BFS as follows: Start from the 0th hop, we pick up a maximum independent set, then, move on to the first hop, pick up another maximum independent set.

Second, we construct the CDS by selecting connector nodes C from V nI to interconnect independent nodes as follows: Obviously, for any two 2-hop neighboring independent nodes, at least one node in G is adjacent to both of them. Hence, the node is possible to be selected as a connector node.

We further color the CDS to be CCDS as follows: We divide all nodes in CDS into several sets according to their minimum hops to c in CDS. As CDS is based on $G^2(i)$, the number of hops from independent nodes to c in the CDS is even, and the number of hops from connector nodes to c in the CDS is odd. Therefore, we obtain I0; I2; I4; . . . and C1; C3; C5; . . . . In addition, dominated nodes B could be divided into B0;B2;B4; . . . . They are dominated by I0; I2; I4; . . . , respectively. Since any two independent nodes cannot be adjacent, the distribution of independent nodes is actually sparse. It has been proved that each independent node has less than 12 neighbors in I within 2-hop distance. Therefore, G0 could be colored with ch1; . . . ; ch12. Hence, when independent nodes in each layer broadcast simultaneously, they will not cause any collision at connector nodes. We define sending channel as chs(nk) and receiving channel as chr(nk) for each node nk, corresponding to channels in which nk sends packets and receives packets, respectively. Each node nk in Ii gets its chs(nk) according to its color, and each node nt in Ci obtains its chr(nt) according to the color of one of its parents in I_{i-1}. In addition, we color the subsets Ui;j and Wi-1;j with clj(0 ≤ j ≤ 3) in each layer. Hence, when connector nodes in each layer (i.e., $W_{i-1;j}$, (0 ≤ j ≤ 3) broadcast simultaneously, they will not cause any collision at independent nodes in the next layer (i.e., Ui;j, (0 ≤ j ≤ 3). Each node nk in Ii gets its chr(nk) according to the color of Ui;j that it belongs to, and each node nt in Ci obtains its chs(nt) according to the color of Wi;j that it belongs to. While, each node ns in Bi obtains its chr(ns) according to the sending channel of an independent node in Ii which dominates ns.

3.3 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-bylevel offset schedules for the traffic paths [7]. Fig. 4 shows the two level-by-level offset schedules: 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.

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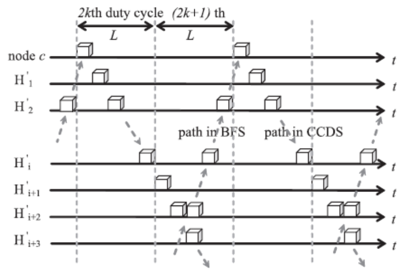

Fig. 4. Two periodic level-by-level offset schedules.

Nodes in H0 obtain slots for downlink traffic according to their hops in H0 and the sequence number of duty cycle;

Nodes in Bi obtain the same slot as C_{i+1} for downlink traffic. For example, a sensor node nj in H_1 obtains slot L-1 in odd duty cycles for uplink traffic. On the other hand, nj may also be in H'_2 , and it obtains slot 2 in even duty cycles for downlink traffic [7]. Furthermore, for nodes which are both in H_{2mL+s} and H'_{2nl+t}, when s + t ¼ L, nodes will be assigned the same slot for uplink traffic and downlink traffic, i.e., nodes need to wake up for only one time slot every two duty cycles and it can receive the possible alarm transmitted both in uplink and downlink.

3.4 An Example:

In order to show the assignment more clearly, we give an example shown in Fig. 5, where the numbers in brackets denote the frequency channels, and the numbers in front of brackets denote the time slots in a duty cycle. The length of duty cycle is set 10. Consider two nodes a and b (shown in Fig. 5a), which are in H2 and H1, respectively, in the BFS. Suppose node a detects a critical event. It will originate an alarm packet and sends it to node b at time slot 9 in the earliest odd duty cycle in channel ch1. When node b wakes up at time slot 9 in channel ch1 and receives the alarm, it sends the alarm to the center node c which wakes up at time slot 0 in each even duty cycle in channel ch1. After receiving the alarm, node c begins to broadcast the alarm packet among the CCDS. From Fig. 5b, all the transmissions at the same time slot do not cause any collision, and the broadcast is executed level-by-level without waiting. Furthermore, since the alarm can be quickly relayed to center node in an uplink path and center node could immediately begin to broadcast it, the broadcasting delay is much lower. In addition, the energy consumption of nodes is also very low, since most nodes stay awake for only one time slot in each duty cycle. Moreover, the center node and nodes with the same wakeup slots for uplink traffic and downlink traffic [10], stay awake for one time slot every two duty cycles. Obviously, Ii, Ci, and Bi are used only for downlink traffic to solve the collision [10]. Nodes in Ii broadcast alarms to C_{i+1} and Bi, and nodes in C_{+1} broadcast alarms to I_{i+2}. While, nodes in Bi do not need to send alarms.

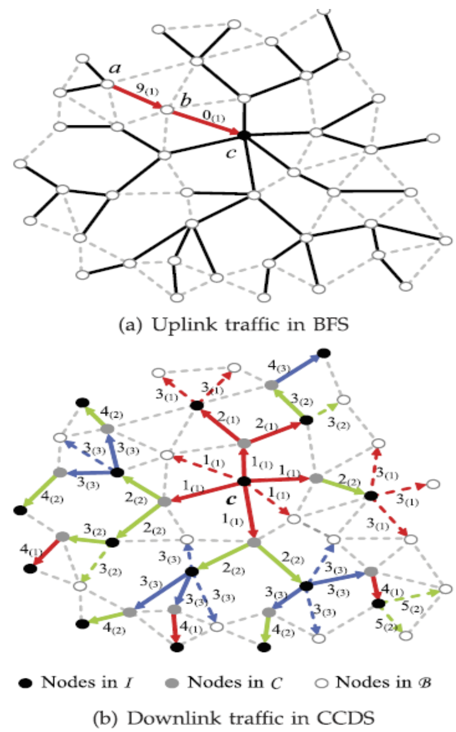

Fig. 5. An example of the alarm broadcast with the proposed scheduling method.

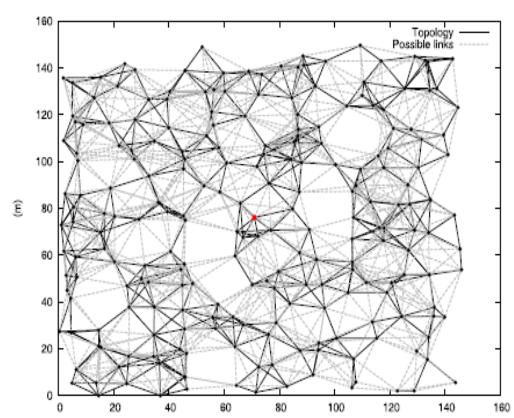

Fig. 6. The distribution of nodes in an unsteady WSN.

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IV. ANALYSIS AND SIMULATION

4.1 Performance Analysis

Lemma 1: The maximum hop of the shortest path in the CCDS from any node to the center node is no more than 2D.

Proof: Consider any independent node nj, there must be a parent in C connecting another independent node which is closer to the center node than nj. If the parent is in the same layer with nj in the BFS, then, it increases the hops of nj to c in the CCDS.

Lemma 2: The upper bound of alarm broadcasting delay in WSN is no more than 3D + 2L.

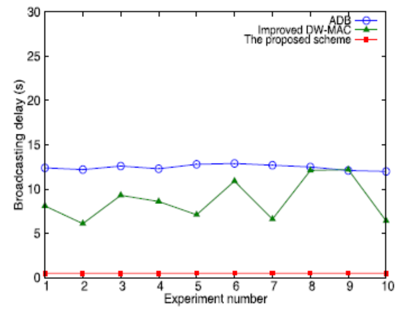
Proof: According to the proposed scheme, alarm packet can be transmitted along the uplink traffic path in the BFS without waiting. When the center node gets the packet, it immediately broadcasts the packet along the downlink traffic paths in the CCDS without waiting.

4.2 Simulations in Unreliable Environment

We use ns-2 simulator to evaluate the performances of the proposed scheduling method in unsteady WSNs. In Fig. 6, 225 sensor nodes are randomly deployed in an area of 150*150 m^2. The successful communication probability p to characterize the wireless link between any two nodes is employed. Considering the interference caused by non neighboring nodes, we define the worse link quality than that in practice with assumption $p=1-(d/20)^2$where d is the distance between two nodes and d < 20. The links with p 50 % are chosen to form the topology of network for the proposed scheme, as shown in Fig. 6. The dashed lines are the links with p < 45%. The duty cycle is 1 s.

4.2.1 Different Sizes of Time Slot

We first set the size of the time slot to be the minimum time for sensor nodes to transmit an alarm packet, e.g., 2 ms. When an alarm transmission fails between two adjacent nodes with the proposed scheme, the sender node has to retransmit the alarm after 2 duty cycles. While, for the ADB and the improved DW-MAC schemes, the sender node retransmits the alarm after 1 duty cycle. Fig. 7a shows the broadcasting delay with the three schemes in the WSN shown in Fig. 6. Obviously, the proposed scheme does not exhibit good performance in the case of minimum time slot. To improve it, we set the size of the time slot to be 10 ms.



(c) Time slot = $20ms$

Fig. 7. Broadcasting delay with different sizes of time slot.

4.2.2 Multiple Alarms

To deal with the collision, we design a mechanism for the proposed scheduling as follows: Suppose the time slot is denoted as k . When a sensor node having detected the event is going to send an alarm packet, it keeps transmitting the packet randomly with the probability 1=2 during the time slot. We evaluate the performance of the mechanism with a simple and typical network model. Suppose there are M nodes that need to send packets to a parent node which keeps awake for 20 ms every two duty cycles periodically. The quality of the link between the parent node and each child is 72 percent. Suppose the range of the event region is smaller than that of nodes' radio detection.

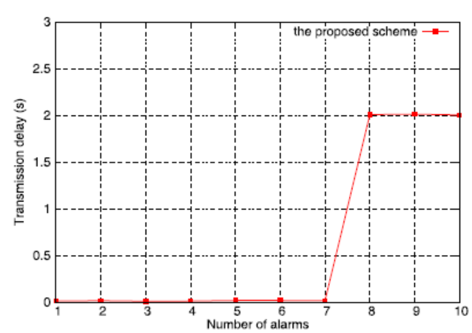


Fig. 8 shows the time when the parent node successfully receives a packet.

4.2.3 Energy Consumption

We also analyze the energy consumption of sensor nodes with the proposed scheme in WSN. Since the energy consumption is mainly due to the idle listening when there is no critical event most of the time, it is reasonable for us to approximatively calculate the energy consumption according to the length of wake-up duration in a duty cycle. For example, when a MicaZ node turns on its radio module, its current is about 20 mA. Hence, the energy consumption within 5 ms wake-up duration is about **3.3 V* 20 mA *5 ms=3.3 mJ.**

V. CONCLUSIONS

In this paper, we proposed a novel snooze scheme for dangerous incident 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. Theoretical analysis and conducted simulations showed that the broadcasting delay and the energy consumption of the proposed scheme is much lower than that of existing methods.

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