

# Sleep Scheduling for Critical Event Monitoring in Wireless Sensor Networks

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**Abstract:** *Wireless sensor network have used in many applications like forest fire detection, earth monitoring, air monitoring etc. When a critical event happen in the monitoring area it is find out by a sensor node. 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.*

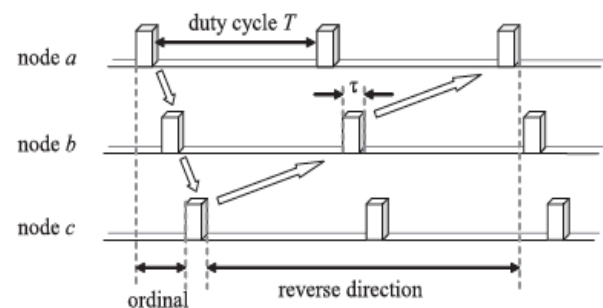
**Keywords:** Wireless Sensor Network (WSN), critical event monitoring, sleep scheduling.

## Introduction

Wireless Sensor Networks (WSN) is a collection of spatially deployed wireless sensors by which to monitor various changes of environmental conditions (e.g. forest fire, air pollutant concentration and object moving) in a collaborative manner without relying on any underlying infrastructure support. Recently, a number of research efforts have been made to develop sensor hardware and network architecture in order to effectively deploy WSNs for a variety of applications. Many network parameters such as sensing range, transmission range and node density have to be carefully considered at the network design stage, according to specific applications. To achieve this, it is critical to capture the impacts of network parameters on network performance with respect to application specifications. Since a distributed network has multiple nodes and services many messages and each node is a shared resource, many decisions must be made. There may be multiple paths from the source to destination. Therefore, message routing is an important topic. The main performance measures affected by the routing scheme are throughput (quality of service) and average packet delay (quantity of service).

## 1. 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. The implementation of obtaining topology and broadcasting scheduling is introduced in Section Experiments of supplementary file, which can be found on the Computer Society Digital Library. The following terms are defined in this paper.



**Figure 1:** The level-by-level offset schedule

- **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  $\tau$ . For example, to transmit a simple packet with a size of several bytes using the radio chip *Chipcon CC2420*;  $\tau$  could be less than 2 ms. The length of each duty cycle is  $T = L * \tau$ , i.e., there are  $L$  slots in each duty cycle.
- **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  $f(n_i) = s$ ,  $s \in \{0, \dots, L-1\}$ , it means that node  $n_i$  wakes up only at slot  $s$  to receive packets. Meanwhile, we define  $f(n_i)$  as the channel assignment function which assigns a frequency channel to node  $n_i$ .

## 2. Design Overview

### A. System Model and Assumptions

Consider a homogeneous, static sensor network, in which sensor nodes work in a duty cycling mode. In such a toggling period (TP), a node keeps active for  $TP \cdot DC$  where DC is the duty cycle. Although the active period of neighbor nodes may be different, the communication among them can be guaranteed based on a MAC protocol. In the active state, a node may detect targets within its sensing radius  $r$ , and communicate with other nodes within its communication radius  $R$ . Assume that every node is aware of its own location and is able to determine a target's position at detection. In addition, assume that the sensor nodes are locally time synchronized using a protocol. In fact, as long as the distance between to target is more than two times of the communication radius of nodes, the sleep scheduling actions triggered by them will not overlap [1].

Components of sleep scheduling protocol:

- Target prediction. The proposed target prediction scheme consists of three steps: current state calculation, kinematics-based prediction and probability based prediction. After calculating the current state, the kinematics based prediction step calculates the expected
- Awakened node reduction. The number of awakened nodes is reduced with two efforts: controlling the scope of awakened regions, and choose a subset of nodes in an awakened region.
- Active time control. Based on the probabilistic models that are established with target prediction, schedules an awakened node to be active, so that the probability that it detects to target is close to 1.

### B. Traffic Model

Fig. 1 depicts the kinds of communication paths in the network, namely,

- Forward direction (downlink): The base station sends a message to one of nodes in the network.
- Backward direction (uplink): A regular node sends a message to the base station.

Several sensor nodes today, are often equipped with passive event detection capabilities that allow a node to detect an event even while it is in sleep mode. Still others provide ultra low-power, low-rate periodic sampling mechanisms for rare event detection. Upon the detection of an event, the sensor node is immediately woke up (within several  $\mu\text{sec}$ ) and is ready to transmit a notification message to the base-station. Similarly, the base-station is often required to transmit imperative commands or queries to sensor nodes that may originate asynchronously. Messages in either direction, thus, originate at random times (asynchronously) and this implies that messages may potentially originate at an in opportune time when all other nodes in the network are in sleep mode and not ready to receive the message [5]. While these messages occur infrequently, they reflect urgency; as such their delivery demands non-negotiable worst case delay bounds. In this paper, delay is defined as the time duration between generations of a message at a node (base-station or a regular node) until its eventual delivery at the destination

node.

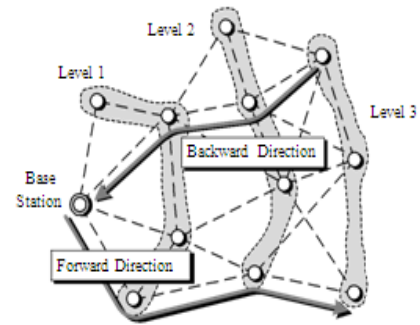


Figure 2: Networks and Traffic Model

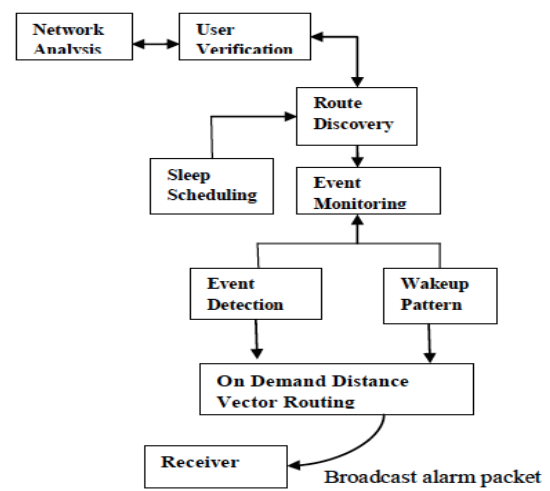


Figure 3: System Architecture

### C. Critical Event Monitoring

Whenever a critical event occurs, the critical event is detected by the nearby sensor nodes. Immediately these sensor nodes should broadcast an alarm message to the entire network. Sleep scheduling is used to reduce the energy consumption which leads to increase network lifetime. But it leads to the broadcasting delay, especially in large scale WSNs. So we need to balance both energy efficiency and delay aware. In this paper, a delay optimized sleep scheduling method is proposed to reduce the delay of alarm broadcasting in WSNs. When a critical event occurs, an alarm is immediately transmitted to a center node, and then it is quickly broadcasted by the center node to the entire network without any collision. In sleep scheduling, sender nodes should wait until receiver nodes are active and ready to receive the message. Sleep scheduling should increase the network life time but it could cause transmission delay. Whenever the network scale increases, the broadcasting delays also increase. So a delay aware sleep scheduling method needs to be designed to provide low broadcasting delay from any node in the WSN.

Most of sleep scheduling methods is introduced to minimize the energy consumption. To minimize the broadcasting delay in WSN, it is needed to minimize the time wasted for waiting during the broadcasting. The destination node is wake up immediately when the source nodes obtain the broadcasting packets. Here, the broadcasting delay is reduced. Sleep scheduling in wireless sensor network is shown in fig 2.2.

Whenever a critical event occurs, it is detected by the nearby sensor nodes and immediately it.

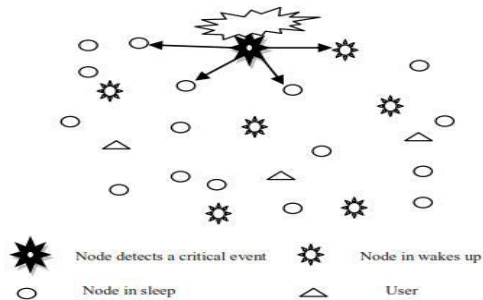


Figure 4: Critical Event Monitoring with a WSN

### 3. The Proposed Scheduling Method

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. As an example, Fig. 3 illustrates these two phases of the processing. 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. Each node needs to wake up properly for both of the two traffics. Therefore, 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.

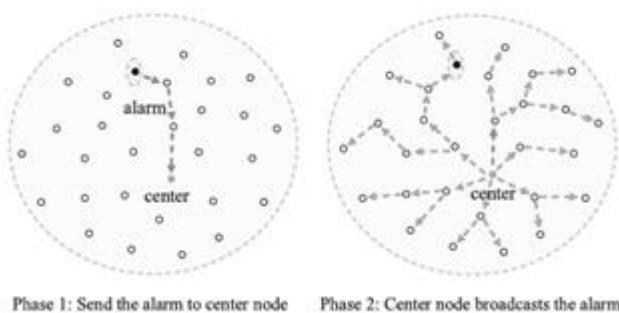


Figure 5: Two phases of the alarm broadcasting in a WSN

#### • Traffic Paths

Select certain node as center node. Then construct the BFS tree from node to the center node in the network. Here BFS tree divides all nodes of network into layers  $H_1, H_2, H_3, \dots, H_D$ , where  $H_i$  is the node set with minimum hop  $i$  to  $c$  in the WSN. With this BFS tree the uplink from the node to the center node is easily established. A Colored Connected Dominant Set (CCDS) is established in downlink traffic to reduce the broadcasting delay. To 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 (Iterative Minimal Covering) algorithm Proposed in

3) Color the CDS to be CCDS with no more than 12 channels.

#### • 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. Fig. 6 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. Hence, when an alarm packet is originated, it could be quickly forwarded to the center node along a path in the BFS, then, the center node immediately broadcasts it along the paths in the CCDS.

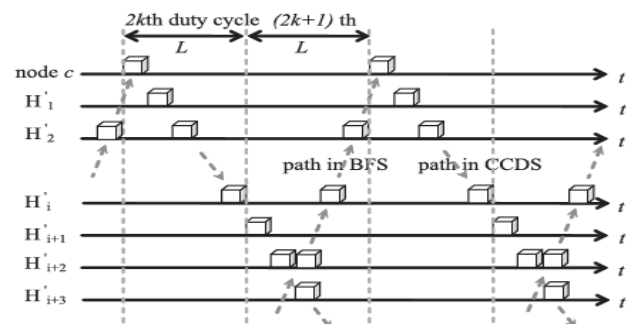
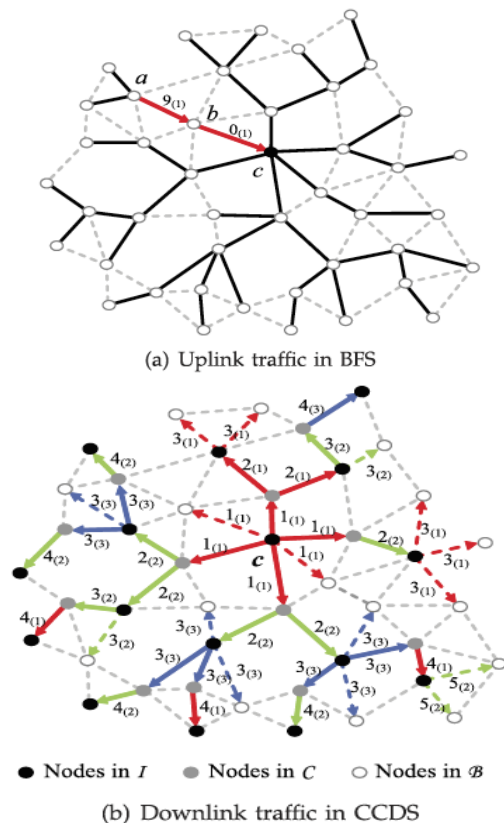


Figure 6: Two periodic level-by-level offset schedules

Since it is hard to predict when the alarm occurs, the two level-by-level offset schedules are taken periodically as shown in Fig. 6. 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 2, 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  $H_0$  obtain slots for downlink traffic according to their hops in  $H_0$  and the sequence number of duty cycle; 3) nodes in  $B_i$  obtain the same slot as  $C_{i+1}$  for downlink traffic. For example, a sensor node  $n_j$  in  $H_1$  obtains slot  $L - 1$  in odd duty cycles for uplink traffic. On the other hand,  $n_j$  may also be in  $H_{02}$ , and it obtains slot 2 in even duty cycles for downlink traffic. In addition, it is obvious that, whenever a sensor node detects a critical event, it waits for no more than two duty cycles before its time slot for uplink traffic comes.

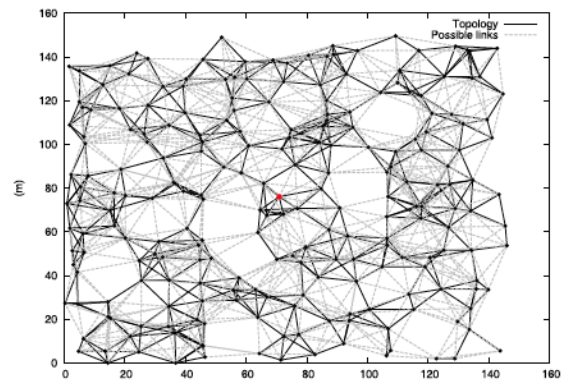




**Figure 7:** An example of the alarm broadcast with the proposed scheduling method

#### • An Example

In order to show the assignment more clearly, we give an example shown in Fig.7, 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. 7a), 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, as shown in Fig. 7b. The solid lines are the paths in the CCDS. In the broadcasting phase (i.e., in even duty cycle for nodes a and b), node a and node b are in H03 and H01, respectively, in the CCDS. Therefore, they wakeup at time slots 3 and 1, respectively, in each even duty cycle in their receiving channels (channel 3 and channel 1, respectively). When receiving the alarm packet, node a broadcasts it in its sending channel (channel 2), while node b does not broadcast the packet as it is a dominated node. From Fig. 7b, 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.



**Figure 8:** The distribution of nodes in an unsteady WSN.

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 wakeupslots for uplink traffic and downlink traffic, 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. Nodes in Ii broadcast alarms to Ci+1 and Bi, and nodes in Ci+1 broadcast alarms to Ii+2. While, nodes in Bi do not need to send alarms.

## 4. Conclusion

The sleep scheduling technique is used to detect and monitor the critical event that occurs in wireless sensor network. This can be done by predetermining the route and synchronous wakeup pattern. The upperbound 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 broadcasting delay and the energy consumption of the proposed scheme are much lower than that of existing methods. In future sleep scheduling method can be used to broadcast multiple alarm without collision.

## 5. Acknowledgments

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## References

- [1] Peng Guo, Tao Jiang Senior Member, IEEE, Qian Zhang, Fellow, IEEE, and Kui Zhang "Sleep Scheduling for Critical Event Monitoring in Wireless Sensor Networks," IEEE Transactions On Parallel And Distributed Systems, VOL. 23, NO. 2, February 2012.
- [2] G. Lu, B. Krishnamachari, and C. Raghavendra, "An Adaptive Energy-Efficient and Low-Latency MAC for Data Gathering in Wireless Sensor Networks," Proc. 18th IEEE Int'l Parallel and Distributed Processing Symp., pp. 224-230, Apr. 2004.
- [3] G. Lu, N. Sadagopan, B. Krishnamachari, and A. Goel, "Delay Efficient Sleep Scheduling in Wireless Sensor Networks," Proc. 24th IEEE Int'l Conf. Computer Comm.,

- pp. 2470-2481, Mar.2005.
- [4] N.A.Vasanthi and S.A., "Energy Efficient Sleep Schedule for Achieving Minimum Latency in Query Based Sensor Networks," Proc. IEEE Int'l Conf. Sensor Networks, Ubiquitous, and Trustworthy Computing, pp. 214-219, June 2006.
- [5] M.I. Brownfield, K. Mehrjoo, A.S. Fayez, and N.J. Davis IV., "Wireless Sensor Network Energy-Adaptive Mac Protocol," Proc.Third IEEE Consumer Comm. and Networking Conf., pp. 778-782, Jan. 2006.
- [6] A. Keshavarzian, H. Lee, and L. Venkatraman, "Wakeup Scheduling in Wireless Sensor Networks," Proc. Seventh ACM Int'l Conf. Mobile Ad Hoc Networking and Computing, pp. 322-333, May 2006.
- [7] Y. Sun, S. Du, O. Gurewitz, and D.B. Johnson, "DW-MAC: A Low Latency, Energy Efficient Demand-Wakeup MAC Protocol for Wireless Sensor Networks," Proc. Ninth ACM Int'l Conf. Mobile Ad Hoc Networking and Computing, pp. 53 -62, 2008.
- [8] Y. Sun, O. Gurewitz, S. Du, L. Tang, and D.B. Johnson, "ADB: An Efficient Multihop Broadcast Protocol Based on Asynchronous Duty-Cycling in Wireless Sensor Networks," Proc. Seventh ACM Conf. Embedded Networked Sensor Systems, pp. 43 -56, Nov.2009.
- [9] N. Bouabdallah, M.E. Rivero-Angeles, and B. Sericola, "Continuous Monitoring Using Event-Driven Reporting for Cluster-Based Wireless Sensor Networks," IEEE Trans. Vehicular Technology, vol. 58, no. 7, pp. 3460-3479, Sept. 2009.