Sensor Node Activity Scheduling Approach

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Abstract

Sensor networks, once deployed, are expected to continue to function unmanned. However, energy of the sensors is typically unrenewable thus making it a very scarce resource. Therefore, in order to extend the life of the sensor networks for the duration of a particular mission, energy has to be managed wisely. In this paper, we consider the problem of energy conservation for grid-based sensor networks. A wireless sensor network architecture that is based on mobile base station is presented. Based on this architecture, we propose an asynchronous duty-cycle scheduling scheme for extending the lifetime of the grid-based wireless sensor networks.

Keywords: Wireless sensor networks, Sleep/Walkup scheduling, Mobile base station.

1. Introduction

Wireless sensor networks (WSNs) are autonomous networks that are comprised of a large number of battery-powered sensor nodes and one or several base stations. Typically, each sensor node consists of sensing, processing, and low-power RF units. A base station is a much more powerful node with rich computational, memory, and radio resources. It serves as the data sink/processor, and as the interface between the sensor network and the external world. Usually, WSNs are deployed over a sensing field to perform certain tasks (e.g., environment monitoring, habitat monitoring, military surveillance [15, 16]) where current wired sensor technology would virtually be imposable to deploy (e.g., in harsh and sturdy environments).

However, the sheer number of the sensor nodes and their ad-hoc deployment in remote environment that are not conveniently accessible brings numerous challenges in managing wireless sensor networks efficiently. For example, energy is one of the fundamental bottlenecks in the contemporary sensor networks [4]. This is because sensor nodes are typically disposable as their battery is not easily recharged or replaced and they are expected to function unattended until their energy decimates. Hence, energy is a very scarce resource and must be managed judiciously in order to extend the lifetime of the sensor networks. As a result, energy consumption optimization in wireless sensor networks has been a very active area of research.

In this paper, we address the problem of maximizing sensor network lifetime for grid-based sensor networks with emphases on sensor node sleep scheduling problem. We define sensor network lifetime as the number of successful data gathering trips (or cycles) that are possible until connectivity and/or coverage are lost [20]. One way to save energy and extend the lifetime of a sensor network is by dynamically scheduling sensors' work/sleep cycles (or duty cycles) while maintaining the same sensing coverage. A scheme to adjust the sleep-awake periods of sensor nodes for energy optimization to extending sensor network operational lifetime is discussed in [13]. TRAMA [1] reduces energy consumption by coordinating transmission schedules of nodes and by placing nodes in sleep mode when they are not communicating. In S-MAC [2], nodes not actively communicating are allowed to periodically sleep. Neighbouring nodes form virtual clusters and synchronize their sleep schedules such that the entire neighbourhood is not asleep. However, in most of existing sleep scheduling schemes, a single static base station and a single static gateway is used. In contrast we use multiple gateways and a mobile base station (MBS).

Although several studies have demonstrated the practicality of combining sensor networks and a mobile base station [5, 7, 20], these previous approaches focus on data collection issues while we focus on extending the wireless sensor network life time through sensor node sleep/walk-up scheduling problem. For example, an architecture for data collection using the concept of data mobile collectors is presented in [5, 7]. Mhatre and Rosenberg [20] consider sensor networks containing two types of sensors. Regular sensors use either single or multi-hop communication to send their data to their respective cluster-heads (CHs), have a smaller energy budget, and the same transmission radius. The other type of sensors has more energy, and can serve as CHs for regular sensors. CH sensors send data directly to a helicopter, therefore requiring the same

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energy. They aggregate received data (energy needed for aggregating is proportional to number of incoming reports) before transmitting to the helicopter. Also, some of these protocols assume a single hop environment and, thus, it is not adequate for sensor networks which require multi-hop communications, which we are concerned in this paper.

A major focus of this paper is the design of a self-scheduling sleep protocol for grid-based coverage model with mobile base stations such that the node consumes the least amount of energy possible when it is not involved in sensing or relying activities. First, we present an architecture for sensor data collection that eliminates the need for lengthy multi-hop routing by ordinary sensor nodes using the concept of mobile data collector. Based on this architecture, we propose an asynchronous sleep/walk-up scheduling scheme. Finally, we show, through simulation, that the proposed algorithm do conserve energy substantially.

The rest of the paper is organized as follows. In Section 2, we present the grid-based coverage model. In Section 3, we present an architecture with mobile base station for grid-based coverage model. Also, the proposed sleep/walk-up scheduling algorithm is discussed. In section 4, we present the performance analysis along with the results. Section 5 summarizes the paper and discusses some future directions.

2. Grid-based Coverage Model

Grid-based sensor networks have been discussed in [18, 19]. For example, grid-based distributed sensor networks for surveillance and target location is discussed in [18]. Approaches to balance the energy load fairly across the sensor grid are discussed in [19]. However, all these schemes suffer from the uneven energy depletion phenomenon and the creation of energy holes in grid-based wireless sensor networks.

Fig. 1 shows the grid-based coverage model used in this paper. Note that by varying the grid size, we can model diverse coverage requirements, ranging from a coarse-granularity coverage corresponding to a large grid size) to a fine-granularity coverage (corresponding to a small grid size). The system consists of a set of $\mathbf{S} = \{s_{1,1}, s_{1,2}, \ldots, s_{n,k}\}$ energy-constrained static sensor nodes deployed as $n \times k$ grid and a mobile base station (MBS) which moves through the network and collect data from the sensor nodes. Every sensor node, $s_{i,j} \in \mathbf{S}$, (where i and j refer to rows and columns of the grid) in the sensor grid consists of embedded operating system, processor, storage, sensors, battery, transceiver and receiver. Each sensor has a non-renewable energy and when the energy supply is exhausted, the sensor becomes in-operational (i.e., dead). Also, since sensors energy cannot support long haul communication to reach a remote sink node, the sensory data collected by the sensors is routed to the remote sink node through one or closest sensor nodes (i.e., multi-hop network). Once deployed, the sensor nodes must work *unattended* as it is either impractical or infeasible to devote attention to individual sensors.

In this paper, we assume that the sensor nodes are capable of buffering sensed data and a mobile base station visits the area periodically and gathers data about the activity in the area from the sensor nodes. Normally, sensor networks follow the model of a command node or base station, where sensors relay streams of data to a base station either periodically or based on events. However, in many applications sensor data can be captured and stored or even processed by a remote node before it is transmitted to the central base station. For example, a temperature sensor that periodically senses and records the cargo temperature during transit for several days, and when the cargo gets to its loading dock for unloading, the device can detect the presence of a network and transmit all the accumulated temperature data to the network base station.

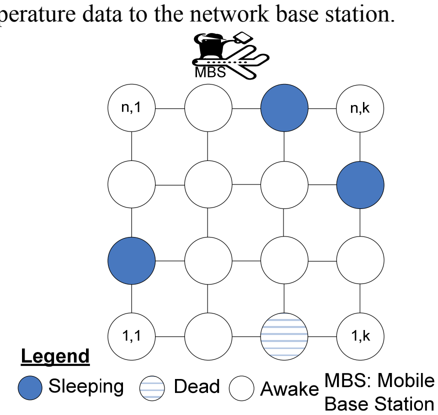

Fig. 1. Grid-based WSN Model

In this paper, we assume a single mobile data collector such as an unmanned aerial vehicle (UAV) that flies around the field being monitored. When MBS arrives at a *collection station*, it stays there long enough to collect the data until such time that the node's buffer is emptied. The mobile base station is assumed to have a portable set with transmission, reception, and processing capabilities. It

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manages the network, perform data fusion to correlate sensor reports and organize sensors by activating a subset relevant to required missions or tasks.

A sensor node alternates between sleeping periods and awake periods. The dynamic change in topology as a result of such duty-cycling has potentially disruptive effect on the operation and performance of the network. We explore the design of good sensor sleep schedules for grid-based coverage model with mobile base stations.

3. Scheduling Node Duty-cycle

Given the fact that most sensor nodes are deployed with non-rechargeable batteries that have limited lifetime, a major design consideration of a sensor network is how to increase the network operational lifespan (i.e. lower energy consumption) to a maximum within cost, technological and deployment limits. Also, since replacing a sensor node's battery may not be feasible practically, physically or economically, other ways of energy conservation schemes to prolong sensor network operational lifetime while maintaining the same sensing coverage is paramount.

To this end, we propose a new sensor node duty cycle (i.e., awake/sleep) scheduling protocol for grid-based sensor networks (see Fig. 1) to minimize over all WSNs energy consumption problem. We consider static sensor nodes and a single mobile base station which moves through the network for collecting data from the data stations. The fundamental idea of the proposed algorithm is to schedule the sleep and wakeup rate dynamically, according to the characteristics of the MBS movement scheduling. To achieve this, our algorithm combines three novel approaches: virtual cluster architecture, dynamic cluster head and scheduled wakeup/sleep components as discussed in the following subsections.

3.1 Virtual Cluster Architecture

We group sensor nodes into units, called *virtual clusters*, as shown in Fig. 2. Node clustering is commonly considered as one of the most promising techniques for dealing with maximizing network lifetime [8]. Clusters are formed based on the direction of the MBS and the communication distance between sensors and the MBS. Specifically, neighbouring nodes (i.e., nodes that are located within the radio/communication range) form virtual clusters to set up a common sleep schedule. As shown in Fig.2, there are 4 clusters (C_1, C_2, C_3, C_4) formed for the n, k grid of Fig. 1.

Each virtual cluster, C_i, has a set of cluster heads (also called data collection station). Unlike exiting approaches, there is no fixed cluster head in the proposed model. Rather cluster heads for a given cluster at any given time is dynamically determined based on the position of MBS (see Fig. 2). For example, the cluster head for cluster C_1 is the (1, k) sensor node when the MBS is at the right end corner. In the next data collection cycle, the cluster head will change such that one of the closest nodes to the MBS will assume the cluster head responsibility.

3.2 Data Collection Scheduling

Every node in the sensor grid senses an event and sends it towards the cluster head, which in turn relay it, downstream towards the MBS through the last cluster head node in the grid. Nodes may use multi-hopping to communicate with their closest cluster heads. The MBS visits cluster heads to collect data so that it does not have to obtain data from each and every sensor node in the network.

The MBS data collection movements could be scheduled in several ways. For example, a mix of clock-wise and anticlockwise direction as showing in Fig. 2 could be used to schedule the data collection activities of the MBS. When MBS arrives at the collection station (i.e., cluster head), it stays there long enough to collect the data accumulated at the cluster head, emptying the cluster head's buffer.

The MBS makes the time between visits to the same cluster head evenly spaced during each round. In each round, the travelled path of the MBS can be represented by a cycle consisting of *m* nodes, each representing a visit to one of the cluster heads. Due to space limitations, we will not discuss this point further.

3.3 Duty-cycle Scheduling

The nodes that could go to sleep mode is determined by the position of the MBS. For example, all the border nodes just visited by MBS could go to sleep. The necessity of extending network lifetime demands a minimum set of nodes that stay active and perform either sensing or forwarding duties. This set is determined by current cluster node and the next cluster that MBS will visit. The granularity of the sleep interval is also determined by the location of the MBS. The further the MBS is the longer a sensor node could afford to spend in sleep mode.

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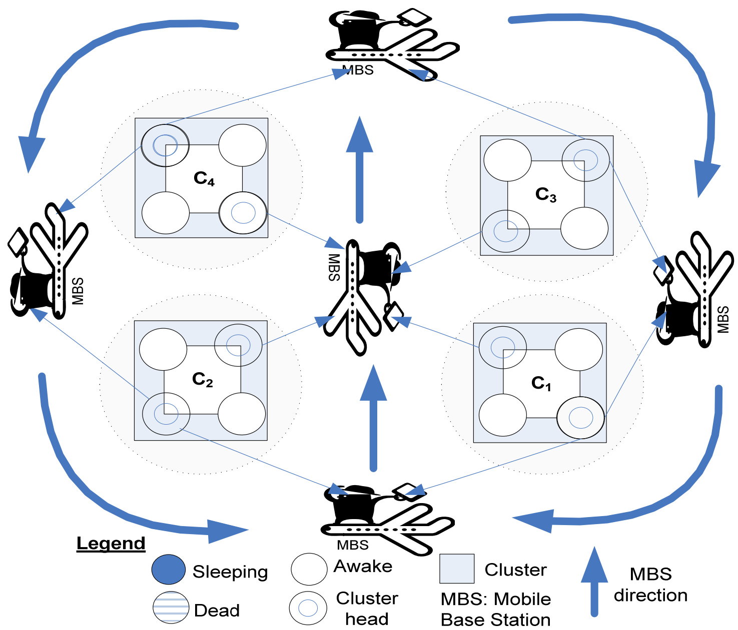

Fig. 2. Cluster formation and cluster head

3.4 Advantages of the Scheme

Some advantages of the proposed algorithm include: (a) the energy consumption due to overhearing is minimized as nodes can determine when they are expected to send and receive packets. To facilitate energy savings during event occurrence, smart sleeping schedule can allow nodes to sleep for short periods when a node is neither transmitting nor receiving; (b) in grid-based sensor networks, there will be extra burden on the nodes, which are located around the command node, as most of the traffic will be routed through them. However, by alternating the cluster head, the energy of the intermediate nodes can be conserved; (c) dynamically changing cluster heads solves the impact of dead nodes. Note that due to the dead node, a hole is created in the network that undermines relaying activity of other nodes. Consequently, if any of the active nodes fails (either due to energy depletion or due to unexpected failures), the network may experience a temporary loss of coverage or connectivity; and (d) the MBS visits cluster heads to collect data so that it does not have to obtain data from each and every sensor node in the network. Also, using a mobile data collector provides many advantages. First, MBS may cross long distances and hazardous terrain to reach the field. Second, only one or a few collectors are needed and they can be refuelled more easily than recharging thousands of sensor nodes. Third, a typical node may collect tens of bytes of data every second. Data gathered by the sensor nodes are stored in the buffers of the cluster heads until collected by the mobile collector which can visit the cluster heads periodically eliminating the need for continuous collection by the collectors.

4. Analysis of the Algorithms

In this section, we highlight our preliminary results of the proposed sensor node sleep scheduling approach with a version of the algorithm that does not use sleep/wakeup scheduling using energy consumption at different traffic load. We used the same parameters as in [17] to investigate the performance of the proposed algorithm through simulation. We used a 10×10 grid with a linear network topology where adjacent nodes are separated by 200m. We fixed the time the nodes go to sleep while total energy of each sensor is set to 3 joules. Packet size is set to 240, 1200 bits while energy dissipated for receiving (sending) is set 50 nJ/bit. Bandwidth is set to 40 kbps.

4.1. Energy Consumption

Fig. 4 shows energy consumption of the proposed scheduling approach (i.e., clustered-schedule) as compared to the "Walkup" and "Flat Schedule" approaches as a function of message inter-arrival period. In the Walkup approach, the nodes never sleep while in the "Flat Schedule" no particular organization (e.g.,

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clustering) is imposed on the nodes in the network.

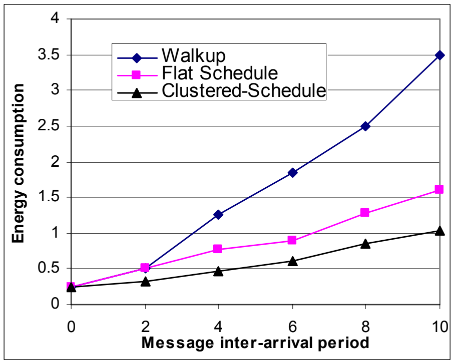

Fig. 4: Energy consumption as a function of message inter-arrival period.

The results show that putting the nodes to sleep in some organized way is important in prolonging sensor networks. In addition, the result shows that the proposed scheduling saves energy consumption substantially as compared to the baseline scheduling policies. This is because the proposed policy clusters nodes in groups and make them sleep also in groups based on the location of the mobile station. Therefore, by allowing sensor nodes more sleep opportunities, the nodes are able to better conserve their batteries, which lead to an operational lifetime extension. Also, the packet overhead in the proposed algorithm is reduced and energy efficiency is always guaranteed for any network traffic condition

4.2. *Border Node Lifetime*

Network availability depends mostly upon the relaying activity. Since, the relaying load increases considerably upon the nodes closest to the gateway, under normal circumstances, these nodes are the first ones to die out thus making the network effectively futile. In this experiment, we investigate the benefits of having fixed cluster heads and dynamically changing cluster heads on the life time of the sensor nodes, specially the border nodes in the grid.

Figure 5 shows the energy consumption as a function of message inter-arrival period when fixed cluster heads and dynamically changing cluster heads used. Border nodes in the grid are critical nodes in the network. The critical nodes determine the effective lifetime or the availability of a sensor network since these nodes bind individual nodes into a network. By using MBS and dynamically changing cluster-head, we solve the common problem of grid-based sleep scheduling problem, since nodes neighbouring the sink node consume power very fast and then fail, they may not always provide improvements in energy consumption. The result suggests using dynamically changing cluster-heads provide network longevity by balancing the energy consumption across the grid as even as possible.

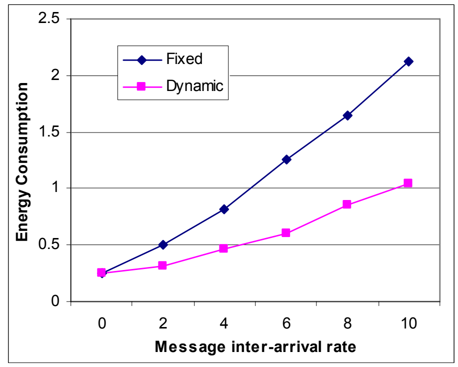

Fig. 5: Energy consumption as a function of message inter-arrival period when fixed cluster heads and dynamically changing cluster heads used.

4.3. *Cluster-head Overhead*

We note that many clustering approaches have been proposed for efficient selection of a cluster-head such as randomized lowest cluster-ID, or highest degree of connectivity [16, 17]. However, if load is not balanced among the cluster it can lead to increased latency in communication, inadequate tracking of targets or events and finally results in failure of the gateway. Our preliminary investigation shows that dynamic selection of the cluster-heads proposed in this paper have none of these problems although further investigation is needed to positively proof this assertion.

5. Conclusion

The primary design goal of wireless sensor networks is to minimize power consumption of sensor nodes in order to prolong network lifetime and reduce its cost of maintenance. In this paper we discussed a sensor node sleep scheduling approach and shown that it optimizes sensor network energy for a network deployed as sensor grids. We plan to extend the proposed algorithm in many ways some of which are as follows

The following are planned for future work: (i) The sensed data are not immediately transmitted to the base station after being sensed but buffered at the sensor nodes and possibly at the cluster heads; hence, it is important to ensure the latency is within an acceptable range; (ii) We plan to extend the proposed work for sensor nodes to stores data in a buffer and transmits the data when the buffer exceeds the optimal buffer threshold.

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We should find the optimal buffer threshold for both the sensor nodes and the cluster heads; (iii) One crucial question that we are currently looking at is in delayed data collection problem. Is the stable store required in each node bounded? This question is important in the case that the collector is delayed in a collection schedule; (iv) Extend it to a different deployment models; and (v) Perform extensive analytical and practical analysis of the proposed algorithm.

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