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Performance of a Connected Random Covered Energy Efficient Wireless Sensor Network

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Abstract**—**For the sensor network to operate successfully, the active nodes should maintain both sensing coverage and network connectivity. Furthermore, scheduling sleep intervals plays critical role for energy efficiency of wireless sensor networks. Traditional methods for sensor scheduling use either sensing coverage or network connectivity, but rarely both. In this paper, we use random scheduling for sensing coverage and then turn on extra sensor nodes, if necessary, for network connectivity. Simulation results have demonstrated that the number of extra nodes that is on with upper bound of around 9%, is small compared to the total number of deployed sensor nodes. Thus energy consumption for switching on extra sensor node is small.

Keywords**—**Wireless sensor networks, energy efficient network, performance analysis, network coverage.

I. INTRODUCTION

WIRELESS Sensor Networks (WSNs) have attracted a great deal of research attention due to their wide range of applications, ranging from military application (for intrusion detection) to civilian application, such as battlefield surveillance, tracking, machine failure, diagnosis, biological detection, home security, smart spaces, managing inventory.

Wireless Sensor Networks consists of a large number of tiny sensor nodes that are densely deployed inside the phenomenon or very close to it. Each sensor is composed of sensors, processors, memory and wireless transceivers. Due to their small dimension within several cube millimeters [3], they have very limited power supply. Energy efficiency is a critical concern in wireless sensor network, since a WSN is expected to operate for long time with sensor node's limited power supply and because of large number of sensors or hostile environment, charging or changing the battery is impossible.

In addition to energy efficiency, sensing coverage and network connectivity are critical requirements in sensor networks. Sensing coverage for sensing the area and detection of the events, that can be considered as the measure of quality of service of sensor network [13]. The unit area is covered if any point in that area is within sensing range of an active node.

The network is connected if any active node can communicate with any other active node. With connectivity information collected by sensing coverage can be sent to sink or base station. As the number of sensor nodes in sensor network is more than what is required by scheduling nodes to sleep and tuning off redundant sensor nodes can be achieved both coverage and energy efficiency at the same time. Researches [15], [4], [5], [11], [8], [10], [13], [9] are existing coverage- preserving scheduling scheme while GAF [14], SPAN [2], ASCENT [1] and STEM [7] are topology management protocols that maintain the network connectivity.

This work deals with joint problem of sensing coverage and network connectivity without certain constrains such as grids or relation between the radio range and the sensing range. In addition with this method, each active sensor node knows at least one path to the sink node and so at the same time routing problem is solved and no additional routing protocols are needed.

II. ALGORITHM DESIGN

The work that has been done by [6] is taken as reference. First randomize scheduling algorithm [12] for sensing coverage has been designed that does not assume the availability of any location or directional information. It is a purely distributed algorithm thus scalable for large networks. Assume that sensor nodes constitute a set *S*. Given a number *k*, each sensor node randomly joins one of the k disjoint subsets of set *S*. once the *k* subset are determined they work alternatively. At any given time, there is only one subset working, and all the sensor node belonging to this subset will turn on. The intuition is that when the network is sufficiently dense, each subset alone will cover most part of the field. Fig. 1 shows an example. if there are eight sensor nodes (with IDs 0, 1, ..7) randomly deployed in a rectangular area. Let say there are two subsets S_0 and S_1 (k=2). Each sensor randomly select 0 or 1 and join one of the corresponding subsets S_0 or S_1. Assume that sensor nodes 0, 3, 4, 6 select number 0 and thus join subset S_0, and sensor nodes 1, 2, 5, 7 select number 1 and join subset S_1. Then subset S_0 and S_1 work alternatively means that when sensor nodes 0, 3, 4, 6 (solid circles) are active, sensor nodes 1, 2, 5, 7 (dashed circles), fall asleep and vise versa.

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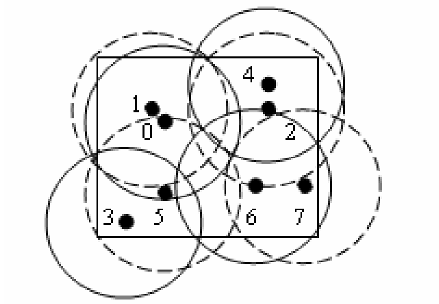

Fig. 1 An example of the randomized coverage-based algorithm

Second, after the randomize coverage-base scheduling scheme, there are *k* subnetworks formed, each of which correspond to a specific subset and consists of all the nodes assigned to that subset. Using the following extra-on rule ensures that each subnetwork is connected, given that the original network before scheduling is connected. Besides, it also guarantees that the path from any sensor node to the sink node has the global minimum hop count.

Assume that each sensor node knows its minimum hop count to the sink node *S*. A sensor node *A* is called the upstream node of another sensor node *B*, if node *A* and node *B* are neighboring nodes and the minimal hop count of node *A* to the sink node is one less than that of node *B*. Node *B* is also called node *A*'s downstream node (Fig. 2).

A.. Extra-on rule

If a sensor node *A* has a downstream node *B*, which is active in time slot *i*, and if none of node *B*'s upsteam node is active in that time slot, then node *A* should also work in time slot *i*. In other words, besides working in duty cycles assigned by the randomized coverage-based scheduling, node *A* is required to work in extra time slots, e.g. time slot *i* in this case. To enforce the extra-on rule we do the following steps:

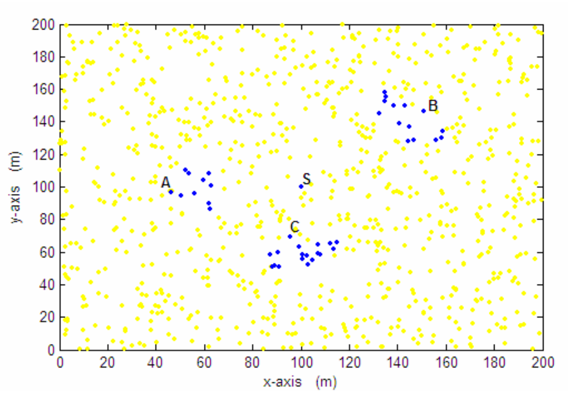

Fig. 2 200 by 200 meters area with 878 sensor nodes (Coverage intensity=0.9). Nodes *A*, *B* and their upstream nodes. Node *C* and it's downstream nodes. Sink node *S* in the center of area

1. Step 1. Propagate the Minimum Hop count

This step starts from the sink node at the time when it broadcasts a Hop advertisement message to its immediate neighboring sensor nodes. Each Hop advertisement message contains the minimum Hop count to the sink, the nodeID and its subset decision. In the packet broadcast from the sink, the minimum Hop count is set to 0. initially, the minimum Hop count to the sink is set to infinity at each sensor node. Each node, after receiving a Hop advertisement message, will put the message in its buffer. It will defer the transmission of the Hop message after a backoff time and only rebroadcasts the Hop message that has the minimum Hop count. Before the rebroadcast of the Hop message, the hop count value in the Hop message is increased by 1. With this method, Hop message broadcasts with a nonminimal Hop count will be suppressed if the Hop message with the actual minimal Hop count arrives before the backoff time expires. If no packets are lost, this method can guarantee that at the end of this step, each sensor node will obtain the minimum Hop count to the sink node (Fig.3). In practice, packets may be lost due to collisions or poor channel quality. Nevertheless, packet losses will not impact the successful operation of joint scheduling scheme, i.e. the network will still be connected even if some nodes may have only a nearly shortest path to the sink node.

2. Step 2. Exchange information with local neighbors

Each sensor node locally broadcast its minimum Hop count, its nodeID, its subset decision, the nodeIDs of its upstream nodes and their subset decisions. The upstream nodes are the nodes from which the current node receives its minimum Hop count. Each sensor node records and maintains all the information it receives from its immediate neighbors.

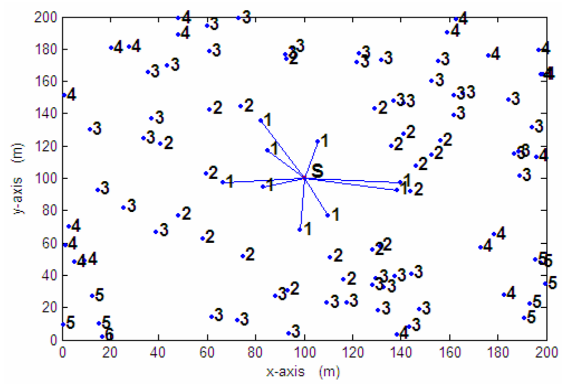

Fig. 3 An example of minimum hop count. Sink node *S* located in the center of the area. The numbers indicates the minimum hop count of each sensor from the sink node *S*

3. Step 3: Enforce the extra-on rule

Based on the extra-on rule and the information from step 2, each sensor node decides extra time slots it has to remain active to ensure network connectivity and updates its working schedule accordingly. Then the updated working schedule is broadcasted locally to neighboring sensor nodes. It is easy to see that the update of a sensor node's working schedule can impact the working schedule of its upstream nodes and the neighboring nodes with the same minimum Hop count to the sink. To minimize the number of broadcast of working schedule updates, it is desirable that a sensor node updates its working schedule after it receives all the latest working schedules from its downstream nodes. This is exactly the reverse process of step 1. As an example, assume that the network consists of one sink node and four sensor nodes A, B, C and D as shown in Fig. 4.

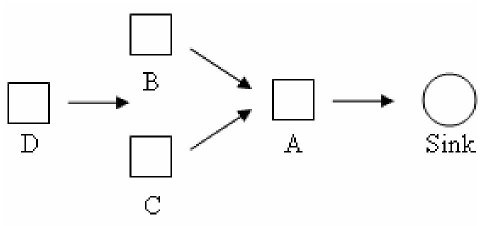

Fig. 4 An example of the extra-on rule

D is tree Hop away, B and C are two Hops away, and A is one Hop away from the sink node. Assume that at the end of step 1,A, B, C and D are assigned to different subsets. D broadcasts its updated working schedule first. B and C are its upstream nodes and in step 2 they know that node D does not have an upstream node in its assigned subset. After they receive D's working schedule update, there are several possibilities.

Case 1: B and C can hear each other. If B broadcasts its working schedule prior to C, B will work in D's working subset in addition to its own working schedule and C will work in its assigned working subset only. On the other hand if C broadcast its working schedule first, C will work in one extra subset that is D's working subset whilst B only works in its own subset.

Case 2: B and C cannot hear each other both of them will work in extra subset or D's working subset.

In both cases, from the latest working schedules received from nodes B and C, node A will work in extra subsets that are B, C, and D's working subsets to ensure network connectivity.

III. Performance Analysis

A.. *Performance Metric*

There is a clear trade-off in the randomize scheduling algorithm. Generally a large k value means more subsets, and thus a subset can wait longer until its next turn to work. As such, but a larger k value means smaller number of sensor nodes in each subset and, thus, potentially worst network coverage. A proper k value is needed so that the energy can be saved with desirable network coverage. For this we need to clearly define the network coverage.

1. *Coverage Intensity for a Specific Point*

For a given point *p* in the field, the coverage intensity for this point is defined [6] as:

$$C_p = \frac{T_c}{T_a} \,. \qquad (1)$$

Where T_a is any given long time period and T_c is total time during T_a when point p is covered by at least one active sensor. It is obvious that C_p depends on both the number of sensor nodes deployed in the neighborhood of C_p and scheduling scheme. Due to randomness in the sensor deployment strategy and the scheduling scheme, C_p is a random variable. Hence, the expectation of C_p reflects the average time fraction when point p can be monitored. Notably, the expectation of C_p for any point inside the field is equal because sensors are independently and uniformly distributed in the field. Because of this reason, the expectation of C_p is a network-wide metric and could be used to evaluate the coverage quality of the whole network.

A..2. *Network Coverage Intensity*

The network coverage intensity, C_n, as the expectation of C_p is defined by [6] is given in the following equation:

$$C_n = E[C_p]. \qquad (2)$$

Since the main task of wireless sensor network is to detect and report interesting events within the monitored field and the coverage intensity C_n reflects the probability that an event can be detected, C_n can be considered as the coverage measurement of sensor node networks. The ideal value of C_n is 1, which indicates that with the probability 1 every point in the field is covered by at least one active sensor at any given time.

But, achieving this ideal value may require very dense deployment and is extremely expensive. Since different applications have different requirements on acceptable coverage intensity, a good coverage scheduling scheme should set the number of simultaneous working sensor nodes merely enough to fulfill a given coverage requirement. For a given *k*, the lower bound on the number of sensor nodes n, required in the whole network to provide a network coverage intensity of at least *t* is

$$n \geq \left\lceil \frac{\ln(1-t)}{\ln(1-\frac{q}{k})} \right\rceil \qquad (3)$$

where $q = \frac{r}{a}$.

r is the size of the sensing area of each sensor and *a* is the size of the whole field.

IV. Result and Discussion

In this section a Matlab simulator has been implemented using CSMA/CA MAC layer protocol. Sensor nodes are deployed randomly in a 200 meters × 200 meters region. The sink node is located at the center of the area. The total number of sensor nodes is selected according to (3) to meet any network coverage intensity. The sensing range of 10 meters is set for each sensor node. The traffic load is very light such that packet losses are mainly cased by network partition or channel errors. To prevent packet losses due to broadcast collision or channel errors, a perfect medium channel without medium contention should be adopted. Under each simulation scenario, 100 runs with different random nodes have been executed.

Fig. 5 shows the packet delivery ratio (PDR). That is defined as the ratio of total number of packets received at the sink node over the total number of transmitted packets from sensor nodes. Since the traffic load is very light, this metric can be an indicator of network connectivity. It can be observed that the packet delivery ratio cannot achieve 100 percent without using the extra-on rule and for coverage intensities 0.9 and 0.95 the graph is almost same. With the extra-on rule, network can always achieve 100 percent packet delivery ratio and so can achieve guaranteed network connectivity.

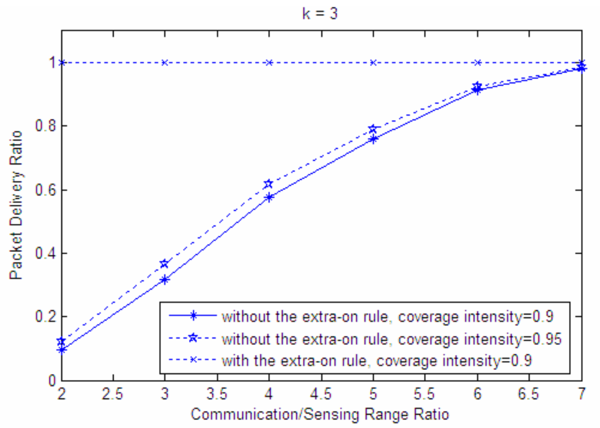

Fig. 5 PDR versus Communication/Sensing Range Ratio

The ratio of extra-on nodes has been shown in Fig. 6. That is defined as the ratio of the number of sensor nodes, which should remain active beyond their working schedule assigned by randomized algorithm, to the total number of deployed sensor nodes. Small ratio of extra-on sensor nodes denotes that for maintaining connectivity after randomized scheduling for coverage, small extra energy is required. The upper bound for the ratio of extra-on sensor nodes is around 9%, that is acceptable compared to [6] with upper bound of around 6%.

We can see the influence of number of subsets k on the ratio of decreases with the increase of k. Since larger k value for a given coverage intensity means larger total number of deployed sensor nodes, so the ratio of extra–on sensor nodes will be decreased with the increase of k. Also from Fig. 6, we can see with sufficiently high coverage intensity and sufficiently large communication range, the number of extra sensor nodes needed to turn on is very small for connectivity maintenance, compared to the total number of active nodes for coverage.

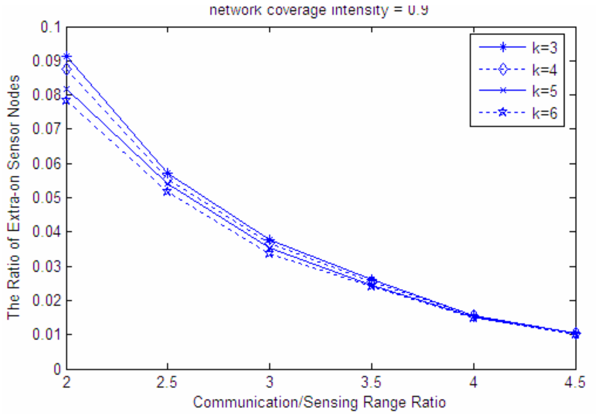

Fig. 6 Average number of extra-on nodes versus Communication/Sensing Range Ratio

V. Conclusion

In this paper we have considered both sensing coverage and network connectivity for a wireless sensor network whereas it can achieve substantial energy saving. First we have used randomized scheduling algorithm for sensing coverage that using node sleep scheduling method to save energy. Then we switch on extra sensors for connectivity. Simulation results have demonstrated that the number of extra-on sensor nodes to ensure connectivity is small compared to the total number of deployed sensor nodes. Thus energy consumption for switching on extra sensor node is small.

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