A Performance Comparison Study of a Coverage-Preserving Node Scheduling Scheme and Its Enhancement in Sensor Networks

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Abstract. In large wireless sensor networks composed of large numbers of low-powered unreliable sensors, one of the most important issues is saving and balancing the energy consumption of sensors to prolong the life time of the network while maintaining the full sensing coverage. In this paper, we analyze an efficient node scheduling scheme which uses the coverage-based off-duty eligibility rule and backoff-based self-scheduling scheme to perform the job. We give some enhancement to this node scheduling scheme, reducing its overhead without losing much of the capability. In simulation, we make the performance comparison from several aspects of the original coverage-based node scheduling scheme and our enhancement version.

Keywords: Coverage · Node scheduling · Sponsored area · Wireless sensor networks

1 Introduction

Recently there is a huge improvement in the affordable and efficient integrated electronic devices, which leads to the advancing of large wireless sensor networks. Sensor networks [1–3] are usually composed of large numbers of randomly deployed stationary sensors. These sensors are designed to perform information collection task. The data collected will finally be gathered and sent to the users via wireless channel. Sensor networks are the basic platform of a broad range of applications related to national security, surveillance, military, health care, and environmental monitoring. In sensor networks, sensing coverage is the area or discrete points of the target field which could be sensed by a predefined number of sensors [4, 5]. In this paper, we will assume the coverage to be only area coverage. A critical issue of the design of sensor networks is the energy consumption problem, which is how to scheduling the sensor nodes to save their scarce power and prolong the life time of the whole network while maintaining the desired degree of sensing coverage which is an important QoS measurement.

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In most cases, the density of sensor nodes in a sensor network is much higher than needed [6]. This redundancy can be used to prolong the life time of the network. The whole sensing period of the network can be divided into rounds by making the sensors take turns to work. The non-working nodes are put into sleep mode to save energy, thus the network's life time is prolonged. There are many node scheduling schemes (also called density control) in sensor networks. Node scheduling is, concretely, selecting a set of sensor nodes to work in a round and another random set in another round. In each round, the coverage requirement can be guaranteed. PEAS [7, 8], GAF [9], OGDC [10], et al. are all this kind of algorithms.

In this paper, we analyze one of the efficient node scheduling schemes proposed by Tian and Georganas in [11]. This *coverage-preserving node scheduling scheme* (CPNSS) develops a *coverage-based off-duty eligibility rule* (COER) and a backoff-based self-scheduling scheme. The underlying principle of COER is that, for each sensor, if all its working neighbors can cover its own sensing area together, it is eligible to turn off. We give a variation to COER by replacing the neighbors' position information by directional information, which can efficiently reduce the calculation and also communication overhead. For CPNSS's backoff-based scheduling scheme, which aims at avoiding 'blind spot', we propose a corresponding ID-based self-scheduling scheme to reduce the latency. The simulation results show that these variations can help to reduce overhead largely while introducing some redundancy, which can provide more reliability in some demanding applications.

The rest of the paper is organized as follows. In Sect. 2, we give a brief summary of the existing related work. In Sect. 3, we introduce and analyze the CPNSS. Section 4 is the performance comparison study of these schemes by simulation. Section 5 is the conclusion remarks and our future work.

2 Related Work

As mentioned above, there exist several node scheduling schemes in sensor networks. In [12], Slijepcevic *et al.* have proved the problem of finding maximal number of covers (each cover is a set of sensor nodes that can work together to ensure the predefined degree of sensing coverage) in a sensor network to be NP completeness. Therefore, all these schemes are approximate algorithms.

Ye *et al.* [7, 8] developed a distributed density control algorithm named PEAS, which is probing based. In PEAS, a sleeping node wakes up and broadcasts a probing message within a certain range at the end of its sleeping period. This node will turn on to work if no reply is received after a timeout. The node will keep working until it depletes its energy. The probing range can be adjusted to achieve different degree of coverage overlap. But PEAS can't guarantee full coverage, the 100 % coverage of the monitored area. Xu *et al.* [9] introduced GAF. This method divides the monitored area into rectangular grids, selects a leader in each grid to be the working node. The maximum distance between any pair of working nodes in adjacent grids is within the transmission range of each other. Again, this method cannot ensure full coverage. Recently, Zhang and Hou's work [10] gets more attention. They introduced a distributed, localized density control algorithm named OGDC which could provide full coverage. In the ideal case, when all the nodes have the same sensing range and transmission range, every three closest nodes in a cover can form an equilateral triangle with the side length $\sqrt{3}rs$, where rs is the sensing range. Thus the overlap of sensing areas of all the nodes is minimized. The working nodes can be activated by a starting node which is randomly generated in a progressively spreading way. Simulation results show that OGDC has better performance than other algorithms in both coverage and energy consumption aspects. But this algorithm is complicated, may require much execution power and time.

In [13], Yan *et al.* proposed an adaptable sensing coverage mechanism which could provide differentiated surveillance service. In their protocol, nodes could dynamically decide their own working schedule to provide not only full coverage, but α degree of coverage, α could be smaller or bigger than 1. A monitored point needs the coverage degree to be 2 means that it needs to be covered by two sensors together all the time. It's a protocol that achieves both energy efficiency and differentiated degree of sensing coverage. It aims at providing varied degree of coverage, but their current algorithm cannot guarantee correctness when $\alpha > 2$. Some other researchers have also done some work in this field, such as [14].

3 Coverage-Preserving Node Scheduling Scheme (CPNSS)

In [11], Tian and Georganas proposed a coverage-preserving node scheduling scheme (CPNSS). There are two parts in CPNSS. One is a coverage-based off-duty eligibility rule (COER), which tells a sensor whether it should turn itself off; the other is a backoff-based self-scheduling step, which provides the exact turn off procedure for a sensor node who is eligible to turn off, to avoid ‘blind spot’.

3.1 Coverage-Based off-Duty Eligibility Rule (COER)

In CPNSS, each sensor node can independently decide its status to be ‘active’ or ‘sleep’ according to the scheme's coverage-based off-duty eligibility rule.

Here we assume the sensing area of a sensor node to be a disk centered at this node with the diameter r, which is this sensor's sensing range. All the sensors have the identical sensing range. The transmission range of a sensor node is also r. Therefore, a neighbor node B to the sensor node A means that they are in each other's sensing range (A's neighbor set can be defined as $N(A) = \{B \mid d(A, B) \leq r, A \neq B\}$, d (A, B) is the distance between them). The main objective of the node scheduling is to turn off the redundant nodes. We can figure out that the ‘redundant’ node is the sensor node whose all sensing area can be covered by other sensor nodes. The redundant node can then be turned off without hurting the whole coverage. Here comes the concept ‘sponsored area’. Sponsored area is the sensing area of one sensor node that can be covered by another sensor node. Such as in Fig. 1(a), the shaded area SB → A is the sponsored area of sensor node B to A (also is SA → B). In order to simplify the calculation, another related concept ‘sponsored sector’ is introduced. In Fig. 1(b), the shaded sector area is the sponsored sector ΦB → A. Since A and B are in each other's sensing disks, the sector area must be smaller than the original crescent sponsor area. Therefore, this simplicity won't reduce coverage.

It is easy to see that if the sponsored area provided by all (or some) of the nodes in A's neighbor set can cover A's sensing disk, A is safe to turn off. We can calculate the union of all A's sponsored sectors. If the union result is 2Π, then A is said to be eligible to turn off (see Fig. 1(c), the area of disk A is equal to $\cup \Phi Bi \rightarrow A$, B$i$ is nodes in A's neighbor set). After getting the information about neighbor nodes' distance and direction from itself, node A can use $2\arccos(\frac{d(A,B)}{2\times r})$ to calculate each neighbor's sponsored sector. The authors also give the calculation when sensor nodes have different sensing ranges. We won't give further discussion about it in this paper.

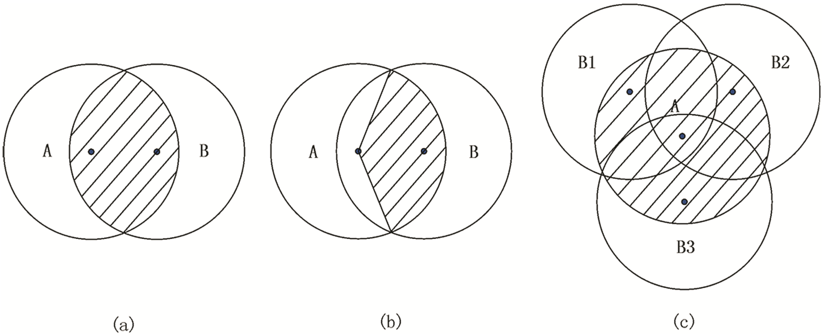

Fig. 1. (a) Sponsored area SB → A. (b) Sponsored sector ΦB → A. (c) Node A is eligible to turn off.

3.2 Backoff-Based Self-scheduling Step

The above discussed node scheduling method is localized. Each sensor node broadcasts a *Position Advertisement Message* (PAM) including its ID and position and also receives others' messages to get its neighbor set. Each node then decides its status according to the coverage-based off-duty eligibility rule. It is obvious that a 'blind spot', an area not within any sensor node's sensing range, may occur because two sensor nodes assume each other to cover their overlap area and make decision to turn off at the same time. To avoid 'blind spot', a backoff step is introduced.

The main idea is to insert a random backoff time Td before an eligible node turns itself off. The node should broadcast a *Status Advertisement Message* (SAM) to notify its neighbors that it is off when the time Td expires. If a sensor node receives a SAM during its backoff time, it will recalculate to see whether it is still eligible to turn off without the sponsored area provided by the sender node of the SAM. If not, this sensor node cancels its waiting and decides not to turn off. This scheme may lead to redundant overlap but reduces the possibility of the occurrence of 'blind spot'. If the size of random number selected as backoff time is W, the possibility for two eligible sensor nodes to turn themselves off together is $1/W^2$. Although the possibility may be very small, the 'blind spot' may still exist. To further avoid 'blind spot', another backoff time *Tw* is introduced. *Tw* is inserted after Td expires and SAM been sent out. The sensor node will wait another *Tw* time before really turn itself off. Again, if this node gets some SAMs during the waiting, it recalculates according to the eligibility rule by deleting the senders of SAMs from its neighbor set. Once a node has decided to be on, it won't change its status in this round.

4 Performance Evaluation and Simulation

In this section, we will use simulation to show the performance of the CPNSS and our variation versions to it. In order to simplify the denotation, we will use COER-PO to denote the original coverage-based off-duty eligibility rule using nodes position information, and COER-DI as the new rule using nodes direction information.

4.1 Simulation Environment

We set up the simulation in a $50 \times 50\ \text{m}^2$ network areas. Sensor nodes are randomly distributed in it initially and remain stationary once deployed. To calculate sensing coverage of the whole sensor network, we divide the space into 500×500 unit grids. If the center point of a grid is covered by some sensor node's sensing disk, we assume the whole grid being covered. In the same way, if the required coverage sensing degree is more than 1, say, D, (every point in the target area is supposed to within the sensing area of at least D sensor nodes), then still the center point of each grid is the representative of the whole grid. In the simulation, we will use the middle $(50 - \text{r}) \times (50 - \text{r})\ \text{m}^2$ as the monitored target area to calculate the coverage ratio, in order to ignore the edge effect, for in real case the monitored area will be sufficient larger than the sensor's sensing disk. Since we assume the transmission range of a sensor to be the same with its sensing range r, full coverage of the whole target area implies connectivity of all the sensor nodes. We only need to concentrate on the coverage and energy consumption issues in the simulation.

4.2 Parameters Used and Performance Metrics

In order to evaluate the capability and performance of these schemes, we set several parameters to be tunable in the simulation. They are as follows. (1) The node density. We change the number of deployed nodes (N) from 100 to 1000 to see the effect of node density on the efficiency of the schemes. (2) The sensing range (r). We change the sensing range of the sensor nodes from 6 m to 13 m. (3) Coverage sensing degree (D). Sometimes, more reliability is desired, so D could be more than 1. We vary D's value from 1 to 5 to see the corresponding performance of the schemes.

The performance metrics are: (1) The percentage of coverage, i.e., the ratio of the D degree covered area to the total monitored area. We will use the 500×500 bit map to denote them. (2) The percentage of working sensor nodes to all deployed nodes in one round. Since the fewer working nodes needed, the less energy consumed and the longer the network lives.

4.3 Simulation Results and Comparison

In order to analyze all these schemes' performance, we simulate the following four combinations, COER-PO with backoff-based self-scheduling, COER-PO with ID-based self-scheduling, COER-DI with backoff, and COER-DI with ID. In Fig. 2, we can see that when the required sensing coverage degree is small, all these four algorithms have almost full coverage. With larger *D* (above 2), the coverage ratio will decrease. The algorithm COER-PO with backoff-based self-scheduling (CPNSS) decreases the fastest and COER-DI with ID the slowest. This is because COER-DI has more coverage redundancy by turning off fewer sensor nodes. ID-based self-scheduling has more redundancy than backoff-based one, but this redundancy increase is less significant than COER-DI to COER-PO.

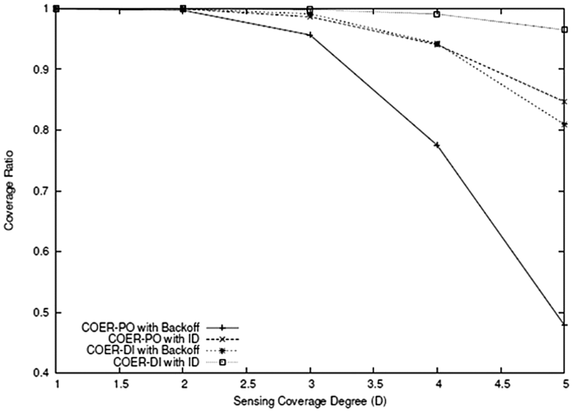

Fig. 2. Coverage ratio with different coverage sensing degree (*D*) ($r = 10$ m, $N = 500$).

We can see that COER-DI will have more working nodes than COER-PO, but it can reduce the communication overhead and the redundancy is useful when higher sensing coverage degree is required. ID-based self-scheduling scheme will introduce another amount of redundancy compared with backoff-based scheme, but it can save time. Overall, these variation to CPNSS can reduce the overhead by large and without losing too much of performance.

5 Conclusions and Future Work

In this paper, we do some research to one of the efficient node scheduling schemes CPNSS which uses a coverage-based off-duty eligibility rule as well as a backoff-based 'blind spot' avoidance method. In order to reduce overhead, we put forward some enhancement to CPNSS. Instead of position information of sensor nodes, we use directional information, and we remove CPNSS's backoff period to save time. The simulation results show that this variation of CPNSS can provide full coverage, but will introduce more coverage redundancy. Therefore, in some cases where reliability is critical or high coverage sensing degree is demanded, these new schemes are more adaptive. In the future, we will do more research on both improving existing node scheduling schemes and developing new schemes. We can use the two-element tuple (degree, ID), degree is the number of a sensor node's neighbors, to replace the ID in ID-based scheme. This is because the more neighbors a sensor node has, the higher possibility that it can contribute much to the overall coverage if it is turned on. Therefore, we give this node low priority to turn on.

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