Managing Target Coverage Lifetime in Wireless Sensor Networks with Greedy Set Cover

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Abstract

The lifetime maximization problem in target coverage application can be addressed by the following question: how to partition sensors into an optimal number of sets and schedule their operating intervals so that the coverage requirement can be satisfied and the network lifetime can be maximized? In this paper, we address this problem by using cover set approach. A greedy algorithm that produces disjoints and non-disjoints set covers is proposed. Simulation results show good performance over some other solutions found in the literature that used the same paradigm.

1. Introduction

Wireless sensor networks are systems of small, low-powered networked sensing devices, often deployed over an area of interest (AoI) for events monitoring and/or performing application specific tasks. Coverage problem is one of the fundamental issues in wireless sensor networks. It refers to how well the sensors observe the physical space. In this paper we address the lifetime maximization problem in the context of target coverage application. We assume that several low power sensors are randomly deployed in an AoI where a finite set of targets with known locations have to be monitored. We propose a set cover based centralized approach that partitions sensors into a maximum number of set covers, and schedule sensors activities by activating these sets consecutively. At some point during the life time of the network, only a subset of the deployed sensors is activated, and all the sensors belonging to this subset are in charge of targets monitoring. All other sensors are in standby mode until the set to which they belong is activated.

We begin with Section 2 for reviewing related works from the literature. In Section 3, we first introduce the set covers generation strategy; secondly we present the proposed algorithm (Greedy-MSSC). Performance evaluation of our algorithm is presented in Section 4. Section 5 concludes this paper.

2. Related Works

Several works from the literature address the lifetime maximization problem by means of sensors' activities scheduling. Sensors can be partitioned in multiple disjoints or non-disjoints sets in centralized or distributed fashion. When building disjoint sets, sensors are partitioned into a maximum number of disjoints sets and sensors in one set are scheduled to be continuously active. Then the lifetime of the network is multiplied by an equal factor with the number of disjoint set covers [2-4]. With non-disjoints set covers, there each sensor can be part of multiple sets and the sum of energy expended by one sensor in all sets it belongs to is less or equal than its initial energy [5,6]. Proposed protocols in [2-6] are centralized in that they consider the presence of a base station, which is responsible for sensors repartition through set covers, as well as sensors activities' synchronization by periodically sending short beacons.

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3. Set Covers Generation

3.1. Selection strategy

In what follows, we define these variables such as: $S_0 = \{s_1,..,s_n\}$, and $Z_0 = \{z_1,...,z_m\}$ are respectively the initial set of sensors, and targets to be monitored. E_k represents the initial energy supply of one sensor s_k ; S^j is the subset of sensors that can monitor target z_j, and Z^k represents the subset of targets that can be monitored by sensor s_k ; finally e_i^k denotes the energy expense of s_k if set cover C_i is activated.

The number of sensors that cover the critical target (the most poorly covered target after the deployment) places an upper bound on the number of computable set covers. This bound is called the theoretical maximum. To compute the closest number of set covers to the theoretical maximum, the number of sensors in a set cover must be as minimum as possible. Hence, an efficient sensor selection strategy must be adopted. This latter must avoid including more than one sensor covering the critical targets in one set cover. Accurate selection can be achieved by designing a profit function,which represents the contribution of each sensor. We model this contribution by a profit function that evaluates the sensors' cost effectiveness. The cost effectiveness of s_k with respect to Z_0 is illustrated in equation (1).

$$w_{Z_0}^k = \sum_{z_j \in Z_0} \frac{p_j^k}{mE^k \sum\limits_{s_l \in S_0} \frac{p_j^l}{E^l}} \qquad (1)$$

Where p_j^k equals to 0 if sensor z_j is covered by s_k, and 1 otherwise.

3.2. Greedy-MSSC

We propose in this section a greedy set cover algorithm (Greedy-MSSC), which computes sensors' set covers. In our previous work [1], when building set covers, all available sensors were evaluated using the equation (1) and the sensor having the greatest cost is selected. We can avoid the cost effectiveness calculation for two reasons: i) if only one sensor covers the maximum number of targets, then it has the highest likelihood of being selected during this stage; ii) if multiple sensors cover the maximum number of targets, equation (1) can be applied for tie breaking. The algorithm might consume fewer resources during its execution. The pseudo-code of Greedy-MSSC is shown in Algorithm 1.

Algorithm 1: Greedy-Minimum Sensors Set Cover (MSSC)

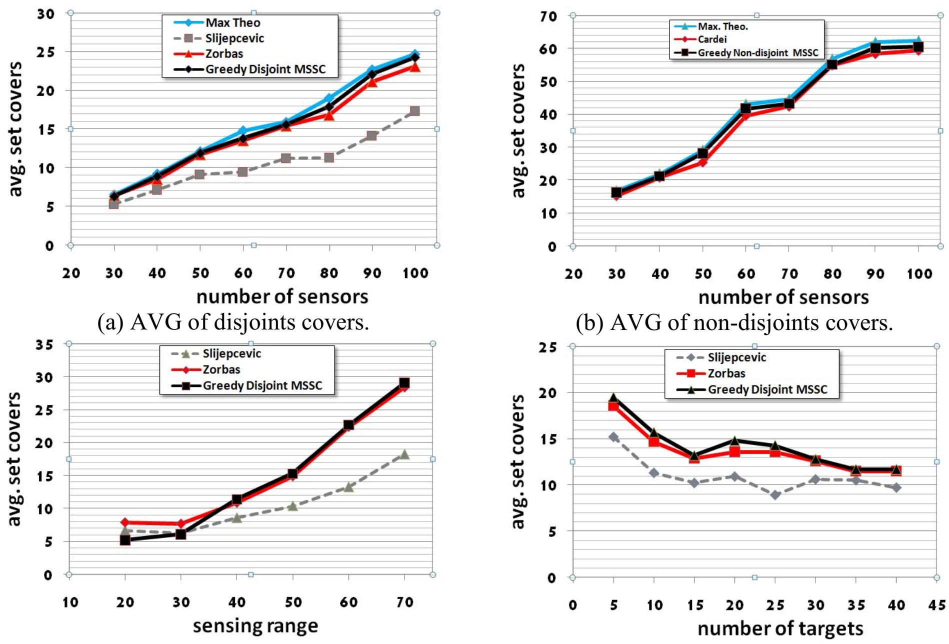
```
input  : Z_0 = {z_1, .., z_m}, S_0 = {Z^1, .., Z^n}
output: C_i

Uncvd = Z_0, C_i = φ;
while Uncvd ≠ φ do
    Evaluate all sensors s_k in S_0 with the ratio |Z^k ∩ Uncvd|;
    if only one sensor maximizes |Z^k ∩ Uncvd| then
        Pick this sensor (s_max) and goto 13 ;
    end
    if multiple sensors maximize |Z^k ∩ Uncvd| then
        foreach  s_k that maximizes |Z^k ∩ Uncvd| do
            Compute the cost effectiveness function w^k_{Z_0};
        end
        Pick the sensor (s_max) that has the maximum cost;
    end
    C_i = C_i ∪ s_max;
    Uncvd = Uncvd − Z^max;
end
Return C_i;
```

The process can be explained as follow. At the beginning all sensors send their coordinates to the BS, which is responsible for set covers calculation. The BS executes the algorithm and sends back the results to sensors for execution. The algorithm can be executed as long as there remain enough available sensors to form a set cover. Sensors set covers can be disjoints or not depending on their energy expense when the set cover they belong is activated. If sensors are activated continuously, until they run out of energy, then form disjoint set covers. When building non-disjoints set covers, sensors can be part of multiple set covers as long as they survive with enough residual energy. The approximation ratio of Greedy-MSSC is verified to be $\log(m)$, as it has been proved with the classical greedy set cover [7]. m is supposed to be the number of targets. When all available sensors are used during the execution of the algorithm, for set covers computation, the worst case complexity of Greedy-MSSC equals to $O(dn^2m)$, where d equals to the ratio $\frac{E_k}{e_i^k}$, the number of times that a sensor may be part of a set cover.

4. Performance Evaluation

We simulate a network with static sensors and target points randomly located in a 100m X 100m area. An implementation prototype of Greedy-MSSC is developed in MATLAB 7.0[1]. For topology generation, targets are spread first in the area by generating random coordinates, followed by sensors such that each target is covered by at least one sensor. We consider a sensor covers a target if the Euclidean distance between the sensor and the target is less than the sensing range.

In the first experiment, we vary S_0 from 30 to 100, fixing the Z_0 to 10, and the sensing range to 30 m. E_k is set to 1J and the runtime of each cover set equals 0.5 time units. In parallel with the evolution of the number of set covers for disjoints and non-disjoints sets when sensors number increases, we can remark the closeness of our results with the theoretical maximum. These results highlight the efficiency of our cost effectiveness function, which enables sensors' cost-effective selection.



(a) AVG of disjoints covers. (b) AVG of non-disjoints covers.

(c) AVG of covers vs sensing range. (d) AVG of covers vs number of targets.

Figure 1: Average of computed set covers after ten times execution.

[1] www.mathworks.fr/products/matlab/

Beside the closeness of our algorithm with the theoretical maximum, we compare the average of set covers computed by disjoint Greedy-MSSC, MC-MCh[2] and B{GoP}[4], and secondly we compare non-disjoint Greedy-MSSC with Greedy-MSC[5]. We consider the same parameters of the first experiment, and we drive the simulation 10 times before plotting the mean values of the number of set covers in figures (1.a) and (1.b). Considering the disjoint set covers, simulation results show a constant evolution and superiority tendency when we compare our algorithm with the other ones. The distance between the results in [2] and the other ones shows that the adopted strategy for managing the critical targets does not guarantee the lack of multiple targets covering. So each time a new set cover is built, there is at least one target covered more than one time. Finally, we vary the number of targets and the sensing range to observe the impact on the number of set covers. The general remark is that the same tendency is kept in figure (1.c) and (1.d). Clearly when the sensing range increases, this may improve consistently the number of sets since each sensor may cover more targets. This implies a growth in the coverage redundancy, which may increase the number of sensors that cover the critical targets. When the number of targets increases, the likelihood of the coverage redundancy may be reduced, and the number of set covers may also decrease.

5. Conclusion

When several low-power sensors are dispersed in a field to monitor a finite set of targets, managing sensors energy dissipation becomes essential to obtain a long-lived network. A well-known mechanism to perform energy saving is to schedule sensors activities, such as to keep active only the optimum necessary to satisfy the coverage requirement. To achieve this, we used the set cover approach and proposed a greedy algorithm that selects a minimum possible number of sensors to cover the entire set of targets. Performance evaluation of our greedy algorithm shows some improvement over other works from the literature based on the same approach.

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