AN ENERGY EFFICIENT COVERAGE GUARANTEED GREEDY ALGORITHM FOR WIRELESS SENSOR NETWORKS LIFETIME ENHANCEMENT

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Abstract:

One of the most significant difficulties in Wireless Sensor Networks (WSNs) is energy efficiency, as they rely on minuscule batteries that cannot be replaced or recharged. In battery-operated networks, energy must be used efficiently. Network lifetime is an important metric for battery-powered networks. There are several approaches to improve network lifetime, such as data aggregation, clustering, topology, scheduling, rate allocation, routing, and mobile relay. Therefore, in this paper, the authors present a method that aims to improve the lifetime of WSN nodes using a greedy algorithm. The proposed Greedy Algorithm method is used to extend the network lifetime by dividing the sensors into a number of disjoint groups while satisfying the coverage requirements. The proposed Greedy algorithm has improved the network lifetime compared to heuristic algorithms. The method was able to generate a larger number of disjoint groups.

1 Introduction

Wireless sensor networks (WSNs) are a collection of sensors, computers, and other devices that can perceive, compute, and communicate with one another via a wireless channel. They can be used for a variety of purposes, including environmental monitoring, habitat study, and military surveillance and reconnaissance. They can also be used in search and rescue situations, in industries for condition-based maintenance, smart home implementation, and many more applications. Nowadays, large quantities of sensors are deployed in a high-density for getting high resolution of the environment. The deployment of wireless sensor nodes is one of the most crucial issues in the development of WSN protocols. Node deployment can be random or deterministic.

The Deterministic approach allows senor nodes to be sited at prearranged stations to achieve the required expected lifetime, connectivity and coverage. However, this approach is suitable to limited setups, such as office buildings, factories, hospitals and so on. In hostile situations, such as battlefields, deserts, forests, a predetermined sensor nodes arrangement is problematic to execute. In such scenario, nodes are deployed by air dropping from an aircraft or dispersed in other means, resulting in a random placement [1]. The majority of randomly deployed WSN applications are designed to monitor a region or a collection of targets by deploying in huge numbers. If the deployment is random then it requires special self-organizing communication protocols resulting in a multi-hop communication. As a result, routing becomes challenging and communication suffers from a considerable overhead, which affects node resources. Many of the issues unique to sensor networks stem from the severe limitations of each sensor node resources, namely; energy and computational resources. Since it is very difficult to recharge batteries in remote environments, optimizing power consumption is critical to improve the lifetime of WSNs. Network lifetime is perhaps the most important metric for evaluating sensor networks. It is defined as the amount of time before the sensor runs out of energy [2]. If each sensor operates in a continuously active state for the duration of one unit of time, then continuous

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activation of all sensors results in a total network lifetime of one unit of time as well. In other words, the effective operating time of a network, sometimes referred to as lifetime, is limited. Therefore, network longevity is an important consideration in the development of WSN applications. To extend the network lifetime, a number of energy-efficient protocols have been proposed. Several approaches are available to maximize the network lifetime such as data aggregation, clustering, topology, scheduling, rate allocation, routing, and mobile relay. The proposed method uses a greedy algorithm to extend the network's lifetime by dividing the sensor network into several sets.

The algorithm follows a problem-solving heuristic of choosing local optimal at each stage with the hope of getting a global optimum by iteratively making one greedy choice after another. The remainder of the paper is structured as follows. The related study for wireless sensor network lifetime improvement is described in Section 2. The system model and specifics of the proposed greedy algorithm are presented in Section 3. The simulation results are addressed in Section 4, and the important conclusions of the paper are summarized in Section 5.

2 Related Works

In [3], [4], WSNs routing protocols categories are listed. But the recent energy-efficient mechanisms that are used for mobile sink and multi-sink are not included. Several energy-aware routing protocols considering factors such as mobility, data cycling, topology control, and data-driven techniques are mentioned in [5], [6]. Authors in [7], [8] presented a survey of Target coverage, which is a key metric of quality of service (QoS). The authors stated that at least one sensor should be able to detect each target in the physical region of interest. The authors modeled sensors as disjoint cover sets, with cover sets (i.e. a set of sensor nodes) monitoring all targets entirely [9].

The Maximum Set Covers (MSC) problem, on the other hand, was shown to be NP-complete and was reduced to a maximum flow problem, which was then modeled as mixed-integer programming [9]. They transformed the problem of Disjoint Set Covers (DSC) maximization into a maximum-flow problem (MFP) for maximizing the number of DSC. Authors in [10] took this difficulty a step further by allowing sensors to participate in and be active in many sets. Linear Programming (LP)-MSC and greedy-MSC are two heuristic techniques developed to tackle the MSC problem. The authors demonstrated that the greedy-MSC algorithm is less difficult than LP-MSC and that greedy-MSC improves network lifespan better than LP-MSC. The maximum number of DSC was determined using a genetic approach by the authors in [11]. In addition, the study established an upper bound for key targets. Using heuristics and a binary integer programming framework, it was shown in [12] that increasing the number of DSC could lengthen the WSN's lifetime. A greedy algorithm called B{GoP} was proposed in [13] to produce disjoint sets by modifying the sensor's selection strategy that considers their coverage status. Authors in [14] proposed a greedy algorithm by improving the B{GoP} algorithm that generates non-DSC.

Two variations of the algorithm were presented; the static CCF and the dynamic CCF, differing on the way the weight used for describing a sensor association with a critical target is calculated (i.e., statically or dynamically). Critical target is a target covered by set of sensors in which the sum of the energy of the sensors covering this particular target is less than or equal to the sum of sensors energy consumed for covering each of the other targets.

3 Methodology

This section explicitly details the proposed system model and the proposed greedy algorithm for WSN lifetime enhancement. The following notations are used throughout this paper for describing the problem.

Table 1. List of Notations.

Symbol	Notation
S	Set of sensors $\{s_1, s_2, s_3..., s_m\}$
T	Set of Targets $\{t_1, t_2, t_3, ..., t_n\}$
$\|S\|$	The number of sensors in S
$\|T\|$	The number of targets in T
$S(t_j)$	Set of sensors that can cover target j
$T(s_i)$	Set of targets that sensor i can cover
E_i	Initial energy of sensor i
C_l	The l[th] set cover, $l = 1, 2, 3, ..., q$
$\|C_l\|$	Number of sensors in set cover C_l
$T(C_l)$	Set of targets that cover set C_l can cover
L_i	The network lifetime for sensor s_i
L	Network lifetime

The network lifetime for sensor s_i is given by:

$$L_i = \frac{\text{Initial Energy}}{\text{Energy Consumption per unit time}} = \frac{E_0}{E_i} \tag{1}$$

The total network lifetime of a WSN is given by then:

$$L = \min_{i=1,2,3,...m} L_i \tag{2}$$

3.1 Disjoint Set Covers

In DSC the available sensors are partitioned into disjoint subsets of sensors that are to be activated consecutively. All sensors are considered to have the same amount of initial energy and consume the same amount of energy. If a set cover is set to remain active indefinitely, all of the sensors in the set cover will die at the same time. Each DSC is active until it dies, and then the rest of the DSC are activated one at a time. The goal coverage duration in this case is equal to the number of set covers multiplied by the runtime of a single set cover.

The goal of the lifespan maximization problem can then be reduced to finding the greatest number of DSC that satisfy the coverage constraints. For complete target coverage all targets should be covered all the time. The complete coverage requirement is given by Eq. (3) [15].

$$(T, C_l) = \begin{cases} 1 & if\ T(C_l) = T \\ 0 & otherwise \end{cases} \tag{3}$$

Given a finite set $S = \{s_1, s_2 ... s_m\}$ of m sensors and a finite set $T = \{t_1, t_2 ... t_n\}$ of n targets, an element denoted C_l of the collection C of sensors subsets is a cover for the subset of targets denoted $T(C_l)$, if it can sense all the targets of $T(C_l) \subseteq T$,($l \in \{1,\cdots, q \leqslant m\}$), where:

- Each target t_j is covered by at least one sensor of S.
- Each sensor s_i sense a subset $T(s_i) \subseteq T$ of targets.
- For all $i \neq j$, $T(s_i) \cup T(s_j) = T(s_i, s_j)$ is a subset of targets sensed by the pair (s_i, s_j).
- A subset C_l is considered as a cover if $T(C_l) = T$.

As a result, the WSN's lifetime could be optimized by determining the maximum number of covers that could be used for the longest time. According to the DSC paradigm, each sensor is used in one cover for all of its available energy and life. Given a collection C = $\{C_1, C_2, ..., C_q\}$ of subsets of S, a DSC C_l ε C is a part of S denoted as $S(C_l)$ such that all element of S belongs to one and only one cover C_l (l = 1,…,q) and $|S\ (C_l)| \leqslant m$, i.e., for all $l \neq h$, $C_l \ \cap C_h \ = \emptyset$. Based on the descriptions above, the WSN lifetime maximization problem, which is based on energy consumption optimization, can be considered as a combinatorial optimization problem, with the goal of finding the optimum combinations of sensor sets that maximize sensor network lifespan. Under the following constraints [16-18], the goal function is the number of disjoint sets covers as a representation of the network lifetime:

- A sensor can be included in one set of covers at most.
- Each DSC should have sensors that can monitor all of the targets.

The primary function, assume that the cover C_l is set to monitor the targets T for a period k of time units equal to y_l, and that the maximum number of covers is q. As a result, the following Objective function must be maximized to maximize the lifespan.

$$Maximize \sum_{l=1}^{q} y_l \tag{4}$$

Subject to:

$\sum_{l=1}^{q} R_{il}\ E_i\ (y_l) \leq\ E_i$ i =1, 2, 3...m (Energy constraint)
$\{C_l\}$ = T for all C_l (coverage constraint)
$C_l \cap C_h = \emptyset$ for all l≠h (disjoint constraint)
$(S_i, C_l) \in \{0, 1\}$ for all S_i, C_l (inclusion constraint)

The energy constraint is written as: If the total energy required by a sensor s_i for a period of time k is E_i(k), and sensor s_i can be included in every cover C_l, which can be scheduled for a number of times y_l, (l = 1,…, q and R_{il} = 1), then

$$\sum_{l=1}^{q} R_{il} E_i(y_l) \leq E_i\ i = 1,2, \dots, m \tag{5}$$

$$R_{li} = \begin{cases} 1 & \text{if sensor } i \text{ is included in cover } l \\ 0 & \text{otherwise} \end{cases}$$

As a result, the best solution is one that can provide the values of $y_1, y_2 \dots y_q$ with a maximum sum, while not surpassing the sensor's starting energy, E_i. If a set cover C_l is set to monitor all the targets T for a number of periods y_l, each of which lasts k units of time, and the maximum number of covers is q, the lifetime is represented as:

$$L = k \sum_{l=1}^{q} y_l \tag{6}$$

For a WSN with m sensors and q possible covers, Eq. (5) can be utilized to produce m linear inequality constraint equations with q unknowns. As a result, the linear programming optimization technique may be utilized to determine the unknown values that optimize the linear objective function L in Eq. (4). Assume a set of q covers could be found from randomly deployed sensors set S and a set T of targets. Then one can find the q covers through the coverage relations matrix denoted R, using the individual coverage relations matrix M, in two steps as follows:

Let's create the individual cover relations matrix M:

$$M = M_{ij} = \begin{bmatrix} m_{11} & \cdots & m_{1n} \\ \vdots & \ddots & \vdots \\ m_{m1} & \cdots & m_{mn} \end{bmatrix}$$

$$M_{ij} = \begin{cases} 1 & if\ sensor\ i\ can\ cover\ target\ j \\ 0 & otherwise \end{cases}$$

In this matrix, a row *i* includes the set T(s_i) of targets that sensor s_i covers and each column *j* includes the set *S(t_j)* of sensors that can cover target tj.

Let's create the set covers matrix R, which models the relations between m sensors and q covers as follows:

$$R = R_{li} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{q1} & r_{q2} & \cdots & r_{qm} \end{bmatrix}$$

$$R_{li} = \begin{cases} 1 & if\ sensor\ i\ is\ included\ in\ cover\ l \\ 0 & otherwise \end{cases}$$

Due to the binary relations of sensors into covers, the total number of possible covers becomes q = 2^m - 1. In this matrix R, a row is a potential cover. The solutions set will include this cover if the latter can cover all the targets as a constraint. The following steps intend to find from R the set covers that can meet the total coverage constraint.

1) Thus, for each row in *R*, the set of targets covered by the included sensors must be equal to T. Now, finding a set cover with the minimum number of sensors in *R* is possible. From the previous step, each row with a set of sensors covering totally all targets is a candidate cover. The summation of each row in *R* gives the number of sensors in this cover.

2) Thus, finding the cover with minimum sensors is finding the row with the minimum sum. Recall back the DSC, when the covers are found, there are no additional efforts required for scheduling and finding the optimal energy distribution through the covers because there is no shared sensor among DSC. Now removing the DSC constraint, a sensor has the opportunity to join more than one cover. To maximize lifetime, we solved a second subproblem consisting of determining the maximum time a sensor from *S* must spend with each cover.

3.2 Greedy Algorithm for Generating DSC

In the disjoint set-covering (DSC) problem the data consist of finite sets *S* = *{*s_1, s_2 ... s_m*}* and positive numbers *C* = $\{C_1, C_2, ..., C_q\}$. denote ∪(s_j : 1 ≤ j ≤ m) by *I* and write *I= {1, 2, ..., m}*, *J = {1, 2, ..., n}*. A subset *J** of *J* is called a cover if $\cup\ (s_j\!: j \in J^*) = I$; the cost of this cover is $\sum(c_j\!: j \in J^*)$. The issue is to find a cover that uses the least amount of energy. The set-covering issue is well-known for being difficult; indeed, it is known to be NP-complete. The relative importance of heuristics for addressing the set-covering issue grows as a result of this fact. The purpose of this note is to establish a tight bound on the worst-case behavior of a rather straightforward heuristic.

The following shows the steps for generating the optimal DCS in the greedy algorithm.

Step 0: Set J* = (∅).

Step 1: If S_j = (∅) for all j then stop: J* is a cover. Otherwise, find a subscript k maximizing the ratio $|S_j|/C_j$ and proceed to Step 2.

Step 2: Add k to J*, replace each by $S_j = S_j - S_k$ and return to Step 1.

Figure 1 shows the flowchart of the greedy coverage algorithm. To keep track of available sensors two sets (S_a and S_c) and Two (2) nested loops are used in the flowchart. S_a contains sensors available for future cover sets use and S_c stores current cover set sensors. Once a sensor is selected it is removed from S_c, avoiding the sensor inclusion into multiple cover sets. An inner loop for finding targets to be covered by a given cover set (C_i) sensors while an outer loop searches for the availability of sensors. At a time one sensor is selected for possible inclusion into a cover set (C_i). When a cover set contains enough sensors that can cover all the targets, that particular cover set is then considered to be complete. All cover sets that are complete are then included into the cover set collection (C). If there are no more available sensors within S_a, the search terminates by returning cover set collection (C).

Pseudocode of the Greedy Algorithm

1. Set lifetime of each sensor to *1*
2. SENSORS = S
3. *l=0*
4. **while** each target is covered by at least one sensor in SENSORS **do**
5. /*a new DSC C_l will be formed*/
6. ***l = l + 1***
7. $C_l = \o$
8. TARGETS = T
9. **while** T $\neq \o$ **do**
10. find a critical target $t_c \epsilon$ T
11. select a sensor s_i ϵ S with the greatest contribution, that covers t_c
12. $C_l = C_l \cup s_i$
13. **for all** targets t_n ϵ T **do**
14. **if** t_n is covered by s_i **then**
15. T = T -t_n
16. **end if**
17. **end for**
18. **end while**
19. **for all** sensors $s_a \epsilon C_l$ **do**
20. lifetime s_a = lifetime s_a-*r*
21. **if** lifetime s_a == 0 **then**
22. S = S- s_a
23. **end if**
24. **end for**
25. **end while**
26. return q-number of disjoint sets covers and the DSC C_1, C_2, ..., C_q.

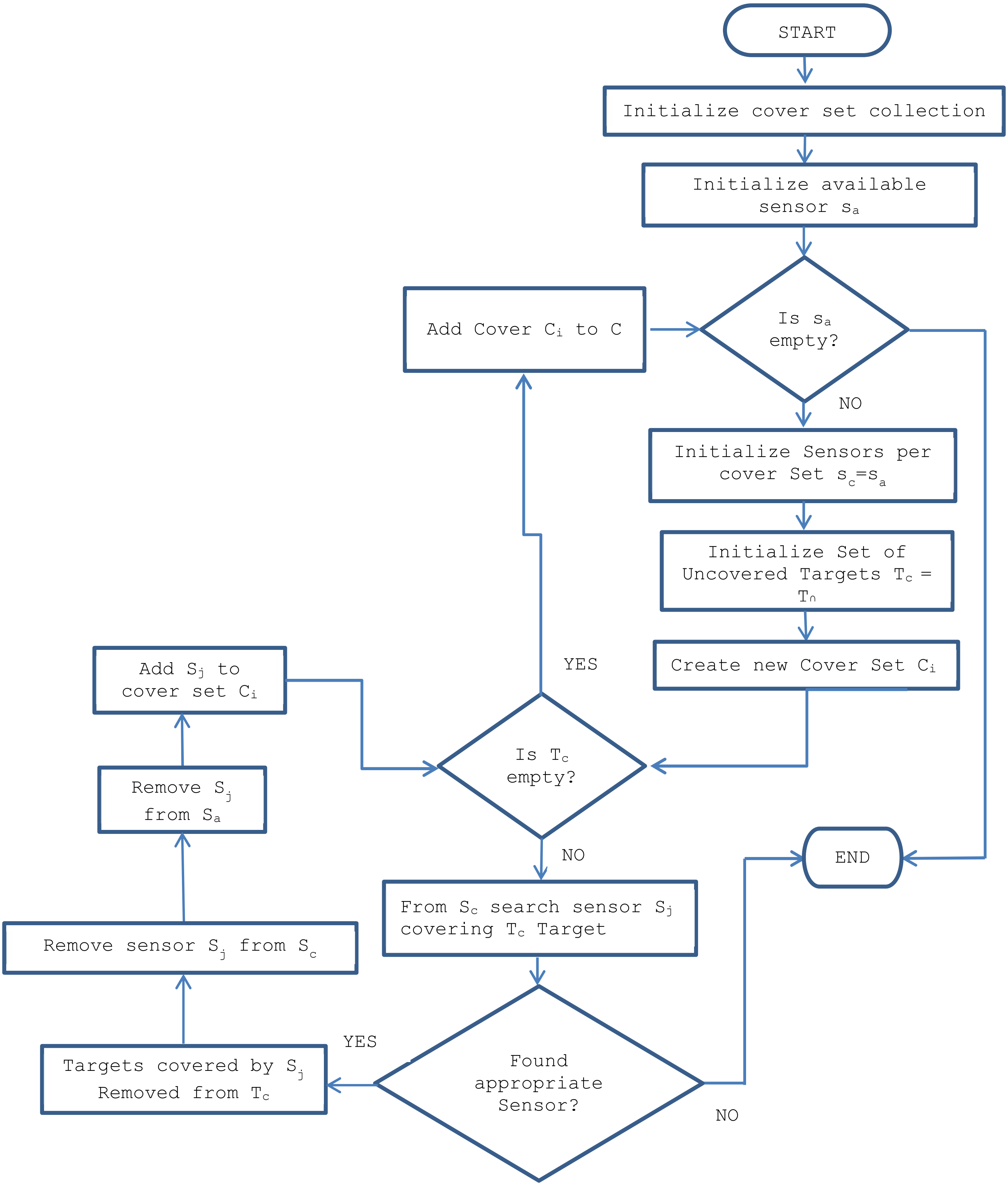

Figure 1. Flowchart of the greedy algorithm.

4 Results and Discussion

A two dimensional 100m by 100m stationary network area with static targets and randomly deployed sensors around the targets is simulated. The number of targets is also constant. Several low power homogeneous sensors are deployed. The initial energy, lifetime and range of each sensor are assumed to be equal. The death energy was set to 5% of Smax. Within these simulations the number of targets, and the number of sensors were set to 50, and 100, respectively. Each experiment setup was simulated 10 times and then the mean network lifetime was computed.

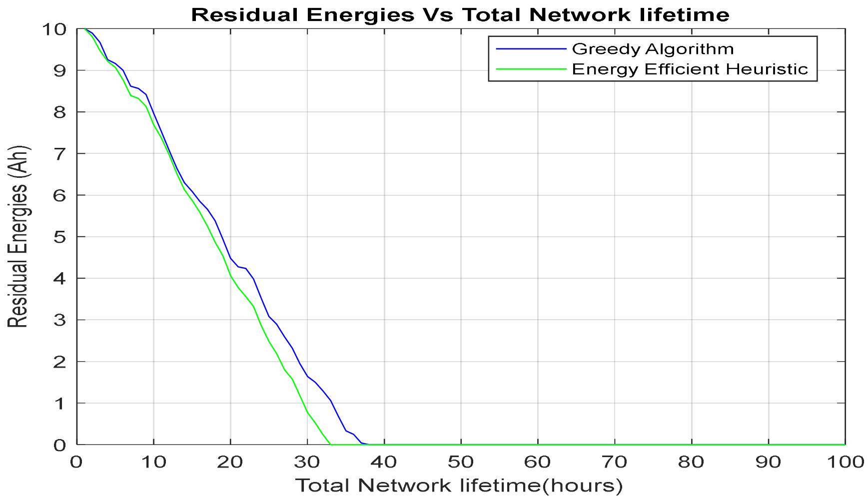

Figure 2. Total network lifetime DSC at 2.

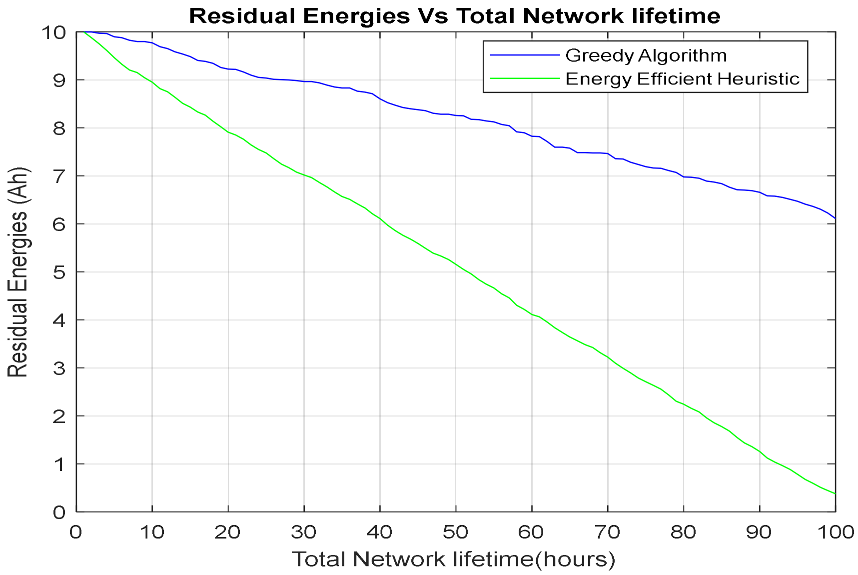

Figure 3. Total network lifetime DSC at 5.

Figure 2 and 3, show the results obtained for the evolution of the network lifetime while increasing the number of DSC. The lifetime of the network in using DSCs is equal to lifetimes of one set cover times the number of disjoint sets. Figure 2 and 3 show that the lifetime of the network is highly improved when DSCs are produced in the greedy algorithm. This remark becomes more interesting when the number of DSC is increased.

The disjoint constraint associated with the target's coverage redundancy has improved the network lifetime. Using Greedy algorithm, the Mean lifespan and improvement at DSC 2 is 44 hours, while it is 38 hours for the Heuristic. At DSC 5 the Mean lifespan for the Greedy algorithm and the Heuristic method is 225 and 87 hours, respectively. Consequently, the result shows that the greedy algorithm performing better than the heuristic. Moreover, the network lifetime improves with the increasing DSC. The Greedy algorithm optimally generates DSCs.

5 Conclusion

This paper presented a greedy approach for enhancing the lifetime of WSNs. The suggested approach is based on the solution of a lifetime maximization problem, in which the goal is to identify the greatest number of DSCs that match the coverage conditions. In the active state, all sensors are considered to have the same amount of initial energy and consume the same amount of energy. Each DSC is active until it dies, and then the rest of the DSCs are activated one at a time.

The goal coverage duration is equal to the number of these set covers multiplied by the runtime of a single set cover in this configuration. The algorithm run time is relatively slow when compared to the energy-efficient heuristic approach that leads to a local maximum solution. However, the algorithm suggested in this paper outperformed the competition.

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