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Proficient QoS-Based Target Coverage Problem in Wireless Sensor Networks

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ABSTRACT Assuring the coverage towards the predefined set of targets, power-constrained wireless sensor networks (WSNs) consist of sensing devices (i.e., sensor nodes) that are associated with limited battery life and fixed sensing range. All the sensors are collectively responsible for covering these sets of objects. The standard target coverage problem is the one where continuous coverage is provided over a predefined set of targets for the maximum possible duration so that the scarce resource (battery power) can be optimally utilized. Therefore, in order to incorporate quality of service (QoS) in the network and ensure smooth monitoring of the desired target set, the paper addresses target Q-Coverage, which is one of the variants of standard target coverage problem where a target is covered by at least Q-sensors (pre-defined number) in every cover set. A cover set is a subset of sensors which cover whole targets in a single iteration. In this paper, a greedy heuristic based technique, i.e., maximum coverage small lifetime (MCSL) has been proposed, which restricts the usages of those sensors that poorly cover targets and promotes the usage of those sensors that have maximum coverage and energy. Simulations are performed on static wireless sensor network with varying Q values to test the efficiency of the proposed method. The performance of the proposed heuristic is compared with optimal upper bound based on network lifetime, and results prove that performance is improved by 94%. The obtained results are further compared with the existing approaches to prove the superiority of the proposed work via extensive experimentations.

INDEX TERMS Coverage constraint, critical target, energy-efficient network, maximum coverage small lifetime, maximum lifetime target coverage, q-coverage.

I. INTRODUCTION

Wireless sensor networks (WSNs) have enormous applications that are related to military, environment, health, entertainment, transportation, crisis management, smart spaces, and disaster prevention [1]. WSNs consist of a large number of sensing devices known as sensor nodes with associated battery life and sensing range. A sensor node can monitor the environment, falling within its sensing range. Depending on the application requirement and feasibility, sensors can be deployed either randomly or deterministically [2]–[4]. Coverage in WSNs is defined as “how well sensors monitor

a sensor network”. In literature, broadly three categories of coverage are addressed, based on the types of coverage of the subject, which includes area coverage [5]–[8], target coverage [9]–[12], and barrier coverage [13]–[17].

While providing area coverage, the primary objective is to divide the total designated area into smaller parts and then form subsets of sensors in such a way that each subset is capable of monitoring all the parts of that area. Similarly, in target coverage, one has to schedule the sensors’ activity in such a way that at a given instance, a subset of sensors covers all the targets.

The brute force strategy is the one where one can activate the complete set of deployed sensors at a time to ensure full coverage over the provided region and is used

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to cover defined set of targets. As mentioned earlier, sensors have a limited battery life; therefore, this method is not appreciated [18], [19]. In order to efficiently utilize sensors' limited energy, it is advisable to constitute a subset of sensors called sensor cover or cover sets such that each cover is capable of covering all the targets in the given terrain [20], [21].

In general, the sensor gets operated in two major modes: active and sleep mode [22], [23]. During active mode, a sensor can be a part of currently activated sensor cover (collection of nodes monitoring the full target set) to collect information in the surroundings while in the sleep state, the sensor is turned off for the time being to save energy.

Since wireless sensor network is power-constrained, energy-efficiency is a crucial issue [24]–[26]. Therefore, by alternating the sensors' state between these two modes, the overall network's functional duration can be maximized by activating only a few sensors (subset) at a time so that they entirely cover the complete target set. This ensures the remaining sensors to go into sleep mode. Thus, the sensors' scheduling mechanisms play a vital role, which directly impacts the network's lifetime. The network lifetime is the period during which all the targets are covered [27], [28]. Hence, the primary concern of all the coverage heuristics is to maximize the number of cover sets in order to increase the total network lifetime.

In regular target coverage problem, a cover set is capable of covering each target by at least one sensor. Such type of coverage is enough for those applications, which includes indoor surveillance, environmental or habitat monitoring. Sometimes, the coverage requirement may change for the same application depending on the situation. For example, to detect fire in dense forest, the requirement of coverage may be high during the dry season, whereas it is low in the rainy season. Further, the level of coverage is high for video surveillance systems while monitoring territorial activity in the desired military area. Thus, in such scenarios, merely covering all the targets is not the only concern, specifically so when the quality of coverage also matters.

In order to achieve this, a QoS parameter is calculated, which is measured for each cover set. Further, this QoS parameter is different for different applications as the degree of coverage varies for every other application. For example, one application works efficiently when targets are covered by a cover set in such a way that at least one sensor should be there in cover-set to monitor each target while another application require different degree of coverage (i.e., targets need to be monitored not only with one sensor in cover set but with multiple sensors simultaneously). Apart from this, if any environmental change takes place once the sensor network has been deployed, the coverage requirement may change. Such quality-based coverage is known as Q-Coverage, where pre-defined Q-number of sensors must monitor a target under every cover set, and such cover set is known as Q-Cover.

The major objectives of this paper are:

- 1) Designing a novel metaheuristic titled "Heuristic with Maximum Coverage Small Lifetime" to solve Q-coverage issue in WSN.
- 2) Extensive simulation and experimentation of proposed metaheuristic- MCSL on varying values in MATLAB.
- 3) Detailed analysis and performance comparison of the proposed MCSL approach with Greedy and HESL techniques to determine the improvement in coverage and network lifetime performance for different values of w .

The rest of the paper has been organized thus: Section II defines target Q-Coverage and presents the working model. Section III highlights the existing literature produced by several researchers about target full coverage, target connected coverage, partial coverage and target Q-Coverage. Section IV elaborates the motivation behind the proposed heuristic and discusses the varied definitions and terminologies. Section V gives detailed, in-depth coverage of proposed heuristic for Q-Coverage problem solution and network lifetime enhancement. Section VI covers simulations and experimentations performed with the proposed approach to test the overall performance as compared to existing methods. Section VII concludes the paper with future scope.

II. TARGET Q-COVERAGE PROBLEMS

In this section, the system model and linear programming formulation is highlighted.

A. SYSTEM MODEL

In a given deployed network, let TARGETS = $\{t_1, t_2, \dots, t_n\}$ be the set of targets which are covered by SENSORS = $\{s_1, s_2, \dots, s_m\}$, set of sensors. Here, it is assumed that nodes are randomly deployed and every sensor s_i is associated with energy E_i and sensing range R_i . It is assumed that a target t_i is covered by a sensor s_j if the sensing range of s_j completely covers target t_i . The Q-Cover, S_q , is defined as the collection of sensors which collectively cover each and every target by Q-number of sensors. Every Q-Cover is assigned working time w , which is either minimum battery of a sensor participating in the given Q-Cover or user-defined. Network lifetime (N_{life}) is represented as the sum of all these weights (w) respective to each cover set. While generating Q-Covers, one has to ensure that not even a single sensor is used more than its initially allotted battery life (E_i). The standard Q-Coverage is discussed in many research works, and further, it is shown NP-Complete [8], [29].

B. LINEAR PROGRAMMING FORMULATION

The above-defined Q-Coverage problem can be represented as a standard linear programming formulation. In order to define that, a constraint matrix LP is defined in equation (1).

$$LP_{ij} = \begin{cases} 1, & \text{if sensor } s_i \in S_j(Q - \text{Cover}) \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

The Q-Coverage problem's linear program is defined in equation (2).

$$\begin{aligned} & \text{Maximize } \sum_p w_p \\ & \text{subject to } \sum_p LP_{ip} w_p \leq E_i \quad \forall s_i \\ & w_p \geq 0, \quad \forall Q - \text{Covers } S_p. \end{aligned} \quad (2)$$

The defined matrix, LP is known in advance only if one can compute the complete set of covers beforehand. Due to the dense network, it is not possible to generate all the Q-Covers in advance; therefore, none of the conventional algorithms can be applied to solve the linear programming as LP is not known explicitly.

III. LITERATURE SURVEY

As discussed in section I, the environmental coverage in wireless sensor networks can be broadly classified as area coverage, target coverage, and barrier coverage. The scope of this paper is limited to target coverage, and this section covers recent contributions towards various variants proposed by other researchers, which includes target full coverage, target connected coverage, target partial coverage, and finally, target Q-Coverage. All the algorithms on coverage perform the same task (provide coverage), but the process to constitute cover set differs.

A. TARGET FULL COVERAGE

Cardei *et al.* [29] presented the regular target coverage problem as the maximum set covers problem and proposed a linear program and greedy approach to solve the target coverage issue. The addressed greedy method tries to give priority to those sensors which have maximum available battery life and covers maximum uncovered targets while forming a cover set. The generated cover sets are non-disjoint in nature, whereby a sensor can participate only once in the cover set formation process.

Manju *et al.* [30], [31] proposed energy-based heuristic to extend the network lifetime further. They introduced a heuristic to constitute cover set with the objective of prioritizing sensors based on remaining energy and coverage of the poorly covered target. By doing so, the generated cover set may have redundant coverage, so energy consumption is minimized. The same strategy was followed in [31], where a meta-heuristic was proposed to form a cover set for the target coverage problem. Saadi *et al.* [32] proposed a maximum lifetime target coverage (MLTC) heuristic, which depends on minimally covered target (covered by least sensors). The proposed algorithm calculates the upper bound by observing such least covered targets and design subsets to monitor targets iteratively. Katti [33] suggested another energy-efficient method that generates both types of cover sets that is disjoint and non-disjoint. After creating these sets, an optimized path is constructed that connects the cover set and the sink node.

B. TARGET CONNECTED COVERAGE

A sensor network is termed as connected only if, any live node is capable of communicating with the rest of the network nodes either directly or by making use of their next-hop neighbor nodes. There are many applications in sensor network, where merely providing coverage is not sufficient; instead, the nodes selected in the cover set have to be connected to the base station where they can forward their collected data for further processing. While finding such path towards base station, the major aim is to select the least required sensors so that the generated path consumes less power. In literature, such type of coverage with connectivity is called connected target coverage. There are many research works which deal with providing connected coverage [12], [22], [34]. Roselin *et al.* [22] proposed heuristic with three QoS metrics, namely residual energy of sensors, target coverage, and finally connectivity via relay nodes among the nodes to provide target coverage towards the base station. The proposed heuristic selects those nodes as relay nodes that do not contribute to the current cover set. By doing so, the burden on active sensors is reduced.

Qin *et al.* [34] aimed to reduce coverage holes caused by over usage of the same set of sensors for providing coverage as well as connectivity in consecutive iterations via constructing intersection connected sensor cover with updated energy and coverage. The methodology prolongs the total network lifetime and also reduces computation overhead in the deployed network. Wang *et al.* [12] proposed an energy-based coverage heuristic to provide connected coverage. The proposed method utilizes Particle Swarm Optimization (PSO) paradigm to maintain a balance between energy cost and coverage by merely adjusting the sensing range of sensors.

C. PARTIAL COVERAGE

These days, another promising variant of regular coverage problem is addressed by many researchers [35], [36], [37]. It is observed in specific applications that to make deployed network functional for extended hours, one can avoid covering a fraction of the target in each cover set. This type of coverage is called partial coverage and also known as α -Coverage. Manju *et al.* [35] proposed a greedy heuristic to extend the total network lifetime where a fraction of targets is not covered in each cover set.

In order to form a cover set, they prioritize sensors based on remaining energy and coverage of maximum targets, which are not yet covered. In this process, the generated cover set may not be minimal, so, the cover set is minimized by removing extra sensors. Carrabs *et al.* [36] proposed a method for combining the column generation approach and meta-heuristic, which is partially inspired by the genetic algorithm paradigm. The strategy aims for prolonging network lifetime for α -Coverage by designing energy-based fitness function, which forms cover set in the form of chromosomes. Further, work by Castaño *et al.* [37] addressed a column generation based hybrid approach that is used to form a cover set to

schedule in successive iterations. In this approach, constraint programming based strategy was used.

D. TARGET Q-COVERAGE

The quality of coverage becomes a vital need to make the network fault-tolerant, providing security (primarily in-house monitoring), or collecting peculiar data (during military operation). In such critical applications, the deployed network is not only supposed to provide coverage instead, it has to ensure quality of coverage (i.e. Q-Coverage) [38]. Since lots of research has been done to extend network lifetime by applying various methodologies [39]–[42] for other variants of coverage, this section gives deep insight into the Q-Coverage only, addressed in [43]–[46].

In order to provide Q-Coverage, one has to give a scheme so that every target is covered by a pre-specified number (Q) of sensors in every Q-Cover. Literature reveals various recent works pertaining to it. [38], [45], [47], [48]. Chaudhary and Pujari [38] addressed the problem by proposing an energy-based approach (named as HESL) where a sensor with higher remaining power will be given priority to be a part of the current Q-Cover. The objective behind this strategy is to keep sensors alive with less residual energy so that the network remains operational for an extended time. Jiguo *et al.* [45] proposed another heuristic for calculating network lifetime by providing K-Coverage (i.e., Q-Coverage). While designing cover sets, a three-fold criterion is proposed, which includes sensor converge, remaining energy, and K-Coverage to the uncovered targets. Thus, nodes that fulfil this condition at once will stay active otherwise, they go into a sleep state. Next, this work also ensures connectivity of the nodes of cover set to the central sink either directly, if they are one hop far from sink or through relay nodes. ÖZDAĞ [47] proposed EM-based algorithm to extend the functional network duration when achieving the solution for the target Q-Coverage variant. The EM is a meta-heuristic that simulates the pulling and repulsive both types of movements of any charged particles placed in a predefined electromagnetic field [48]. The proposed meta-heuristic algorithm tries to optimize the battery usage while forming cover sets by minimizing energy consumption.

Most of the addressed heuristics algorithms [38], [45], [47] to obtain network lifetime for target Q-Coverage problems have not given attention to the poorly covered target (called critical target). Since the coverage of poorly covered target is the deciding factor, as shown in the subsection IV. However, to calculate upper bound on the achievable network lifetime, the usage of such critical targets has to be limited. In order to maximize the network lifetime, our proposed heuristic tries to keep these critical targets alive for a longer period by limiting their role in each cover set.

IV. MOTIVATION

LP formulation discussed in section II for target Q-Coverage problem is hard to solve because it is computationally complex due to the unpredictable (maybe exponential) size of

matrix LP. Most of the approaches discussed so far in the literature aim at prolonging the network lifetime. In order to follow the same progress, a new energy proficient heuristic algorithm is proposed. For the sake of a deep understanding of new method, certain terminologies have been defined, which are used in the subsequent sections of the paper.

A. COVERAGE RELATIONSHIP MATRIX (K)

Let, $n \times m$ coverage matrix K is defined in equation (3).

$$K_{ij} = \begin{cases} 1, & \text{if sensor } s_i \text{ covers target } t_j \\ 0, & \text{otherwise} \end{cases} \quad (3)$$

B. Q-COVER (S_q)

A Q-Cover, (S_q), set of sensors that collectively cover the whole target set. For a given K, a Q-Cover S_q can be defined as the collection of only those rows of K where each column j of K is such that, there are q_j rows i_1, i_2, \dots, i_{q_j} at a minimum in S_q such that $K_{ij} = 1$. The Q-Cover, S_q , is known as minimal cover only if for any Q-Cover S_1 , $S_1 \subseteq S_q$ only if $S_1 = S_q$.

C. BATTERY LIFE (E_i)

The battery life assigned to the sensors is fixed and limited that cannot be renewed or replaced. The proposed approach considers the homogeneous sensors with battery life as 1 unit.

D. MAXIMUM ALLOWABLE LIFETIME OF COVER (W)

At most lifetime, which is allowable (w) to a Q-Cover S_q is the minimum available of all the lifetimes of participating sensors is represented in equation (4).

$$\max_lifetime(S_q) = \text{Min}_{s_i \in S_q} E_i \quad (4)$$

E. NETWORK LIFE (N_{life})

The network lifetime, (N_{life}), is described by aggregating the working times of all the constituted cover sets. For instance, if there are X number of Q-Covers in total with w working time each then, the network lifetime (N_{life}) is defined in equation (5).

$$N_{life} = \sum_{i=1}^X w_i \quad (5)$$

F. UPPER BOUND (UB)

It is determined by dividing the aggregated battery life of the sensors covering the critical target by user-defined nodes (Q), which are required for covering all the targets. Network lifetime cannot exceed this initial upper bound.

$$UB = \text{Min}_j \frac{\sum_i K_{ij}}{q_j} \quad (6)$$

An initial upper bound generally bounds the total network lifetime achievable for Q-Coverage. The upper bound on the number of Q-Covers is determined by the weakly covered targets (called critical targets) in the networks. This upper bound

is obtained by dividing the aggregated sum of battery life of sensors covering this critical target by the defined sensor nodes required to monitor each target at any time. The next section introduces the terminology required to understand the functionality of the proposed heuristic.

V. HEURISTIC WITH MAXIMUM COVERAGE SMALL LIFETIME (MCSL)

All the heuristics to solve the target Q-Coverage problem have the same objective that is, of prolonging network life under the battery constraint. All these heuristics differ only in the way that they select the sensor while constructing Q-Covers. Here, it presents a naïve energy-efficient method to provide a platform which calculates the total network lifetime for Q-Coverage problem in a homogeneous network. Our proposed work mainly focuses on the battery life of the sensors and avoids redundant coverage of critical targets as the critical targets had the highest probability of being uncovered earlier in the network. By this, network life can be increased very efficiently. The granularity parameter $w \in (0, 1]$ is indirectly helpful in achieving the optimal solution. This section discusses the proposed MCSL heuristic, which consists of three main steps as follows:

A. GENERATE A Q-COVER (S_q)

The proposed MCSL heuristic constitutes Q-Cover by selecting a sensor (s) that covers at least one critical target (t_k) with the highest remaining battery life (E_i). Since critical target's coverage is a deciding factor on network lifetime, for remaining uncovered targets, sensors are chosen which are not covering t_k , and have highest remaining energy with maximum uncovered target coverage. After this, MCSL heuristic minimalizes the generated cover set to remove redundant sensors.

B. ASSIGN LIFETIME TO Q-COVER

The proposed MCSL heuristic has two choices to assign working duration the Q-Cover, which is formed in the above step. It can either assign the lifetime as computed in (4) or assigns a user-defined constant w . By doing so, it improves the efficacy of MCSL heuristic by not consuming the entire battery of the sensors, which are part of the current cover set. This strategy makes these sensors available for the next iterations.

C. UPDATING PRIORITIES OF SENSORS

In order to avoid the construction of the same Q-Covers over consecutive iteration, MCSL updates the preferences of the active sensors by subtracting their energy with w . The pseudo-code of the proposed algorithm is given below.

The above-proposed heuristic follows all the necessary steps defined as below:

In line 1, required initializations are done, Line 2-21 consists of all the steps necessary to generate a Q-Cover. Line 4 initializes the value of q for all the targets, and in line 5;

Algorithm 1 Proposed Algorithm

INITIALIZATION

1. $S =$ all sensors, $SUB = \emptyset$, $S_q = \emptyset$, $N_{life} = 0$
2. //Generate Q-Cover
3. **while**(each targets is covered by q_j sensors)
4. **for** all the targets t , uncovered (t) = q_j
5. **Find** critical target t_k
6. **while** (uncovered(t_k) > 0)
7. **Select** sensor $s \in S$ with highest E_i which covers t_k with uncovered (t)>0.
8. $S_q = S_q \cup s$, $S = S - s$;
9. **for** all the target set t which is covered by s
10. uncovered(t)= uncovered(t) - 1;
11. **end while**
12. $SUB =$ set of sensors $\in S$ which do not cover t_k .
13. **while** (uncovered(t) $\neq \emptyset$ for some (t))
14. **Select** a sensor $s \in SUB$ with highest E_i which covers uncovered target with uncovered (t) > 0.
15. $S_q = S_q \cup s$
16. $S = S - s$;
17. $SUB = SUB - s$;
18. **for** all the target set t which is covered by sensor s
19. uncovered(t)= uncovered(t) - 1;
20. **end while**
21. // minimize generated Q-Cover
22. **Minimalize** S_q
23. //Assign working time to generated Q-Cover
24. **Compute Max lifetime** (S_q)
25. $w \leftarrow \text{Min}(E_i \in S_q)$
26. //Update remaining energy of sensors selected in above Q-Cover
27. **for** all $s_i \in S_q$,
28. $E_i = E_i - w$
29. **if** $E_i = 0$, then $S = S - s_i$
30. **end while**

the critical target is identified among the rest of the targets. In line 7, the sensor s , which has the highest remaining energy and covers a critical target gets selected as a part of the current Q-Cover (S_q). The coverage value q for the respective targets covered by sensor s is decreased by one in line 9-10. In line 12, a set of sensors (SUB) is being computed to complete ongoing Q-Cover. Line 13 to 20 repeat the process of covering the rest of targets by choosing sensors which have maximum E_i with the highest coverage of uncovered targets. The generated Q-Cover may have redundant sensors (not minimal) so, further, it is minimalized (line 22), where it removes extra sensors. Line 24-25 assigns working time to the minimalized Q-Cover. Then, in line 27-28, the battery life of each sensor, which is a part of the current Q-Cover, is updated. During this process, if any of the sensors run short of battery then, it will be removed from the overall set of sensors S in line 29. The whole process (line 3-29) is repeated until all the Q-Covers are generated.

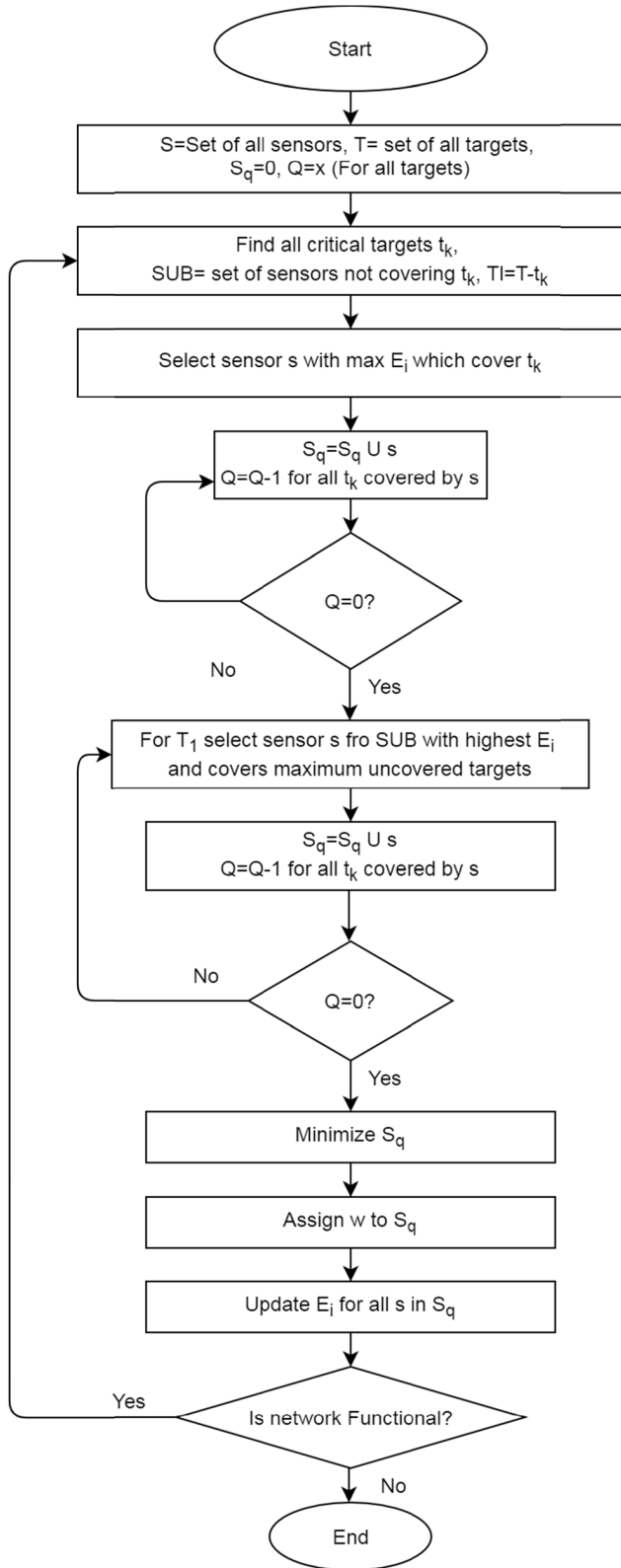


FIGURE 1. Flow chart of the proposed algorithm.

VI. SIMULATION RESULTS

All the simulations are performed in MATLAB (R2016b) on a core i3 processor with 2.10 GHz processor and 4GB

TABLE 1. Various parameters and their values.

Parameter	Description
Sensing Area	(100*100)
# Targets	20-100
#Sensors	20-100
Sensing range	50 meters
Initial (E)	1 J
Working time of cover set	1, 0.75, 0.65, 0.50, 0.20
Quality factor q	2, 3

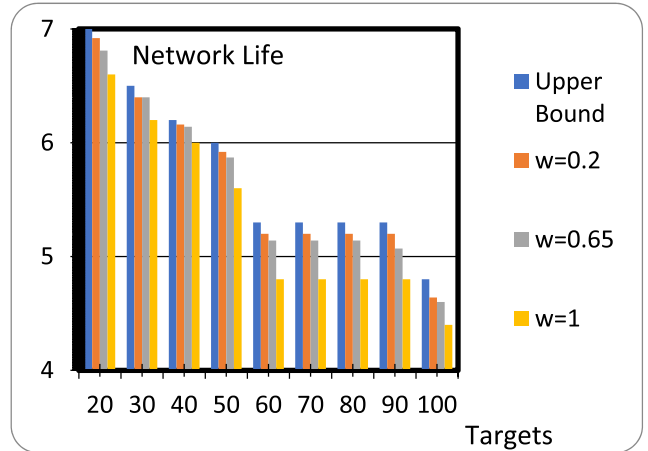


FIGURE 2. Network lifetime obtained with fixed 50 sensors, and varying w = 1, 0.65, 0.2 by MCSL.

RAM system. During experimentation, a fixed sensing square area of size 100M*100M is considered with varying numbers of sensors and targets (20-100). The Pseudo-random number generator is applied while generating sensors and target coordinates. It is also assumed that the considered network is homogenous, where fixed sensing range $R_s = 50m$ is assigned to each sensor. Being a homogeneous network, sensors are allocated a unique battery life E_i of one unit. For each simulation scenario, the average of 50 random instances is taken. Simulations are performed for all the cases with varying w and Q .

The performance of the proposed (MCSL) algorithm is compared with existing algorithms (Greedy [29] and HESL [38]) under the same simulation environment [49]–[51]. MCSL, Greedy [29], and HESL [38] differ only in the way i.e., how sensors are selected to generate Q-Cover. All the simulation parameters are described in Table 1.

A. EXPERIMENT 1

In this experiment, 50 sensors are used for simulation and different targets in the interval [20, 100] with an increment of 10. Figure 2 shows the performance of MCSL for different values of w as 0.2, 0.65, and 1.0 and for $q_j = 2$ for all the targets j .

Figure 2 depicts that the network lifetime decreases with an increased number of targets because the same number of sensors cover these increased targets. Due to these

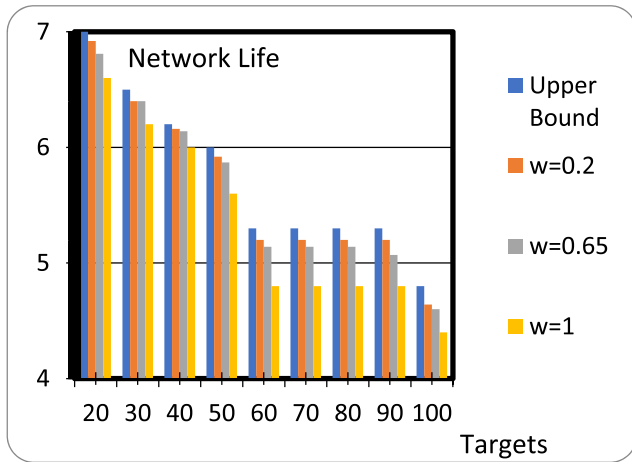


FIGURE 3. MCSL and HESL performance for 50 targets, $w = 0.75$ and $q_j = 3$ for all targets.

TABLE 2. Network lifetime obtained by MCSL and HESL [38].

SENSORS	UPPER BOUND	MCSL	HESL
20	1.21	0.81	0.8
30	2.1	1.92	1.9
40	2.72	2.56	2.52
50	3.94	3.83	3.72
60	5.42	5.34	5.1
70	6.41	6.32	6.1
80	7.52	7.38	7.31
90	8.67	8.48	8.21
100	9.78	9.62	9.53

extended number of targets, network lifetime decreases. Further, a smaller value of w also results in extended network lifetime. The reason behind such outcomes is that, by assigning smaller w , sensors are kept available for a longer duration, which results in prolonged network lifetime.

B. EXPERIMENT 2

Here, fifty targets (fixed) are experimented and varying sensors are used in the interval [20, 100] with an increment of 10. Figure 3 shows the performance of MCSL with HESL [38] for w as 0.75 and fixed $q_j = 3$ for all j targets. It is clearly demonstrated that MCSL outperforms HESL in terms of total network lifetime. Further, it is observed that with the increase in the number of sensors, there is an increment in network lifetime as well. The reason behind this increment is that with the extended quantity of sensors, the same number of targets within the fix region will be covered for a longer time period.

Table 2 shows the experimental values obtained by the proposed MCSL heuristic and HESL [38]. Each value is an average of 50 instances.

C. EXPERIMENT 3

In this experiment, simulation IS performed for 50 sensors and varying targets in the interval [20, 100] with an increment of 10. The network lifetime achieved by MCSL with HESL [38] is shown in Figure 4 when $w = 0.2$, in Figure 5 when $w = 0.65$ and Figure 6 when $w = 1$,

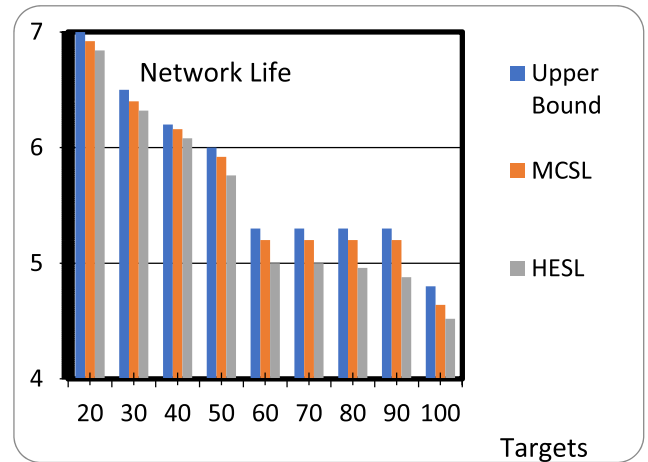


FIGURE 4. Performance of MCSL and HESL with 50 targets, $w = 0.2$ and $q_j = 2$.

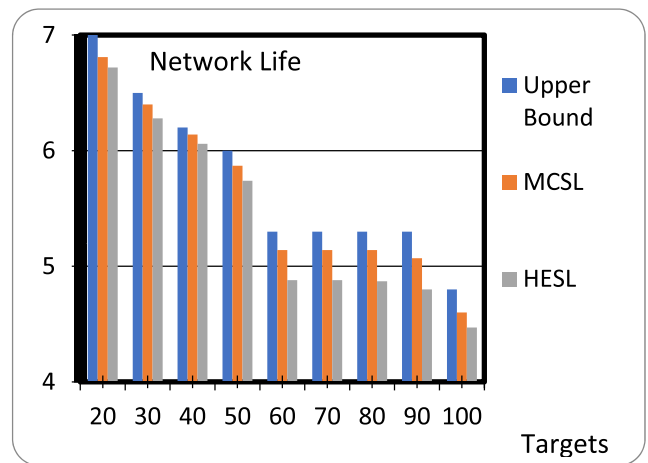


FIGURE 5. Performance of MCSL and HESL with 50 targets, $w = 0.65$ and $q_j = 2$.

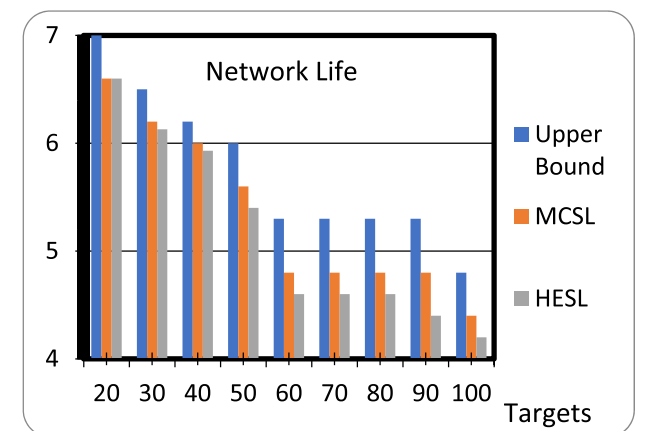


FIGURE 6. Performance of MCSL and HESL with 50 targets, $w = 1$ and $q_j = 2$.

with fixed $q_j = 2$ for all j targets. It is observed that MCSL outperforms HESL in terms of total network lifetime under various values of w .

TABLE 3. Network lifetime obtained by MCSL and HESL [38].

TARGETS	UPPER BOUND	MCSL	HESL
20	7	6.89	6.81
30	6.52	6.4	6.21
40	6.31	6.2	6.1
50	6	5.89	5.61
60	5.32	5.2	5.01
70	5.37	5.24	5.01
80	5.37	5.23	4.91
90	5.3	5.29	4.9
100	4.81	4.6	4.41

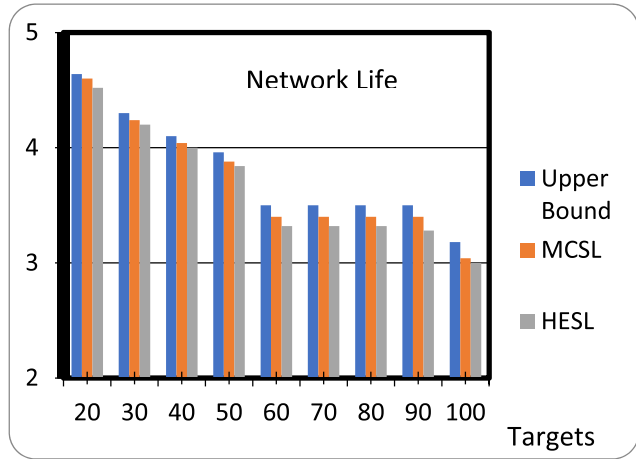


FIGURE 7. Performance of MCSL and HESL with 50 sensors, $w = 0.2$ and $q_j = 3$.

Table 3 shows the experimental values obtained by the proposed MCSL heuristic and HESL [38]. Here, $w = 0.2$ and fixed $q_j = 2$ for each target j . Each value is an average of 50 instances.

D. EXPERIMENT 4

In order to investigate the impact of Q , simulation performed for 50 sensors and varying targets in the interval [20, 100] with an increment of 10. The network lifetime achieved by MCSL with HESL [38] is shown with $w = 0.2$ in Figure 7, with $w = 0.5$ in Figure 8 and with $w = 1$ in Figure 9 for fixed $q_j = 3$ for all j targets.

Table 4 shows the experimental values obtained by the proposed MCSL heuristic and HESL [38]. Here, $w = 0.5$ and fixed $q_j = 3$ for each target j . Each value is an average of 50 instances.

Table 5 shows the experimental values obtained by the proposed MCSL heuristic and HESL [38]. Here, $w = 1$ and fixed $q_j = 3$ for each target j . Each value is an average of 50 instances.

It can be concluded from Figure 7, Figure 8 and Figure 9 that network lifetime achieved by MCSL outperforms HESL [38]. Also, it is clearly observed that assigning smaller w results in increased network lifetime because sensors will be available for an extended period, which results in more number of Q -covers. Further, if the achieved network

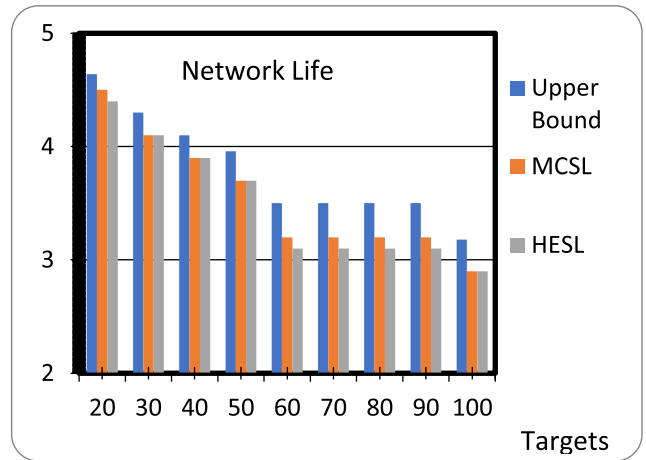


FIGURE 8. Performance of MCSL and HESL with 50 sensors, $w = 0.5$ and $q_j = 3$.

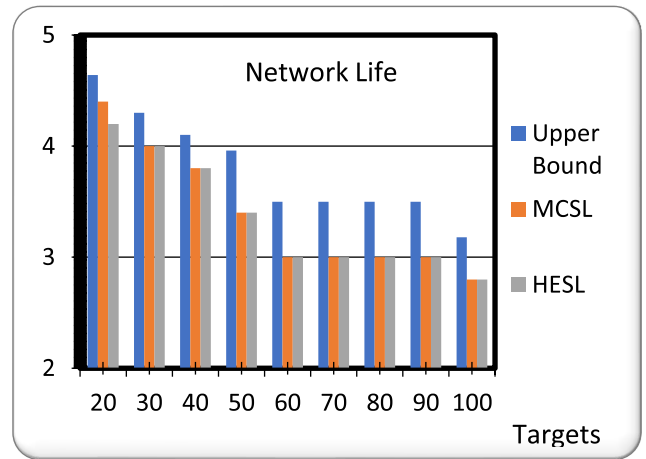


FIGURE 9. Performance of MCSL an HESL with 50 sensors, $w = 0.1$ and $q_j = 3$.

TABLE 4. Network lifetime obtained by MCSL and HESL [38].

TARGETS	UPPER BOUND	MCSL	HESL
20	4.64	4.47	4.35
30	4.38	4.19	4.18
40	4.1	3.91	3.91
50	3.95	3.73	3.72
60	3.51	3.18	3.16
70	3.51	3.18	3.16
80	3.5	3.17	3.17
90	3.5	3.17	3.17
100	3.22	2.91	2.88

lifetime compared with both the heuristics with $q_j = 2$ (shown in Figure 4, Figure 5, and Figure 6), it is observed that network lifetime decreases with an increase in q_j . This is due to the fact that with higher q_j , more sensors are required to cover each target in Q -Cover, which results in reduced network lifetime.

E. EXPERIMENT 5

Here, simulation is done for 50 sensors and different targets in the interval [20, 60]. Figure 10, Figure 11, and Figure 12,

TABLE 5. Network lifetime obtained by MCSL and HESL [38].

TARGETS	UPPER BOUND	MCSL	HESL
20	4.65	4.39	4.22
30	4.29	4.01	4.01
40	4.1	3.85	3.84
50	3.96	3.43	3.41
60	3.5	3.02	3.01
70	3.5	3.02	3.01
80	3.4	3.01	3
90	3.4	3.01	3
100	3.22	2.91	2.88

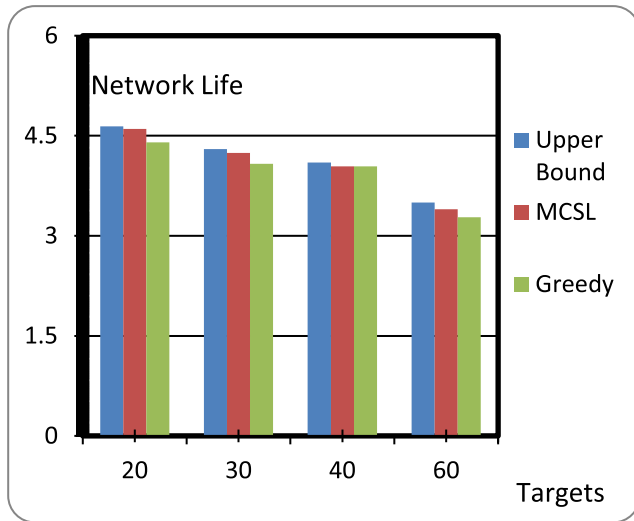


FIGURE 10. The average of lifetime obtained by MCSL and Greedy [29] for $w = 0.2$ and $q_j = 3$ for different j .

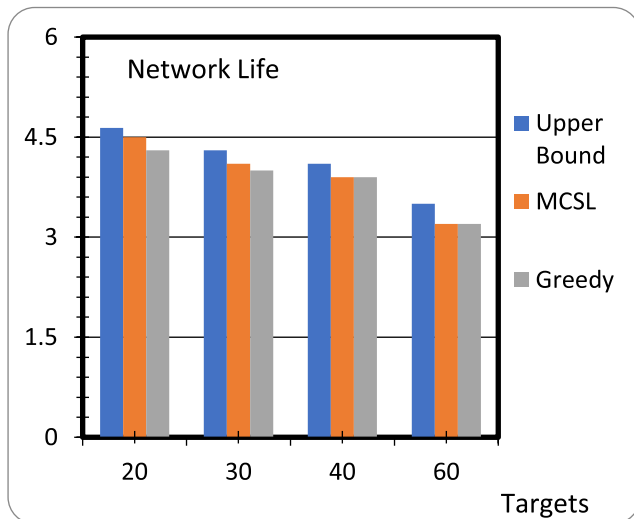


FIGURE 11. The Average of lifetime obtained by MCSL and Greedy [29] for $w = 0.5$ and $q_j = 3$ for different j .

shows the performance of MCSL with Greedy [29] for the values of w as 0.2, 0.5, and 1.0 respectively and fixed $q_j = 3$ for all j targets.

It has been observed that MCSL outperforms Greedy [29] in terms of total network lifetime. Further, results show that

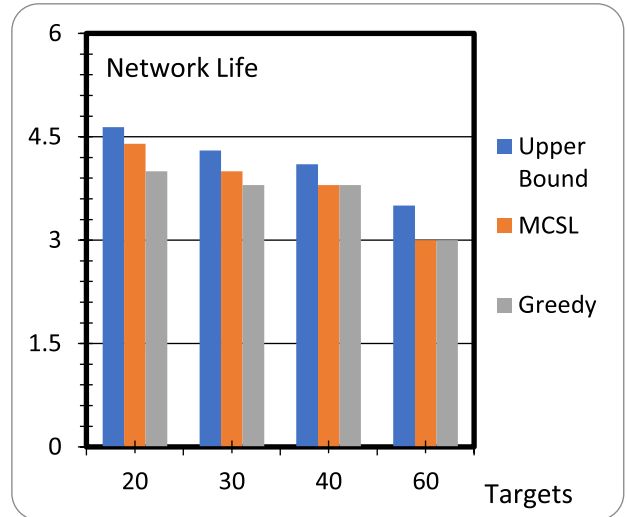


FIGURE 12. Average of lifetime obtained by MCSL and Greedy [29] for $w = 1.0$ and $q_j = 3$ for different j .

smaller w should be preferred to prolong the whole network lifetime. Additionally, one can also observe from all the results depicted in various tables and figures that the network lifetime increases with the increase in the number of deployed sensor nodes and decreases with an increased number of targets. It happens because an increased number of sensors will help to generate more cover sets, which in turn prolongs the total network lifetime. Similarly, increased targets need more sensors to cover them in respective cover sets, which results in decreased network lifetime.

VII. CONCLUSION

In this paper, a new energy-based heuristic MCSL (Maximum Coverage Small Lifetime) giving high priority to the sensors with maximum residual battery life and covering a minimum of uncovered target and avoiding redundant covering of critical target has been proposed. The proposed approach i.e., MCSL, performs better as compared to Greedy [29] and HESL [38] in terms of network lifetime. Experimental results clearly state that the algorithm performs well in all the scenarios (i.e., varying sensors, targets, and w).

In future, the work will cover other variants of coverage problems, which include connectivity, adjustable sensing range, partial coverage, and many more. Further, mobility will be added to the network where a node can move from location to another to fulfill specific application requirements.

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