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Abstract*—Efficient energy management schemes are essential in a wireless sensor network, since sensor nodes are battery powered. To subdue the energy problem, it is important to have efficient deployment and scheduling mechanisms. A heuristic to solve simple coverage problem, which schedules sensor activity so that all sensor nodes need not be active at the same time, is proposed. Results match the theoretical upper bound for all the experiments. The performance of ABC (Artificial Bee Colony) algorithm in solving deployment problem of wireless sensor networks is also investigated. Since random deployment does not always lead to effective coverage, especially if the sensors are inordinately clustered and there is an inadequate concentration of sensors in some parts of the terrain, this type of deployment at computed optimal locations proves effective. Experiments are carried out for complex cases when certain targets in the region need to be monitored with greater certainty. Preliminary results show that swarm algorithms like ABC and PSO can also be effectively used for area and target coverage problems, in 2-D and 3-D terrains.

Keywords-wireless sensor network; deployment; coverage; swarm algorithms

I. INTRODUCTION

Wireless sensor networks finds its application in military, environment and habitat monitoring, industrial process monitoring, home automation, traffic control among many others. Some major issues that arises in wireless sensor networks are localization, tracking, deployment and coverage. Coverage problems can be classified into two: Area coverage and Target coverage. Area coverage focuses on providing coverage for an entire region, and target coverage aims at providing coverage for certain point objects located in a region [1].

Target coverage can be categorized as simple, *k* and Q-coverage. A target is required to be monitored by at least one sensor node for simple coverage problem. *k*-coverage problem arises when all the targets need to be monitored by at least *k* sensor nodes, where *k* is a predefined integer constant. In case of node failures or to increase the accuracy of monitoring, higher values of *k* are preferred. When all targets T = $\{T_1, T_2, \ldots, T_n\}$ should be monitored by Q = $\{q_1, q_2, \ldots, q_n\}$ number of sensor nodes such that target T_j is monitored by at least q_j number of sensor nodes, where *n* is the number of targets and 1 *d” j d” n*, it is defined as Q-coverage problem. It is proposed to extend network lifetime by dividing the sensor nodes into sensor covers, such that each target is monitored by at least *k*/Q sensor nodes in all sensor covers. Sensor covers are determined by weight-based priority and are activated one after the other. The sensor covers alternate over time, as the battery power deteriorates.

Random deployment of sensor nodes fails to be optimal when nodes are deployed where no targets need to be covered, resulting in wastage of energy. The drawbacks of random deployment can be overcome by having a method to compute the optimal deployment positions. Here, the sensor deployment problem is modeled as a clustering problem and the optimal locations for sensor deployment are obtained using Artificial Bee Colony (ABC) algorithm. The variation in sensing range with an increase in number of sensor nodes is analyzed and sensitivity analysis test is carried out to find the variation in sensing range if the sensor nodes are deployed in a near optimal position.

A. Importance

Each application may have its own coverage requirement. The coverage level of some applications like home security can be set to a low value. Higher coverage levels are required if sensors work in a hostile environment such as battlefields or chemically polluted areas. In some cases, for the same application, the coverage requirement may vary. For example, for forest fire detections, the coverage level may be low in rainy seasons, but high in dry seasons [2]. In a video surveillance system deployed for monitoring hostile territorial area, some sensitive targets like a nuclear plant may need more sensors cooperate to ensure source redundancy for precise data [3]. These requirements lead to the necessity of having an efficient deployment and coverage scheme.

The rest of the paper is organized as follows: In Section II, we briefly review some of the related work. The problem is formulated formally in Section III. The proposed methods to solve the problem are presented in Section IV. Simulation results and discussions are presented in Section V followed by concluding remarks and future scope in Section VI.

II. RELATED WORK

Clouqueur et al. [4] propose a method to determine the number of sensors to be deployed to carry out target detection in a region of interest. The minimum exposure is used as a measure of the goodness of deployment, the goal being to maximize the exposure of the least exposed path in the region. Watfa et al. [5] present a method to compute the minimum number of sensor nodes required for complete coverage of a 3D region. Andersen et al. [6] present an approach called discretization which modeled sensor deployment problem as a discrete optimization problem. The main drawback of discretization is that it is not possible to guarantee *k*-coverage of the complete region. Karaboga et al. [7] present a survey of algorithms based on bee swarm intelligence and their applications. Karaboga et al. [8] show that ABC algorithm can be efficiently used for solving constrained optimization problems. Karaboga et al. [9] compare the performance of ABC algorithm with the traditional back propagation algorithm and the genetic algorithm which is a well-known evolutionary algorithm. Karaboga et al. [10] compare the performance of ABC algorithm with that of DE (Differential Evolution) and PSO (Particle Swarm Optimization) algorithms, and EA (Evolutionary Algorithm) for a set of well-known bench mark functions. Simulation results show that ABC algorithm performs better and can be efficiently employed to solve the multimodal engineering problems with high dimensionality.

Cardei et al. [11] designed LP-MSC (Linear Programming-Maximum Set Covers) and Greedy-MSC (Maximum Set Covers) to solve simple coverage problem. Since Greedy-MSC has a lower running time compared to LP-MSC, it is more suitable for larger networks. A comparison on the network lifetime achieved using Greedy-MSC and the theoretical upper bound shows that for higher number of sensors, Greedy-MSC could not achieve the upper bound. Ammari et al. [12] derived the minimum sensor spatial density to ensure *k*-coverage of a 3D space based on the geometric properties of Reuleaux tetrahedron. Li et al. [2] developed PCL-GS (Perimeter Coverage Level Greedy Selection) and PCL-GSA (Perimeter Coverage Level Greedy Selection Algorithm) to solve the *k*-coverage problem. GS deals with the case where sensors have fixed sensing range and sensors are divided into disjoint cover sets. GSA deals with the case where sensors can adjust their sensing range and sensors are divided into non-disjoint cover sets. Our approach resembles GS where the sensing range is fixed. Experimental results of GS show that the network lifetime can be 90% of the ideal network lifetime.

Q-Coverage problem has been addressed in [3] and [13]. A method was proposed by Gu et al. [3] based on column generation, where each column corresponds to a feasible solution. The column with the steepest ascent in lifetime has to be identified, and based on that a search for the maximum lifetime solution will be iteratively performed. Chaudhary et al. [13] presented a greedy heuristic, HESL (High Energy and Small Lifetime), to generate Q-covers by prioritizing sensors in terms of the residual battery life.

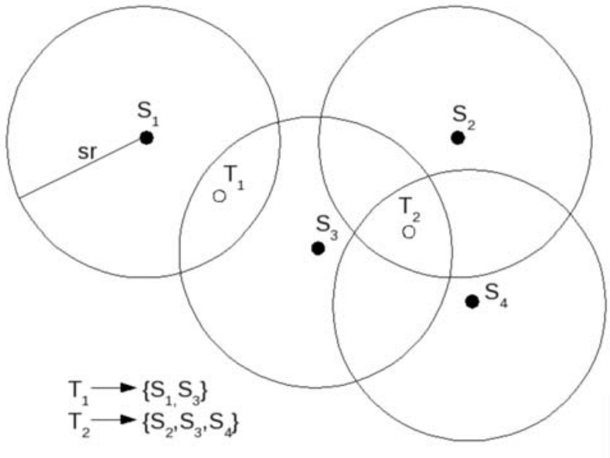

Figure 1. Sample Topology

III. PROBLEM DEFINITION

A. Optimal Sensor Scheduling for Coverage Problem

1) 1-Coverage Scheduling: Definition 1: Given an energy constrained wireless sensor network with *m* randomly placed sensor nodes and *n* targets, schedule the sensor nodes such that all the targets are continuously monitored and the network lifetime is maximized. In other words, given a set of sensor nodes S = $\{S_1, S_2, \ldots, S_m\}$ with battery power B = $\{b_1, b_2, \ldots, b_m\}$, energy consumption rate e_i for S_i, 1 *d” i d” m* and a target set T = $\{T_1, T_2, \ldots, T_n\}$, find a schedule $\{C_1, \ldots, C_y\}$ for time tick $\{t_1, \ldots, t_y\}$ such that for all ticks, all the targets in T are monitored by at least one of the sensor nodes and the network lifetime is maximized. Fig. 1. shows an example topology where 2 targets are monitored by 4 sensor nodes.

B. Optimal Sensor Deployment for Target Coverage

Given a set of targets T = $\{T_1, T_2, \ldots, T_n\}$ located in $u \times v \times w$ region and a set of sensor nodes S = $\{S_1, S_2, \ldots, S_m\}$, the objective is to cover all the targets by at least one sensor node and to minimize the function

$$F = \left(max\left(distance(S_i, P_g)\right)\right) \forall_i \quad (1)$$

where P is the set of all targets monitored by S_i, $i = 1, 2, \ldots, m$, $g = 1, 2, \ldots, h$, where h is the total number of targets that the sensor node S_i monitors. This study is also extended to *k*-coverage and Q-coverage problems. It also aims to conduct sensitivity analysis test which reveals the variation in sensing range requirement if the sensor nodes are deployed at near-optimal positions.

C. Optimal Sensor Deployment and Optimal Scheduling by Minimizing Sensing Range and Communication Range Requirement for Target Coverage Problem

Given a set of targets T = $\{T_1, T_2, \ldots, T_n\}$ located in $u \times v \times w$ region and a set of sensor nodes S = $\{S_1, S_2, \ldots, S_m\}$, the

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```
for each Be do
var = 0
repeat
if var = 0 then
Calculate distance between each target and all the sensor locations
Form clusters by assigning targets to 1/k/Q sensor nodes
which are at minimum distance
if all sensor nodes form cluster then
Move the sensors to the centroid of all target location
points that are associated to it
var = 1
else
Move sensors without assigned targets to random target locations
end if
end if
until var = 1
end for
```

Figure 2 : Pseudocode: Cluster Formation

```
Initialize the solution population B
Evaluate fitness
Produce new solutions based on cluster centroids
Choose the fittest bee
cycle = 1
repeat
Search for new solutions in the neighborhood
if new solution better than old solution then
Memorize new solution and discard old solution
end if
Replace the discarded solution with a newly randomly
generated solution through a scout bee
Memorize the best solution
cycle = cycle + 1
until cycle = maximumcycles
```

Figure 3. Pseudocode: Proposed Method

objective is to maximize network lifetime by deploying the sensor nodes such that cover schedule $\{C_1, \ldots, C_y\}$ can be computed for $\{t_1, \ldots, t_y\}$ and sensing range and communication range requirement is at minimum with all T = $\{T_1, T_2, \ldots, T_n\}$ being covered by at least one sensor node. This study is extended to k-coverage and Q-coverage problems.

IV. PROPOSED APPROACH

A. Optimal Sensor Deployment for Target Coverage

The target locations are assumed to be stationary. A solution is a set of locations where the sensor nodes can be deployed to cover all the targets and sensing range is optimal. Initial solutions are randomly generated. Let the solution population be B. Each solution corresponding to a bee e is denoted as

$B_e = \{(x_1, y_1, z_1), (x_2, y_2, z_2), \ldots, (x_m, y_m, z_m)\}$ where $e = 1, 2, \ldots, d$, d represents total number of bees and m represents total number of nodes to be deployed.

The initial task is to form clusters according to their location. Each cluster has a sensor node associated as cluster centroid with it. The Euclidean distances of the targets and the sensor locations are calculated. Clusters are formed based on this distance measure. Clusters are generated in such a way that no sensor location in a solution is left idle without being part of a cluster. The number of targets in a cluster will be less if sensor to which the cluster is associated is located at a remote place. The number of clusters formed is exactly equal to the number of sensor nodes to be deployed. The employed bees return with the solution having cluster centroids. All the deployment locations in a solution are replaced by the corresponding cluster centroid. The pseudo code for forming clusters is given in Fig. 2.

The Euclidean distance between each target and the sensor location to which it is associated is used as the fitness function to evaluate the solutions. Let $D_i = (D_{i1}, D_{i2}, D_{i3})$ be the cluster centroid of i^{th} cluster. $F(D_i)$ refers to the nectar amount at food source located at D_i. After watching the waggle dance of employed bees, an onlooker goes to the region of D_i with probability p_i defined as,

$$p_i = \frac{F(D_i)}{\sum_{f=1}^{nf} F(D_f)} \qquad (2)$$

where nf is the total number of food sources. The onlooker finds a neighborhood food source in the vicinity of D_i by using,

$$D_i(t+1) = D_i(t) + \delta_{id} \times v \qquad (3)$$

where $\ddot{a}_{id}$ is the neighborhood patch size for d^{th} food source, v is random uniform variate [-1, 1] and t is the cycle number. The onlooker bee then evaluates the fitness function based on the new value D_i $(t + 1)$. It should be noted that the solutions are not allowed to move beyond the edge of the region. The new solutions are also evaluated and compared using the fitness function. If any new solution is better than the existing one, the new one is retained and old one is discarded. Scout bees search for a random feasible solution. The solution with the least sensing range is finally chosen as the best solution. The pseudo code of proposed method is given in Fig. 3.

B. Optimal Sensor Scheduling for Target Coverage

Let us assume m sensor nodes $\{S_1, S_2, \ldots, S_m\}$ randomly deployed to cover the area R with n targets $T = \{T_1, T_2, \ldots, T_n\}$. Each sensor node has an initial energy E_0 and a sensing radius, sr. A sensor node S_i, 1 d” i d” m, is said to cover a target T_j, 1 d” j d” n, if the distance $d(S_i, T_j)$ between S_i and T_j is less than sr. The coverage matrix is defined as,

$$M_{ij} = \begin{cases} 1 & \text{if } S_i \text{ monitors } T_j \\ 0 & \text{otherwise} \end{cases} \qquad (4)$$

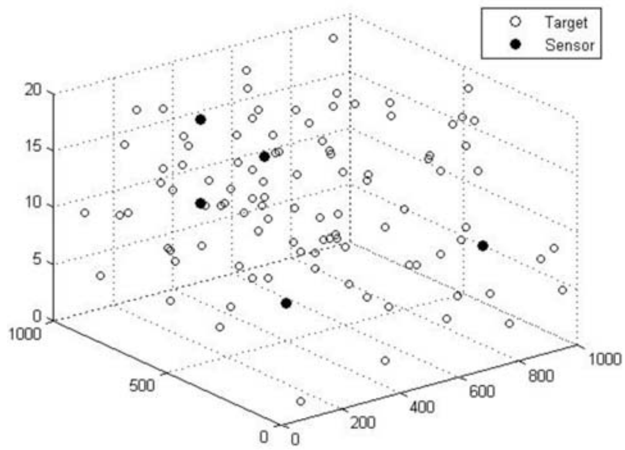

Figure 4. Random placement of sensor nodes

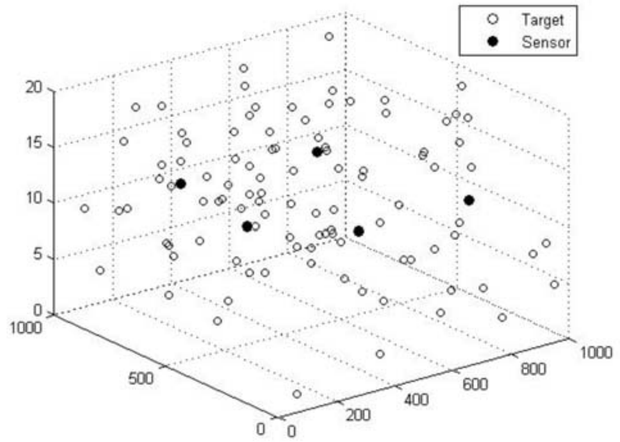

Figure 5. Deployment positions computed using ABC algorithm

The three major steps involved in the proposed scheduling algorithm are weight calculation, cover formation and cover optimization. Weight assignment is performed to decide the priority of sensor nodes. The more the weight of a sensor node, the higher the priority of the sensor node. Cover sets are decided based on this priority. In the order of priority, if any new sensor node contributes to simple coverage requirement, it will be added to the cover set. In general, a sensor node S_i can be added to a cover set *Cov_S* if and only if *Cov_SU*$\{S_i\}$covers any new target.

V. RESULTS AND DISCUSSION

A. Optimal Sensor Deployment for Target Coverage

We consider a 200×200×20m region for experiments. Initially, the sensors are randomly deployed in the region.

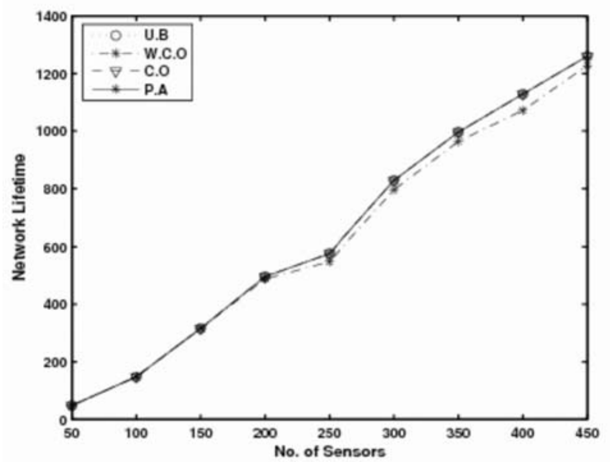

Figure 6. Comparison of upper bound (U.B), network lifetime without cover optimization (W.C.O), network lifetime with cover optimization (C.O) and network lifetime using proposed approach (P.A) for simple coverage problem

ABC algorithm is then used to find the minimum sensing range required to cover all targets, for different instances. The number of bees is taken as 10 and the number of cycles is 500. The number of clusters increases as we increase the number of sensor nodes. As expected, when the number of sensor nodes to be deployed increases, the sensing range requirement decreases. The results reveal that for higher number of targets to be covered, the sensing range requirement need not essentially be high. Sensing range requirement is highly dependent on the location of the targets to be covered. The results can also be used to find the minimum number of sensor nodes required to cover specific number of targets in the 3-D region.

Further experiments are carried out to find optimum sensor deployment positions in a 3-D terrain in order to satisfy different target coverage criteria, namely, simple, *k*-coverage and Q-coverage. Extensive simulations are carried out with varying number of sensor nodes, number of targets, *k*-values and values of vector Q to find the minimum sensing range requirement. The sensing range requirement does not increase

in same proportion with increase in *k* or Q requirements. Table 1 and Table 2 show the sensing range requirement for *k* and Q coverage problems respectively.

It may be hard to deploy the sensors exactly at positions where sensing range is optimal. Sensitivity analysis is conducted to show that if the optimum sensing range is *r*, a minor variation in the deployment position will increase the sensing range by *r*+Ä*r*. The optimum deployment positions are changed by ± 0.05 and the new sensing range is calculated. Ä*r* in our experiments is found to be of less significance. With short variations in deployment locations, the sensing range is unlikely to change by a great deal. Fig. 4. shows a 1000×1000 ×20m region where 5 sensor nodes are randomly deployed to cover 100 targets. It is evident that random positioning of sensor nodes will lead to higher sensing range requirement. Fig. 5. shows the sensor positioning using ABC algorithm.

N.T[1]	Instance	N.S[2]	k=1				k=3				k=5			
			Best	Mean	Std.dev[3]	SA[4]	Best	Mean	Std.dev[3]	SA[4]	Best	Mean	Std.dev[3]	SA[4]
		10	38.88	38.88	0.00	38.91	92.23	93.47	1.07	92.40	109.89	109.99	0.16	109.96
	1	20	24.34	25.37	0.92	24.41	53.61	53.94	0.54	53.68	64.96	64.96	0.00	65.08
		30	19.45	20.00	0.96	19.59	41.76	41.82	0.05	41.85	56.08	56.17	0.15	56.16
		10	39.38	40.07	0.83	39.42	90.91	91.25	0.29	91.00	104.15	104.70	0.47	104.21
100	2	20	24.61	25.34	1.05	24.72	54.43	54.86	0.61	54.51	61.62	61.62	0.00	61.70
		30	19.46	19.72	0.22	19.53	46.91	47.60	0.59	46.99	57.17	58.87	1.54	57.20
		10	35.66	36.55	0.98	35.78	87.77	88.38	0.61	87.84	108.71	108.90	0.32	108.86
	3	20	26.20	26.46	0.46	26.23	55.24	55.52	0.24	55.32	65.37	65.79	0.74	65.45
		30	18.79	19.18	0.60	18.91	39.51	39.51	0.00	39.59	59.43	59.44	0.01	59.53
		10	38.21	38.21	0.00	38.35	86.31	86.70	0.34	86.44	106.06	106.55	0.74	106.16
	1	20	26.53	27.22	0.60	26.93	53.63	54.38	0.65	53.73	67.34	67.81	0.78	67.50
		30	21.48	21.80	0.45	21.56	41.99	42.24	0.42	42.32	56.41	56.68	0.45	56.51
		10	39.53	39.80	0.48	39.61	99.44	99.89	0.59	99.91	108.68	108.68	0.00	108.74
150	2	20	26.64	26.89	0.22	26.70	54.62	55.54	1.33	54.83	70.06	70.22	0.14	70.12
		30	21.02	21.39	0.33	21.12	43.23	43.67	0.43	43.51	62.05	62.05	0.00	62.14
		10	40.93	40.93	0.00	41.00	91.05	91.09	0.08	91.13	109.16	109.78	1.08	109.28
	3	20	25.70	26.63	0.80	25.85	53.86	54.34	0.42	53.96	66.21	66.21	0.00	66.30
		30	21.39	22.28	0.91	21.50	42.81	43.37	0.65	42.92	58.60	58.83	0.37	58.73
		10	42.24	42.30	0.08	42.33	95.85	96.58	0.68	95.96	111.42	111.85	0.69	111.54
	1	20	30.14	30.29	0.27	30.22	58.95	59.71	0.71	59.05	70.60	70.60	0.00	70.72
		30	23.39	23.71	0.56	23.52	47.74	48.37	0.85	47.90	66.00	66.96	0.92	66.11
		10	41.22	42.03	1.13	41.32	99.37	99.77	0.35	99.49	111.54	111.74	0.17	111.63
200	2	20	28.95	29.09	0.17	29.08	56.74	56.94	0.34	56.89	70.22	70.22	0.00	70.34
		30	23.18	23.43	0.24	23.36	47.13	47.13	0.00	47.56	59.36	59.80	0.38	59.45
		10	42.51	43.08	0.64	42.68	98.06	98.12	0.06	98.19	114.09	114.27	0.27	114.18
	3	20	29.57	29.73	0.28	29.66	59.20	59.72	0.53	59.34	71.54	71.88	0.60	71.60
		30	24.01	24.54	0.77	24.13	47.49	47.73	0.25	47.61	62.02	63.17	1.53	62.09

TABLE I. Sensing range requirement for k-coverage problem

[1] Number of targets

[2] Number of sensor nodes

[3] Standard Deviation

[4] Sensitivity Analysis

N.T[1]	Instance	N.S[2]	Q=1-5				Q=3-5			
			Best	Mean	Std.dev[3]	SA[4]	Best	Mean	Std.dev[3]	SA[4]
		10	111.64	112.29	0.65	111.75	125.27	126.16	1.15	125.34
	1	20	65.03	65.96	0.81	66.03	89.50	89.65	0.17	89.65
		30	48.25	48.49	0.29	48.39	61.20	62.24	1.12	61.29
		10	112.96	115.28	2.01	113.10	146.83	147.63	1.01	146.96
100	2	20	65.81	66.71	1.33	65.93	96.11	97.48	1.27	96.24
		30	48.48	49.14	0.58	48.62	65.11	65.79	0.62	65.20
		10	98.50	99.14	0.58	98.64	134.47	135.21	0.93	134.52
	3	20	61.17	61.62	0.40	61.25	93.50	93.93	0.62	93.58
		30	47.65	48.33	0.80	47.74	65.16	65.77	0.53	65.29
		10	111.57	112.89	1.24	111.64	132.40	132.97	0.54	132.53
	1	20	70.76	71.16	0.41	70.89	93.12	93.72	0.65	93.22
		30	56.06	56.60	0.49	56.10	70.19	70.48	0.41	70.28
		10	109.87	110.16	0.29	109.98	133.55	133.93	0.43	133.67
150	2	20	68.19	68.51	0.53	68.30	99.69	99.97	0.33	99.88
		30	55.83	56.04	0.23	55.89	72.07	72.12	0.06	72.19
		10	119.52	120.06	0.58	119.66	143.10	144.05	0.95	143.14
	3	20	72.36	72.78	0.49	72.50	99.59	101.81	1.96	99.74
		30	59.92	60.32	0.32	59.99	68.53	69.10	0.61	68.60
		10	122.21	122.74	0.51	122.27	138.19	139.06	0.78	138.24
	1	20	78.75	79.52	0.73	78.81	101.28	101.88	0.55	101.31
		30	63.42	63.50	0.07	63.50	77.60	77.98	0.41	77.69
		10	123.74	124.60	0.74	123.80	142.20	143.88	1.61	142.25
200	2	20	71.36	72.17	0.80	71.43	104.95	106.23	1.11	105.00
		30	59.83	60.67	0.74	59.88	68.49	68.89	0.35	68.54
		10	117.21	117.24	0.06	117.28	140.37	142.09	1.60	140.44
	3	20	70.14	70.22	0.11	70.21	101.79	101.95	0.25	101.83
		30	54.04	55.00	0.84	54.09	75.82	76.04	0.78	75.89

TABLE II. Sensing range requirement for Q-coverage problem

B. Optimal Sensor Scheduling for Target Coverage

We consider a 500×500m region with the number of sensors varying from 50-450 to monitor 25 targets. Sensing range of all sensor nodes is fixed as 75m. The network is modeled as both sparse and dense to study the impact of varying number of nodes. Higher the number of nodes, higher is the network lifetime. The proposed method finds a cover sequence such that the network lifetime matches the theoretical upper bound for all experimented simulations, as shown in Fig. 6.

II. CONCLUSION

Many heuristics and swarm intelligence algorithms are proposed in the literature for solving different NP-hard and NP-complete problems. However, not much of studies have been done for application of these type of algorithms in sensor network domain. We have applied few swarm intelligence algorithms coupled with some heuristic for some sensor network problems and initial results are encouraging [14][15][16]. Deployment and maintenance cost can be minimized by using such cost effective schemes. The sensitivity analysis shows the robustness of the deployment scheme. It is found that slight change in the actual placement of nodes does not result in much change in the required sensing range. The method can also be used to find the minimum number of sensor nodes required for a specific sensing range to monitor targets in the region. We plan to extend this work to compute optimal deployment positions by minimizing sensing and communication range requirement. It is also proposed to have an in-depth study of different swarm intelligence algorithms along with some heuristics to solve coverage and deployment problems.

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