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Maximizing Ad Hoc Network Lifetime Using Coverage Perturbation Relaxation Algorithm

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Abstract— An algorithm is implemented to increase and maximize network lifetime due to any perturbations in sensor-target coverage for a number of cases of different configurations. Such coverage perturbations can be seen in the assumed values of sensor-target failure probabilities. The main goal is to maximize the lifetimes of sensors by varying sensor positions within limited space, according to their minimum coverage failure probabilities. Different sensor subsets are energized according to their coverage failure probabilities, and minimum required value of coverage failure probability.

***Keywords-* lifetime, coverage, perturbations, WSN, algorithm, failure probability**

1. INTRODUCTION

The widely used wireless sensor networks (WSN) in home and industrial applications are proved to be useful and adequate nowadays, although they are short lived, unreliable and limited radio range, memory and processing capacities [1]. One typical characteristic of these networks is the possibility of deploying many nodes in a small area in order to sense signals in remote and inaccessible environments, in which preserving their energy and prolonging network lifetime, is critical, and in which, their area coverage is to be maintained.

Typical problem of using WSN is the interface of large number of neighboring nodes with each other in numerous routes, as well as consuming large transmission power; thus limiting network lifetime. Area coverage can be resolved either by deploying sensors to cover sensing zones completely, or make sure that all zones are covered by a certain number of sensors, such as one-coverage or k-coverage [2][3], or select active sensors in a densely deployed network to cover all zones [4][5][[6][7][8]. The last case is known as an Activity Scheduling Problem (ASP) [9][10], which is divided into four classes: area, barrier, patrol or target coverage.

Due to the mobility characteristics of sensor-target nodes as well as variation in network coverage, optimal usage of saving energy, is required in order to prolong network lifetime. It's focused in this study to maximize network lifetime due to coverage and position perturbations in the sensor-target network.

Previous work were proposed aiming to organize sensors in a number of subsets, such that each set completely covers all zones, thus enabling time schedules for each subset to be activated at a time, thus removing redundant sensors which may waste energy and consequently reduce network lifetime [11]. To solve this problem, many algorithms are applied such as generic, linear programming, greedy algorithms [12][13][14][15][16]. One important technique is to improve reliability in cases when sensors may become unavailable due to physical damage, lack of power or malfunctioning.

This problem has been addressed in the literature before; namely the α-Reliable Maximum Sensor Coverage (α-RMSC) problem. In this paper, algorithms and their simulations of wireless sensor networks due to perturbations in network coverage and distance variations are implemented to include network lifetime reliability and lower failure probability of the sensor subsets which cover and monitor all zone targets.

It's well know that urban networks coverage might change with time due to continuous building developments, which requires the repositioning of transmitters and antennas nearby. It would be then beneficial to opt an algorithm that increases the lifetime of transmitters-receivers, with such repositioning. This can also be extended to sensor-target networks. The opt of network sensors repositioning is more applicable.

Firstly, we consider a set S of n sensors in which each $s \in S$ can sense m interested targets within its sensing range over a large two-dimensional area, as shown in Fig.1.

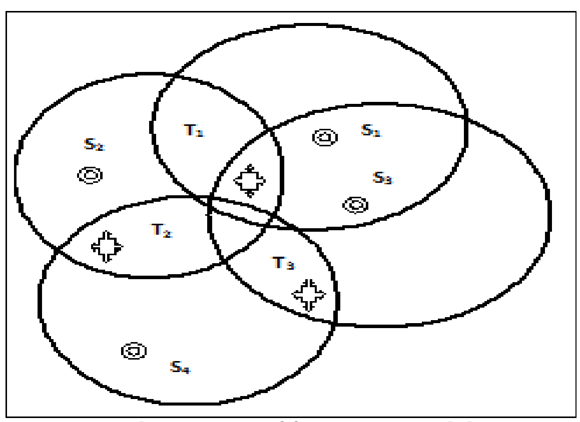

Figure 1; Planner view of four sensors and three target zones

We assume that the sensing and transmission ranges of node s are open discs, centered at s_i with radius r and R, where $R > r$, which covers a target t_j if the Euclidean

distance between s_i and t_j is smaller than or equal to the sensing range *r*.
We then assume each sensor s_i has a failure probability associated with each t_j in the monitored area (denoted by *sfp*), and contributes with a certain energy when active in a duty-cycling manner with adjacent nodes. This sensor failure probability depends on point-to-point coverage which varies inversely with the square root of the sensor-target distance. Any variations of distance or coverage perturbations will vary sensor failure probability.
It is not reasonable to turn on all sensors in the monitoring area to cover all the targets, because more than one sensor can cover the same target. So it is necessary to divide the n sensors to a couple of subsets in which each subset can cover the relevant targets. In each time slot, only one subset is active in a duty cycle in order to save energy and prolong the lifetime of the WSN.

2. RELAXATION AD HOC PROCEDURE

Consider a sensor-target network depicted in Fig. 2, that shows a collection *S* and a finite set *T*, we want to find a family of sensor covers *C* with time weights tw_1, tw_2 ..tw_k in [0,1] and sensor cover failure probabilities cp_1, ..cp_k, where *k* is the maximum number of sensor covers we can find.

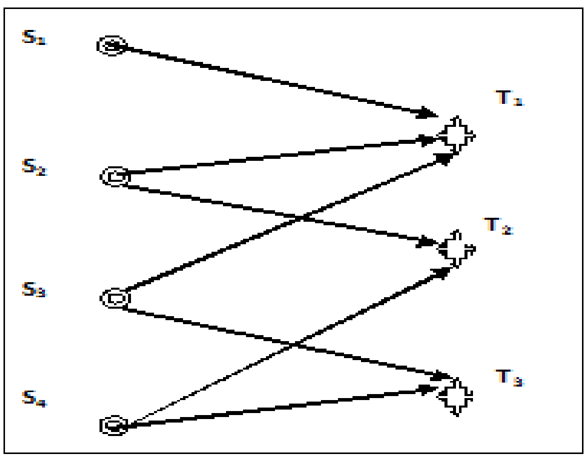

Figure 2; Sensor failure probabilities

Thus for the probability that a sensor cover $C_r=\{s_1, s_2, ..s_l\}$, $l \in [1,n]$; $r \in [1,k]$, fails to cover all the target set $T=\{t_1, t_2,..t_m\}$ is

$$Cfp_r=1-\prod (1-tfp_j) \quad (1)$$

$$tfp_j=\prod sfp_{ij} \quad (2)$$

where *tfp* is the target failure probability of *j* targets by *r* sensors subsets ($r \in [1, k]$), thus

$$Cfp_r=1-\prod_{j=1\rightarrow m} [1-\prod_{i=1\rightarrow l} (sfp_{ij})] \quad (3)$$

where sfp_{ij} is the failure probability of sensor *i* to target *j*, and cfp_r is coverage failure probability of a subset or group of sensors covering all targeted zones, which is assumed to be less than α; a predefined maximum failure probability *tfp* is target failure probability of one targeted zone by all sensors.

Now, consider perturbations n the sensor-target network, which leads to variations in the sensor failure probabilities. This will require to adjust sensors' positions accordingly in order to maximize and optimize network lifetime. This is depicted in Fig. 3

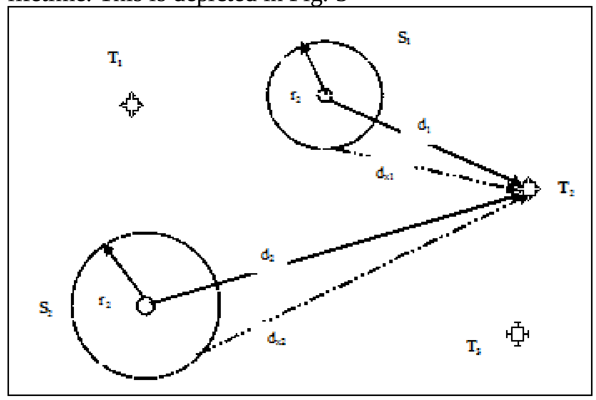

Figure 3; Network position perturbations

Any perturbations in the sensor-target network will be reflected in the values of signal failure probabilities in same proportions as shown in Fig. 4. It is assumed that the sensor position can be varied in the polar variables r and x.

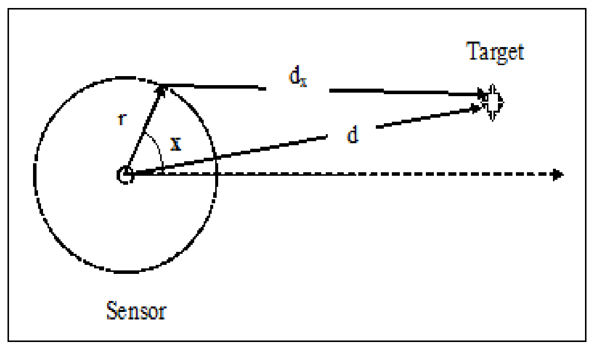

Figure 4; Position radial and angular variations

It can be seen that the relation between d and d_x is

$$d_x =\{ [d \cos(y)-r \cos(x)]^2 + [d \sin(y)-r \sin(x)]^2\}^{0.5} \quad (4)$$

where $y= \tan^{-1}[(y_T - y_S)/(x_T-x_S)]$, (x_S,y_S) and (x_T,y_T) are the sensor and target coordinates respectively.

We are considering here both models of the received power of transmitter-receiver in free space

$$P_r(d)=P_t\, G_r\, G_t\, \lambda^2 / \{(4\pi)^2 d^2 L\} \quad (5)$$

Where G_r and G_t are equal to $4\pi\, A_e /\lambda^2$ for receiver and transmitter, A_e is the effective antenna distance aperture, λ is wavelength, L is a lost factor, d is covered distance and P_t is transmitted power, and for the non-free space

$$P_r(d)=P_t\, G_r\, G_t\, h_r^2\, h_t^2/ d^4 \quad (6)$$

Where h_r and h_t are receiver and transmitter heights.

Thus, the sensor failure probability sfp is corrected as

$$Sfp_{new}=sfp_{old}\,(d_x/d)^2 \tag{7}$$

for free space model and

$$Sfp_{new}=sfp_{old}\,(d_x/d)^4 \tag{8}$$

for non-free space

It's required to find these k sensors subsets activation in order to maximize the network lifetime as

$$T=\max \sum t_k\, w_k \tag{9}$$

Where t_k and w_k are lifetime of each sensor subset and its effecting weight; here taken as 1, with the assumption that lifetime of each sensor is normalized to a value of 1.

For comparison, a sensor-target (S-T) case study model [17] [18] is implemented initially in this study, in which a number of targeted zones are to be covered by a number of sensors, with coverage pattern distributed randomly over a two dimensional planner view. This model is further extended to a number of different patterns of sensors-target networks of different parameters.

The following table I, depicts the implementation of the proposed relaxation algorithm on an Ad Hoc comprising three sensors and two targets, which are covered by each sensor.

Table I, Network Lifetime and Position Perturbations of a Sensor-Target Matrix

Sensor	Target	$(sfp)_{old}$	Required α	old-new coordinate X	old-new coordinate Y	Lifetime improve
3	2	0.2	0.3	3→3.7071 3→3.7071 4→4.0607	2→2.2929 5→5.2929 7→7.9393	2→3
3	2	0.6	0.6	2→2.3536 3→3.7071 3→3.7071	2→1.6464 4→4.2929 7→7.2929	1→3
3	2	0.8	0.8	2→2.3536 3→3.7071 3→3.7071	2→1.6464 5→5.2929 8→8.2929	1→3
2	2	0.9	0.1- 0.6	2→2.3536 3→3.7071	2→1.6464 6→5.2929	1→2
2	3	0.9	0.1- 0.9	3→4.4142 4→5.4142	3→1.5858 8→6.5858	1→2
2	4	0.7	0.1- 0.2	4→3.3536 4→5.9319	3→2.6464 7→7.4824	1→1 1→2

The table shows the increase of network lifetime 200% and 300%, with position coordinates perturbations of sensors. It can be seen that in all investigated cases, network life times are increased to a number equal to the individual network sensors, which is maximum. It also shows that this has not been affected by number of covered target zones, or sensor failure probability (*sfp)* value, even when fixed and variable *sfp* values are considered for the different sensors. It is required here to find the maximum lifetime of sensors used in order to cover at most *α*; a predefined sensor coverage failure probability value.

On the other hand, it is noted that the execution time required for solving these scenarios increases largely with the model size, thought this has not been investigated in this study.

3. ALGORITHM AND FLOWCHART

The following flow chart (Fig. 5) depicts procedures and functions of the simulation program implemented on a Matlab platform.

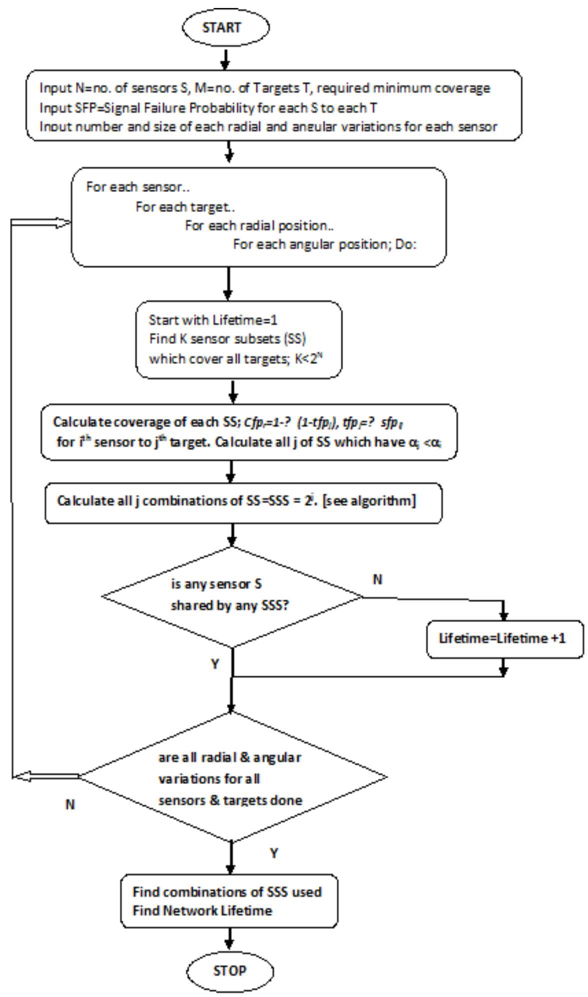

Figure 5; Flowchart of the simulation program

The main procedure of program flowchart is finding subsets of N sensors that can cover M target zones within specific required coverage failure probability α as a percentage. There can be maximum $k=2^N$ subsets, but normally less, in order to fulfill the condition of achieving α, or less. The above mentioned case study is applied [17], which shows that as the number of sensors in one subset increases, failure probability is reduced. For example, in a 4 sensors network, there are 9 possible sensor subsets among the maximum of 24 possible subsets, which can cover all targeted zones. These subsets are: {1,4}, {1,2,3}, {1,2,3,4}, {1,2,4}, {1,3,4}, {2,3}, {2,4}, {2,3,4}, {3,4}. The Sensor subset coverage of these 9 subsets, are simulated and the result is listed in the following table:

Table II; Nine sensor subsets, with coverage failure probabilities

Group	Sensors Subset	Coverage	Maximum Lifetime
[1]	{1,4}	0.9460	[1]+[6]=2
[2]	{1,2,3}	0.9521	1
[3]	{1,2,3,4}	0.6015	1
[4]	{1,2,4}	0.6919	1
[5]	{1,3,4}	0.8349	1
[6]	{2,3}	0.9530	[6]+[1]=2
[7]	{2,4}	0.7270	1
[8]	{2,3,4}	0.6090	1
[9]	{3,4}	0.8464	1

It can be shown that this failure probability is minimum for subset {1,2,3,4} in which all sensors are active, whereas it's maximum when only 2 or 3 sensors active as a group in a subset. Note that there exists no subset with only one sensor to cover all targets, as formulated in this case example.

It can be seen that as demanded failure probability is increased, network lifetime is increased, but saturated to a maximum value of 4 since there are 4 sensor lifetimes which can be operated individually. Further, it is shown that network lifetime is dropped to a value of 1 when α reaches the value of least failure probability of all sensors. This would reduce options of manipulating with failure probabilities and the network lifetime options.

4. SIMULATIONS OF ALGORITHM

This algorithm is to calculate network sensors lifetime for any required coverage for the target zones. That's to find the subsets of all sensors that cover all targets, in which one or more subset may contribute in covering all targets. It must be noted, that if one sensor is shared in more than one subset, then the total activation time of that sensor cannot exceed its normalized lifetime.

Firstly, the failure probability of all sensors *(i=1 to N)* to target *j (j=1 to M)*, is calculated according to $tfp_j=\prod sfp_{ij}$, where sfp_{ij} are sensor failure probabilities for a number of sensors to any target.

Next, a procedure is to calculate the coverage of the *k* sensors subsets to the *M* targets, as $scfp_r=1-\prod(1-tfp_j)$, in which $r \in [1, k]$; in which target failure probability *tfp* is entered as a vector for the *N* individual targets. All possible subsets covering all targets successfully, are compared with a required coverage, inputted by user, to find a new subset: SSS={{SS_1}, {SS_2}……..{SS_r}}; $r \in [1, k]$, SS={S_1, S_2,……….S_k}.

As seen, there are maximum 2^k subsets of SS_r, in which some utilize one or more same sensors in S_k , thus the algorithm identifies this in order to find the combing SS_r sets which in effect can increase their sensors lifetimes. This is depicted in the following procedure:

```
%INPUTTING S-T COVERAGE FAILUR PROBABILITY
n=input('Input number o sensors = ');
m=input('Input number of targets = ');
for i=1:n
x(i)=input(['Input decimal number of
sensor',num2str(i)’]
sx(i)=input(‘Input sensors coordinates’)
nr(i)=input(‘Input sensors radial variation steps’)
nx(i)=input(‘Input sensors angular variation steps’)
for i=1:m
tx(i)=input(‘Input target coordinates’)
sfp=Input_Decimal_to_Binary(d,n,m);

%FINDING SENSOR SUBSETS COVERING ALL TARGETS
ss=subset(n);
k=length(ss);
for i=1:k
in=ss{i};

%LOOPING FOR N SENSORS, M TARGETS, NR(N) RADIAL
%POSITIONS & NX(N) ANGULAR VARIATIONS
For 1→n
For 1→m
For 1→nr(n)
For 1→nx(n)
Calculate sensor-target disstance
Calculate  new sfp=old sfp(new distance/old distance)^2

%UPDATING SENSOR-TARGET COVERAGES
tfp=Target_Failure_Probability(sfp,in,m);
scfp=Sensor_Cover_Failure_Probability(tfp,in,m);
cover(i)=scfp;

%LOOPING FOR α NUMBER OF COVERAGE FAILURES
%FINDING SUBSETS OF MINIMUM REQUIRED COVERAGE
[coverage,s]=Less_Min_Coverage(cover,ss,k,alpha);
nn=length(coverage);
sss=subset(nn);
Max=1;
kk=length(sss);
x=cell(kk);
for ij=1:kk
ijij =sss{ij};
x=[s(1,sss{ij}(1))];
jiji=length(sss{ij});
if jiji>1
for ji=1:jiji
x=[x   s(1,sss{ij}(ji))];

%CALCULATING LIFETIMES
[t(ij) group]= lifetime(x);
if t(ij) > Max
Max=t(ij); G{i}=group; tt(i)=Max;
```

Only small sensor-target networks are considered due to the fact that execution time may be increased to a very large value, i.e. 2^r, $r \le k=2^N$, which corrupts the program and terminates with an error, but as long as both N and r are within reasonable values, then algorithm executes successfully as listed in this study simulations.

In all simulations, different values of *α's* are chosen for sensor subsets, ranging from 0.1 to 0.9; the higher α value the more subset choices. It was seen from the above case study, that in order to maximize lifetime of sensors, it would be appropriate to activate many sensor subsets to operate at different times, thus elongating their lifetime.

Full Sensor-target (S-T) network coverage of three sensors and two targets pattern, but with sensor failure probability *sfp* =0.2, 0.4, 0.6 and 0.8, as shown in Fig. 6, which shows that network coverage lifetime largely increases to 3 normalized time units, even with required coverage of *α*=0.5, as *sfp* decreases from 0.8 to 0.2. Further, the effect of the reduction of each sensor *sfp* is more dominant than the required value of *α*

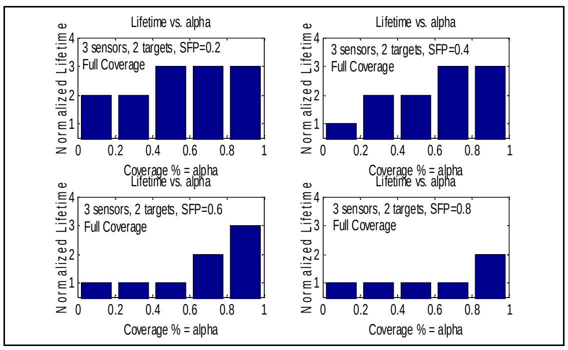

Figure 6; Lifetime of 3 sensors-2 targets network with full coverage of different failure probabilities

Figure 7 depicts the same results for 4 sensors + 3 targets. The figure indicates that full coverage between every sensor and target, is superior to partial coverage conditions with different *sfp* of 0.5 for all sensors, 0.1-0.9 or 0.9-0.1which have same lifetime vs. *α* patterns. It can thus be deduced, that full coverage is important measure for maximizing network lifetime.

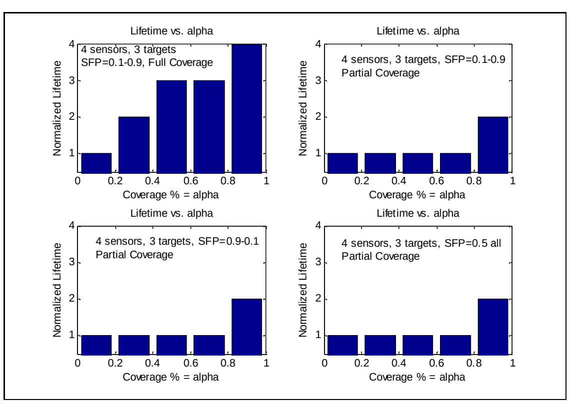

Figure 7; 4 sensors-3 targets simulations of different and random scenarios of coverage parameters

Figure 8 depicts the improvement in network lifetime when the adopted ad hoc relaxation algorithm is implemented on a three sensors covering two targets. It can be seen that network lifetime is increased from one normalized period to two and three, which is maximum, depending on the network coverage parameter α, for different values of sensor failure probabilities (*sfp*).

The figure also indicates that network lifetime improves with the decrease of both α and sfp, as predicted. Only 10% variations in sensors' locations are considered, in both radial and angular directions. This is valid for both free and non-free transmitter-receiver models.

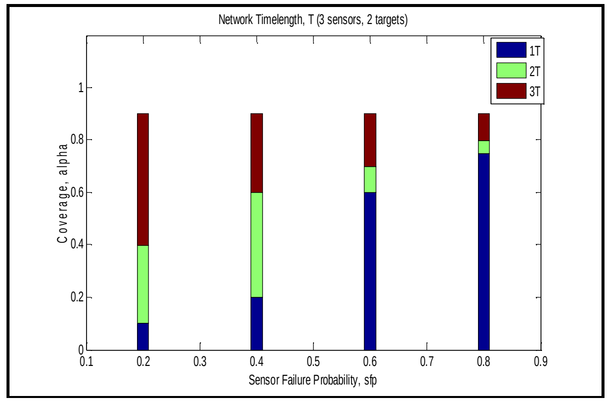

Figure 8; Network lifetime with coverage and sensor failure probability

Different network configurations are considered, implementing same ad hoc relaxation algorithm, such as 4S-3T, 4S-4T, 4S-5T and 4S-6T networks, as depicted in Fig. 10. It can be seen that although network lifetime is increased from one normalized time period to three, yet it is less than the maximum of four, due to only 10% variations in position variations.

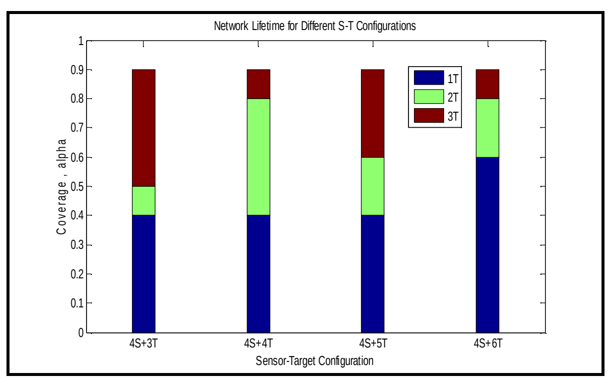

Figure 9; Network lifetime for different sensor-target configurations.

Figure 10 depicts a planner view of 3S-2T network, before and after the implementation of the ad hoc relaxation algorithm of this study. Different symbols are used in the figure to differentiate between targets and sensors, beforeand afterposition variationss. The size of the sensors' symbols indicates network coverage *reserves* that reflects increase of network lifetime.

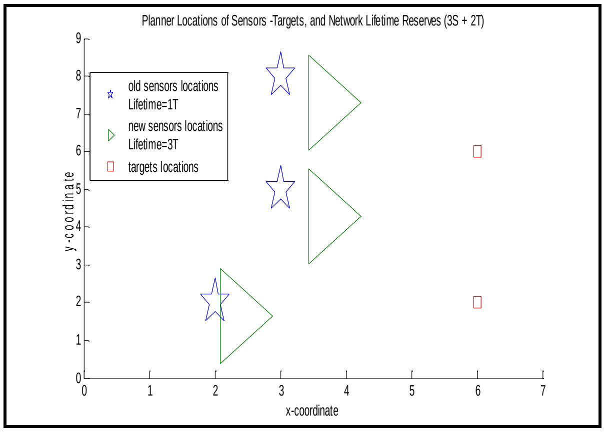

Figure 10; Planner sensor-target variations in location (3 sensors + 2 targets)

Different sensor-target configurations are also considered for four sensors and three targets, in which Figure 11 depicts locations of sensors on one side opposite to the targets position on the other, whereas Figure 12 shows the same network with the targets surrounding all sensors in a circle round pattern.

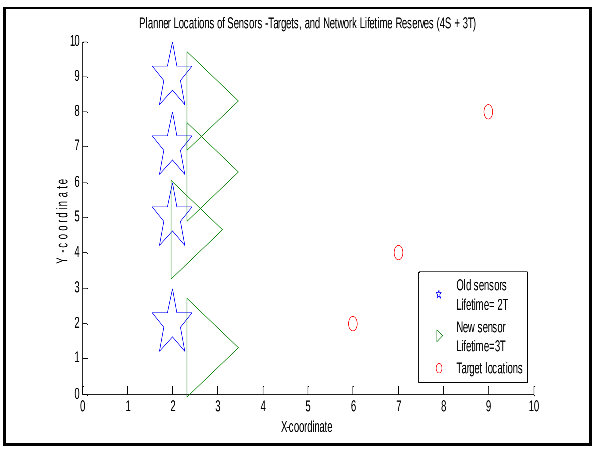

Figure 11; Planner sensor-target variations in location (4 sensors + 3 targets)

It can also be noted from figure 12, that network lifetime increased further when 20% variations in sensors positions are considered. This can be seen from the network *reserves* as indicated by sensor symbols.

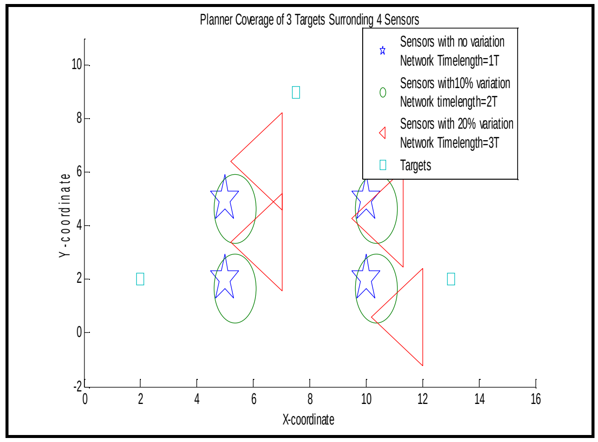

Figure 12; Planner sensor-target variations in location (4 sensors + 3 targets)

5. CONCLUSION

A relaxation algorithm for wireless sensors ad hoc network covering a number of target zones has been proposed and implemented with simulation on Matlab platform. This algorithm is of two major parts, the first of which is a collections of many procedures written in script files to input sensor-target probabilities, calculate network coverage, selecting the covering subsets of sensors within specified required network failure probabilities, as well as finding the combing subsets and their lifetimes. The second part is ad hoc relaxation algorithm for repositioning of sensors locations according to small perturbations. The major aim is to maximize lifetime, which was displayed for a number of scenarios.

It is assumed that sensors locations can vary in both radius and angle within sensors vicinities. Both free pace and non free space models of transmitter-receiver radiation lobes are used, being assumed analogous to sensor-target networks.

Comparing main platform cases scenarios [17][18] of 2 and 3 sensors with 3 and 4 targets, with and without the relaxation ad hoc algorithm, it has been seen that network lifetime has been increased from 1 to 2 as well as from 1 to 3 lifetimes. This implies 200% and 300% increase in sensors' lifetime.

Implementing this case study to different scenarios of sensor-target patterns, shows that maximum lifetime can reach 4 when utilizing 4 sensors with full coverage of 3 targets. It can be deduced from simulations that lifetime can be increased with more sensors of full coverage to fewer target zones.

Same increase in lifetime is noted for different network configurations, such as in-line sided sensors-targets, and sensors surrounded 360o by targets. Further; when 20% variations in sensors positions or locations, network lifetime increased to a maximum.

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