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# Algorithm of Ad Hoc Network Sensors Lifetime And Target Zones Coverage Simulations

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***Abstract—* An algorithm to study network sensors lifetime versus target zones coverage is implemented for a number of cases of different configurations and sensor-target failure probabilities. The algorithm is simulated on a Matlab platform, with a step-by-step evaluations of the case studies. The main goal is to maximize the lifetimes of sensors by sharing sensors subsets which cover a number of targeted zones, 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, sensor network, algorithm, simulation, failure probability**

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## I. INTRODUCTION

Sensor networks are normally deployed in areas of interest such as home appliances, healthcare applications, environment monitoring, etc. in order to collect information about events of these areas. Although using a large number of wireless low power ad hoc networks would be adequate, they are short lived, unreliable and limited radio range, memory and processing capacities[1]. An important function of these wireless sensor networks is 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.

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], which is divided into four classes: area, barrier, patrol or target coverage, in which this paper is focused on [10].

In order to maximize network lifetime and preserving zones coverage, many algorithms propose 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.

In this paper, algorithms and their simulations of wireless sensor networks are implemented to include network lifetime reliability and lower failure probability of the sensor subsets which cover and monitor all zone targets. This problem has been addressed in the literature before; namely the α-Reliable Maximum Sensor Coverage (α-RMSC) problem. A number of algorithms, are introduced for a general S-T (sensor-target) coverage situation; each with a special task in a step-by-step simulation manner.

## II. PROBLEM FORMULATION

An S-T coverage problem is for S sensors covering T targets according to failure probabilities of a number of different subset groups of sensors, in which the target failure probability *tfp* of *j* targets by *r* sensors subsets ( $r \in [1, k]$ )are:

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

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

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 $\alpha$; a predefined maximum failure probability
*tfp* is target failure probability of one targeted zone by all sensors.

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

$$\text{Max} \sum(tw)_k \qquad (3)$$

Where $t_k$ and $w_k$ are lifetime of each sensor subset and its effecting weight, with the assumption that lifetime of each sensor is normalized to a value of *1*. The aim is to increase this lifetime not on the expense of reducing the coverage.

A general sensor-target (S-T) case study model [17] is implemented initially in this study, in which three targeted zones are to be covered y four sensors, as depicted in Fig.1, 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. Execution time required for solving these scenarios increases largely with the the model size, thought this has not been investigated in this study.

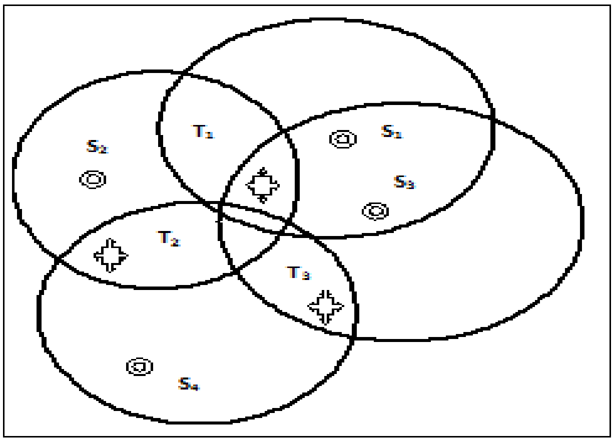

Figure 1; Planner view of four sensors and three target zones.

It can be seen that sensor $S_1$ covers target $T_1$ only, whereas $S_2$ covers $T_1$ and $T_2$, sensor $S_3$ covers $T_1$ and $T_4$, and sensor $S_4$ covers $T_2$ and $T_3$. It is assumed that two dimensional coverage pattern is assumed with the sensors allocated apart from the targeted zones' centers. Thus each sensor covers each target with a certain failure probability value (*sfp*), ranging from 0 to 1. A value of sensor failure probability of 1 indicates no coverage. Since each target is covered by one or more sensors, 100% coverage can be achieved in which alternative sensors alone or in groups, or subsets, can be switched on and off in such a way so that the lifetime of all sensors may be increased. The following figure depicts the values of *sfp* of each sensor to each target

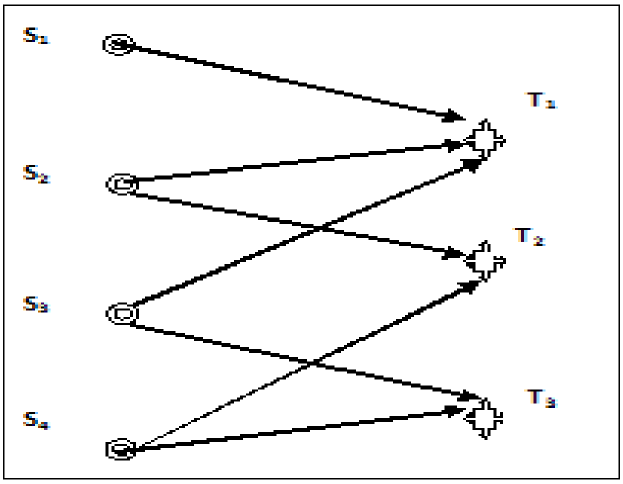

Figure 2; Sensor failure probabilities.

It can be seen that in order to insure 100% coverage of the targeted zones, there exists 9 possible sensor subsets or groups:{1,4}, {1,2,3}, {1,2,4}, {2,3}, {2,4}, {1,2,3,4}, {2,3,4}, {1,3,4} and {3,4}. Note that, a failure probability of one (1.0) in one of the targets, indicate no coverage to that target zone. So for the case of {1}, targets 2 and 3 are not covered, and for subset {1,3}, target 2 is not covered. The assumed values of sensor-target failure probability are listed as shown in the following table

Table I, Sensor failure probabilities

| Sensor | Target | SFP |
|---|---|---|
| 1 | 1 | 0.7 |
| 2 | 1 | 0.3 |
| 2 | 2 | 0.5 |
| 3 | 1 | 0.2 |
| 3 | 3 | 0.9 |
| 4 | 2 | 0.7 |
| 4 | 3 | 0.4 |

It is required to find the maximum lifetime of sensors used in order to cover at most $\alpha$; a predefined sensor coverage failure probability value. Figure 3 depicts network sensors lifetime against a variable $\alpha$ ranging from 0.1 to 0.9. It also shows the same network but for full coverage of every sensor to every target, with random *sfp* values, ranging from minimum 0.1 to maximum 0.9

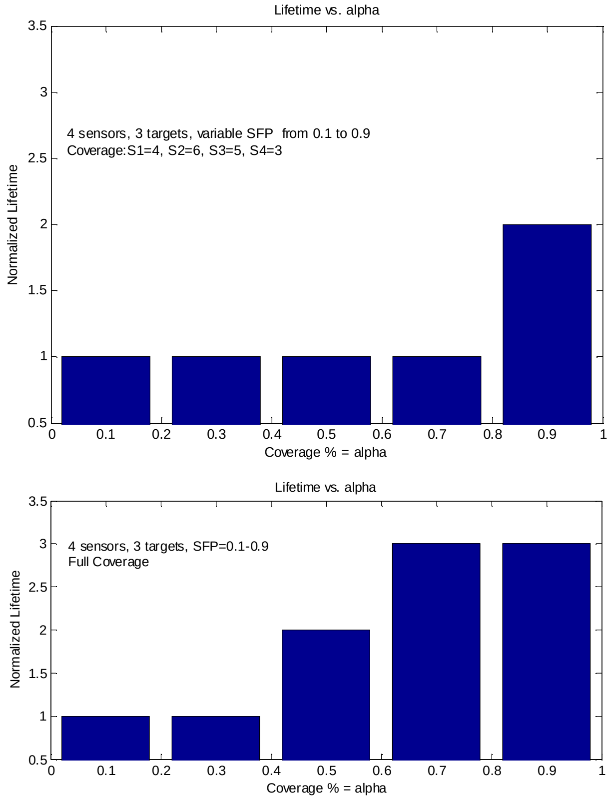

Figure 3; Sensors lifetime versus coverage failure.

As seen, network lifetime, is increased from a normalized value of 2 to 3 when full coverage was implemented, even when coverage probability failure α (alpha) is reduced from 0.9 to 0.7. Note that lifetime of 2 can be achieved with α=0.5. The sensors network lifetime, displayed above, is the maximum lifetime, which can be spared, else lesser lifetime values, or fractions of whole numbers can be achieved. This can occur for example, when sensor subsets operate with different time periods.

## III. FLOWCHART OF SIMULATION PROGRAM

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

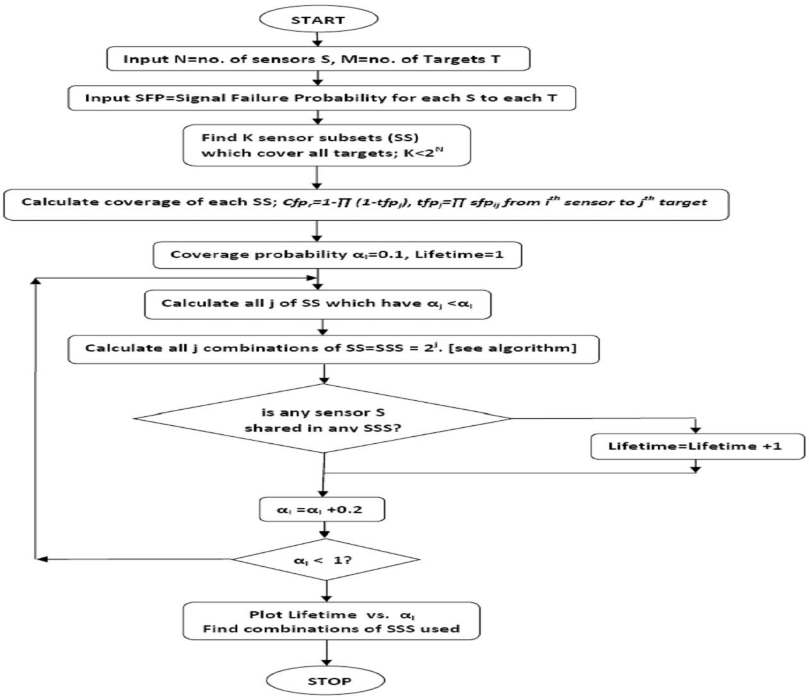

Figure 4; Flowchart of the simulation program.

The main procedures 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 next procedure is to investigate among all these subsets, the possible shared subsets j whose sensors are not shared; thus enabling each subset to operate alone and independently. As a result, network lifetime is increased. The procedures are repeated for a number of α ranging from to 0.1 to 0.9, and lifetimes are plotted for different scenarios.

The above mentioned case study is applied, which shows that as the number of sensors in one subset increases, failure probability is reduced. 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, shown in the first row against coverage failure probabilities shown in the second row

| **{1,4}** | **{1,2,3}** | **{1,2,3,4}** | **{1,2,4}** | **{1,3,4}** | **{2,3}** | **{2,4}** | **{2,3,4}** | **{3,4}** |
|---|---|---|---|---|---|---|---|---|
| **0.9460** | **0.9521** | **0.6015** | **0.6919** | **0.8349** | **0.9530** | **0.7270** | **0.6090** | **0.8464** |

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.

All sensors coverage failure probability are checked to be less than a certain assigned value of *α;* say 0.75, as listed in this algorithm:

**Sensor subsets less then alpha of 0.75 are = 0.6015 0.6919 0.7270 0.6090**

These coverage failure probabilities correspond to the following subsets: {1,2,3,4},{1,2,4},{2,4}and {2,3,4}.

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.

## IV. LIFETIME VERSUS COVERAGE 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 $(i=1 \text{ to } N)$ to target $j$ $(j=1 \text{ to } M)$, 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, as shown:

$$SSS=\{\{SS_1\}, \{SS_2\}\ldots\ldots\{SS_r\}\}; \quad r \in [1, k] \qquad (4)$$
$$SS=\{S_1, S_2,\ldots\ldots\ldots S_k\}$$

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 Matlab script file

```
%INPUTTING S-T COVERAGE FAILUR PROBABILITY
n=input('Input number o sensors = ');
m=input('Input number of targets = ');
 for i=1:n
   d(i)=input(['Input decimal number of sensor',num2str(i) ' = ']);
 end;
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};
   tfp=Target_Failure_Probability(sfp,in,m);
   scfp=Sensor_Cover_Failure_Probability(tfp,in,m);
   cover(i)=scfp;
end;
%LOOPING FOR  A NUMBER OF COVERAGE FAILURES (α)
for i=1:5
  a(i)=input('alpha= ');
  alpha=a(i);
%FINDING SUBSETS OF MINIMUM REQUIRED COVERAGE
  [coverage,s]=Less_Min_Coverage(cover,ss,k,alpha);
  for j=1:length(coverage)
    w(j)=input('Input w for ');
 end;
%FINDING COMBINED SUBSETS WITHOUT SENSOR SHARE
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))];
          end;
   end;
%CALCULATING LIFETIMES
   [t(ij) group]= lifetime(x);
        if t(ij) > Max
           Max=t(ij);
          G{i}=group;
        end;
   end;
   tt(i)=Max;
end;
%DISPLAY AND PLOT LIFETIME AND THE USED SUBSETS
for i=1:5
   disp ([a(i)  tt(i)]);
   disp('Group');
       celldisp(G(i));
end;
ploat(a, tt);
```

It can be seen that program 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 $r$, then algorithm executes successfully as listed in this study simulations

## V. SIMULATIONS

In all simulations, different values of $\alpha$*'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. But this would be on the expense of coverage failure probabilities.Then the weight factor indices *w's* are assigned to each sensor as well as to each target according to the importance of contributing sensors and targets to be covered. These weight indices are dependent on several factors, such as priority of targeted zones or sensors reliability, and therefore they will be included in the coverage lifetime of the contributed subsets. For evenly distribution of sensors and targets priorities, a value of unity is assigned to all *w's*, then, the maximum network lifetime is calculated according to the above-mentioned algorithm. The following simulations are implemented:

1. Full Sensor-target (S-T) network coverage of different S-T patterns with increasing number of targets from 3 to 6; i.e. 4S-3T, 4S-4T, 4S-5T and 4S-6T, as depicted in Fig. 5. It's assumed here that a sensor failure probability *sfp =0.5* is used for all configurations.

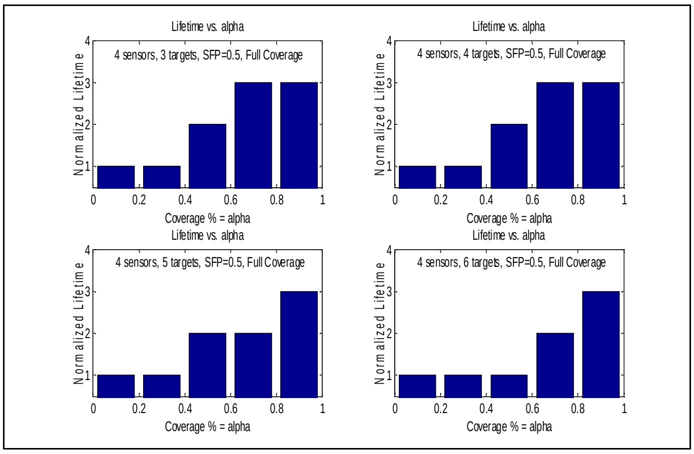

Figure 5; Network lifetime against required coverage failure probabilities for four sensors, all with full coverage of different targets but different failure probabilities.

As seen, the coverage lifetime is reduced, as the number of targets increases. Maximum lifetime is 3 normalized times, which can be achieved even with reduced failure probability α from 0.9 to 0.7, and with α reduced down to 0.5, lifetime is doubled.

2. 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 $\alpha=0.5$, 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*

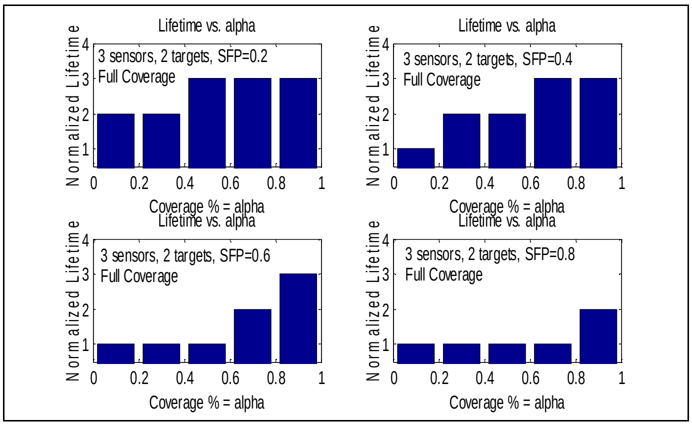

Figure 6; Lifetime of 3 sensors-2 targets with full coverages of different failure probabilities.

3. Different scenarios of a S4-3T pattern; i.e. four sensors covering 3 target zones with different *sfp* as well with partial/full coverage of sensors, as depicted in Fig. 7. It can be seen that a network lifetime of 4 can be achieved. The figure shows 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.

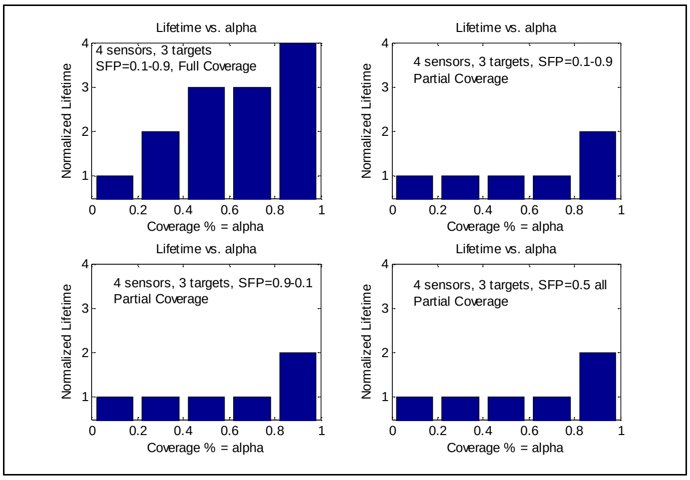

Figure 7; Four sensors-three targets simulations with different and random scenarios of coverage parameters.

4. Variable number of target zones, in which three sensors covering different numbers of targets ranging from 1 to 6; each with full coverage with *sfp=0.5* as an average value for this case. 3-D bar plot of lifetimes against required coverage failure probabilities ranging from 0.1 to 0.9, is depicted in Fig. 8. As expected, it can be seen, that with less number of target zones, lifetime is increased, and may reach to a maximum value of three normalized time periods, depending on the required network failure probability $\alpha$. The same results are depicted in a 2-D stem diagram of Fig. 9, in which both; the maximum and minimum values of sensor-target coverages are displayed, instead of network lifetimes. These maximum & minimum values correspond to the subsets utilized. The above-mentioned used algorithm calculates coverage value ranges for every subset found, which can cover the target zones with less than required failure probabilities.

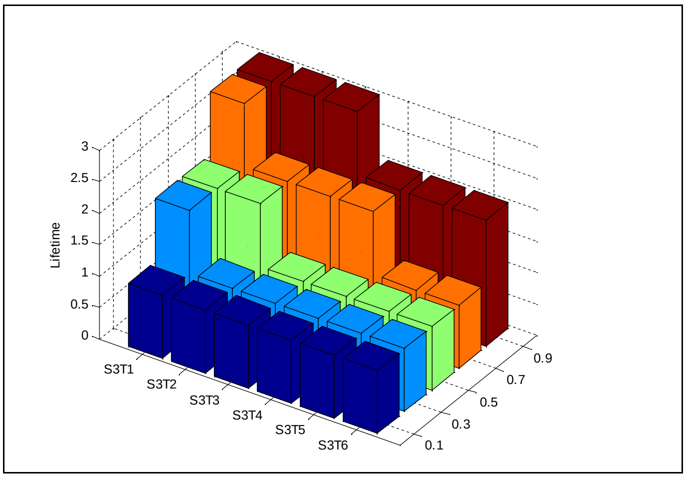

Figure 8; Lifetimes of three sensors with different number of targets and different coverage failure probabilities.

The maximum-minimum stem diagram of Fig. 9 below, can help in selecting the most appropriate combinations of covering subsets that have same lifetimes, and thus imposes priorities in choosing the right subsets.

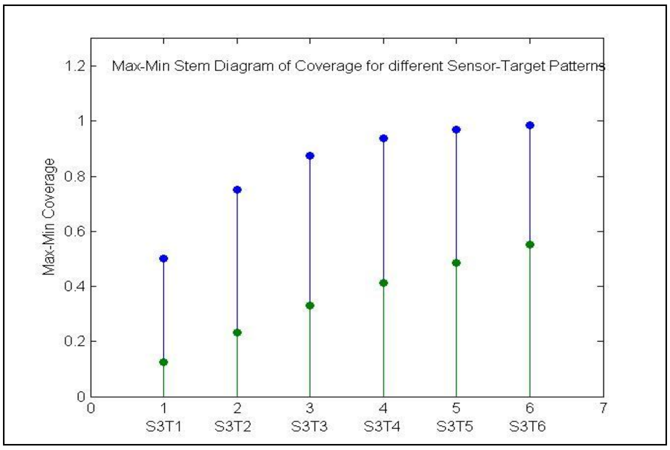

Figure 9; Maximum-minimum coverage values with different target zones by three sensors.

## VI. CONCLUSION

Algorithm of *wireless* sensors network covering a number of target zones has been successfully implemented and simulated on Matlab platform. This algorithm is part of many procedures written in a script file to input sensor-target probabilities, calculate network coverage, selecting the covering subsets of sensors within specified required network failure probabilities, finding the combing subsets and their lifetimes. The major aim to maximize lifetime, which was displayed for a number of scenarios as a testing mean of the study algorithm. The algorithms can be applied on any number of sensors and target zones, as well as sensor-target failure probabilities ranging from 0.1 to 0.9 and in any manner. Execution time for *this* main algorithm increases largely with network size of more than 10 sensors and targets, which cannot be estimated. Such study was not conducted in this study.

A case study of 4 sensors targeting 3 zones, has been used as a main platform, before updating, in a step-by-step simulations for different values of failure probabilities As expected, It has be seen that network lifetime can be increased with increasing sensors-targets coverages, reducing failure probabilities as well as reducing the demand for a certain required network coverage. Updating 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.The algorithm also calculates maximum to minimum ranges of coverages of the utilized combing subsets, and thus can be used for selecting the most appropriate subsets for maximum network lifetimes.

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