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PROLONGING NETWORK ENERGY-LIFETIME OF LOAD SWITCHING WSN SYSTEMS

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Abstract

Wireless sensor network energy and consequently lifetime are prolonged using an Ad Hoc algorithm with different parameters and coverage load in demand, as well as sensor-target configurations. The main goal is to increase WSN energy of sensors by selecting appropriate sensor subsets to satisfy the minimum required value of overall coverage failure probability. The algorithm investigates the different sensor subsets, according to their coverage failure probabilities, and switching intervals of target load demands.

Keywords: lifetime-energy, WSN,algorithm, failure-probability,switching-load.

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1. INTRODUCTION

The two most important issues related to the widely used wireless sensor network (WSN) beside adequate target coverage, are energy and lifetime. Wireless sensor networks are widely used in home and industrial applications alike, but suffering from short lived energy and lengthy and extended lifetime [1]. Typical characteristic of such wireless 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, in order to preserve the required coverage.

The interfacing of normally large number of neighboring nodes in WSN with each other in numerous routes, as well as consuming large transmission power, can limit network lifetime and performance. Target zones coverage utilization can be improved 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 of such literature is known as an Activity Scheduling Problem (ASP) [9][10], which is divided into four classes: area, barrier, patrol or target coverage.

Another WSN characteristic is the mobility of sensor-target, the variation in target zones coverage, and target load in demand, thus an optimal usage of saving energy is required in order to prolong network lifetime. It's focused in this study to maximize network energy by prolonging their lifetime; the two of which are related.

Previous work attempts 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]. In the literature many algorithms are proposed 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 mobility, physical damage, lack of power or energy malfunctioning. This problem has been addressed in the literature before; namely the α-Reliable Maximum Sensor Coverage (α-RMSC) problem.

In this study, an algorithm is adopted to prolong network sensors energy by the continuous switching and energizing sensor subsets according to different target load in demand, in order to satisfy a required minimum overall network coverage value.

We consider as in related literature [17] [18][19] a set S of n sensors in which each $s \in S$ can sense m interested targets; in this case *{t1, t2, t3}* within its sensing range over a large two-dimensional area, as shown in Fig.1

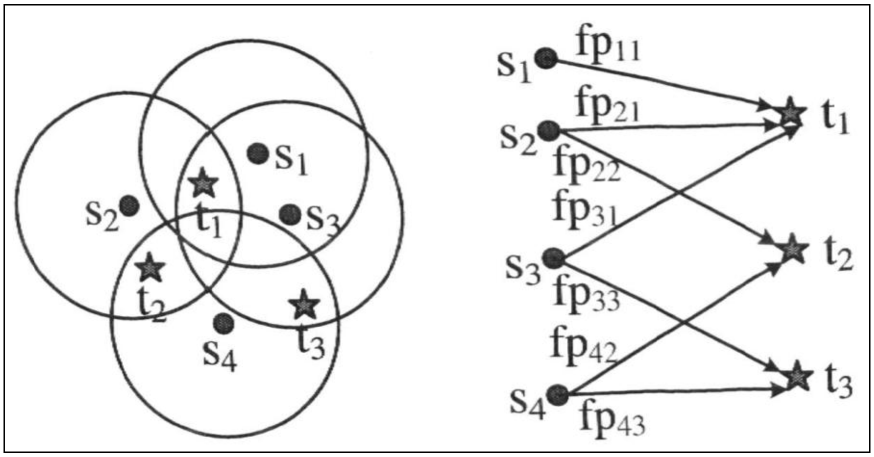

Figure 1. Planner view and symbolic view of four sensors and three target zones

It is shown that 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 linearly with their energy and inversely with the square root of the sensor-target distance, but we shall focus on energy in this study. It is not reasonable to energize all sensors in the coverage area to cover all the targets, because more than one sensor can cover the same target.

Further, the coverage load in demand of the target zones is alternating or switching through the day, so it is necessary to distribute the n sensors to a couple of subsets in which each subset can cover the relevant targets in each time slot. Therefore only one subset is active in a time slot of the duty cycle, in order to save overall energy and prolong WSN energy-lifetime.

2. Problem Formulation

The above sensor-target network, depicts sensor collection *S* and target zones *T*, with a number of subsets of sensor covers *C* with time weights tw_1, tw_2 ..tw_k and sensor cover failure probabilities cp_1, ..cp_k, as shown in Fig. 2, where *k* is the maximum number of sensor covers we can find. It can be seen that for this example, there exist 4 such sensor subsets.

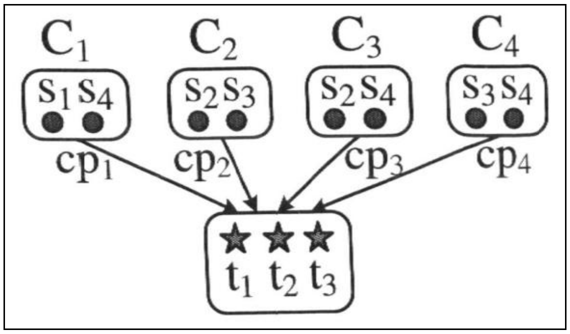

Figure 2. Sensor failure probabilities

Thus for the probability that a sensor cover $C_r=\{s_1, s_2, ..s_l\}, l \epsilon [1,n]; r \epsilon [1,k]$, 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 ($r \epsilon [1, k]$), thus

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

where sfp_{ij} is the failure probability of sensor *i* to target *j*, and *cfpr* 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, which is target failure probability of one targeted zone by all sensors.

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

$$T = max \sum t_k w_k \qquad (4)$$

Where t_k and w_k are the 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.

It is assumed that the transmitted and received power are related according to the following free space model

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

And for the non-free space

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

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 h_r and h_t are receiver and transmitter heights. It can be deduced that sensor power and consequently sensors energy are linearly proportional with the switching target load in demand, and therefore any target energy in demand will be reflected linearly on the sensors energy.

Figure 3 exhibits a case study in which two time intervals are considered for the three target zones load demands, whereas each target requires a different load demand, as shown. A maximum 100% load is the default WSN design reference, so that energy can be preserved when the target load is below this reference, and might reach infinity when there was no demand, i.e. energy is saved for future demand.

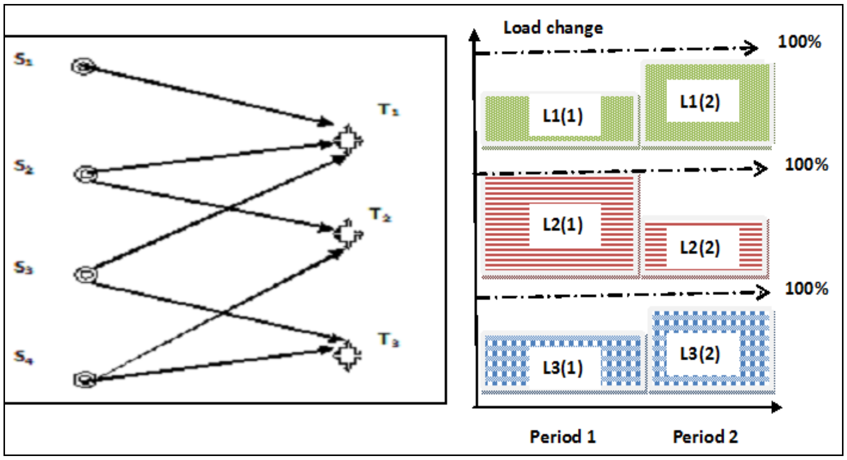

Figure 3. Switching target load demand of WSN

Three considerations are taken into account for the above algorithm:

1. The required overall network failure coverage probability α is adjusted as

$$\alpha_{new} = \alpha_{old} + (1 - max(L_i(j))) \qquad (7)$$

Where Li(j) is for all i^{th} targets in the j^{th} interval *t*. If this value exceeds unity, then it is equated to 1. This would increase the number of possible sensor subsets and therefore a possible lifetime increase.

2. The individual target failure probabilities of the j targets are increased by their load demands $L_i(j)$ as specified in time period intervals as

$$tfp_{i,\,new} = tfp_{i,\,old} + (1 - L_i) \qquad (8)$$

Again, if this value exceeds unity, then it is equated to 1.

3. The total subset lifetime T_{totl} is calculated as

$$T_{total} = \sum T_j \qquad (9)$$

In which T_j is lifetime preserved or saved for period interval *j*, which is evaluated as:

$$T_j = i\ T_j / \sum L_i \qquad (10)$$

i.e. individual period lifetime is increased by $i/\sum L_i$ due to the fact that maximum default or reference energy is equal to the number of target time zones $i/t(j)$

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, and for each time interval of target load demands. There can be maximum $k=2N$ subsets, in order to fulfill the condition of achieving α, or less. It is required 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.

The total lifetime is computed by adding all lifetimes of the switching load periods, according to the area under the load demands, as depicted in equations 9-10.

3. Switching WSN algorithm

The following flow chart (Fig. 4) depicts procedures and functions of the simulation program implemented on a Matlab platform. This algorithm is to compute WSN sensors energy for any load demand of target coverage, by finding all possible subsets of sensors that achieve overall required coverage over several time periods of target load demands. It is 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.

Following previous work analysis [17][18][19], 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. Then the coverage of the k sensors subsets to the M targets, as $scfp_r=1-\prod(1-tfp_j)$, in which $r \in [1, k]$, is calculated, i.e. $SSS=\{\{SS_1\}, \{SS_2\}\ldots\ldots\{SS_r\}\}; r \in [1, k]$, in which $SS=\{S_1, S_2, \ldots\ldots S_k\}$

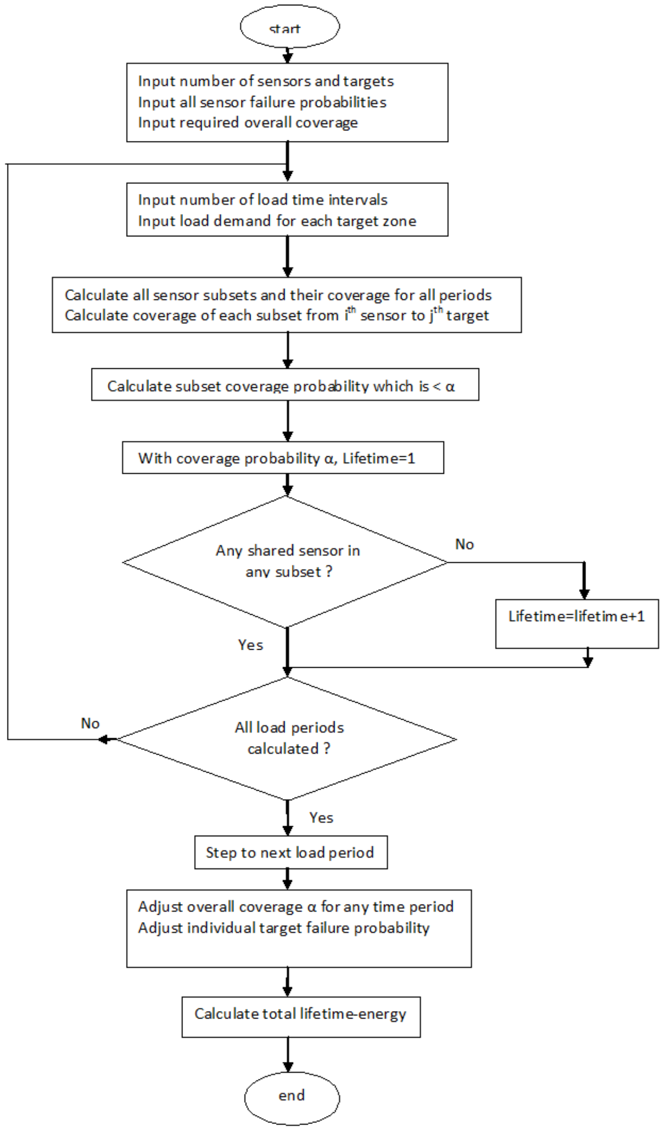

Figure 4. Flowchart of energy-lifetime algorithm

There are maximum *2k* subsets of SS_r, in which some utilize one or more same sensors in S_k. The procedure is repeated for each identified time period, according to the target load demands which are inputted. Total lifetime - energy is summed up for all periods with reference to the total area under the load demand intervals.

Execution time required for solving these scenarios increases largely, depending only on the number of sensor subsets, i.e. $2r,\ r \leq k=2N$, which corrupts the program and terminates with an error, but as long as both N and r are within reasonable values, then the algorithm executes successfully even with so many time periods of load intervals.

The algorithm differentiates between different cases such as on-off load pattern, similar load distributions for all time periods, variable load distributions for the targets in each time interval, or a combination of all these cases.

4. Simulations

In order to maximize lifetime and energy of WSN systems, it would be appropriate to activate many sensor subsets to operate at different times, but this might 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.

Ten different simulation cases are studied for a two sensors-two target system, with an overall coverage failure probability $\alpha=0.1$ and randomly selected *sfp* values as listed in Table 1

Table 1. Selected values of *sfp*

	→1	→2
sfp 1→	0.2	0.3
sfp 2→	0.4	0.1

Further; only two time periods are chosen to be 20% and 80% of the total load demand time. Among all cases, three special cases are analyzed in details as follows:

Case (a): with the following load distribution (Fig.5):

Load demand for target 1=L1=50%, for both periods. Load demand for target 2=L2=50%, for both periods

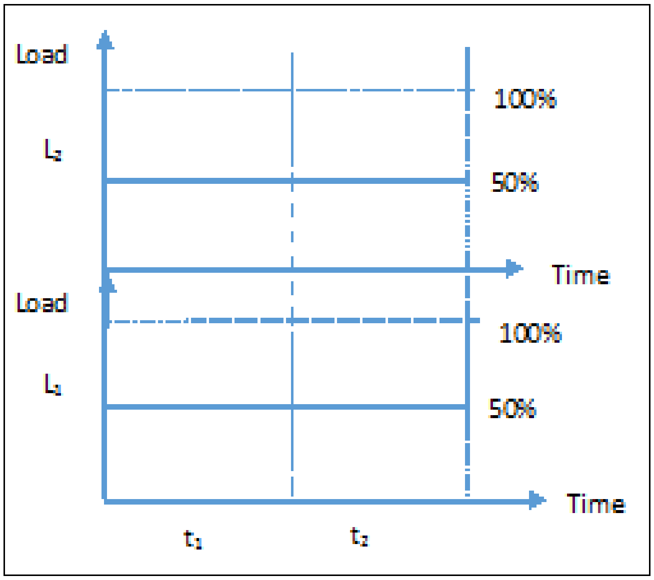

Figure 5. Load distribution of case (a) target demand

As shown, the load is symmetrical for the two load intervls, as equal to 50% throughout. This case serves as a verification for other cases too. A lifetimme increase to 4 is depictedin the following figure (Fig. 6).

Next, we shall explore a case in which the load is random for each target zone and in each time period.

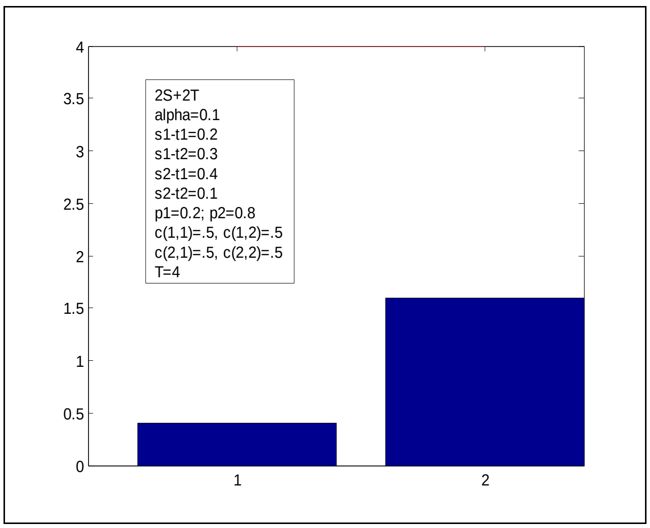

Figure 6. Case (a) lifetime of individual target zone load

Case (b): with the following load distribution (Fig.7):

Load demand for target 1=L1=30%, for period 1,and =70% for period 2, Load demand for target 2=L2=70%, for period 1 and =30% for period 2

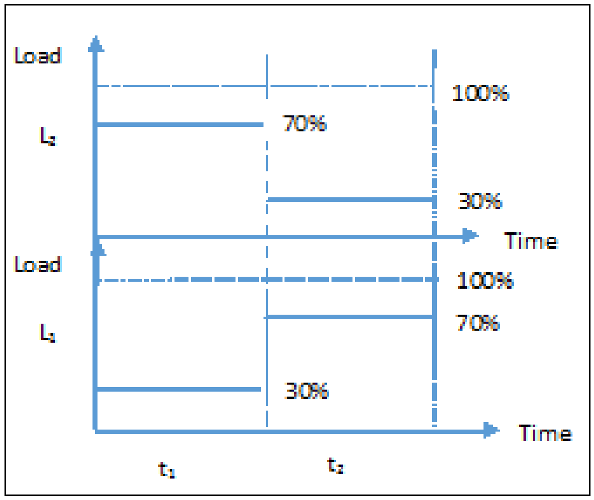

Figure 7. Load distribution of case (b) target demand

A lifetimme increase to 2.8571 is depictedin the following figure (Fig. 8)

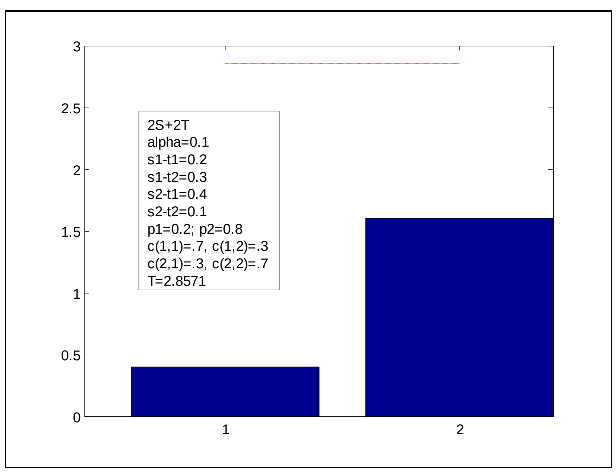

Figure 8. Case (b) lifetime of individual target zone load

Case (c): with the following sensor failure probabilities for a two sensor-three target zones (2S-3T) WSN system, listed in Table 2

Table 2. Selected values of *sfp* for 2S-3T

	→1	→2	→3
Sfp 1→	0.1	0.5	0.3
Sfp 2→	0.4	0.9	0.7

Together, with four load time periods of 10%, 40%, 20% and 30% respectively. Also, target load demands for these four periods are selected as follows in Table 3:

Table 3. Load distribution for case (c)

	Period 1	Period 2	Period 3	Period 4
Target 1	0%	100%	100%	0%
Target 2	50%	20%	30%	100%
Target 3	70%	70%	60%	90%

This is also depicted in Fig. 9, as shown target load for period 1= {30%, 50%, 100.}, period 2={30%,80%,0%}, period 3={40%, 70%, 0%}, and period 4={10%, 0%, 100%}

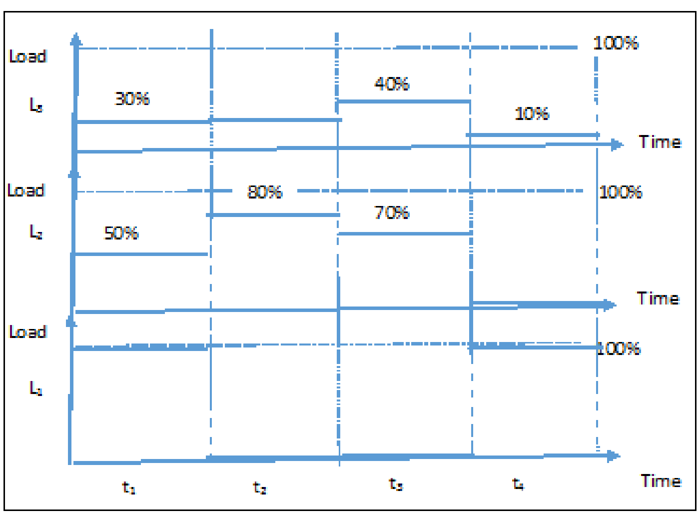

Figure 9. Load distribution of case (c) target demand

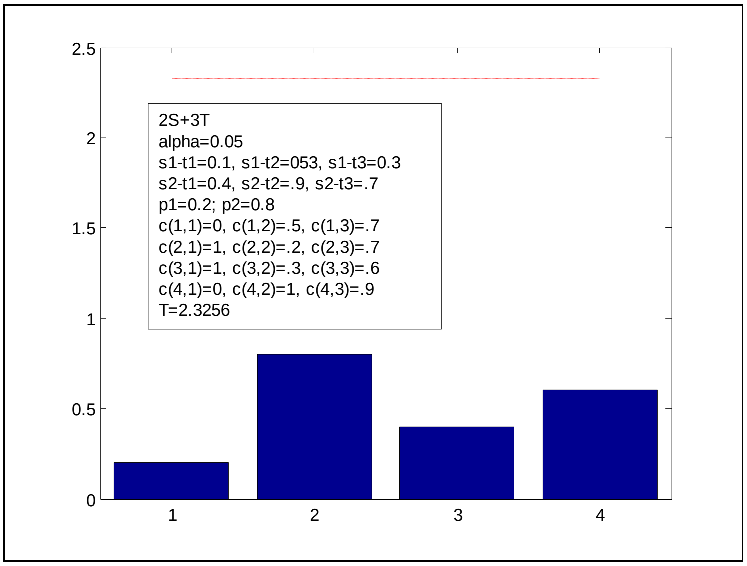

Figure 10. Case (c) lifetime of individual target zone load

The following table (Table 4) summarizes conducted simulation results for different case studies as shown

Table 4. Listing of cases studied

#	Case Study	Lifetime/ Energy
1	L1=100%, for both periods L2=100%, for both periods	1.0
2	L1=0%, for both periods L2=0%, for both periods	∞
3	L1=50%, for both periods L2=50%, for both periods	4.0
4	L1=30%, for both periods L2=70%, for both periods	3.2258
5	L1=70%, for both periods L2=30%, for both periods	5.2632
6	L1=30%, for T1, 70% for T2 L2=70%, for T1, 30% for T2	2.8571

<table>
<tr><td>7</td><td colspan="5">L1=70%, for T1, 30% for T2
L2=30%, for T1, 70% for T2</td><td>2.8571</td></tr>
<tr><td>8</td><td colspan="5">L1=0%, for T1, 100% for T2
L2=100% for T1, 0% for T2</td><td>2.5</td></tr>
<tr><td>9</td><td colspan="5">L1=100%, for T1, 0% for T2
L2=0% for T1, 100% for T2</td><td>9.0</td></tr>
<tr><td rowspan="4">10</td><td></td><td>T1</td><td>T2</td><td>T3</td><td>T4</td><td rowspan="4">2.3256</td></tr>
<tr><td>L1</td><td>0%</td><td>100%</td><td>100%</td><td>0%</td></tr>
<tr><td>L2</td><td>50%</td><td>20%</td><td>30%</td><td>100%</td></tr>
<tr><td>L3</td><td>70%</td><td>70%</td><td>60%</td><td>90%</td></tr>
</table>

5. Conclusion

An algorithm to prolong Ad Hoc WSN lifetime and consequently sensors energy has been successfully implemented and simulated on Matlab platform. A number of switching time periods are considered according to load demand of the target zones. Sensors energy reserve, which is linearly related with their lifetime value, is increased. This algorithm is part of many procedures written in a script file to input sensor-target data and load demand, 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 major aim is to maximize energy for a number of switched load scenarios.

The algorithm was verified when considering both 100% and 0% load demand over the entire multi-switched period, giving energy-lifetime values of unity and infinity respectively. When load demand is reduced to 50% for entire switching period, energy-lifetime is increased to 4, as expected.

Different load demand for the individual target zones, in which 30% load in demand was for target 1 and 70% for target 2, are considered. An increase of 3.2258 in energy-lifetime reference is obtained. And when these load demand figures are swapped to 70% and 30%, energy-lifetime reference was increased to 5.2632. This discrepancy is due to the two different switching time periods of 20% and 80% respectively. Thus a reduce in the predominate time period would result a larger energy reserve.

A further scenario is studied, in which different load demand for the individual targets, and for each time period is considered. It has been found that when load demand is decreased to 30% and 70% for two target zones in period one, and 70% and 30% in period two, would increase energy-lifetime reference to 2.8571. When these load demand for the target zones, were swapped, energy-lifetime is increased by the same value, suggesting that sensor subsets didn't change. Further detailed study is thus required. When these figures are changed to 0% and 100% respectively, the reference is increased to 2.5 and 9 respectively. Again, this is due to the different period times of only 20% in period one, and the dominating 80% in period two.

Finally, a random scenario is considered with two sensors and 3 target zones with 4 switching time periods of 20%, 30%, 40% and 10% of entire time. Random sensor failure probabilities are assumed. Also different load demands for the individual target zones and for each period time are considered. Energy-lifetime reference is increased to 2.3256. It would be advantageous to switch sensors according to the proposed algorithm, following targets load in demand over several time periods, in order to increase network energy and lifetime, in which only constant changes of load were considered in this study.

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