

Energy-Lifetime Control Algorithm for Variable Target Load Demands of Ad Hoc Networks

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Abstract— The energy and lifetime of Ad hoc wireless sensor-target networks are improved using load control algorithm with different parameters and coverage load in demand, as well as sensor-target configurations. The main goal is to increase the lifetime 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 varying intervals of target load demands.

Keywords— Algorithm, Lifetime-Energy, Target Demand, Variable Load, Ad Hoc, Failure Probability.

I. INTRODUCTION

Wireless sensor networks (WSN) are widely used in home and industrial applications alike, but suffering from short lived energy and lengthy and extended lifetime [1]. Therefore Ad Hoc networks lifetime and power are the two most important issues related to these wireless sensor network, beside an adequate target 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.

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 control and prolong network sensors energy and lifetime 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 $\{t_1, t_2, t_3\}$ within its sensing range over a large two-dimensional area, as shown [20] in Fig.1

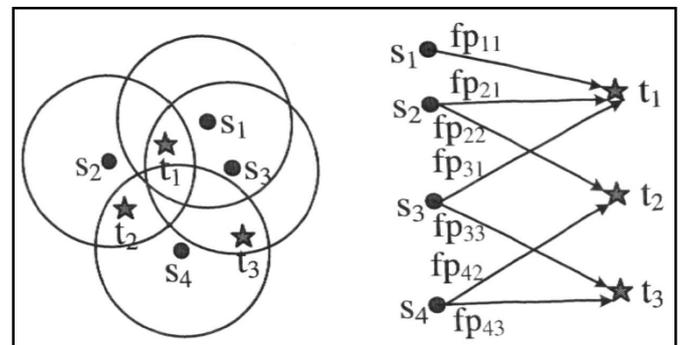


Fig.1: Planner view and symbolic view of four sensors and three target zones

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. 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 throughout 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.

There are different polynomials defining the target load demands over time period. These polynomials can be of different orders depending on the number of measuring points in any one period of time, as depicted in the following figure

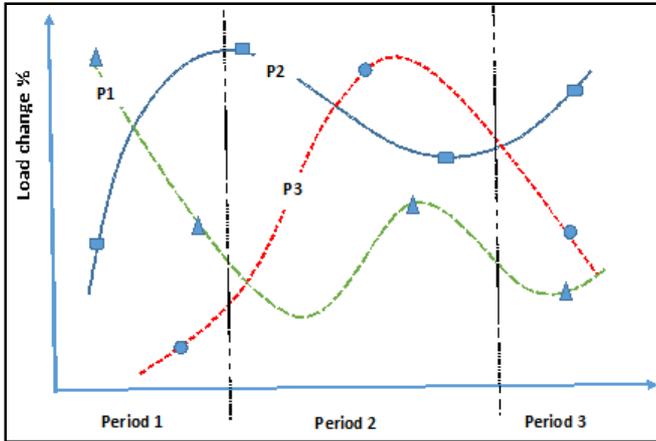


Fig.2: Target load polynomials

Figure 2 exhibits a case study in which three time periods 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. Note that any number of measuring points per period can be taken in principle, but we shall consider one measuring point per period here. The polynomial orders can be of any size for the different targets.

II. POWER/LIFETIME 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 $t_{w1}, t_{w2} \dots t_{wk}$ [0,1] and sensor cover failure probabilities $cp_1, \dots cp_k$, as shown in Fig. 3, 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.

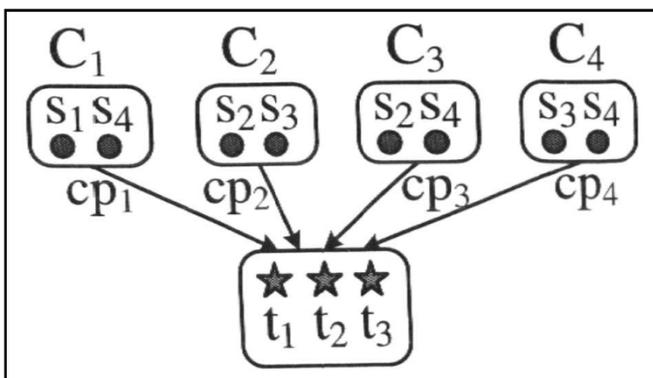


Fig.3: Sensor failure probabilities

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

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

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 , 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

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

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

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

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 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 energy are linearly proportional with the switching target load in demand, and thus on sensors energy.

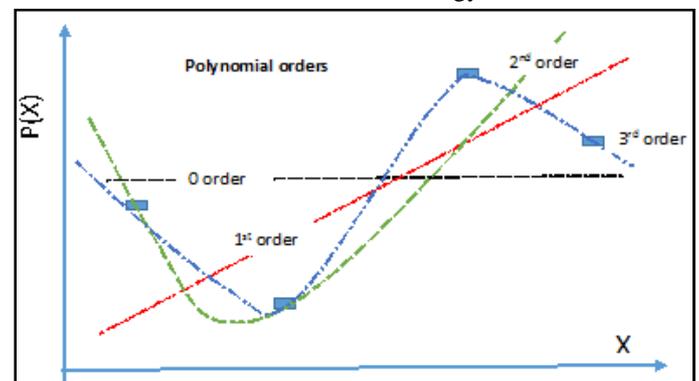


Fig.4: Order of polynomial degree order with 4 measuring points

The target load demand polynomial degree r can be of any order depending on measuring points p , in which $n < p$. Figure 4 shows that different polynomial degree 0^{th} , 1^{st} , 2^{nd} , 3^{rd} can be generated from the shown 4 measuring points.

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.

Three considerations are taken into account for the above algorithm:

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

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

Where $L_i(j)$ 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

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

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

3-The total subset lifetime T_{tot} is calculated as

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

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

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

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 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.

III. PROGRAM ALGORITHM PSEUDOCODE

The main procedure of program 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 program algorithm pseudocode (Fig. 5) 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

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input number of sensors=n
input number of targets=m
for i=1:m
    input number of target load zone=k
    for j=1:k
        input target demand load in the kth zone
    end;end;
input lowest coverage failure probability=e
input number of period calculations=N

for i=1:m
    input degree of polynomial required=d
    for j=1:k    P(m)=poly(i) end; end;

function ln(n,m)
for i=1:n    for j=1:m
                sfp(i,j)= input(); end; end; end;

for no=1:N do

function tfp=Target_Failure_Probability(sfp,in,m)
for i=1:m tfp(i)=1;
    for j=in
        tfp(i)=tfp(i)* sfp(j,i); end; end; end;

function sfp=Input_Decimal_to_Binary(d,n,m)
for i=1:n while d(i) ~= 0
    for j=1:m if rem(d(i),2)==0 bb(m-j+1)=0;
                else bb(m-j+1)=1; end;
                d(i)=floor(d(i)/2); end; end;
                sfp(i,:)=bb; end;
    for i=1:n    for j=1:m
        if sfp(i,j)~=1; sfp(i,j)=input()
            else sfp(i,j)=1; end; end; end; end;

function [scfp]=
    Sensor_Cover_Failure_Probability(tfp,in,m)
for i=1:in scfp(i)=1;
    for j=1:m    scfp(i)=scfp(i)*(1-tfp(j)); end;
                scfp(i)=1-scfp(i); end; end;

function
coverage=Less_Min_Coverage(scfp,k,alpha)
count=0; for i=1:k
    if scfp(i)<alpha count=count+1;
        coverage(count)=scfp(i); end; end; end;

function
coverage_time=Coverage_Time(coverage,w)
tt=0; ii=length(coverage);
for i=1:ii tt=tt+(1-coverage(i)); end;
for i=1:length(coverage)
coverage_time(i)=(1-coverage(i))^ii *w(i)/tt; end;
disp (coverage_time); end;
    
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Fig.5: Program pseudocode of energy-lifetime algorithm

Following previous work analysis [17][18][19], 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. Then the coverage of the k sensors subsets to the M targets, as $sfcpr_r = 1 - \prod_j (1 - tffp_j)$, in which $r \in [1, k]$, is calculated, i.e. $SSS = \{\{SS_1\}, \{SS_2\}, \dots, \{SS_r\}\}$;

Where $r \in [1, k]$, in which $SS = \{S1, S2, \dots, Sk\}$.

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.

At each period, several measuring load demands are taken for each time period and for each target. A polynomial of required degree is formed for each target load pattern. 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.

IV. MATLAB SIMULATION OF CASES

Throughout the different cases studied here, a minimum coverage failure probability of 0.1 is selected, which maintains at least 90% of required sensors-targets coverage. Two sensors are selected to cover 4 targets with the following sensor failure probabilities sfp , which are of a random nature, as depicted in Table I.

Table .I: Sensor-Target failure probabilities

Sensor→Target	sfp
1→1	0.1
1→2	0.3
1→3	0.5
1→4	0.8
2→1	0.8
2→2	0.5
2→3	0.3
2→4	0.1

The algorithm is tested on a general case study with target load demands, each having a polynomial of different degree, i.e. 1,2,3 and 4 degree. Up to 5 measuring load points are taken depending on polynomials. Also, 10 switching intervals are chosen, for the sensors over the period. The network lifetime is increased to 2.8574 times the lifetime when no switching is imposed. This is shown in Fig. 6

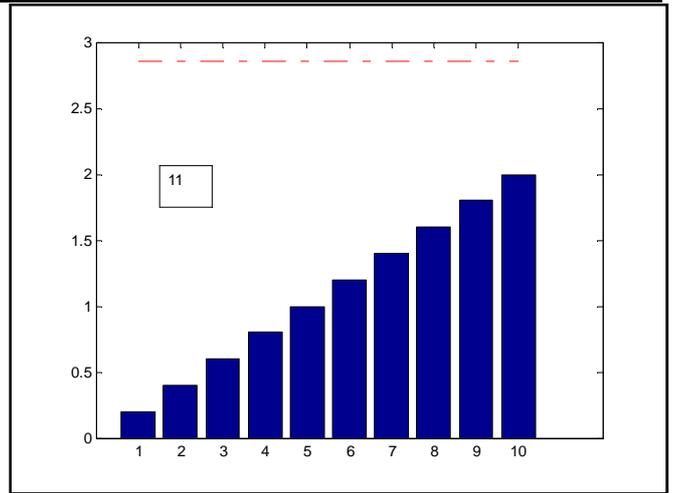


Fig.6: The general case study

It can be seen that at the end of each switching interval, a certain amount of lifetime, and consequently sensors energy and power, has been increased.

Then the following cases are studied, in which each of the four targets are having the following different load demand polynomials:

- (1) Constant polynomial for all targets, in which each of the targets is having a constant load demand, as depicted in Table II. The lifetime is increased by 2.5 P.U.

Table.II: Constant load demand

T	Time (P.U.)			Load (P.U.)			Polynomial/d egree
	1	2	3	1	2	3	
1	0.1	0.5	0.9	0.5	0.5	0.5	P=0.5 /0
2	0.1	0.5	0.9	0.2	0.2	0.2	P=0.2 /0
3	0.1	0.5	0.9	0.8	0.8	0.8	P=0.8 /0
4	0.1	0.5	0.9	0.4	0.4	0.4	P=0.4 /0

- (2) Linear polynomial for all targets, in which each of the targets is having a different linear load relation with time, as depicted in table III. The lifetime is increased by 2.25 P.U.

Table.III: Linear load demand

T	Time (P.U.)			Load (P.U.)			Polynomial/degree
	1	2	3	1	2	3	
1	0.1	0.5	0.9	0.1	0.5	0.9	P=X /1
2	0.1	0.5	0.9	0.9	0.5	0.1	P=-X +1 /1
3	0.1	0.5	0.9	0.5	0.3	0.1	P=-0.5X +0.55 /1
4	0.1	0.5	0.9	0.1	0.3	0.5	P=0.5X + 0.05 /1

- (3) Parabolic polynomial for all targets, in which each of the targets is having a different parabolic load

relation with time, as depicted in table IV. The lifetime is increased by 3.25 P.U.

Table.IV: Parabolic load demand (degree 2)

T	Time (P.U.)			Load (P.U.)			Polynomial/degree
	1	2	3	1	2	3	
1	0.1	0.5	0.9	0.2	0.6	0.4	$P=-1.8750X^2 + 2.1250X+0.0062$ /2
2	0.1	0.5	0.9	0.9	0.4	0.7	$P=2.5 X^2 -2.75X + 1.1500$ /2
3	0.1	0.5	0.9	0.4	0.6	0.5	$P=-0.9375X^2 + 1.0625X+0.3031$ /2
4	0.1	0.5	0.9	0.8	0.4	0.6	$P=1.875X^2 - 2.125X + 0.9938$ /2

- (4) Then this parabolic load demand nature (case 3) is approximated with both a linear polynomial relationship of degree 1, and a constant polynomial relationship of degree 0, in which the network lifetimes are increased by 3.6 and 3.35 respectively. It can be noted that this polynomial degree fitness correlation depends on the load nature. This is depicted in Table V.

Table.V: Parabolic load demand (degree 1 and 0)

Degree 1							
T	Time (P.U.)			Load (P.U.)			Polynomial/degree
	1	2	3	1	2	3	
1	0.1	0.5	0.9	0.2	0.6	0.4	$P=0.25X+0.275$ /1
2	0.1	0.5	0.9	0.9	0.4	0.7	$P=-0.25X+0.791$ /1
3	0.1	0.5	0.9	0.4	0.6	0.5	$P=0.125X+0.437$ /1
4	0.1	0.5	0.9	0.8	0.4	0.6	$P=-0.25X+0.725$ /1
Degree 0							
T	Time (P.U.)			Load (P.U.)			Polynomial/degree
	1	2	3	1	2	3	
1	0.1	0.5	0.9	0.2	0.6	0.4	$P=0.4X$ /0
2	0.1	0.5	0.9	0.9	0.4	0.7	$P=0.6667X$ /0
3	0.1	0.5	0.9	0.4	0.6	0.5	$P=0.5X$ /0
4	0.1	0.5	0.9	0.8	0.4	0.6	$P=0.6X$ /0

- (5) Varying number of switching points, in which the parabolic load demand polynomial of the above case study (case 3), is varied with different switching intervals. It can be also noted that the correlation depends on the target load pattern nature. This is depicted in Table VI

Table.VI: Variable switching periods

Number of switching	Lifetime
2	2.8
5	3.25
10	3.35

- (6) Varying polynomial for same target load measuring points, in which the load demand of case 3 is formulated as degree 2, 1 and 0. The lifetime is increased to approximately 3.5 depending on the individual target load profile. This is depicted in Fig. 7

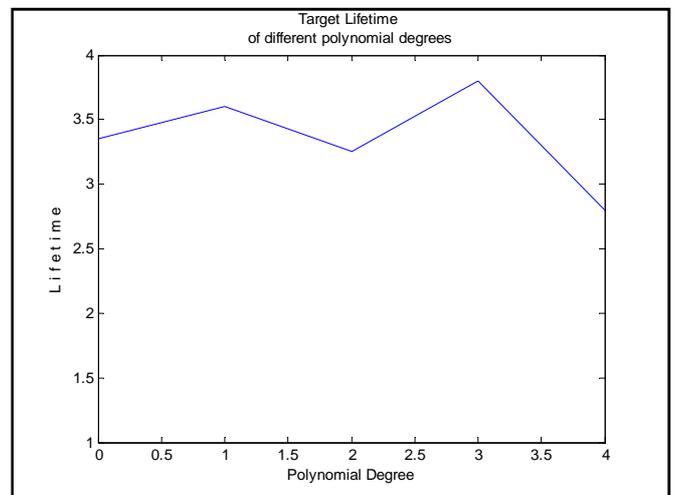


Fig.7: Lifetime versus load polynomial degree

V. CONCLUSION

A lifetime-energy control algorithm of an ad hoc network has been successfully implemented and simulated on the Matlab platform, in which a wireless sensor network (WSN) comprising of two sensors and 4 targets is analyzed. A number of different cases of target load profiles, as well as the number of switching of sensors subsets, are considered.

A case study; in which a minimum coverage failure probability of 0.1 is studied with sensor failure probabilities of random nature, ranging from 0.1 to 0.9. Target load demand profiles are assumed with different polynomial degrees ranging from 0 to 4. The network lifetime is increased to 2.8574 times the lifetime when no switching is imposed.

The control algorithm reads 3 values or measuring points of each target load demand over a per unit period of time. This is fixed for all scenarios studied. As load demand is reduced from rated levels, the network lifetime is increased from 2.25 to 3.6 P.U. depending on the nature of load polynomials. It is deduced that this increase depends on the individual load profile nature, and doesn't follow a certain

profile. Six different scenarios are studied:

1. Constant load profiles for all targets
2. Linearly varying profiles for all targets
3. Parabolic varying profiles for all targets
4. Polynomial degrees of degree 0 to 2 fitting the same load values
5. Variable switching periods from 2 to 10
6. Formulating parabolic varying load into polynomials of degree 0 to 2

There was no correlation among these different scenarios, although the lifetime is increased up to 3.6 P.U.

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.

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