Balancing Energy Dissipation in Data Gathering Wireless Sensor Networks Using Ant Colony Optimization

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Abstract. Formulation of energy efficient protocols is of utmost importance for wireless sensor networks because of energy constraints of sensor nodes. When a number of nodes is deployed in a field located away from the base station, the nodes undergo unequal energy dissipation while transmitting information to the base station primarily due to two reasons: i) the difference in the distances of nodes from the base station and ii) the variation in inter-nodal distances. The schemes presented here better network lifetime by taking into account these two issues and try to equalize the energy dissipation by the nodes. While constructing the chain we also use Ant Colony Optimization algorithm instead of greedy approach used in PEGASIS. Application of ACO ensures that the chain formed is of shortest possible length and thus further helps enhance network performances by reducing the inter-nodal transmission distances as much as possible. Extensive simulations performed corroborates that the proposed schemes outperform PEGASIS by a significant margin.

Keywords: Wireless sensor network, data gathering round, Ant Colony Optimization, network lifetime.

1 Introduction

Wireless sensor networks (WSN) can be considered as a collection of mobile or static nodes capable of collecting data more cost-effectively as well as autonomously without any fixed infrastructure. The sensor networks are required to transmit gathered data to the base station (BS) or sink. Network lifetime thus becomes an important parameter for sensor network design as replenishing battery power of sensor nodes is an impractical proposition. The definition of network lifetime in case of sensor networks may be regarded to be application specific [3]. For most situations it can be said a network is useless if a major portion of the nodes die. Moreover it is accepted universally that balancing the energy dissipation by the nodes of the network is a key factor for prolonging the lifetime [3].

Here we consider a WSN where the base station is fixed and located far off from the sensed area. Furthermore it is assumed that all the nodes are static, homogenous, energy constrained and capable of communicating with the BS. The network being homogenous no high energy nodes are available hence communication between the

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nodes and the base station is expensive affair. Moreover all nodes have information about their respective distances from the BS in the static environment as stated in [2]. Individual nodes thus take rounds in transmitting to the base station which also distributes the dissipated energy more or less uniformly amongst the nodes.

The LEACH [1] and PEGASIS [2] propose elegant solutions to the problem. In this paper we try to provide a far more competent solution than the existing ones to the energy utilization problem. In our scheme a chain is formed in a way similar to PEGASIS but instead of using greedy algorithm we use Ant Colony Optimization (ACO) for chain formation. Though ACO is a widely accepted optimization tool its use in wireless sensor networks so far has been limited. Only a few applications of ACO in sensor networks [4-5] are available. Unlike [4-5], in our schemes we have tried to analytically remove the factors resulting in uneven energy dissipations and have only used ACO as a tool to enhance the performance.

In our paper here, instead of making all nodes transmit to the base station the same number of times, the network lifetime and performance has been increased by allowing the individual nodes to transmit unequal number of times to the base station depending on their distances from it.

2 Energy Dissipation Model

We consider the first order radio model as discussed in [1,2] with identical parameter values. The energy spent in transmission of single bit is given by

$$etx(d)=e_{t1}+e_{d1}d^{n} \tag{1}$$

where e_{t1} is the energy dissipated per bit in the transmitter circuitry and e_{d1}*dn is the energy dissipated for transmission of a single bit over a distance d, n being the path loss exponent (usually 2.0≤n≤4.0). For simulation purposes we have considered a first order model where we assume n=2. Thus the total energy dissipated for transmitting a K-bit packet is

$$Etx(K,d)=(e_{t1} + e_{d1}d^{2})K= e_{t}+e_{d}d^{2} \tag{2}$$

where $e_t = e_{t1}*K$ and $e_d = e_{d1}*K$. If e_{r1} be the energy required per bit for successful reception then energy dissipated for receiving a K-bit packet is

$$Erx(K)=e_{r1}K=e_{r} \tag{3}$$

Where, $e_r = e_{r1}*K$. In our simulations we take e_{t1} = 50 nJ/bit, e_{d1} = 100 pJ/bit/m2 and $e_{r1} = e_{t1}$ as mentioned in [2] with K = 2000 bits. It is assumed that the channel is symmetric so that the energy spent in transmitting from node *i* to *j* is the same as that of transmitting from node *j* to *i* for any given SNR.

3 Balancing Energy Dissipation in Data Gathering WSNs

In our schemes we aim at building a system that would ensure that total energy dissipation is divided equally among all the nodes of the network. Let us assume that there are '*N*' nodes in the network. The nodes are at first distributed randomly in the play field. The central idea in our schemes is similar to PEGASIS in which a chain is formed among all the nodes. One node is elected as leader. Each node receives a data packet from it neighbor, fuses it with its own data packet and then transmits it to its other neighbor in the chain. The data packet thus reaches the leader which is entrusted with the duty of transmitting the data packet the sink. Hence so far the work is just an illustration of PEGASIS.

But here we take this opportunity to bring into focus some of the drawbacks of PEGASIS. Although [2] tries to distribute the load evenly among all the nodes in the network this goal has not been fully achieved. Firstly, because the chain is formed using the greedy approach the inter-nodal distances tend to become larger towards the end of the chain resulting in greater energy dissipation. This is one of the primary reasons why we have considered ACO for chain formation. Another aspect which has been ignored in [2] is the variable distances of the nodes from the base station. A greater balancing in energy dissipation may be achieved if one burdens the nodes to transmit to the base station depending on their distances from it. An important point needs to be emphasized here. A network may last for a considerable amount of time with the nodes in the network gradually dying as time elapses. But it needs to be noted that the network may not serve its purpose at all after a certain percentage of node deaths. Hence the objective must be to ensure that all nodes remain completely functional for a larger length of time.

4 Chain Formation Using Ant Colony Optimization (ACO)

In this section we discuss the Ant Colony optimization algorithm used for chain construction. ACO makes sure that none of the inter-nodal distances becomes extremely large during chain construction ie. they never exceed a threshold value. Ant Colony Optimization is inspired by the behavior of real ants searching for food. The main objective of ACO is to utilize both local information (visibility) as well as information about good solutions obtained in the past (pheromone), when constructing new solutions.

To apply ant algorithm in our problem, we place ants arbitrarily on the nodes. Each ant is a simple agent with certain memory attributed. According to a probability, an ant chooses the next node into which it has to move into. This probability is a function of inter-nodal distance and pheromone deposited upon the link. Every ant has a taboo table recording nodes which the ant has already accessed. The Taboo table forbids the ant to move into previously visited nodes. At the end of travelling an ant deposits pheromone on the paths it has travelled through. Based on the information collected an ant determines an ant's choice of anode from its neighborhood. The mathematical formulations are omitted here due to the lack of space. In this way the entire chain is constructed. The chain is reconstructed using ACO when a node dies, but by bypassing it and by following all the above mentioned facts.

5 Energy Efficient Protocols

In this section we propose certain energy efficient protocols and assess how these perform when compared with PEGASIS.

***Scheme A*:** In this scheme we construct the chain using ACO instead of the greedy algorithm as proposed by PEGASIS. The basic approach of the network functioning is similar to that in PEGASIS and as described in Section 3. However the use of ACO helps to form chains with uniform intermodal distances. This fact is demonstrated in Section 6. This strategy no doubt indicates an enhancement in the network performance but this improvement gradually weans away and we get similar performance as compared to PEGASIS for larger percentage of node deaths. Therefore we see that there is surely further scope of amelioration.

Scheme B: In ***Scheme A*** we tried to nullify the differences occurring in energy dissipation of the nodes due to varying inter- nodal distances by constructing the chain using ACO. However the varying distances from the base station still need to be taken into account. To address this issue and to prevent a degradation of network performance Scheme B allows the individual nodes to become leader variable number of times depending on their distances from the base station. This is achieved in the following way. Let d_{Bi} denote the distance of the i^{th} node from the base station. Thus making use of (2), the energy dissipated (E_{Bi}) by the i^{th} node when it transmits a data packet to the base station is given by

$$E_{Bi} = (e_t + e_d d_{Bi}^2). \tag{4}$$

Now among the '*N*' nodes constituting the network we choose the node which is farthest away from the base station as reference, because it has to dissipate the maximum amount of energy during its turn of transmitting to the base station as compared to the other nodes. This node is denoted as the reference node. Let x_i be the number of times the i^{th} node is elected as the leader. The above discussion leads to the following relation,

$$x_i = (d_{Bref}^2/d_{Bi}^2)\ x_{ref}\ . \tag{5}$$

To determine the precise value of x_i for various values of i we choose $x_{ref} = 10$. The reason for not choosing $x_{ref}=1$ and using its scaled version $x_{ref} = 10$ for determining the different x_is is to minimize the error obtained by rounding of the value of x_i to its nearest integer.

Scheme C: A further enhancement in network performance may be achieved if somehow the nodes are made to dissipate equal amount of energy in a round. We assume that '*C*' data gathering rounds constitute a cycle and that the i^{th} node is selected as the leader x_i number of times in one data gathering cycle. Now let d_i be the inter-nodal distance corresponding to i^{th} node where d_i is the average of distances of the i^{th} node from its two neighbors. Let d_{Bi} denote the distance of the i^{th} node from the base station. Thus we have, the energy dissipated (Esi) by the i^{th} node in each round as,

$$Esi = A_i C + B_i x_i \tag{6}$$

with $A_i=(e_t+e_r+e_d d_i^2)$ and $B_i=e_d(d_{Bi}^2-d_i^2)$. Since it is desired that every node should spend an equal amount of energy in each round we assume Esi=Ess for all *i*. Therefore, from equation (6), we have

$$x_i = (Ess - A_i C)/B_i ; \therefore C = \sum_i x_i = Ess\sum_i \frac{1}{B_i} - C\sum_i \frac{A_i}{B_i} ; \Rightarrow x_i = \left(\frac{C}{B_i}\right)[(1+\sum_i \frac{A_i}{B_i})/(\sum_i \frac{1}{B_i}) - A_i]$$

Now for the system to be realizable, we should have, $C > x_i \geq 0$. Now, $x_i \geq 0$ is only possible if

$$[(1+\sum_i A_i / B_i)/(\sum_i 1/B_i) - A_i] \geq 0 \Rightarrow (1+\sum_i A_i / B_i) \geq A_i \sum_i 1/B_i$$

As $B_i = e_d(d_{Bi}^2 - d_i^2) + e_r$ is positive for all i as $d_{Bi} > d_i$ in all cases. Further under most circumstances, the relation $d_{Bi} >> d_i$ is also valid. This discussion helps us to write the above inequality as,

$$A_i \le (1 + \sum_i A_i / B_i) / (\sum_i 1/B_i) \tag{7}$$

Therefore, A_i can be approximated as (e_t+e_r) and B_i as $e_d d_{Bi}^2$ .However in order to ensure that $x_i \ge 0$ is valid for all values of i, we need to estimate an upper limit on the inter-nodal distance from the above inequality expressed in (7). The inequality in (7) takes the form

$$(e_t + e_r + e_d d_i^2)\ (A_i \text{ corresponding to maximum possible } d_i) \le e_d / \sum_i \frac{1}{d_{Bi}^2} + (e_t + e_r)$$
$$\therefore d_i^2 \le (d_{Brms}^2 / N) \tag{8}$$

with d_{Brms} as the root mean square of distances from the base station of the nodes. The other condition $x_i < C$ with identical approximations also gives the same inequality as found in (8). Therefore our system will be always viable if condition (8) is ensured. This is not very difficult to ensure as we also consider that the base station is placed away from the play field. The chain formation in this case too was done with ACO as before now but with the constraint that the inter-nodal distance satisfied (8). This distance satisfying (8) was taken as the threshold while simulating PEGASIS.

6 Simulation Results

In this section we demonstrate how our schemes outperform PEGASIS which in turn means that our schemes would perform far better than LEACH.

Results for Scheme A

We now demonstrate how ACO based chain construction approach performs better than the greedy chain. All simulations were done on a 50m*50m area and nodes were randomly distributed in this region. As mentioned in Section 5 in majority of the cases chain formation with the greedy approach results in chains with large inter-nodal distances towards the chain end. Table 1 demonstrates the fact that the greedy algorithm forms inferior chains with large inter-nodal distances.

Table 1. Number of rounds passed when 1% of nodes die for a node distribution in which the greedy algorithm forms a chain with large inter-nodal distances

Base Station Location	Energy/node(J)	Greedy chain	ACO chain	Percentage Improvement
(25,175)	0.75	1940	2703	39.33
(25,200)	0.25	697	841	20.67
(25,150)	1.00	3256	3890	19.47
(25,250)	0.75	1890	2218	17.35

Figures 2 and 3 portray the chains formed by greedy and ant algorithm for the same node distribution. It depicts clearly how the inter-nodal distances increase towards the end of the chain when the greedy algorithm is used. The lines in black indicate the inter-nodal distances which are larger than the threshold.

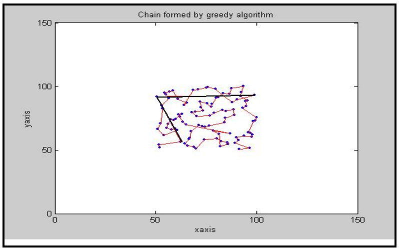

Fig. 2. Chain formed by Greedy Algorithm

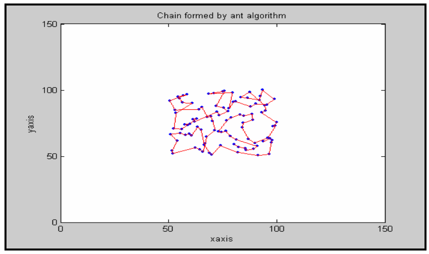

Fig. 3. Chain formed by ACO

Results for Schemes B and C

Our motive in this paper has been to make the network survive without degradation in performance for larger time durations. Schemes B and C take us a step further in this regard. The following table provides a comparative study between PEGASIS, Scheme B and Scheme C.

Table 2. Number of rounds passed when 1%, 10%, 20%, 30%, 40% and 50% nodes die with base station location at **(25,225)**

Energy (J/node)	Protocol	Percentage of node death					
		1	10	20	30	40	50
0. 5	PEGASIS	1490	1659	1680	1702	1726	1751
	Scheme B	1627	1693	1725	1738	1748	1758
	Scheme C	1692	1711	1725	1735	1745	1756
0.75	PEGASIS	2245	2460	2504	2542	2571	2622
	Scheme B	2469	2549	2577	2590	2608	2636
	Scheme C	2551	2563	2582	2597	2608	2628
1.00	PEGASIS	3042	3283	3355	3424	3459	3508
	Scheme B	3287	3416	3457	3484	3502	3521
	Scheme C	3400	3433	3454	3473	3497	3505

A close examination of the above table helps us appreciate the fact that both Schemes B and C perform better than PEGASIS till more than 50% of the nodes die. In many of the cases depicted, improvement can be seen even when more than 60% of the nodes. After the death of a major percentage of the nodes, the network may be regarded as non-functional because the service provided by it would be so inferior in quality that it would be hardly of any use. Thus we have succeeded in our goal that the degradation in network performance is delayed. Furthermore although PEGASIS shows an improvement over our schemes after the death of more than 50% of the nodes, this enhancement is minimal and the remaining nodes die within a very short span of time.

7 Conclusion

The protocols considered in this paper ensures that a near energy utilization occurs thereby increasing network lifetime. The ACO scheme also helps to enhance the performance of our scheme. The simulation results also help to understand and appreciate the facts stated in the paper. In future we would also like to use other optimization tools for chain construction and observe how they perform as compared to ACO and the greedy algorithm.

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