

An Optimized Energy Aware Chaining Technique for Data Gathering in Wireless Sensor Networks

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ABSTRACT

Wireless Sensor Network (WSN) is a collection of small sensor nodes with aptitude to sense, compute and transmit data that are deployed to observe a physical environment. The sensor node has limited capabilities, especially its energy reserve, its processing ability and its memory storage. Data dissemination and gathering protocols design for WSN are crucial challenges since those protocols should be easy, energy-efficient, and robust to deal with a very large number of nodes. Also, they should be self-configurable to node failures and dynamic changes of the network topology. In this paper, we present a new algorithm for gathering sensor reading based on chain forming using Ant Colony Optimization (ACO) technique. To allow network lifetime extension, the ACO provides the shortest network nodes chaining instead of starting from the furthest node and using Greedy algorithm as PEGASIS do. The leader role duration is defined for each node based on its required energy to do this role in the established chain. Which avoids fast node's energy depletion and then, the network lifetime would be extended. Through simulation, it is proved that the proposed algorithm allows network stability extension compared to the most known chaining algorithm.

KEYWORDS

Wireless Sensor Networks; Data Gathering; ACO; PEGASIS; Network lifetime extension.

1 INTRODUCTION

A Wireless Sensor Network (WSN) is composed of a collection of tiny and lightweight sensor nodes deployed in large number to monitor the surrounding conditions [1]. Those nodes cooperate to collect, process and transmit the surrounding conditions such as temperature, humidity, vibration ... The WSN have many application domains such as environmental survey, smart home, medical and agricultural monitoring, etc.

Some of the early literature works on WSNs have discussed the benefits of this kind of networks compared to MANETs [2, 3, 4]. WSNs have main advantages over the conventional networks deployed for the same purpose such as greater coverage, accuracy, reliability and all of the above at a possibly lower cost.

Since the sensor node has small size, and maybe deployed in hostile region, its available energy is considered as the main constraint. Therefore, much attention must be given to the energy consumption when designing protocols for this kind of networks [5, 6].

WSN research domain is much active so, in the last few years, a variety of protocols have been proposed for prolonging the WSN duration service

when gathering the sensor reading to the sink. The most of those protocols can be divided as either flat or hierarchical based.

In densely deployed sensor network, an event is often detected by more than one sensor and duplicated data are generated. This data redundancy is often eliminated, which cannot only decrease the global data to be transmitted and localized most traffic within individual groups, but also, reduces the traffic and consequently, contention in a wireless network, which allows decreasing energy consumption.

Data aggregation is a way to reduce energy consumption. This aggregation consists of suppressing redundancy in different data messages. This is the key idea for the most hierarchical routing protocols.

In addition, scalability is one of the key design attributes of sensor networks. Since a single-tier network can conduct the gateway to overload with the increase in sensors density, the main objective of hierarchical routing is to efficiently preserve the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion that decrease the number of data messages that would be transmitted to the sink.

In literature, many research works have explored hierarchical routing in WSN from different perspectives. Some of the hierarchical protocols are LEACH [7, 8], PEGASIS [9], TEEN [10,11], SEP [12], DEEC [13] and APTEEN [14].

LEACH is the most popular energy-efficient hierarchical clustering algorithm that was proposed for reducing power consumption in WSN by doing data aggregation. It uses clustering

technique to prolong the lifetime of the WSN where a cluster-head (CH) collects the data from all nodes in its neighborhood, fuses and sends the information, on one data packet, to the Base Station (BS). In order to reduce the data quantity that would be transmitted, the CH uses an aggregation technique that combines the original data into a smaller size of data that carry only meaningful information to all individual sensors. Thus, LEACH reduces the number of nodes communicating directly with BS and allows better network lifetime extension.

PEGASIS [9] is a chain-based protocol that allows minimizing the energy consumption at each sensor node. The main idea of this protocol is doing data aggregation over all the network nodes that are chained. This protocol is considered as an optimization of the LEACH since that rather than classifying nodes in clusters, the algorithm forms chains of all the network sensor nodes. Based on this arrangement, each node transmits to and receives from only one closest node of its neighbors in the chain. Unlike LEACH that uses hierarchical clustering, PEGASIS uses a flat topology that permits to avoid the overhead of dynamic cluster formation as in LEACH. In PEGASIS all sensor nodes are organized to form a chain for data transmission and reception. Each node of the formed chain take turns being the leader for communication to the BS. Data gathering round starts from each endpoint of the chain. Data are aggregated along the path to the designated leader node that transmits the aggregated data to the BS as depicted in Figure 1. Accordingly, PEGASIS achieves a best reduction in energy consumption as compared to LEACH

because it requires only one designated node to send one combined data to the BS.

A greedy algorithm is proposed to be used in PEGASIS to form the chain; each node selects the closest neighbor that is not chained yet and so as until all network nodes are chained. This algorithm is executed before starting the first round of data transmission. To construct the chain, PEGASIS starts with the furthest node from the BS. This is to make sure that nodes farther from the BS have close neighbors, since in the greedy algorithm the neighbor distances will augment gradually because nodes already on the chain cannot be revisited again. After chain formation, data transmission phase will start. In this phase, node can deplete its residual energy, and then the chain will be reconstructed in the same manner to avoid the dead node.

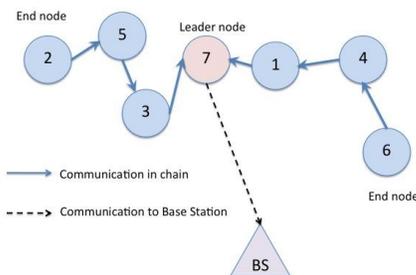


Figure 1: Chain in PEGASIS

To enhance PEGASIS, the paper [15] presented two techniques; The main idea of the first technique consists to allow each node to become leader for $X_i = (d_{Bref}^2 / d_{Bi}^2) \cdot X_{ref}$ times, where d_{Bref} is a distance reference to BS, d_{Bi} is the distance between node i and the BS and X_{ref} is an arbitrary coefficient to overcome the error by rounding X_i to the nearest integer. The second technique

proposed in [15] is to use the Ant Colony Optimization to form the network chain. Both the two techniques start the chain from the farthest node to the BS to ensure that this node has a neighbor. By the provided assessment, a slight enhancement of the network lifetime is observed.

In this paper we present a new technique for gathering data in order to extend the network lifetime. The main object is to reduce the energy consumed by network nodes and then extends the network service duration by choosing the shortest chain. The remainder of the paper is arranged as follows. Section-2 provides the problem statement. The detail of the proposed technique has been discussed in section-3. Simulation parameters and results have been given in section-4. Based upon the simulation results, conclusions have been drawn and some recommendations for future work have been proposed in section-5.

2 PROBLEM STATEMENT

2.1 Problem Definition

In this work we are interested in WSN composed from N wireless nodes deployed randomly in the monitored area. The main object of this work is to extend the network service duration until the first node dies so called stable network lifetime. Which means that the first node has its residual energy depleted and then is failed to play its function in the network. We assume the BS is fixed at a far distance from the sensor nodes that are not mobile.

In this paper we consider a flat network, that the data gathering is based on chain. The network nodes are organized in chain and at any transmission round, one node is selected as leader to collect data in the chain and transmit it to the BS.

PEGASIS [9] and Seetharam et al. [15] propose that the chain forming starts from the farthest node to the BS. As the chain length will not be the shortest one, the network lifetime is not optimized.

2.2 Energy Dissipation Model

In this work, we assume a simple scheme for modeling the radio hardware energy dissipation as discussed in [7]. The transmitter dissipates energy when running the radio electronics and the power amplifier. The receiver dissipates energy to run the radio electronics, as shown in Figure 2. For the experiments described here, the free space channel model is used. Consequently, to transmit an l -bits message over a distance d , the radio expends (1).

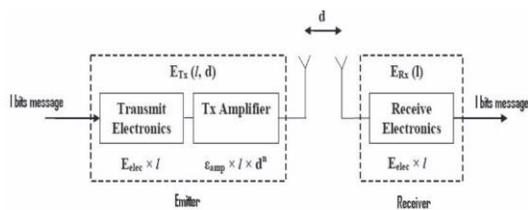


Figure 2. Radio energy dissipation model.

$$E_{TX} = l.E_{elec} + l.E_{amp}.d^2 \quad (1)$$

Where E_{elec} is the energy dissipated per bit in the transmitter circuitry (to run the transmitter or receiver circuitry in case of receiving) and $E_{amp}.d^2$ is the energy dissipated for transmission of a single bit over a distance d .

The electronics energy (E_{elec}) depends on many factors such as the digital coding operation, the signal modulation and demodulation, filtering, and spreading, whereas the amplifier energy, $E_{amp}.d^2$, depends on the distance to the receiver and the acceptable bit-error rate.

The radios have power control and can expend the minimum required energy to reach the intended recipients. The radios can be turned off to avoid receiving unintended transmissions.

To receive an l -bits message, the radio expends (2):

$$E_{RX} = l.E_{elec} \quad (2)$$

It is also assumed that the radio channel is symmetric, which means the cost of transmitting a message from node A to node B is the same as the cost of transmitting a message from B to A .

3 OPTIMIZED ENERGY EFFICIENT DATA GATHERING TECHNIQUE FOR WIRELESS SENSOR NETWORK

In this work we aim at developing a data-gathering scheme that extends the network lifetime by reducing energy dissipation of all the network nodes. Also, we attempt to equitably distribute the energy load between network nodes. As we can consider the nodes chaining problem analog to the traveling Salesman one, we can use the Ant Colony Optimization to form the shortest data gathering chain. Since PEGASIS starts chaining from the farthest node to the sink, it cannot provide the shortest chain as Figure 3 gives an illustration. Ten nodes are scattered randomly in the network area. We use the greedy algorithm to determine the network data gathering chain. Thus as depicted in this Figure, the PEGASIS chain is formed as {1, 7, 6, 4, 3, 9, 8, 10, 2, 5} but the shortest chain is {5, 2, 3, 9, 8, 10, 4, 6, 7, 1}. Comparing the chains length, PEGASIS uses a chain 18.21% long than the short chain. That means that the energy consumption is greater.

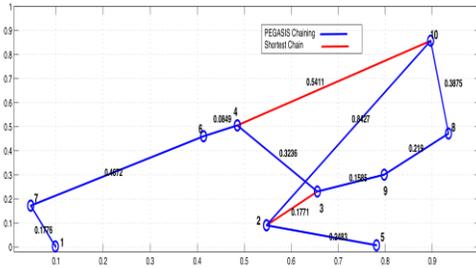


Figure.3. Nodes chaining in PEGASIS is not the energy efficient.

It is so difficult to determine the shortest chain since the problem is NP hardness. We propose a meta-heuristic method based on Ant colony optimization [16]. The problem is then considered as the Traveling Salesman Problem where the optimization searches to find heuristically the shortest path to visit all nodes one time. The ant colony optimization works as follow; an ant n starts from a random node i and selects the next node j randomly based on the probability P_{ij} given in Equation (3):

$$P_{ij} = \begin{cases} \frac{\tau_{ij}^\alpha \cdot \eta_{ij}^\beta}{\sum_k \tau_{ik}^\alpha \cdot \eta_{ik}^\beta} & \text{if } k \in V_i \\ 0 & \text{Otherwise} \end{cases} \quad (3)$$

Where τ_{ij} is the pheromone value of edge (i-j), V_i contains neighbor nodes of node i that are not yet visited by ant n . The parameters α and β control the relative importance of the pheromone. And η_{ij} is the heuristic information, which is given by (4):

$$\eta_{ij} = \frac{1}{d_{ij}} \quad (4)$$

Where the distance between nodes i and j is d_{ij} .

When an ant passes through an edge, it deposits a pheromone value. In order to avoid local optima this algorithm uses the evaporation, which periodically reduces the pheromone value deposited on a trail. Thus, the pheromone τ_{ij} over

the edge (i,j) is updated as follow:

$$\tau_{ij} \leftarrow \tau_{ij} \cdot (1 - \rho) + \sum_k^m \Delta \tau_{ij}^k \quad (5)$$

ρ is the pheromone evaporation rate. τ_{ij}^k is the pheromone quantity deposited by ant k on this edge (i,j) and m is the ants number that are traveled by this edge.

$$\Delta \tau_{ij}^k = \begin{cases} Q/L_k & \text{if ant } k \text{ traveled by edge}(i,j) \\ 0 & \text{Otherwise} \end{cases} \quad (6)$$

Where Q is a constant and L_k is the length of the path traversed by ant k .

After many tours, the algorithm converges to the short path since each edge of this path would have the maximal pheromone.

As the chain is formed, we aim at developing a system that would provide that the total energy dissipation is distributed equally among all the network nodes to ensure that the network nodes die equitably.

In every data-gathering round, a leader node is selected to receive data from the chain and transmit it to the BS. During every round, each node receives a data packet from its neighboring node in the chain, aggregates it with its own data packet and transmits it to its other neighbor in the chain. A simple token passing approach initiated by the leader is used to organize the data transmission in the chain. Often, the data transmission starts from the chain end-nodes to its next nodes in the chain, which do data aggregation and so that until the leader. The leader elected in a particular round receives the fused data packets of the nodes in the chain from its two neighbors, aggregates it with its own data packet and finally this single data packet is transmitted to the base station. Because leader role is energy greedy consuming, PEGASIS ensure that at each transmission round a new node is selected as leader in order to distribute energy load. Since, the nodes consume

different energy when being leader depending on its location in the chain and its distance to the BS, which means that a certain nodes would die quickly.

So, let network node plays leader depending on its energy capacity can ensure best energy load balancing.

Let consider a network formed by N chained nodes and E_{i0} is the initial battery energy of the node i . Let E_{iBS} is the required energy for the node i to transmit to the base station, E_{ij} is the energy to transmit from the node i to node j and E_{rec} is the energy cost required for receiving a packet.

The node i deployed in the monitored area can do T_i transmissions in its lifetime (until the depletion of its residual energy) in which it is the leader. For notation simplicity, we suppose that the chain nodes are organized as follow; $\{1, 2, \dots, N\}$ and then the end chain nodes are 1 and N . For the node 1 , that will be leader for T_1 times, will do T_1 transmission to the BS and $T_2 + T_3 + \dots + T_N$ transmissions to the next node in the chain, lets node 2. Then, the equation (7) must be respected.

$$E_{i0} = T_i \cdot (E_{iBS} + E_{rec}) + (T_2 + T_3 + \dots + T_N) \cdot E_{i2} \quad (7)$$

For a not end chain node i , this node will do T_i transmission to BS (node i will be leader for T_i times) and $2 \cdot T_i \cdot E_{rec}$ from the two chain elements when it is a leader and consumes the energy $(T_1 + T_2 + \dots + T_{i-1}) \cdot (E_{(i)(i-1)} + E_{rec})$ for transmitting to the left element of chain and $(T_N + T_{N-1} + \dots + T_{i+1}) \cdot (E_{(i)(i+1)} + E_{rec})$ to transmit to the right element of the chain. $E_{(i)(i-1)}$ and $E_{(i)(i+1)}$ correspond respectively to the transmission energy from node i to its predecessor and to its successor in the chain. The equation (8) gives the relation between the numbers of becoming leaders for the entire network nodes.

$$\begin{pmatrix} E_{1BS} + E_{rec} & E_{12} & \dots & E_{12} \\ E_{21} + E_{rec} & E_{2BS} + 2 \cdot E_{rec} & E_{23} + E_{rec} & \dots \\ \dots & \dots & \dots & \dots \\ E_{21} & E_{21} & \dots & E_{NBS} + E_{rec} \end{pmatrix} \begin{pmatrix} T_1 \\ T_2 \\ \dots \\ T_N \end{pmatrix} = \begin{pmatrix} E_{10} \\ E_{20} \\ \dots \\ E_{N0} \end{pmatrix} \quad (8)$$

As constraint, all T_i must be positives. We solve the equation above to determine how many times a node can be a leader for the chain. If the solution gives negative results, a linear optimization can be used. With this manner the nodes energies would be consumed equitably.

Since T_i is given, the node i when it is selected as leader it plays this role for T_i consecutive transmission rounds rather than one transmission round as in PEGASIS.

In the following, the proposed technique is described.

3.1 Set-up Phase

The ant colony optimization algorithm is used the find the shortest chain. Thus, N ants are randomly deployed in the N network nodes. Each ant starting from an arbitrary node selects the next node to visit using Equation (3), and so on until it makes a tour. Thus, the pheromones are updated. The same algorithm is run till convergence to the optimal chain.

3.2 Steady State Phase

After the shortest chain is formed, data gathering will start. In every data-gathering round, a leader node is selected to receive data from the chain and transmit it to the sink. During a data gathering round each node in the network receives a data packet from its neighboring node (in the chain), aggregates it with its own data packet and transmits it to its other neighbor in the chain. A simple token passing approach initiated by the leader is used to organize the data transmission. The data transmission starts from the chain end-nodes to its next nodes in the chain,

which do data aggregation and so that until reaching the leader. This leader aggregates the received data with its own and transmits it the sink.

Since the leader consumes considerable energy, and in order to distribute energy load, each node i that becomes leader plays this role for T_i consecutive transmissions rounds.

4 SIMULATION PARAMETERS AND RESULTS

To evaluate the performance of our technique, several *MATLAB* simulations were performed and the represented results are an average. We consider a square network with N nodes deployed randomly in the field. The used parameter values in our work are given in Table1.

Table1: Simulation Parameter Values.

Description	Symbol	Value
Network dimension	$X_m * Y_m$	100m*100m
Number of network nodes	N	10-200
Data packet length	L	2500 Bits
Electronic Energy	E_{elec}	50nJ/bit
Amplifier Energy	E_{amp}	100pJ/bit.m ²

First we run simulation of our scheme called Energy Efficient Data Gathering technique (EEDG) and PEGASIS varying the network nodes number from 100 to 300. All the network nodes have the same initial energy that is 0.5J. The base station is located at (50m, 200m). We are interested at the network lifetime until the first node run out its residual energy. The results are represented in Figure.4. As depicted, our scheme performs better than PEGASIS since the lifetime extension is up to 20%.

In the second situation we intend to investigate the effect of the Base Station location on the performance of the proposed algorithm. We consider a network of 100 nodes with initial energy of 0.5J, and we vary the base station

location from (0.5Xm, 0.5Ym) to (0.5Xm, 3Ym). The simulation results are shown in Figure.5. As depicted, the network lifetime of booth the protocols decrease when the BS is far from the network because the needed energy to reach the sink increases with the distance. The proposed technique allows extension of the network lifetime for every base station position.

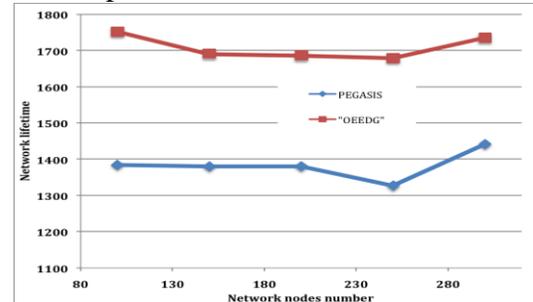


Figure.4. Network lifetime vs. Network nodes number.

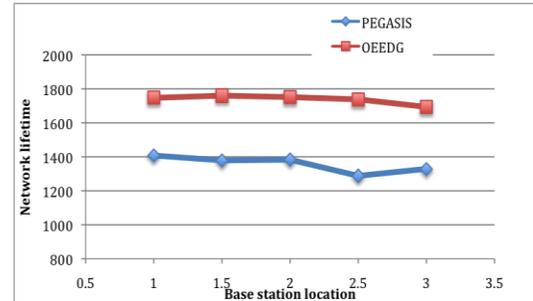


Figure.5 Network lifetime for different BS location.

Figure.6 represents the network lifetime for different node initial energy. As we can observe, the network lifetime is extended for all the considered node initial energy. The relative lifetime extension is between 22,96% and 24,61%.

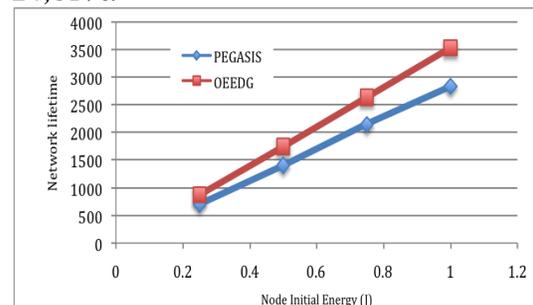


Figure.6 Network lifetime for different nodes initial energy.

The simulation results presented above illustrate that the proposed scheme exploits judiciously the network energy since it selects the short network chain so that the transmission energy is optimized. It exploits, also, the capacity to play leader role for each node to ensure a best energy load repartition over chain nodes.

5 CONCLUSION

Network nodes chaining is a better solution to extend network lifetime since only the leader node that do long transmission to the BS. In this paper, we proposed an Ant colony optimizing technique to form network nodes chain ensuring that this chain is the short one. Chain nodes become leader for a lot of time based on its required energy to transmit to the BS and to its two chain neighbors. The proposed technique allows extra network transmission rounds as compared to PEGASIS. This extension is guaranteed for different number of network nodes, for different BS location and for different nodes initial energies. The simulation results show that our technique outperforms to the well-known protocol for chaining in wireless sensor networks (PEGASIS protocol). In future, we will continue the work investigating the effect of data correlation on the network performance for this kind of routing protocols.

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