Energy-efficient Trust-based Aggregation and Ant Colony Optimization Routing in Wireless Sensor Network

Remya .K, D .Keerna

Abstract— This paper proposed a combination of Energy-efficient Trust based data aggregation (ETA) and a wireless sensor network routing protocol based on ant colony optimization (ACO) algorithm. This method aims to achieve reliable and energy-efficient data aggregation along with energy prediction, to avoid route over-concentration. ETA uses the concept of functional reputation and trust as a means to reach reliability. Functional reputation is used to select nodes that best satisfy the criteria to be an aggregator on the basis of the quality of the node. The ACO algorithm added the factor of energy in the procedure that ants had been searching the optimal path. Cluster- head sent data to sink by multiple-hops transmission. Therefore, the ACO algorithm reduced cluster-heads energy consumption. The simulation results showed that the new algorithm had high reliability, better energy efficiency and the more balanced energy consumption. At the same time, it extended the network lifetime.

Index Terms— Wireless sensor network, Ant colony optimization, Prediction, Trust, Aggregation, Reliability, Energy-efficient.

1 Introduction

Wireless Sensor Network (WSN) is a multiple hops communication network that has many sensor nodes with communication and computing power [1]. It is the core issue how to reduce energy consumption of sensor nodes and prolong the network lifetime due to the sensor node energy limited [2].

Most effective utilization of wireless sensor networks requires minimization of energy consumption through the design of energy-efficient network protocols and algorithms to prolong network lifetime. Since sensor nodes are usually inexpensive hardware components, they are highly vulnerable and often malfunction or fail. Non-malicious behaviour- such as the malfunctioning of radios or sensors- can result in generation of false data which has detrimental effects on the overall performance of the network.

If no reliable data or reliable paths to send data towards the decision nodes exist, the final decision cannot be trusted. On the one hand, these incorrect decisions may lead to serious inefficiencies throughout the whole network; while on the other hand, the energy of sensor nodes is wasted by providing such unreliable and false data.

Data aggregation has been considered as a significant primitive in wireless sensor networks that is widely regarded as being sensitive to attack and failures [3]. Since the base station receives an aggregation instead of the raw data, it loses the ability to filter out erroneous reports. Therefore, it is an important challenge for data aggregation process to ensure that an aggregator does not generate faulty data and does correctly send data to the base station. Due to the fact that an aggregator may become a single point of failure, it is better not to have just one special aggregator all the time. Rather, nodes that satisfy best the necessary criteria can be selected and act as an aggregator.

Data aggregation techniques are tightly coupled with the routing approaches. If some links fail and do not relay sensor nodes' data for a while, the result of the aggregation may be highly inaccurate, which in turn can have a significant negative impact on the overall network performance.

This paper proposed an energy-efficient trust-based data aggregation to achieve reliable data aggregation [4], and ACO routing algorithm [5] for optimal path selection and data transmission. The paper [6] made ACO better meeting the routing protocol on WSN by the pheromone incremental formula which introduced the nodes energy and the transmission distance into ACO.

- *Remya.K is currently pursuing masters degree program in Computer science and Engineering in Bharath University, Chennai, India, PH-9884624930. E-mail: remya.natraj@gmail.com*
- *D.Keerna is currently working as a faculty,Department of computer science, in Bharath University,Chennai,India.*

2. Related Work

Wireless sensor networks and their limited resources introduce new design challenges. One of the major concerns in designing WSN algorithms that has been received significant attention is energy-efficiency. Several energy-efficient routing and aggregation protocols have been studied, which aim to minimize the total transmission energy consumption. Heinzelman [7] et al. Focus on energy-efficiency by reducing number of nodes that directly communicate with the base station. The approach, called LEACH, assume all sensor nodes have enough power to reach the base station if needed. This assumption makes LEACH unsuitable for large scale sensor networks. The paper [8]to stabilize the power utilization of a variety of sensor nodes to solve the excess power utilization problem.

3. SYSTEM MODEL

3.1. Network model

In this paper we consider that N sensor nodes are randomly scattered in a square field A and the following assumptions are made about the sensor network:

1. Sensor nodes are partitioned into several clusters and each cluster has one cluster head which we call the aggregator.
2. The network has only one powerful base station far away the deployment field A.
3. Every sensor node has a transmission range R but it can only choose neighbours located at R/2 as its upstream relay node .
4. The locations of each sensor node and the base station are fixed and are known a priori.

3.2. Trust model

Reputation and trust concepts are used in WSNs to diminish the impact of malicious and faulty nodes and links. Having history of the nodes' activities and links' states can give useful information about their situation, based on which the best policy can be chosen to have an overall efficient network. To evaluate the trust, select Bayesian formulation and to represent reputation, utilize BETA distribution, which is based on using beta Probability Density Functions (PDF).The best way to represent reputation is a statistic probability distribution, but to judge the reputation of the nodes and links we must have numerical values. To this end Trust can be defined as the probability expectation value of the reputation function as in [9].

The beta PDF can be described using the gamma function as:

$$f(p|\alpha,\beta)=\frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}p^{(\alpha-1)}(1-p)^{(\beta-1)} \quad (1)$$

$$0\le p\le 1,\alpha\ge 0,\beta\ge 0$$

where α and β count the number of satisfaction (cooperative) and un-satisfaction(no-cooperative) of a given criteria respectively. Given a reputation metric Rij , we define the trust rate Tij to be expectation of node i about future behaviour of node j. Tij is obtained using the statistical expectation of prediction stated below :

$$T_{ij}=E(R_{ij})=E(Beta(\alpha+1,\beta+1))=\frac{\alpha+1}{\alpha+\beta+2} \quad (2)$$

To measure reliability trust and reputation concepts are used, so each sensor node must maintain two tables: (i) Table about the reputation of its neighboring links (to judge about their availability) which we call Availability Reputation Table (AvRT); and (ii) Table about reputation of its neighboring nodes (to judge about how well aggregation can be performed) which we call Aggregating Reputation Table (AgRT).

3.3. ACO Algorithmic Principle

A cluster-head node in wireless sensor network uses an undirected weighted graph G (V, E), V is the cluster-head nodes set in every round of elections, including sink nodes; E is the link set between each cluster-head. Vi,Vj∈V, e(i,j)=(Vi,Vj)∈E if and only if it can direct communication between Vi and Vj. For LEACH protocol, between each source node and cluster-head nodes, between cluster-head nodes and sink nodes directly communicate by using a single hop. But the communication ability of sensor node is limited, not all the nodes can direct communicate, so, G is not a complete graph. In the ant colony algorithm, each ant respectively selects a path from the start to destination according to the path selection probability, when all ants complete search, a search period ends. In the search process, the distance between the nodes is the main factor of selective probability of nodes. However, the choice of the next node in WSN, the remainder energy of nodes must be considered when selecting the next node and the more remainder energy node must be chosen as the next-hop node with the larger probability. Meanwhile, it still should be considered that energy consumption of some nodes is too fast for these nodes take too many tasks of data forwarding. Therefore, energy prediction mechanism must be brought into the improved algorithm.

The probability of the node i selecting the next node j:

$$P_{(i,j)}^{k}=\begin{cases}\dfrac{[\pi(i,j)]^{\theta_1}*[\lambda(i,j)]^{\theta_2}*[\mu(i,j)]^{\theta_3}}{\sum_{S\in allowed_k}[\pi(i,s)]^{\theta_1}*[\lambda(i,s)]^{\theta_2}*[\mu(i,s)]^{\theta_3}} & j\in allowed_k\\ 0 & \text{Otherwise}\end{cases} \quad (3)$$

π(i , j) is the pheromone strength of the edge e(i , j)

When the ant is from Vi to Vj by e(i,j), the pheromone strength is updated as follows:

$$\pi(i,j)=(1-\rho)*\pi(i,j)+\rho*\Delta\pi(i,j),\ (0<\rho<1) \quad (4)$$

ρ is the pheromone evaporation constant

The pheromone incremental is defined as follows:

$$\Delta\pi(i,j)=\sum_{k=1}^{num}\Delta\pi(i,j)^k \quad (5)$$

num is the number of ants.
The amount of pheromone deposited by k^th ant,

$$\Delta\pi(i,j)^k=\begin{cases} Q/L(k) & \text{The kth ant went through } e(i,j) \text{ path in this round} \\ 0 & \text{Otherwise} \end{cases} \quad (6)$$

Q is the constant and L(k)is the cost of the kth ant's tour. The pheromone values are stored in the node itself.
λ(i , j) is the inspire function of the edge e (i,j)

$$\lambda(i,j)=\frac{1}{(d_{ij})^2} \quad (7)$$

The Euclidean distance between node i and node j,

$$d_{ij}=\sqrt{(x_i-x_j)^2+(y_i-y_j)^2} \quad (8)$$

Smaller the distance between node i and j, then j has the greater probability which is elected as the next hop node.
μ(i , j) is the predicted energy function of the node j in the t time.

$$\mu(i,j)=E_j-n*C \quad (9)$$

Ej is the predicted surplus energy,
n is the selected times of nodes before the t moment
C is the needed energy of nodes forwarding a data.
$allowed_k$ is the set that the node i may select the next node, Tabuk is the node set that ant k has passed, k=1,2,.......,m ; m is the maximum number of ants , so j ∉Tabuk are the weighted parameter.

To evaluate the energy dissipation between node i and node j, the energy costs of transmitting a k -bit data packet between node i and node j with transmission distance d are denoted by $E_{Tx}(i,j)$ is used[10].
If the distance d ≤ threshold d0, free space (fs) model is used,

$$E_{Tx}(i,j)=m*E_{elec}+\varepsilon_{fs}*m*d^2 \quad (10)$$

If the distance d >threshold d0, multipath (amp) model is used,

$$E_{Tx}(i,j)=m*E_{elec}+\varepsilon_{amp}*m*d^4 \quad (11)$$

where ε_{fs} is amplifier parameter in the free space model; ε_{amp} is the amplifier parameter in the multipath model. E_{elec} is energy consumption of the receive electronics or transmit electronics to process 1 bit packet.

Using Ant Colony Optimization algorithm, the cluster-head node uses multi-hop communication, so free-spaced model is used to transfer packet between cluster-heads.

After finding a shortest path S from source node A to destination node B, it has n node in path S, then the energy consumption of the node A sending m bytes to node B is:

$$Cost=2*m*n*E_{elec}+\varepsilon_{fs}*\sum_{i=1}^{n}d_{i,i+1}^2 \quad (12)$$

$\sum_{i=1}^{n}d_{i,i+1}^2$ is the sum of node distance squares in the path;

m, n, E_{elec}, ε_{fs} are constants.

So, the value of energy is proportional to the sum of node distance squares.

4. Problem Statement

Every sensor node in a cluster must send its data to its upstream neighbour which is selected by the base station. Intermediate nodes along the path to the aggregator fuse the data received from the downstream nodes with their own data and forward the local aggregated value towards the aggregator. The cluster head that we call the aggregator must perform final aggregation on the data received from its neighbours and then forward the result to the sink through the sensor nodes belonging to other clusters. The problem we deal with is to find a routing scheme to deliver data packets gathered by sensor nodes to the aggregator and later on from every aggregator to the base station on the basis of links availability and residual energy of the nodes in the path in order to prolong the lifetime of the network, to have a reliable aggregation as well as reliable data delivery to the destinations under the system model given above. Furthermore, we must find a sensor node, which has enough energy and can also play the role of aggregator better than other nodes.

5. Proposed Method

Consider a static cluster-based wireless sensor network. Initially, sink node informs every sensor node about its upstream node. Each relay node must relay data towards the aggregator and the base station. Relay nodes are randomly chosen from all upstream neighbours of a sensor node in the initialization phase. Every sensor node beside the sensing and relaying data

ISSN 2229-5518

must perform some extra tasks to judge the state of its neighbouring links and its neighbouring nodes.

Firstly, we explain sensor's tasks leading to assess links quality. Each sensor node has to send its current sensed data to all of its neighbours every TP1 time period. When neighbouring nodes receive data, they can deduce whether the link between them and the sender is available. If link is available, they increase the α parameter of AvRT for that link, which means these neighbouring nodes can be good candidates to relay data from the sender. Otherwise the β parameter will be increased.

Secondly, there are some tasks aiming to find out how well a neighbouring relay node can perform aggregation task. Each sensor node has to monitor the local aggregation task of its upstream node. In other words, each sensor node which selects a node as the upstream relay node must monitor the aggregation task of its relay node in every TP1 time period, and it as well as its relay node have to perform aggregation. Later on, the sensor node overhears the aggregation result of its relay node and will update its AgRT for its relay node based on the difference between its aggregation value and result of its relay node.

Following that, every node sends its reputation table and its residual energy to its cluster's aggregator every TP2 time period. The aggregator performs final aggregation on the data received from its cluster members and sends them along with the reputation tables and residual energy of its cluster members to the base station using Ant Colony Optimization algorithm

5.1.ACO algorithm

Step1: The cluster-head node matrix--CHead is created, the pheromone matrix--Tau, the best route matrix of all cluster-head nodes--Rhead_best and the best route length matrix of all cluster-head nodes --Lhead_best are initialized.

Step 2: A cluster-head is selected from the cluster-head set, the path matrix Tabu, the best route matrix of each cluster-head--R_best, the best route length matrix of each cluster-head--L_best are initialized. Tauv matrix is initialized to: ones (Cn, Cn) +Tau, Cn is the size of the CHead matrix.

Step 3: Path iteration, it is that m ants will be put in this cluster-head node, and then ants select the next node according to the probability of formula (1) until they reach the sink nodes.

Step 4: Record the best route and the best route length of this iterative, update the virtual pheromones, clear the path matrix, return to step3 until reaching the maximum iterating times.

Step 5: Record the shortest path of the cluster-head node, calculate the prediction energy in the best path of each node according to definition 1, return to step 2, look for the shortest path of the next cluster-head node until all the cluster-head node will find the shortest path.

Step 6: According to Rhead_best, calculate the energy consumption of each cluster-head node.

Upon receiving the reputation tables and residual energy of the sensor nodes, base station will find the best aggregator for the next TP2 time period for each cluster. To find the best aggregator for every cluster, the base station utilizes the equation,

$$C\,(node) = \frac{Eg^{node} \times T^{node}}{Init - Eg^{node} \times Init - T^{node}} \quad (13)$$

$$Eg^{node} > \theta^{Ag}_{Eg},\ T^{node} > \theta^{Ag}_{T}$$

Table.1 Notation used for the equation

E_g^{node}	Node's available energy
T^{node}	Node's reputation (trust value) about its aggregation task
$Init - E_g^{node}$	Node's reputation (trust value) about its aggregation task
$Init - T^{node}$	Initial trust value for the node
θ_{Eg}^{Ag}	Minimum acceptable value for aggregator's energy
θ_T^{Ag}	Minimum acceptable value for trust value of aggregator

6. Analysis And Simulation

To evaluate the performance of the proposed algorithm, compare it with LEACH protocol. Use MATLAB7.0 as the simulation platform, applying the various parameters in the simulation experiments. 100 nodes were randomly distributed to the square monitored area. Other parameters are E_{elec}=50nJ/bit, ε_{fs}=10pJ/bit/m2, ε_{amp}=0.0013pJ/bit/m4 , the sensor initial energy is 0.5 J, packet size is 4000bit, the base station location the top-left corner of the monitored area, α=1, β=5, ρ=0.1, Q=100. Initial trust value for nodes/links is 1, transmit power is 0.660W, receive power is 0.395W, TP1=10, TP2=50, θ_{Eg}^{Ag}= 0.25J ,θ_T^{Ag}= 0.9

6.1. Network lifetime comparison

Compare the number of rounds of the two algorithms respectively at the first node death (1#), 20% nodes death (2#), 50% nodes death (3#) and 80% nodes death (4#). After 80% nodes died, assume the network

ISSN 2229-5518

lost their effect. Figure1.for the network lifetime which monitoring areas are set as: 100m×100m, 200m×200m, 300m×300m and 400m×400m respectively.

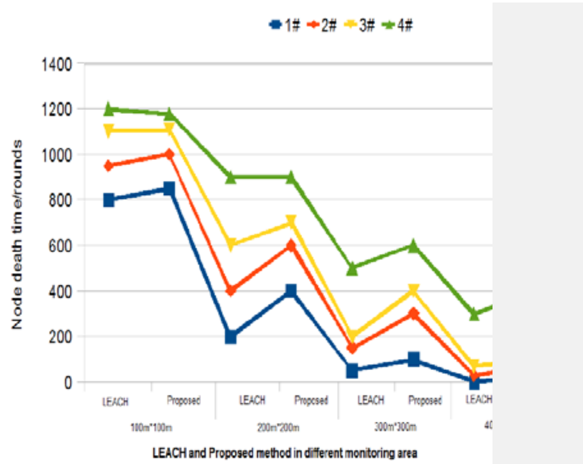


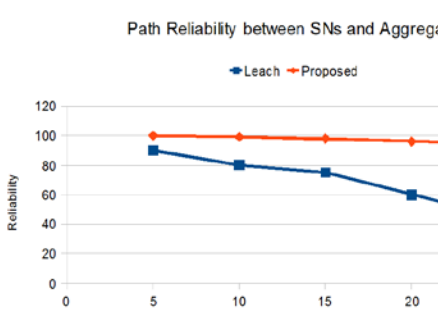
Fig.1 Lifetime in different monitoring area

Figure.1 shows that proposed method and LEACH are not much different from the time of nodes death when the monitoring area is smaller .Sometimes, LEACH protocol is slightly better than proposed algorithm, because ACO algorithm uses multi-hops route, the energy of transmit packet has a decrease, yet this don't compensate for the energy consumption of receiving data when the distance between nodes is very short. As the monitoring area is expanded and the distance between the nodes increases, proposed algorithm was significantly better than LEACH in the network lifetime. And, the time interval to the node death of the first node and 80% nodes in proposed algorithm is obviously shorter than LEACH. This indicates that proposed algorithm is more balance in energy consumption.

6.2. Reliability

The sensor nodes in LEACH send their data directly to the aggregator, when some links fail the data from the nodes near those links cannot be received by the aggregator so the reliability of the algorithm will be decreased drastically when number of failed links increases.

Fig.2 Reliability vs failed links (from sensor nodes to cluster-head)



6.3. Cluster-head energy consumption comparison

The monitoring area of Figure.3 is set as 100m×100m, the number of nodes is 100 and each node begin with 0.25J of energy.

Figure.3 shows that the energy consumption of the vast majority of cluster-heads, each round, is below 0.25mJ in proposed method. Accordingly, it is between 0.25mJ and 0.5mJ in LEACH protocol. The cluster-head count in proposed method is far greater than it in LEACH protocol when energy consumption of cluster-head is below 0.25mJ. In contrast, it is small when energy consumption of cluster-head is over 0.75mJ.These analytical results indicate that energy consumption of cluster-head nodes in proposed algorithm is below to LEACH protocol.

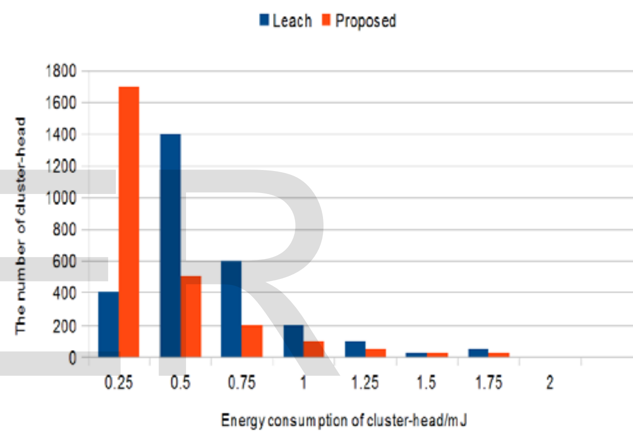


Fig.3 The statistical analysis of energy consumption of cluster-head node

7. Conclusion

This paper proposed a reliable, energy-efficient trust-based data aggregation and Ant Colony Optimization routing algorithm with energy prediction for optimal path selection and data transmission. Base station find the best node based on the residual energy and aggregation reputation to be an aggregator. Role of aggregator changes dynamically between sensor nodes. The simulation results show that the proposed method can prolong the network lifetime and provide high reliability.

Acknowledgment

This paper was supported by Department Of Computer Science Engineering, Bharath University College, Chennai .

REFERENCES

[1] Ren Fengyuan,Huang Haining,Lin Chuang, “Wireless Sensor Networks”, Journal of Software,Science Press,vol. 14,no. 7,pp.1278-1291,2003.
[2]Akyildiz I,Su Weilian,Sankarasubramaniam Y, “Wireless Sensor Networks: A Survey”, Computer Networks, Elsevier, vol. 38,no. 4,pp.393-422,2002.
[3] G B. Przydatek, D. Song, and A. Perrig, “Sia: Secure information aggregation in sensor networks,” in SenSys, Los Angeles, CA,November 2003.
[4]Zahra Taghikhaki, Niravana Meratnia, Paul J.M. Havinga “Energy-efficient Trust-based Aggregation in Wireless Sensor Networks”. University of Twente, Pervaisve Syestems, 7500 AE, Enschede, Netherlands.
[5]Liao Ming-hua, Zhang Hua, Sun Guang,”Energy Aware Routing Algorithm for Wireless Sensor Network Based on Ant Colony Principle”,Journal of Convergence Information Technology(JCIT),Volume7, Number4, March 2012 doi:10.4156/jcit.vol7.issue4.26.
[6]Camilo T, Carreto C, Silva J S, et al, “An Energy-efficient Ant-based Routing Algorithm for Wireless Sensor Networks”, In Proceeding of the International Workshop on Ant Colony Optimization and Swarm Intelligence, pp.49-59,2006.
[7] W. Heinzelman, A. Chandrakasan, H. Balakrishnan, “An application specific protocol architecture for wireless microsensor networks,” IEEE Trans. Wireless Comm. vol. 1, pp. 660–670, April 2002.
[8]N Sandeepkrishna,C Rajendra,”Refuse of sensor's energy consumption in WSN routing protocols”, International Journal of Advanced Research in Computer Engineering & Technology Volume 1, Issue 4, June 2012.
[9] A. Josang, R. Ismail, “The beta reputation system,” Proc. of the 15thBled Conf. Electronic Commerce, pp. 41, 2002.
[10]Wendi, B.Anantha, P.Chandrakasam, “An Application-Specific Protocol Architecture for Wireless Microsensor Networks ”,IEEE Transaction on Wireless Communications, IEEE Communications Society, vol.1, no.4, pp.660-670, 2002.