Design of Energy Efficient Hierarchical Routing Protocol using ACO for WSN

P. Senthiya Prabha

Abstract--- *Wireless sensor network have the some special characteristics such as limited energy, power consumption for processing and low energy. Energy is important criteria because battery has not rechargeable in sensors. In large scale network deployment sensor consume more energy to process data, it leads the lifetime of network will goes down. In this paper we propose the Energy Efficient Hierarchical Routing Protocol using ACO to improve the network lifetime and performance. Initially clusters are formed among the nodes based on node residual energy, node degree and distance. The ACO algorithm is applied to search optimal path, then data transmit via selected optimal path. To solve combinatorial optimization problems the ACO algorithm is used as it is based on heuristic algorithm. Distributed computing, self organization and positive feedback are the characteristics of ACO algorithm which is suited for searching routing in modern communication networks. In this paper we are going to propose intelligent EEHRPs based on ACO for wireless sensor network using NS2.*

Keyterms--- *WSN, Cluster, Ant Colony Optimization (ACO), Hierarchical Routing Protocol*

I. INTRODUCTION

WIRELESS Sensor Network is self-configuring and self healing network of small sensor nodes. They are communicating among themselves using radio signals. They are deployed to collect and disseminate environmental data. The main Challenges while designing the routing protocol in WSN are limited power, memory, no global identification, dynamic changes for each sensor. Sensor nodes have an undersized and finite source of energy. Therefore an economical and cost effective management of energy is need for recovering energy efficiency. WSN have various applications, example includes military, industry, agriculture, habitat monitoring and many other areas.

Based on the network topology, WSN can be categorized into flat routing protocol, hierarchical routing protocol, single path and multipath routing protocol [1]. Recent study on WSNs routing protocols has verified that clustering and multi hop are considered necessary to get better energy efficiency and load balancing.

The ACO algorithm is a meta-heuristic algorithm introduced by Dorigo and its searching for optimal path inside the graph based on behavior of ants finding a path between their colony and food source. The foraging behavior gives approximate solutions to discrete optimization problems, continuous optimization problem and telecommunication problem such as routing and load balancing. Distributed computing, self organization and positive feedback are the characteristics of ACO algorithm which is suited for searching routing in modern communication networks.

The Energy Efficient Hierarchical routing protocols based on such intelligent algorithms as ant colony optimization (ACO), have been proposed to improve the performance and network lifetime

However, integrating the clustering, multi hop and ACO technique are used to improve performance and maximize lifetime of the network in WSNs. By using the advantages of these techniques, this paper proposes an Energy Efficient Hierarchical routing protocols based on intelligent algorithms such ACO for WSNs. The main objective of our work is to maximize network lifetime and achieve better performance. The main assistance of this paper is listed:

- An energy efficient cluster-based routing algorithm based on some parameters (such as remaining energy, node degree and distance to its cluster head) is designed to form clusters among the nodes located in the event area.
- For finding the optimal path between the cluster head (CH) and sink node, an ACO algorithm using many metrics such as residual energy, path length, energy consumption of communication.
- Data aggregation process performed between Cluster head to sink through shortest path selected by CH.

The respite of this paper is organized as follows. Section 2 introduces related routing algorithms. In section 3 explained network model and energy model of routing protocol. In section 4 describe the EEHRP routing protocol. Simulation results are described in section 5. In Section 6 contains the conclusion.

II. RELATED WORK

WSNs are a kind of decentralized network that collect and process data, and send the data to a destination node via wireless links. In the traditional routing protocols, Limited energy nodes are not taken into account, which has major impact on the overall energy dissipation. For that reason, designing new routing protocols is important for WSNs.

A. Hierarchical Routing

Hierarchical technology is mainly capable and has received much attention in the research society. In a hierarchical network, the collected data are transmitted to CHs by the sensor nodes. The sensed data from nodes within one

P. Senthiya Prabha, Dept of Computer Science and Engineering, Kalasalingam University, Anand Nagar, Krishnankoil, Srivilliputtur, Virudhunagar Dist, Tamilnadu, India. E-mail:prabha3sran@gmail.com

cluster usually show high connection, and therefore, a CH can remove redundant data and aggregate only unique data to the sink.

HRPs are an energy efficient routing protocol. The unique feature of this advance is that it provides self-organization capabilities to allow large scale network deployment. Mostly, in a hierarchical architecture, some nodes perform high energy transmission other nodes perform normal task. High energy nodes are selected using Power-aware algorithm for sending the data from normal nodes to the BS. In HRPs cluster-based HRPs and chain-based HRPs are the two types of HRPs based on the topology management. In cluster-based HRPs, sensor nodes are grouped into clusters and each of these has cluster head (CH). Between cluster members and BS communication done over CH. In chain-based HRPs, all nodes are connected in a Chain formation. Then, the most high energy node is selected as the chain leader. The chain leader acts as an intermediate node between the normal nodes and the BS. Other design features applied to improve the performance such as data fusion; threshold values set up, and sleep/idle pairing for both types of HRPs.

Heinzelman et al. proposed LEACH [3] routing protocol. Based on a probability function LEACH performs fair load distribution among all nodes in the network. LEACH uses clustering to prolong the network lifetime. Non uniform cluster size decrease the network efficiency during data transmission performs between the CH to BS. However, all nodes are communicating with any node in the field. LEACH does not allow the network to be scalable and does not guarantee good sharing of CHs. Lindsey *et al.* proposed PEGASIS [4] routing protocol for improve the performance of LEACH. To initiate the chain forming process, it uses the greedy algorithm. In this all sensor nodes are connected in chain instead of form cluster in LEACH. All nodes are communicated only with the nearest neighbor. Assume all nodes have a global knowledge of the network; PEGASIS outperforms LEACH in network lifetime. Thus, PEGASIS not efficient for closely deployed nodes in a particular area. To overcome unnecessary data transmissions in LEACH, Manjeshwar et al. proposed Threshold Sensitive Energy Efficient Sensor Network (TEEN) [5] routing protocol. It mainly designed for sudden changes happen in the environment the network responds immediately. Cluster formation performed same as in LEACH in addition two parameters are used hard threshold (H_T) and the soft threshold (S_T) for changing status of node transceiver while on or off mode. Each node store sensed value (SV) for avoiding send duplicate data to BS. The non-participating nodes will use up their energy for handshaking process. Silent network phenomenon occurred when no drastic changes happen in field the node keep silent, it don't send the current status to the BS. To avoid the silent network phenomenon Manjeshwar et al. proposed Adaptive Periodic TEEN (APTEEN) [5] routing protocol. To trigger periodic reports to the BS, a new parameter count time (TC) is used in this. A sleep/idle pairing technique applies to APTEEN for reducing the highly simultaneous data being sent by the nodes to the CH. Within the cluster time to back up, the sleeping nodes are capable to send critical data to BS at any time without delay. Using the centralized algorithm in routing protocol can invalidate the self-organizing capacity in WSNs. Huei-Wen Ferng et al[13], have proposed in a corona-based wireless sensor network using virtual points, static and dynamic clustering. In that to improving network lifetime, node with highest remaining energy and nearer or center of cluster, nodes are selected as cluster head. In HEED[17] protocol, the cluster head selected based on the node energy, node degree and density to achieve power balance, to minimizing control overhead and improve the network lifetime. Recent studies cover many clustering based routing protocols [18,19].

B. Ant Routing

Ant colony optimization (ACO) is a popular technique to handle the optimization problems such as the asymmetric traveling salesman, vehicle routing and WSN routing. Firstly traditional networks only use the ACO algorithm. Mobile ad hoc networks (MANETs) use ARA [6] algorithm to search for routing in terms of pheromone laying behavior of ants but this algorithm not suitable for WSNs. In recent times ACO based routing protocols proposed in various studies [15,16].

Basic ant routing (BAR) developed by using the advantage of AntNet implemented by Dorigo et al[7]. In this protocol select the routing path based on probability distribution which can support the network lifetime. It not effectively works because of the asymmetric links. Zhang et al. [8] proposed three ant based routing algorithm for WSN that are Sensor-driven cost-aware (SC) ant routing, flooded forward (FF) ant routing ,and flooded piggy (FP) backed ant routing. This algorithm good system start-up for initial pheromone settings but the SC and FF algorithms are provide better energy efficiency at the same time quite effective in latency. Better energy efficiency provided by SC, FF will shorten the delay and FP provide successful data delivery. To maximize the network lifetime of WSNs Camilo et al. [9] proposed an improved ant-based algorithm, namely Energy-efficient ant based routing (EEABR). To reduce the communication load this algorithm maintains energy level of sensor nodes and routed path length on pheromone trail. Okdem et al. [10] proposed Routing using ant colony optimization router chip (ACORC) which provides good energy efficiency than EEABR. If any node faults, it uses multi-path data transmission technique, to achieve unfailing communications. Gunes et al.[12] have proposed the Ant-Colony-Based Routing Algorithm for Mobile Adhoc Networks (ARA) which is the reactive protocol. Forward and backward ants are used as a agent for discovering the route and update the pheromone table. Rajagopalan et al.[14] have proposed the Adhoc Networking and Swarm Intelligence (ANSI). In this decision table are used to update the pheromone. Forward reactive and backward reactive ants are used to broadcast and transmit the data respectively. Wang et al.[20] have proposed Ant colony clustering algorithm (ACALEACH). The algorithm considers distance between the CHs not considering the node residual energy. ACA is mainly applies for reduce the energy consumption to improve network lifetime in inter cluster routing.

However this algorithm mentioned above have some advantage and disadvantage. To conquer the disadvantages of usual ant-based routing algorithms, we propose an energy efficient hierarchical routing protocol using the advantages of hierarchical and multipath routing and ACO approach.

III. System Model

A. Network Model

A WSN collection of a large number of sensors within the radio range and all sensors communicate with each other via wireless links on behalf of direct communication.

- Set of N sensor nodes are uniformly and non-uniformly spread in event area.
- All sensor nodes grouped into clusters in the environment.
- Each sensor nodes has a unique ID.
- The sensor nodes energy cannot be recharged and sensor nodes and sink are keep fixed or less movement once being deployed.
- Sensor nodes are location-unaware, that is it doesn't rely on the Global Positioning System (GPS), for knowing the location information to discover the shortest path to the destination.

The single hop communications are taken between cluster member and its cluster head and multi hop communications are taken between cluster head and sink.

IV. Description of EEHRP

EEHRP consists of three phases. Cluster formation, routing using ACO and data transmission. The first phase in clustering, all sensors in network are homogenous and have same ability of process. The function of CH is managing the cluster; from cluster members collect the data, and transfer them to the base station (BS). In the second phase, aco technique is applied to finding the optimal path to sink. In the last phase CH send the data to sink via selected shortest path.

A. Cluster Formation

In this, clustering is proposed to energy saving in WSNs. The sensor nodes select their cluster head based on the two parameters remaining energy and node degree. And also cluster heads select their members based on the two parameters of sensor remaining energy and distance to its cluster head. Cluster formation algorithm is shown in Fig 1.

Cluster formation done in three levels Initial, hierarchical and final. The initial level only starts at cluster formation in network and final level done after completion of cluster formation in network. However, hierarchical level repeated until entire network become clustering. All sensors collect data around environment compare it, with its neighboring node data. If gathered data was same, sensor node save the message senders ID in the list of its neighbors N_i.

At initial level of cluster, sink or BS that transmit a "Start" message to form cluster in network, with in its transition range of sensor nodes. This message received by sensors nodes which close to BS. The parameters used for cluster formation are list out Table 1.

Table I: List of Parameters Used in Clustering

Variable	Description
E_r	Remaining Energy
N_a	Node degree
d_r	Distance (calculated based on received signal strength)
T	Weight of node
T_{CH}	Weighted value for CH

In Hierarchical level, the sensor nodes received "Start" message from Sink, calculate the value of T by itself, based on two parameters sensor remaining energy E_r and number of neighbors N_a.

$$T = E_r + N_a \quad (1)$$

After calculating value of T, Sensor nodes send it to their neighboring nodes. Sensor nodes compare with its own T value and received T value sended by neighboring nodes. The largest T value selected as a cluster head (CH), after choosing the CH, which selects its member for that it sends the join to me message to neighbors in its range. Sensor nodes calculate the T_{CH} value which are heard this message. The T_{CH} value calculated based on two parameters remaining energy of sensors (E_r) and distance to its CH (d_r).

$$T_{CH} = E_r + d_r \quad (2)$$

After calculated T_{CH} value, the sender of highest T_{CH} value of sensor, selected as its CH. And reply join to u message to it. At the final level, aco technique applied to searching shortest path to sink for data transmission. The hierarchical level will repeated for changing CH position for next level.

Algorithm1: Cluster formation

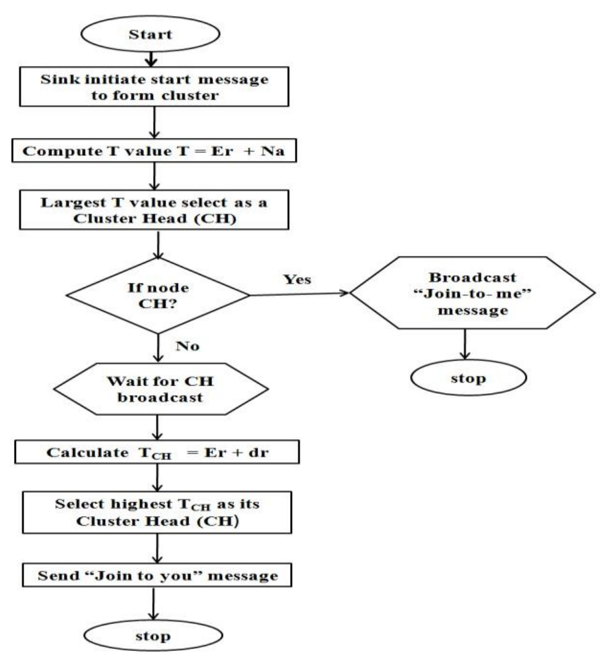

Figure 1: Cluster Formation Algorithm

B. *Constructing Optimized Path*

In EEHRP, ACO algorithm is used to establish several optimal or suboptimal paths from the CH to sink, for deliver data with less energy consumption. Search ant (SANT), backward ant (BANT) and abnormal ant (AANT) are the three kinds of ants used in EEHRP.

After finishing the cluster formation, the CH that creates SANT to find several optimal and suboptimal paths to sink for gets lane information. In order to decrease path discovery time and overheads, the amount of SANTs is associated to the network size and the demand of the purpose.

The format of message brought by a SANT is shown in Figure2.

Message Type	S_ID	D_ID	K	Emin	Ep	H	TTL

Figure 2: SANT Message Format

The field message type denotes that it is a SANT. The S_ID field indicates the previous node identification. The D_ID field indicates the next node identification. The K field denotes the number of a SANT. The Emin field denotes the current node minimum energy. The Ep field indicates the sum of energy consumption till the current node. The H field gives the length of the path. The TTL (time-to-live) field denotes the depth that a SANT can travel, the value of TTL is decreased when a SANT is forwarded. That is the SANT is discarded if TTL equal to zero before the SANT reaches at sink. In order to prolonging the network lifetime and balancing the load among nodes, we change the equations of the basic ACO:

$$P(t) = \begin{cases} \frac{\tau_{ij}^{\alpha}(t) * \eta_{ij}^{\beta}(t)}{\sum_k \tau_{ij}^{\alpha}(t) * \eta_{ij}^{\beta}(t)} & \forall j \in N_i \; and \; j \notin M^k \\ 0, & otherwise \end{cases} \quad (3)$$

Where P(t) is the probability of selecting the next neighboring node j of the present node i. η_{ij} represents the local heuristic value of the link (i,j), and τ_{ij} indicates the pheromone value on link (i,j). α and β are two variants used to control the relative weight of pheromone trail and heuristic value. M^k contains the already visited nodes information. In EEHRP, In order to keep SANT's memory M^k keeping node's memory. This approach can reduce the data size to be transmitted and save energy.

$$\tau_{ij}(t, t+1) = (1-\rho) * \tau_{ij}(t) + \rho * \Delta\tau_{ij}^{k}(t, t+1) \quad (4)$$

$$\Delta\tau_{ij}^{k}(t, t+1) = \lambda * (E_i + E_j)/d_{ij}^2 \quad (5)$$

The above equation are used to update the pheromone value at link (i,j). where ρ is the desertion factor, which serves to reduce the strength of existing path over time. λ is a coefficient. d_{ij} is the distance between node i and j. E_i is the residual energy of node i.

a. *Backward Ant (BANT)*

BANT is also needs to update the pheromone value on link (i,j) when it travel along the reverse path followed by a SANT. The following equation is used to calculate and update the pheromone value.

$$\Delta\tau_{ij}^{k}(t, t+1) = c * \frac{f(t+1) - f_{best}(t^*)}{f_{best}(t^*)} + * f(t+1) \quad (6)$$

The message format of BANT is shown in Figure 3.

Message Type	D_ID	K	Emin	Ep	Length

Figure 3: BANT Message Format

The Message Type field denotes the BANT. The Length field is the length of the path from sink to the present node. The meaning of other fields is same as message mentioned in SANT.

C. *Data Transmission and Route Maintenance*

In EEHRP the CH dynamically select one path to transmit data. The residual energy of the minimum energy node in path, the sum of energy consumption in path and the length of path, which can be used to estimate the delay of a path. The CH calculates the probability and transmits data along the selected path.

In EEHRP, route maintenance is responsible for the maintenance of the paths during the communication. The route maintenance process will be initiated in the following situations,

If the current CH residual energy is lower than 50% of the average energy of all nodes in the cluster, a fresh CH will be selected. If there are additional paths to sink, the fresh CH will send the packets through these paths else the new CH will start a new path discovery process.

V. Simulation Results

The simulation shows the performance of evaluated algorithm mentioned in section 4. The sensor nodes are randomly deployed in field with 500*500 sizes. In these 10 numbers of sources and 1 destination had been used. Increasing number of sensor 50,75,100,125, and 150. The topology also changes to each simulation. The average packet delivery ratio is taken from the result. The data rate 1024 kbps and speed is 5ms. The average energy, minimum energy consumption, packet delivery ratio and standard deviation with error module are taken from simulation results. The proposed routing protocol had been compare to ant colony based routing protocol AntHocNet. The reliability of route decreased when the number of multiple paths is less than two. The current CH will begin a new route discovery process. In Fig 4 shows the result of packet delivery ratio when number of nodes increased in the network. When number of nodes increase the data transmitted through multiple nodes to reach the destination quickly, so the packet delivery ratio is increased. In Figure 5 shows the residual energy in percentage (%). When no of nodes increase the packets sent and receive will also increase so energy consumption also get increased.

VI. Conclusion

For extending the lifetime of wireless sensor networks, we have proposed a Energy Efficient Hierarchical Routing Protocol using ACO. By introducing an objective function to carry out clustering, EEHRP improves the efficiency of data aggregation process, thus, reducing the energy consumption.

We also use an ACO algorithm to search for the optimal and suboptimal paths. Furthermore, balance the load in network.

The CH is choosing one path to transmit data. Performance evaluation shows that EEHRP achieves balancing the load and

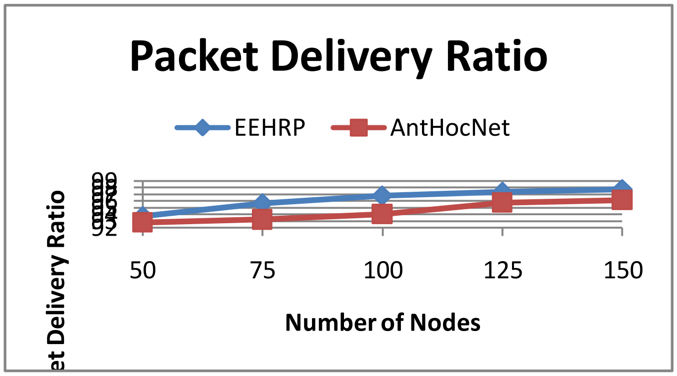

Figure 4: Number of Nodes Vs PDR

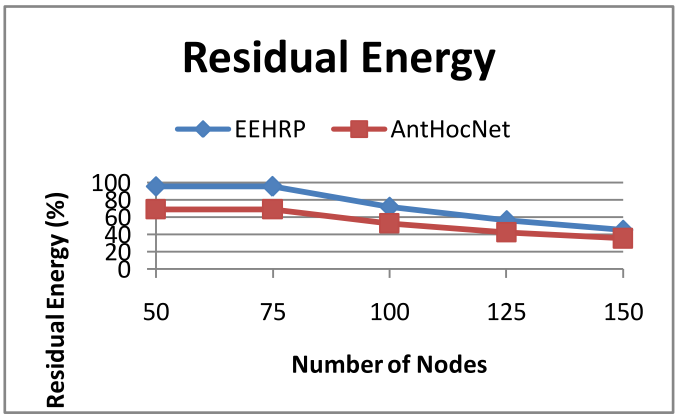

Figure 5: Number of Nodes Vs Residual Energy

Lower consumption of energy, and then, increase the network lifetime.

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P Senthiya Prabha was born in Tamilnadu, India, in 1989. She received the B.E. degree from KLN College of Engineering, Tamilnadu, India and her M.tech degree from Kalasalingam University,Tamilnadu, India in 2010 and 2014 respectively. Her major research interest includes Wireless Sensor Network, MANET, Network Security. (Email: prabha3sran@gmail.com)