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Routing Optimization for Wireless Sensor Networks using Fuzzy Ant Colony

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Abstract

For industrial applications to work efficiently, it is good to establish routes in Wireless sensor networks (WSN) since they operate on battery and maybe restricted in terms of energy. This paper focused on designing a routing technique that increased the energy conservation of a WSN in order to preserve the battery life. Three parameters were considered in making a decision for the route to be taken which were the sensor energy in joules, the amount of traffic in Erlang and the distance in meters required for a packet to be sent from the source to the destination node. The routing protocol was based on fuzzy logic and ant colony optimization algorithm(FACO). Fuzzy logic was used to calculate the total node cost to the gateway by considering the traffic load in the node and the energy of the node. Ant colony optimization(ACO) was used to search and establish the shortest route from source to destination sensor node which was evaluated based on the shortest distance. The results which were done on Matlab simulation shown improved performance in energy conservation as compared to performance of ACO under the same conditions. This improved routing algorithm can be used in industrial applications using WSN.

Keywords: wireless sensor networks, Fuzzy logic, ant colony optimization, energy conservation, routing optimization.

INTRODUCTION

WSN is composed of several sensors which are randomly or deterministically distributed for data acquisition and to forward the data to the gateway for further analysis [1]. WSNs are used in various industrial applications; in street lighting, in smart grid, water municipals, in health care for monitoring the health condition of a patient, in green house monitoring to monitor the condition of water, soil, temperature or humidity levels, in monitoring strength of bridges, in checking the state of equipment WSNs are used to monitor and detect if there is a malfunction in industrial machinery during a normal production activity which will be able to improve on efficiency[2]. In general, WSNs take measurements of the desired application and send this information to a gateway whereby the user is able to interpret the information to achieve the desired purpose. The main importance of wireless sensor network in area of machine monitoring is they can be placed in a rotating machinery, or in a place which is un reachable for the engineer to take measurements by hard wired sensors. In today's world, wired sensors are being replaced by WSN because wireless sensors are cheaper as compared to their counterpart [3].

A sensor node has an in built radio transceiver with an internal antenna to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source which is a battery and a platform for allowing external energy supply if required especially for the sink node. Industries manufacturing WSN are looking forward to produce complete microelectromechanical systems (MEMSs) based sensor systems at a volume of 1 mm^3 [4]. The major challenges of a WSN is energy efficiency, responsiveness, robustness and finally self-configuration and adaptation. Research has been done within the past years to determine the optimal path for a WSN maximizing energy conservation between the source node and destination node. However, the challenge has been to create a good routing algorithm taking into consideration the major challenges mentioned above [5].

WSNs are cheaper in cost and require little or no maintenance costs once installed hence the need for using WSN for the various applications [6]. WSN routing protocols are designed to establish routes between the source and destination nodes. What these routing protocols do is that they decompose the network into more manageable pieces and provide ways of sharing information among its neighbours first and then throughout the whole network [7]. For WSN applications to be efficient and reliable, there is need to design a routing optimization to manage the communication of WSN in energy aware and also traffic and distance aware mechanism. The focus in this research is routing optimization for WSN. The aim is to find the best optimum path for the sensor to send required information to the sink node based on the energy of the sensor nodes, the traffic in the network and the distance between the source node and destination node. The routing technique used is ant colony optimization algorithm and fuzzy logic in order to perform optimal routing with minimum energy consumption to maximize on energy conservation.

The rest of the paper is arranged into different parts. Part II highlights the related work and their limitation in design of routing algorithm for WSN. Part III highlights the algorithm used Fuzzy logic and ant colony optimization. Part IV represents the results obtained from Matlab simulation, Part V is the final part of the paper and it highlights the conclusion.

RELATED WORK

Research has been done within the past years to determine the optimal path for a WSN minimizing energy consumption between the source node and destination node [8]-[12]. However, the challenge has been to create a good routing algorithm taking into consideration all the factors that affect the energy consumption of a WSN, for example in this research work we have considered the amount of energy in the sensor node, the traffic load in the queue and the distance between source node and the destination node.

The author in [13] has represented the use of ACO protocol for establishing routes in WSNs. He states that all the ants will assume the shortest route after a search process is done. He discusses the ants to be grouped into two categories the forward ants and the backward ants. The decision of whichever route will be followed is based on the amount ACO pheromone or smelly trail laid along the shortest path. However, this routing technique does not consider all the parameters that affect energy consumption in a WSN.

In [14] the author has analysed the optimization of WSNs using ACO algorithm. The author has discussed the use of ACO to search and find the route from the source node to the sink node. The author has however added the energy of a sensor node as a parameter in determining the shortest route. The decision of the path to be chosen is based on the amount of ACO pheromone in the shortest route as well as the energy remaining in the sensor node. For this routing technique the performance can be improved by adding more parameter that determine the decision of the route to be taken.

According to the author in [15] he proposed an ACO algorithm along with BFS (Breadth First Search) which is a tree-based search used to enhance the accuracy of the best path selection. The ACO algorithm the author proposed consist of three type of ants, namely the frontward ant, the Bfrontward ant and the backward ant. The frontward ant is used to find the best and shortest path by looking up the information on neighbouring nodes from the routing table. A backward ant is used to the same path back as frontward ant while using the algorithm to adapt to the network changes. The last ant which is Bfrontward ant according to the author was used to enhance the ability to predict the cost of selecting the next node as a path to send data for the next level of transportation. However, more parameters can be added to improve the performance.

The author in [16] used a termite hill algorithm for routing, this termite hill algorithm is also known as ant colony optimization algorithm. In this routing algorithm the only factors of consideration are the energy of the sensor network and the distance between the source and the sink node. Another author in [17] discusses a routing technique based on hybrid of Genetic algorithm (GA) and ACO. He used Genetic Algorithm (GA) to establish cluster and select the cluster head (CH). After CH selection he has used ACO to search and find the shortest route from the CH to the destination node.

From the above related work, we can deduct that the existing routing protocols are using a single routing criteria for example some authors have considered the energy level only while others have considered only the hope count (distance). This type of approach can overload sensor nodes or drain energy in some nodes leading to unbalanced energy levels in the sensor nodes. Therefore, there is need to design a routing algorithm that is aware of the traffic congestion, the energy level and the hop count for reliable and energy efficient communication of sensors for industrial applications. However other techniques for example ANFIS (Artificial Neural Fuzzy Inference System) have not been considered because they are not search based and therefore they cannot be used alone to establish the shortest path between the source node and the sink node.

In this paper, the routing algorithm is modified to take extra considerations which include the traffic load on the sensor nodes in addition to the other considerations like the energy available in the node and the minimum distance between the start node and the sink node. The design has used fuzzy logic and a heuristic search based algorithm ACO to enable efficient data transmission, utilize the energy in the network well, extend the WSN lifetime and hence increase the communication performance for wireless sensor networks.

FUZZY LOGIC AND ANT COLONY OPTIMIZATION (FACO) ALGORITHM

Fuzzy system is a very important tool because we can incorporate the human way of reasoning to operate systems efficiently. This research has used fuzzy logic to incorporate important parameters that will determine the best optimum route for a packet to be sent from source sensor node to the gateway. Fuzzy logic is used to evaluate the optimum node cost with the input parameters to the fuzzy system been the energy of the sensor network and the traffic, the output is the optimum node cost.

The network controller is the sink node; it is the one that sets up routes for each sensor node. It acts as a gateway(destination) for this WSN to collect all the data from the network. The sink node is the one that evaluates the cost of each sensor node to the gateway and sets up the optimum route for each sensor node and broadcasts the route schedule to the sensor nodes. The sink node is the one using a fuzzy logic controller to determine the cost of each sensor node to reach the sink node. It queries all the sensor nodes to send the information about their energy status and the traffic status. The cost of the link is evaluated by the inputs of Fuzzy Logic Controller(FLC) being the transmission energy and the traffic.

The ant colony optimization algorithm is very important search heuristic algorithm. It is in the class of swarm intelligence and it is inspired by the process of ants searching the shortest paths between the nest and the food source. In this research ant colony is used to calculate the shortest path that will be used after the fuzzy system has calculated the optimum node costs. Once the cost of all the possible links to the sink node is computed the route will be determined using the shortest path algorithm for optimum route selection. Once the optimum path has been calculated the sink node is the one that broadcasts the routing schedule to each sensor node to send information.

A. Fuzzy logic

Lotfy Zadeh in 1965, discovered Fuzzy logic. He realized that the way of human reasoning is not precise and cannot be represented by binary values of 0 or 1. Fuzzy logic from the discovery of Lotfy Zadeh is defined as a multivariable logic that allows for the representation of the human way of reasoning in a way which can be processed by a computer for further interpretation [18].

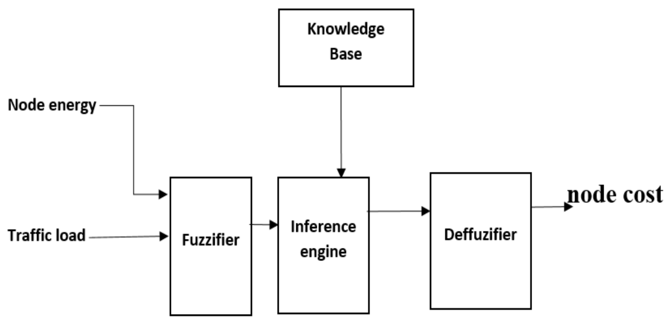

Figure 1: Fuzzy system

From fig. 1. the fuzzifier Scales and maps input variables to fuzzy sets. It is the establishment of the fact base of the fuzzy system. It identifies the inputs and output of the system, defines appropriate IF THEN rules, and uses raw data to derive a membership function. The engineer determines membership functions that map the crisp values of interest to fuzzy values.

The inference engine is used for approximate reasoning and it deduces the control action. Evaluates all rules and determines their truth values. If an input does not precisely correspond to an IF THEN rule, partial matching of the input data is used to interpolate an answer.

The defuzzification process is used to Convert fuzzy output values to control signals. Involves conversion of the fuzzy value obtained from composition into a “crisp” value. It is necessary since controllers of physical systems require discrete signals [19].

B. Ant colony Optimization Algorithm

Swarm **i**ntelligence is an upcoming new discipline that is concerned with the study of self-organizing processes both in nature and in artificial systems. Ant colony optimization is an example of swarm intelligence**.** Ant colony optimization is inspired biologically by the behaviour of ants. A single ant is simple in nature and has a limited amount of memory and therefore is capable of performing simple things. A single ant may not be intelligent enough but ant colonies are, an ant colony represents a complex behaviour in a collective manner by finding intelligent solutions to problems for example searching for the shortest path from the nest to the food source. An ant colony can be able to do the following; plan, find, and optimize routes to food [20].

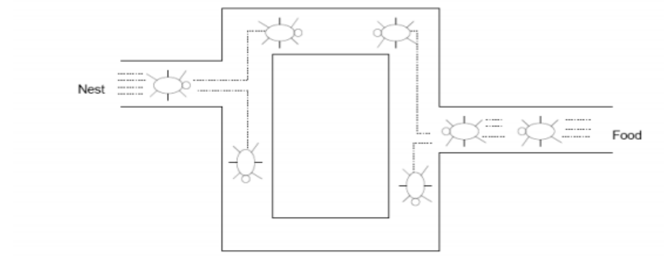

Figure 2: Different routes for ants between nest and food

When ants are moving from source node to sink node, they leave behind a pheromone or smelly trail. For ants following the longer route they will take more time to find food source as compared to the ants who took the shortest path. On the return path to food source, an ant will be laying pheromone as it moves. This implies that more pheromone will be laid on the shorter path than on the longer one. The smelly trail or pheromone will attract other ants to follow that path, these ants will also lay down more pheromone as they move through. After some time, the amount of deposited pheromone will be more on the shorter route and hence all the ants take this route [21].

C. Routing Algorithm

The designed routing model is energy aware, distance aware and traffic aware. This model proved to be effective and reliable in terms of energy consumption and packet delivery. Fuzzy logic determines the best node to be picked by calculating the cost. The best node is used for the selection of the best route using ant colony algorithm as shown in fig. 3 below.

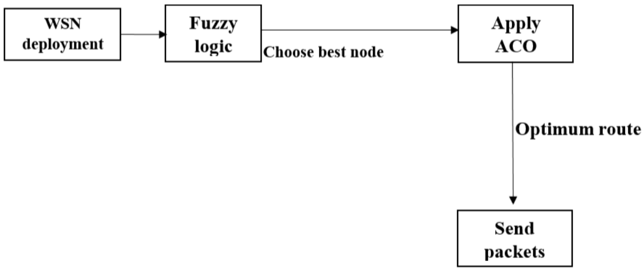

Figure 3: Routing model

In fig. 4 the fuzzy membership functions of each input are represented. The inputs to the system are Energy and the traffic in the queue. The energy of a wireless sensor network is limited since these sensors rely on battery. To minimize energy consumption and maximize on energy conservation, this input is a variable that is used to determine the best node to be chosen in terms of the cost of the node. The energy limits are between 0 and 5 joules, with fuzzy variables low, medium and high.

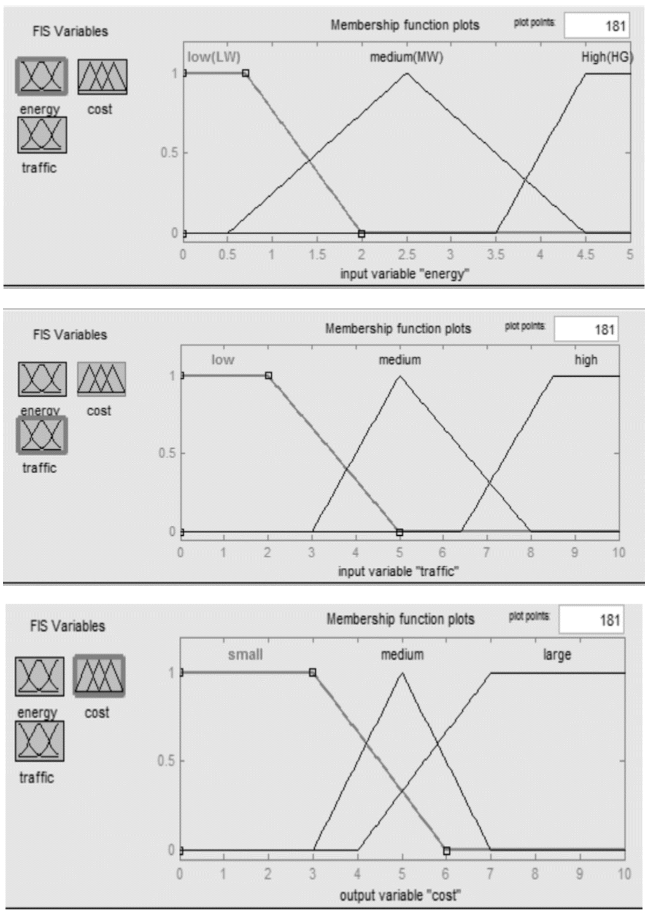

Figure 4: Membership functions for inputs and output

The fuzzy inputs to the system are Energy and the traffic in the queue. The energy of a wireless sensor network is limited since these sensors rely on battery. To minimize energy consumption and maximize on energy conservation, this input is a variable that is used to determine the best node to be chosen in terms of the cost of the node. The energy limits are between 0 and 5 joules, with fuzzy variables low, medium and high. The energy model is based on first order radio model as described by the authors in [22]. The purpose of including first order radio model is to give priority to nodes with the highest energy. When a packet k is being transmitted from source node to destination node through the selected nodes, energy is consumed and some of the nodes may be dead depending on the number of simulated rounds.

$$E_{TX} = E_{e\_tx} * k + \epsilon_{amp} * d^{\alpha} \quad (1)$$

In the above equation for first order radio model, k represents the number of data bits that have been send; α is a constant value that is between 2 and 5; d is the distance between two sensor nodes; ϵ_{amp} is the amplification coefficient that enables minimum bit error rate; and finally $E_{e\text{-}tx}$, is the amount of dissipated energy to operate the transceiver, it is shown in the equation below

$$E\_e_{tx} = Vcc * I_{TP} / K_{data\_rate} \quad (2)$$

Vcc represents the working voltage, I_{TP} represents the transmission current, and K_{data_rate} represents the information transmission rate. The energy usage for information reception is given by the equation below.

$$E_{RX} = E\_e_{tx} * k \quad (3)$$

If the distance is fixed, then the energy usage is directly proportional to the number of data bits, this is from equation (3).

The amount of energy consumed in first order radio model depends on E_{TX} and E_{RX}.

Another fuzzy input is the traffic; it is the number of packets k in the queue which determine how long a packet will take from source node to destination. In route selection the node with less traffic will have a high possibility of being picked because the traffic in the queue is minimized. The traffic limits are between 0 and 10 in bits per second (bps) with fuzzy variables low, medium and high. The traffic intensity is measured in Erlang which is a dimensionless unit. Traffic intensity is a measure of offered load or carried load in a wireless network.

The fuzzy output to the system is the cost of each node. The node with the highest cost will be selected, which is based on the highest energy and the least traffic. The cost limits are between 0 and 10. Once the nodes have been selected based on cost, ant colony algorithm is used to determine the optimum route to be used based on the shortest distance

Ants operate in two different ways either in forward or backward way. In forward direction, ants move from source node to destination node while in backward direction ants are moving in the backward direction from destination node back to source node.

For a given graph $= (N, D)$, two sensor nodes x, y ϵ N are neighbour's if there exists an arc (x, y) ϵ D.

The choice is probabilistically determined by the amount of pheromone trails that were deposited by other ants. The backward ant retraces the route it followed when finding the destination node while at the same time leaving pheromone on the arcs they pass through. The cost determines the amount of pheromone they deposit while in the backward mode. More pheromone is deposited on short paths.

For a period of time, the amount of pheromone that was deposited reduces because of the effect of evaporation. The purpose of pheromone evaporation is to decrease the effect of the amount of pheromone that was deposited in the initial stages of path finding. The pheromone trail is defined by τ_{xy}. When the search process starts every arc is assigned a specific amount of pheromone. For a source node x, an ant m uses the pheromone trails τ_{xy} to evaluate the probability of choosing y as next node.

$$p_{xy}^{k} = \begin{cases} \frac{\tau_{xy}^{\alpha}}{\sum_{l \in N_x^m} \tau_{xl}^{\alpha}} & \text{if } x \in N_y^m \text{ or } 0 \text{ otherwise} \end{cases} \quad (4)$$

Where N_x^m is the neighbourhood of ant m when in node x. equation (4) shows the probability of an ant m to move from source node x to other nodes until it reaches the destination node. In route searching every ant m takes different routes and so the ant with the least path will arrive at the destination node faster. Once an ant reaches the destination, it changes from forward direction movement to backward direction movement. During the backward trip an ant m will deposits an amount of Δ_{τ}^{k} of pheromone on arcs visited. If ant m is in the arc (x, y) the pheromone value changes to τ_{xy} as shown below;

$$\tau_{xy} = \tau_{ij} + \Delta_{\tau}^{m} \quad (5)$$

From equation (5) an ant using the arc connecting node x to node y increases the probability that the other ants will use the same arc. For ants using the shorter route they will take shorter time and hence more pheromone will be deposited in shorter routes. The importance of having pheromone evaporation is to discourage ants from converging in routes which are suboptimal. The speed of pheromone trails evaporation is exponential and its done by using the following equation in all arcs.

$$\tau_{xy} = (1-\rho)\, \tau_{xy} : \forall\ (x, y) \quad (6)$$

where ρ ϵ (0, 1) is a parameter.

The amount of pheromone Δ_{τ}^{k} is added to the arcs after equation (6) is used on all the arcs. Ant colony optimization is achieved with the cycle of ant's movement, pheromone evaporation and pheromone deposit until an optimum path is located [23].

Table I: Fuzzy Rules

energy	traffic	cost
low	low	medium
medium	low	large
high	low	large
Low	medium	small
medium	medium	medium
High	medium	large
low	high	small
medium	high	small
high	high	medium

The simulation was carried out in Matlab C code. The sensors were randomly deployed within an area of 100*100 m^2, with the sink node located at position (50,175). The model utilizes the first order radio model in which the amount of dissipated energy to operate the transceiver is E_{e_tx} which has been initialized to 100 pJ/bits/m^2. The amplification coefficient that enables minimum bit error rate ϵ_{amp} has been initialized to 50 nJ/bits. The traffic load is between 0 and 10 with a packet size of 6400 bits. The distance between two sensor nodes d is simulated as 50 meters. Ant colony parameters have also been initialized for example the evaporation coefficients, the number of ants, the traces effect, the effect of ant's sight and cycles.

Table 2: Simulation Parameters

Parameters	Value
X*Y simulation area	100*100 m^2
Number of nodes	100
Sink node location	50*175
Node initial energy	5 joules

Number of Maximum traffic load	10
Packet length	6400 bits
Transmission distance (d)	50 meters
ϵ_{amp}	50 nJ/bits
E_{e_tx}	100 pJ/bits/m^2
Number of ants (k)	100
Evaporation coefficient(e)	0.1
Number of cycles	100
Effects of ants sight (α)	1
Traces effect(β)	5

SIMULATION RESULTS AND DISCUSSION

The performance of this technique has been compared to the performance of using ACO routing algorithm alone. The performance has been enhanced by adding fuzzy logic to the ant colony algorithm to evaluate the optimum cost for each node.

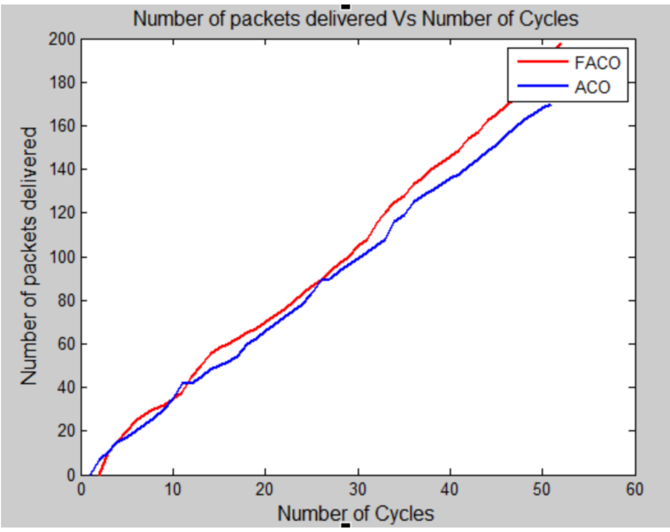

Figure 5: Performance of FACO versus ACO for packet delivery

The performance of fuzzy logic ant colony algorithm is compared to the performance of ant colony algorithm in figure 5. the number of packets delivered to the sink node are higher for FACO routing technique as compared to ACO. This is because FACO includes many parameters that affect the battery lifetime of a WSN. FACO has taken into account the amount of energy remaining in the node, the amount of traffic in the queue and the distance from source node to the sink node. ACO routing algorithm only evaluates the shortest distance from source node to the sink node and hence the number of packets delivered are lower, also in ACO the path with the highest traffic but shortest distance maybe followed leading to delay in the number of packets to be delivered.

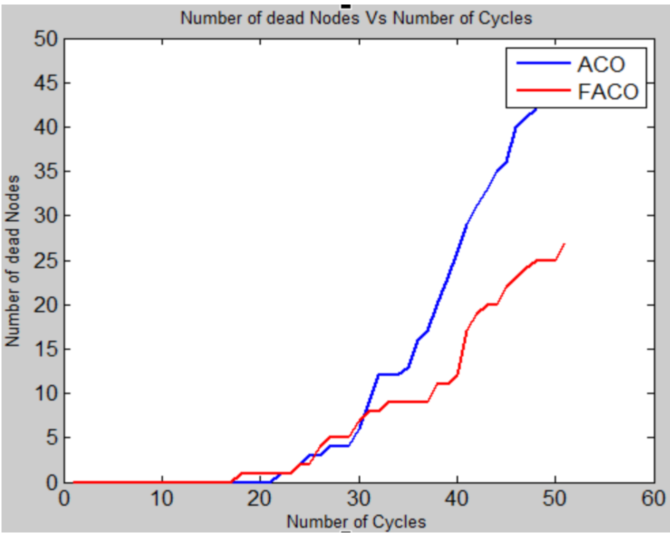

Figure 6: Performance of FACO versus ACO for packet delivery

The performance of fuzzy logic ant colony algorithm is compared to the performance of ant colony algorithm in figure 6. the number of dead nodes are higher for ACO routing technique as compared to FACO technique. This shows that more nodes will be dead as the number of cycles increase for ACO because the algorithm is not energy aware and traffic aware. A WSN node is considered to be dead if all the energy has been depleted. At cycle 45 there is a 20% increase in the number of dead nodes when using ACO routing algorithm as compared to when using the FACO routing technique. This shows an improved performance for the proposed routing algorithm.

The performance of fuzzy logic ant colony algorithm is compared to the performance of ant colony algorithm in figure 7 for 51 cycles. For nodes using FACO protocol the energy consumed is at a lower rate as compared to ACO for the same cycles. The figure shows that FACO is more energy efficient as compared to ACO. At cycle 20, the amount of energy remaining in the node for ACO is 1.4 joules while the amount of energy remaining in the node when using FACO technique is 2.8 joules. This means that more energy is conserved when using FACO as compared to ACO routing algorithm because we are losing more energy in ACO technique. There is an increase in the performance of the proposed algorithm which means that the WSN will be reliable and efficient.

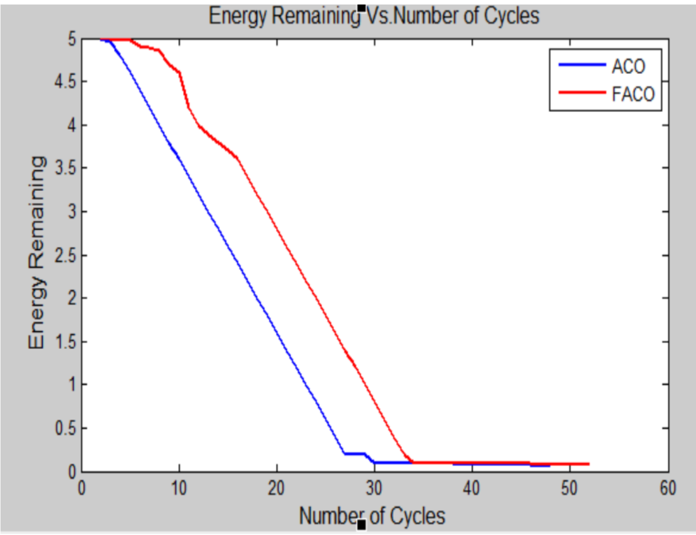

Figure 7: Performance of FLACO versus ACO for Energy remaining

Table 3: Performance Comparison of FACO Vs. ACO

Parameter	ACO	FACO
Number of packets delivered to the sink node at cycle 50	83 bps	89 bps
Energy remaining at cycle 50	0.4 Joules	1.6 Joules
Number of dead nodes at cycle 100	45	25

Table 3 shows the impact of the three parameters (Packet delivery, energy consumption and number of dead nodes) to the network lifetime. For ACO more nodes are dead and the energy consumed is high. The number of packets delivered are as well higher for FACO as compared to ACO. In overall there is an increased performance in the proposed routing algorithm in energy conservation of a WSN.

CONCLUSIONS

The routing model was based on hybrid system of fuzzy logic and ant colony optimization algorithm. Fuzzy logic is applied to choose the best node with the highest cost by considering the traffic in the queue and the remaining energy in each node. The nodes chosen form part of the route to be taken. Ant colony algorithm was used to search the optimum path from source node to the sink node by considering the shortest distance of the chosen nodes. The results have shown enhanced network lifetime by providing a balance between the energy consumption and the network traffic in the queue on FACO as compared to ACO. As the number of cycles increase more packets are delivered and the amount of conserved energy is more for FACO as compared to ACO for both cases. The number of dead nodes increase as the number of cycles increase; more nodes are noted to be dead in ACO as compared to FACO. This routing algorithm can be used in industry for routing of WSNs.

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