

# A Routing Algorithm Based on Ant Colony, Local Search and Fuzzy Inference to Improve Energy Consumption in Wireless Sensor Networks

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## ABSTRACT

Wireless sensor network is a new generation of networks in which the main aim is to collect data from the surrounding environment of network sensors. The major differences of wireless sensor networks with other networks are limited energy resources and relatively low processing capabilities. Therefore, managing power and reducing energy consumption are of great importance in these networks. In this paper, there was presented a mechanism for Wireless sensor network routing which can be more effective regarding the criteria of route length, end-to-end delay and network node energy for the quality of mechanism service. The proposed method used ant colony-based routing algorithm and local enquiry to find optimal routes. Also, a fuzzy inference system was used to determine the route quality which showed better performance compared with equation of route quality. The results of simulating mechanism showed that energy consumption and network efficiency had improved compared with those of previous methods.

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## 1. INTRODUCTION

Wireless sensor networks consist of small nodes which are able to receive, calculate and communicate wirelessly. Due to limited energy resources and relatively low processing capability, the methods of saving energy [1] to overcome the restrictions and challenges must be considered so that the efficiency and energy consumption are improved optimally. Basic routing algorithms [2], [3] are not intelligent enough to find the route. Calculating intelligence methods are used to increase the algorithm intelligence.

Therefore, in the recent years, swarm intelligence methods such as ant and bee algorithms have been widely used to optimize the routing in WSN [4]. Then, we review the related works and in section 2, the details of the proposed algorithm are presented. In section 3, the results of implementation and assessment of the proposed algorithm are introduced and finally the conclusion is made. AntNet Algorithm [5] belongs to Ant-colony algorithms with a better performance than older algorithms. FP [4] algorithm places data packets in the forward packets, named Data-ANT, which are distributed randomly and flooding and keep the node list which is met during forwarding. FP is a version of AntNet and is useful in WSNs in which the probability of data loss is greater than that in constant network. This algorithm has better data delivery rate and great saving of energy consumption. EEABR algorithm is a new communication protocol [6] of hyperactive type which is

based on optimization of ant colony for WSN. In this protocol, each node stores a data structure from ant information including previous node, next node, ant index and timeout value.

In this protocol, each node in network forwards a forward ant in regular time interval to find a specific route. When a forward ant is received, the node looks at its routing table and searches for ant index. When the ant index is available, the ant is removed; otherwise, the node stores the required information, resets the timer and sends the ant to the next node. When the forward ant reaches the destination, it turns into backward ant and the pheromone sequence updates the paved route by the forward ant. In contrast to Ant Net, in this protocol, all the nodes visited are not stored in the memory of forward ant, but the address of the last two visited nodes is stored. Bee sensor protocol is a simple model based on bee factor [7], which has better performance than the optimized version of AODV. Bee routing protocol is simple, scalable and energy conscious. QoS-PSO algorithm is a routing algorithm based on QoS with the help of agent in WSN [8]. Routing based on QoS means that QoS parameters are added to routing protocols so that the efficiency of data transmission is improved. QoS-based protocols can search better routes considering QoS under the dynamic topologic conditions and limited resources and guarantee QoS criteria before data delivery to the target node. In QoS, it is not enough to consider only one parameter to optimize the routing of WSN. It is necessary to use a synthetic QoS. In this protocol, a combination of delay, band width, data loss rate for nodes and communication links parameters are considered.

## 2. ANT ROUTING AND FUZZY-LOCAL SEARCH ALGORITHM

The behavior of our proposed algorithm, named *FACLS*, is based on routing through ant colony algorithm and local search in that there is a local search to establish route and to reach the sink before a global search by ant algorithm. If there is a route to sink, the global search is ignored. The routing process in proposed algorithm is initiated if the route is necessary to be available. Therefore, forwarding the control packets in network is reduced and there will be less overload in network. When there is a data to be sent to sink in the network of a node, the progressive routing table is searched for a route to sink. When a route is available send data to sink, the best one is chosen from the criteria in the table and the data are sent without delay. When there is no route to sink in the routing table, the data packet is placed in a queue for routing layer and then the routing process is initiated by sending the progressive packet in two steps. If the regressive packet is received from local regressive process after the specified time, the best route is calculated in terms of QoS and the data forward is done to sink. Otherwise the process of route discovery is started globally by sending another progressive packet flooding.

### 2.1. Structure of Packets and Routing Tables

The control packets in this algorithm are established in network nodes to make a route for sending data to the destination. These control packets are called forward ant and backward ant. The former collects the information of available nodes in the route to be used to determine the quality rate of route. The header structure of each forward ant, as shown in figure 1, consists of fields of packets type, packet identifier sending source, sending destination, route length, minimum energy of nodes in the route, packets sending delay from source to destination and packet lifetime.

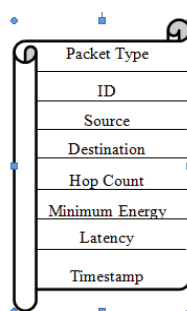


Figure 1. Header structure of forward ant

Backward ants are sent to source in response to receiving backward ants, aiming at establishing and updating the route, so that the route to destination is created in node and update. The difference of header for these ants with those of forward ants is in delta field, which determines the route quality. The value of route

quality is obtained in the sink from the information which forward ant collects while moving to sink. In Figure 2, the structure of backward ant header is shown.

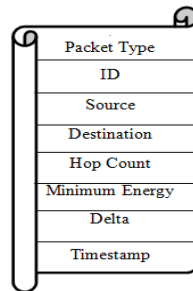


Figure 2. Header structure of backward ant

The information transferred by forward and backward ants stored by routing tables [9] with specified structure in network nodes. *FACLS* algorithm uses two forward and backward routing tables in node routing. The forward routing table is used to store the forward ant information to determine the route of sending to sink and receiving the data packets. To send the data to the next node, the information of forward routing table proportioned with route quality is used so that the greater the value of pheromone, the higher the probability of that route to be chosen. The information stored in forward routing table consists of fields of next nodes to send to sink, pheromone route identifier, the minimum energy of route nodes to sink, route length to sink in terms of the number of its nodes and information time out registered for the route, as shown in Figure 3.

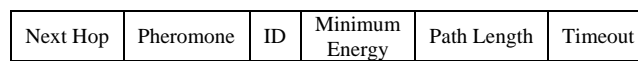


Figure 3. Field structure of forward routing tables

Each of network nodes uses backward routing table to stored forward ant information and while receiving backward ants, they use the information of the table to specify the returning route in *FACLS* algorithm. If there is a need to establish route in network, the backward ants collect the information during their motion to sink. The quality obtained in the sink through the collected information must be used to update the backward routing tables in nodes through which the route is created. According to Figure 4, the backward routing tables consist of source address, the number of forward ant order, previous node identifier, the route length paved from source to the present node and information time out.

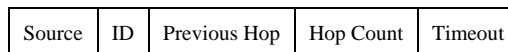


Figure 4. Field structure of backward routing tables

## 2.2. Sending the Forward Ants

For a process of routing to start, the fields of header of forward ants are given suitable values. Having sent the forward ant, the node waits for the corresponding backward ant to reach at the time of the sent forward ant time out. During this time, if another packet exists for sending in the queue, no forward ant is sent. If there appears no route in forward routing table, routing process initiates with a little delay by sending another forward ant flooding.

## 2.3. Receiving Forward Ants

When each node in network receives the forward ant, it examines if packet time out is terminated. If so, the packet is removed, otherwise the node examines the existence of loop. If the loop is available, the

packet is removed and not disturbed in network. Then, it is investigated at if the node which receives the forward ant is the sink node. If so, the route quality is calculated and the process of sending backward ant is initiated as explained in the next section. If the node is not the destination node, it is investigated if a forward ant with same identifier and source is received. If not, the forward ant is diffused in network with the probability of P and a little delay randomly. According to result for different values of P, 0.75 is considered for algorithm. Using large values of P can increase the number of diffusions in the network and routing overload while using small values of P decreases the number of forward ants which reach the destination and the algorithm uses its feature of multi route. For very small values of P, there will not appear a route in network to sink. If a packet with the same characteristics was received by the node, the previous node and the route length paved from source to the present node in previous and present receptions are compared. If the previous node is the same in two receptions or route length to the present node is equal to or greater than that in the previous. Forward ant the packet is removed. If the previous node is different in two receptions and the route proved in the new reception is smaller than that of previous reception, the packet information is inserted in the backward routing table and the packet is removed. Recording the information results in creating some routes between source and destination.

#### 2.4. Sending Backward Ants

If the node receiving the forward ant is destination node, it sends the backward ant after calculating the route quality to make a route to sink or update it. Backward ant travels in the network the opposite route of its corresponding forward ant. For backward ants to be sent the header fields of backward ants are valued with suitable values. Then, the packet is sent for the node which the forward ant is received from.

#### 2.5. Receiving the Backward Packets

Backward ants are received by all the nodes which have sent the forward ants. These nodes list the route to sink in forward routing table, having received the backward ant. If a node receives the backward ant, it examines the packet timeout. If it is terminated, the packet is removed and the transmission stages are finished. If packet time out is not finished, the forward routing table is examined. If there is a route to sink the next node of which is the same as the previous from which the backward ant is received, the information of that route is updated; otherwise there is a new route in forward routing table inserted. For forward routing table to be updated, the evaporation is carried out for all routes in routing table through relationship (1).

$$\tau_{ij}(t+1) = (1 - R) * \tau_{ij}(t) \quad (1)$$

In which 1-R is evaporation coefficient considered to be 0.8.  $\tau_{ij}(t)$  is the pheromone value of the route before the evaporation and  $\tau_{ij}(t+1)$  is the pheromone value after the evaporation. After evaporation, the pheromone value of the route is calculated by the quality in sink from (2) and the calculated quality is announced by backward ant.

$$\tau_{ij}(t+1) = \frac{\Delta}{\phi * Hopcount} \quad (2)$$

$\phi$  is a coefficient considered to be 0.5.  $\Delta$  is the QoS value by sink and hop count is route length from sink to present node. When the forward routing table is updated, the packet is removed; otherwise the packet is sent for all the nodes from which forward ants are received and their information is listed in backward routing table. This process makes some routes between source and destination. Finally, when the route to sink is created in the node, if data packet exists in the queue, it is sent for sink. If there are some routes in the node to send the data, a route is probably chosen which is in direct proportion with pheromone level. Also, sending data packets takes place with a little random delay between 0.01 to 0.001 which reduces the collision and increases the number of packets reaching the destination.

#### 2.6. Calculation of Route Quality by Fuzzy-Inference System

The concept of fuzzy system was first introduced in 1965 which has a more flexible treatment with uncertainty problem. In our proposed method, a fuzzy inference system [10] is used which has some benefits as the criterion of route optimization has some uncertainty. The first step in fuzzy system is to turn the numerical inputs into specified fuzzy terms with certain membership degree for system. The membership functions of figure 5 are used to transform inputs to fuzzy terms.

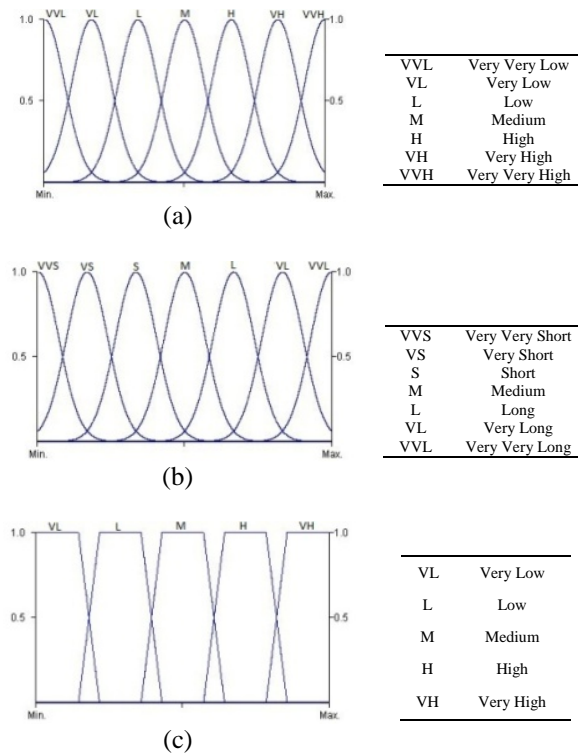


Figure 5. membership functions to transform numerical inputs to fuzzy terms, (a) membership function of energy input, (b) membership function of route length output, (c) membership function of sending delay input

Then, the value of each input is transformed into fuzzy terms with different membership degrees. A set of rules have been used to make decision, consisting of 24 rules, which cover all the possible input states of the system regarding the fuzzy terms.

### 3. SIMULATION AND PERFORMANCE ASSESSMENT

NS-2 simulation [11] was used to simulate the algorithm. The fuzzy part of the system was implemented by x-fuzzy tool [12] and the files created in C language were used in NS-2 environment. The criteria of comparison are; packet delivery rate to destination meaning the rate of data packets reaching the destination to the total number of packet sent in the network. The average of end-to-end delay is the average of time spent from sending a packet to receiving it in the destination. The energy efficiency is the criterion showing the value of energy spent for a kilo bit reaching the destination. The rate of data reaching the destination in the specified time shows the rate of network efficiency. Standard deviation in node energy determines the energy difference in network nodes. Routing overload shows the ratio of control data sent to data sent to sink to in the network. Simulation parameters to assess the algorithm consist of the number of nodes from 10 to 100, the radius of sending data in nodes to 50 m, link band width as 1 mb/s and the initial energy of nodes as 100 joule, sending data is carried out in all nodes and averagely 10 nodes send packets of 64 bite randomly in second. The standard of 802-15-4 is used in the accessibility layer of MAC. The result simulations are based on the 10 runs average from 10 to 100 nodes in 100 seconds. Sink is placed in the central point of simulation area, *ACLS* algorithm in which formula [6] is used to be compared with *FACLS* algorithm. In this comparison, the rate of sending data is independent of the number of network nodes as bite/second.

Figure 6 shows that *FACLS* algorithm has had a good improvement to *ACLS* method in terms of the rate of delivering data. Determining the quality of route is performed by using fuzzy-inference system (considering the criteria of length, route delay and node energy) to choose suitable routed and increase the rate of data delivery to destination.

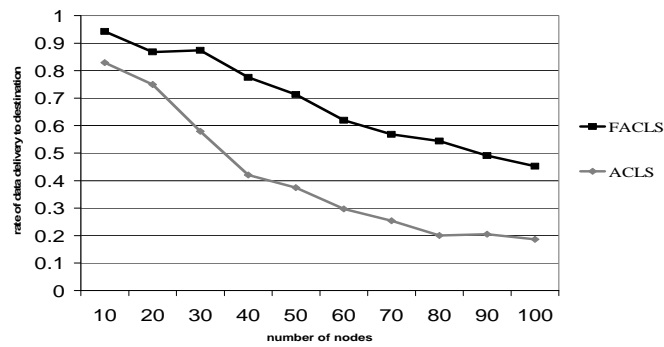


Figure 6. Rate of data delivery to destination

In figure 7, it is shown that with the increase of the number of nodes in network, the end-to-end delay average increases due to the increase of route length, while in fuzzy method, due to the addition of delay criterion in determining route quality, the results became better compared with *ACLS* algorithm which uses formula method to determine quality of route.

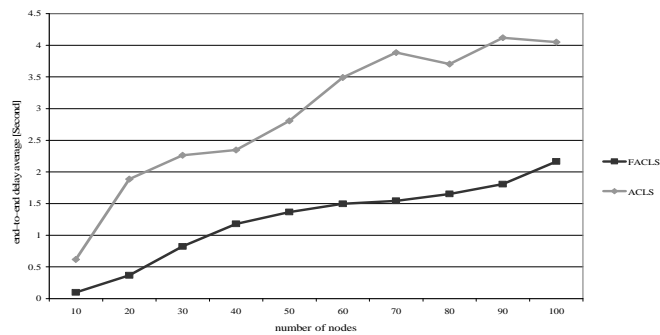


Figure 7. End-to-end delay average

In *ACLS* methods, the energy consumed for the value of data delivered to destination a decrease which is due to the existence of local routing before the global search, making more energy efficiency in *ACLS* algorithm. The figure 8 shows the results.

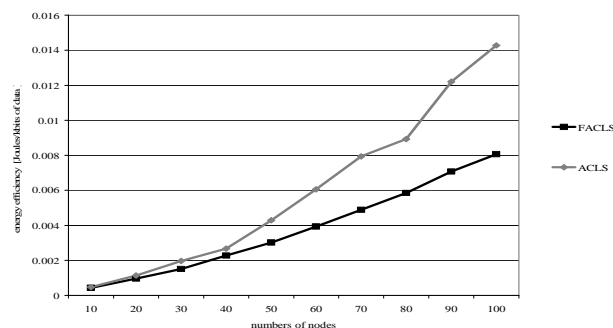


Figure 8. Energy efficiency

In algorithm *ACLS*, sending the control packets through the network decreases due to local routing and therefore routing overload is reduced relatively in the network.

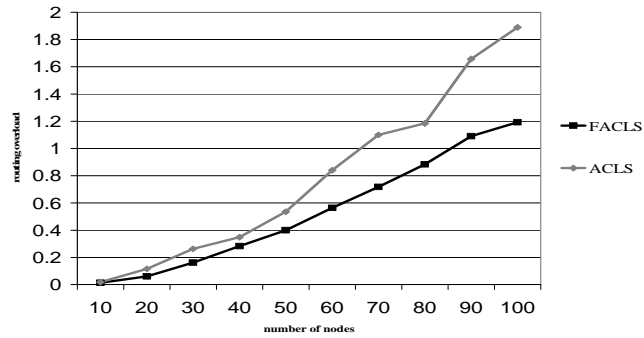


Figure 9. Routing overload

The criterion of efficiency is of great importance in the analysis of WSN. As seen in figure 10, network efficiency is less in *ACLS* method than *FACLS* method.

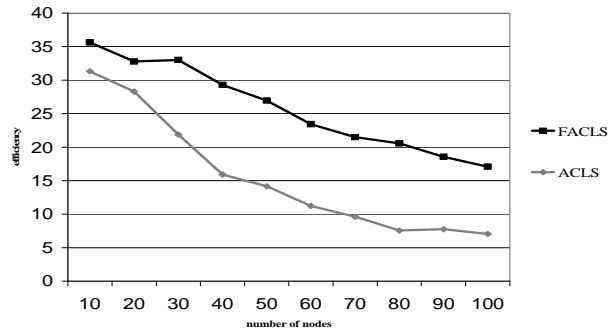


Figure 10. Efficiency

*FACLS* seems to consume more energy due to increase of great rate of data delivery in destination which makes more energy standard deviation. According to figure 11, energy difference of nodes is less than 0.01 of joule. The low value of standard deviation shows the load balance in network.

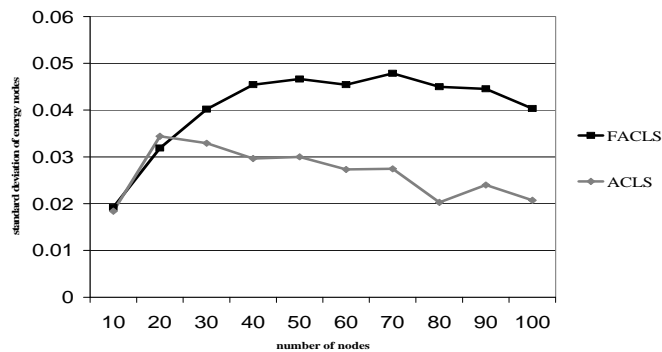


Figure 11. Standard deviation of energy nodes

Here, the proposed algorithm is compared with AODV algorithm in terms of the rate of sending data independent of the number of network nodes.

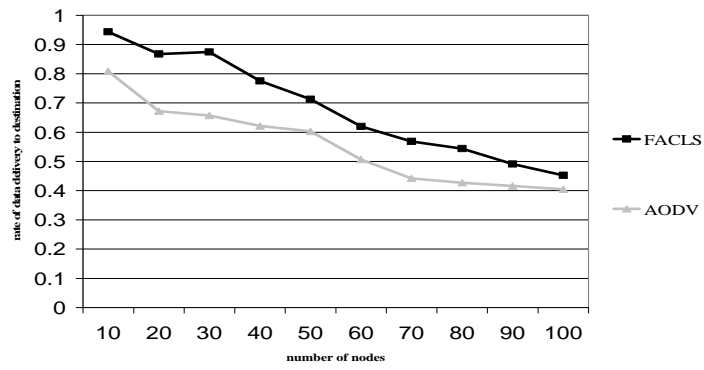


Figure 12. Rate of data delivery to destination

In our proposed algorithm *FACLS*, sending is carried out in a multi route form due to which the rate of data delivery is increased compared with AODV algorithm.

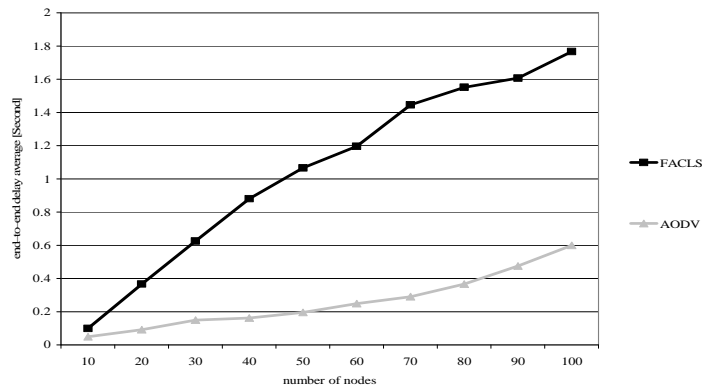


Figure 13. End-to-end delay average

The average of end-to-end delay in proposed algorithm is better than that in AODV algorithm and increases with the increase in the number of nodes in both algorithms. In *FACLS* algorithm, the delay of sending increases due to decision making and periodic updating of routes while AODV algorithm does not do updating due to fixed network topology and fixed routes to end.

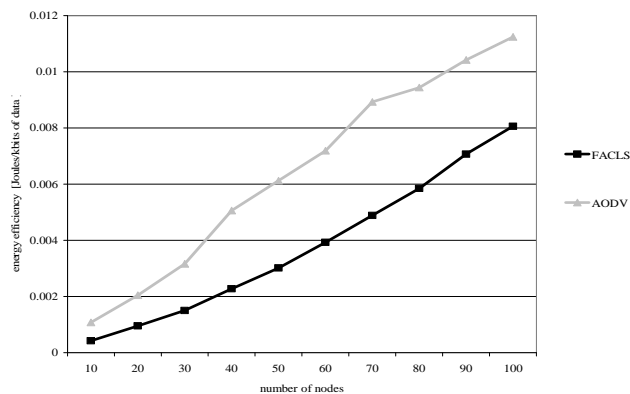


Figure 14. Energy efficiency



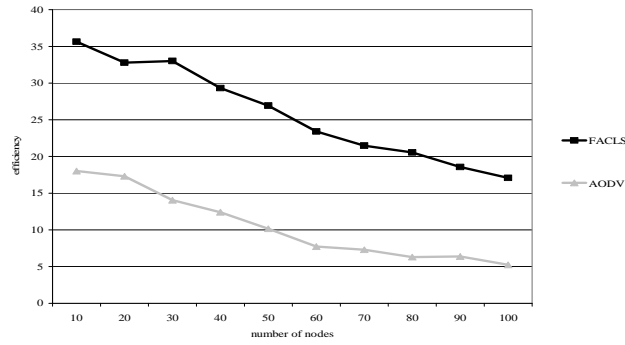


Figure 15. Efficiency

As seen in figures 14 & 15, the proposed algorithm shows better energy efficiency and greater efficiency than AODV algorithm.

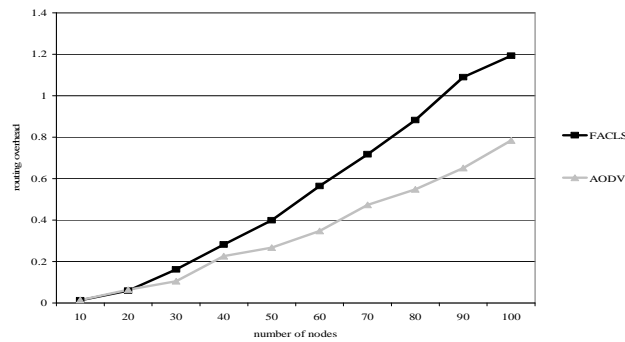


Figure 16. Routing overload

It is seen, in figure 16, that routing overload is greater in *FACLS* algorithm than in *AODV* algorithm which is due to sending more control packets to update routing table and routes in the algorithm.

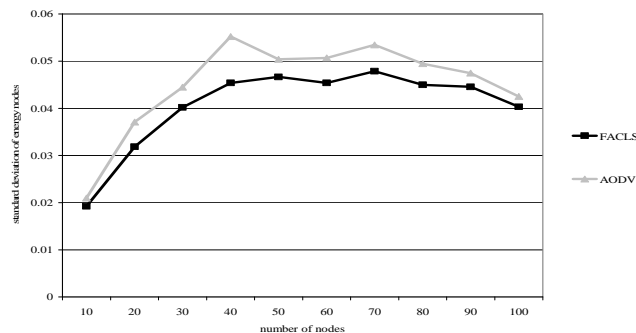


Figure 17. Standard deviation of energy nodes

As seen in figure 17, standard deviation of node energy is less in *FACLS* than in *AODV*, which shows more energy homogeneity resulting from sending data from different routes. To do better comparison, we increased the rate of sending data up to ten times. Figure 18 shows the comparison of criterion of data

delivery to destination for our propose algorithm and other methods. Due to use of end-to-end delay criteria, route length in determining the route quality, the delivery rate is improved in the proposed algorithm.

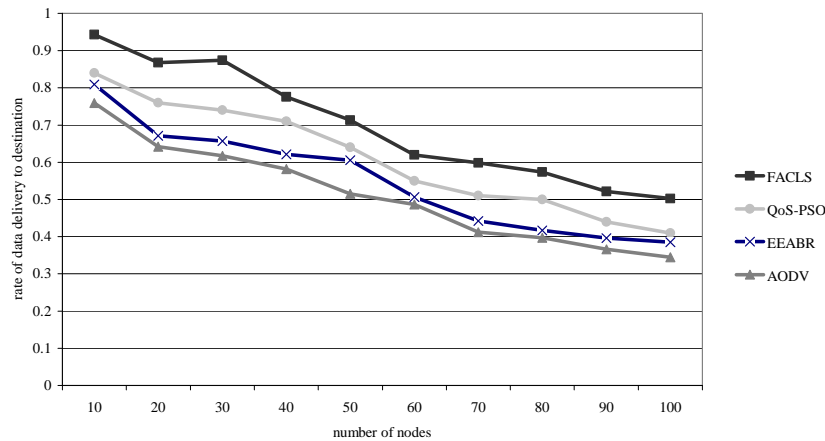


Figure 18. Rate of data delivery to destination

In figure 19, it is seen that end-to-end delay is reduced in the proposed algorithm than in other algorithms which is due to use of route length and end-to-end delay to determine quality of route in fuzzy inference system resulting in choosing shorter routes and less delay in sending data. The greater the number of nodes, the greater the route length and end-to-end delay.

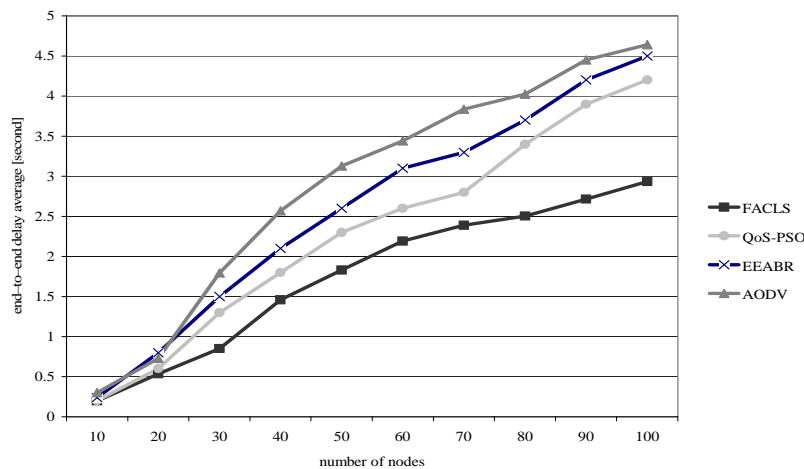


Figure 19. End-to-end delay average

#### 4. CONCLUSION

In this paper, relying on ant optimization algorithm along with local search and fuzzy inference system, we presented a mechanism to find optimal routes and increase energy efficiency in WSN. Regarding the simulation, the proposed algorithm showed better results which confirm the hybrid approach of local search in ant colony algorithm and fuzzy inference system in determining route quality in solving optimization problems. Swarm intelligence algorithms such as bee algorithm and pro algorithm in combination with ant algorithm can be used to solve optimization problems in routing WSN. Also, more powerful local search algorithms combined with ant colony algorithm can be utilized to achieve greater quality and optimum energy consumption.

**REFERENCES**

- [1] Anastasi G, Conti M, Di Francesco M, Passarella A. Energy conservation in wireless sensor networks: A survey. *Ad Hoc Networks*. 2009; 7(3): 537-568.
- [2] Akkaya K, Younis M. A survey on routing protocols for wireless sensor networks. *Ad Hoc Networks*. 2005; 3(3): 325-349.
- [3] Boukerche A, Ahmad M, Turgut B, Turgut D. *A taxonomy of routing protocols in sensor networks*. in: A. Boukerche (Ed.), Algorithms and Protocols for Wireless Sensor Networks. 2008; 129-160.
- [4] Saleem M, Di Caro G.A, Farooq M. Swarm intelligence based routing protocol for wireless sensor networks. *Survey and an International Journal*. 2011; 181 (20): 4597-4624.
- [5] Di Caro GA, Dorigo M. AntNet: distributed stigmergetic control for communication networks. *Journal of Artificial Intelligence Research (JAIR)*. 1998; 9: 317-365.
- [6] Camilo T, Carreto C, Silva JS, Boavida F. *An energy-efficient ant-based routing algorithm for wireless sensor networks*. in: Proceedings of the 5th International Workshop on Ant Colony Optimization and Swarm Intelligence (ANTS), LNCS. Springer, Berlin, Germany. 2006; 4150: 49-59.
- [7] Saleem M, Farooq M. *BeeSensor: A Bee-Inspired Power Aware Routing Protocol for Wireless Sensor Networks*. Springer-Verlag Berlin Heidelberg. LNCS. 2007; 4448: 81-90.
- [8] Liu M, Xu Sh, Sun S. An agent-assisted QoS-based routing algorithm for wireless sensor networks. *Journal of Network and Computer Applications*. 2012; 35(1): 29-36.
- [9] Deng B. W, Huang G. M. *Algorithm of creating routing table for WSNs*. WiCOM'09 Proceedings of the 5th International Conference on Wireless communications, networking and mobile computing. IEEE Press Piscataway. (WiCOM 2009). 2009; 3422-3426.
- [10] Klir G.J, Yuan B. *fuzzy seta and fuzzy logic theory and applications*. Prentice Hall, 1995.
- [11] VINT, *The network simulator – ns-2*, <http://www.isi.edu/nsnam/ns/>, 2008.
- [12] [http://www2.imse.cnm.csic.es/Xfuzzy/Xfuzzy\\_3.0/](http://www2.imse.cnm.csic.es/Xfuzzy/Xfuzzy_3.0/)

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