International Journal of Engineering &Technology, 7 (4) (2018) 6299-6305

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 10.14419/ijet.v7i4.29057
Research paper

An energy aware hybrid firefly multipath distance vector protocol for efficient routing

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Abstract

Mobile Ad Hoc Network (MANET) represents a system of wireless mobile nodes which move freely and also dynamically organizes as network with no pre-existing communication infrastructure. Owing to the traits like the temporary topology along with the absence of a centralized authority a major issue is the routing in the ad hoc networks. This work will evaluate the performance of that of an on-demand multipath routing protocol called Ad hoc On-demand Multipath Distance Vector (AOMDV) routing and also propose a new scheme of multipath routing employing the Fire Fly (FF) algorithm along with the Simulated Annealing (SA) approach. The proposed hybrid FF-SA scheme of routing is effective in finding an optimal solution for the MANET routing problem. The experimental results have proved that this method has achieved better performance.

Keywords:*Mobile Ad Hoc Network (MANET); Energy; Routing; Multipath; Fire Fly (FF) Algorithm and Simulated Annealing (SA).*

1. Introduction

The Mobile Ad Hoc Networks (MANETs) have been considered as self-configured, autonomous multi-hop wireless networks that do not rely on the stationary infrastructure with no centralized control and quickly deployable at anytime and anywhere. In case of the MANET, all the nodes are found to be mobile which cooperate in a very friendly manner and will enter the new nodes into the network and owing to this it is used widely in the military, the civilian and the commercial applications [1]. Routing is one of the most active methods in the MANET. The routing protocols that have been developed for that of a wired network that is not very suitable for the wireless networks owing to its mobility. Such routing protocols are classified within two categories, the table driven routing protocol and the on demand routing protocol.

The Proactive or the table driven routing protocols have been found to be similar to and will be a natural extension of the wired networks. In case of the proactive routing every node will have one or even more tables containing the latest information of routes to the nodes in the network. Every row has the next hop for the reaching of nodes and the cost of the routes. There are several table driven protocols which differ in ways that the information on the change of topology that is propagated in the network nodes [2]. There are however, some differences among the protocols that fall under this category. Also, these routing protocols will maintain various numbers of tables and the proactive protocols will not be for that of the networks that are larger as entries need to be maintained for each node in the routing tables. This will lead to more overheads in the routing table and this will lead to more overheads in this routing table that leads to the consumption of more bandwidth. The examples of these schemes will be the conventional schemes, the Wireless Routing Protocol (WRP), the Global State Routing (GSR), the Fisheye State Routing (FSR), the Hierarchical State Routing (HSR) and the Destination Sequenced Distance Vector (DSDV).

For reducing the routing overheads, the on-demand routing protocols will build and also maintain the needed routes. The widespread and successful deployment of the ad hoc networks depends strongly on the implementation of the efficient network protocols. In recent times, the on-demand routing protocols [3] have got more attention in that of the MANETs compared to the other routing schemes because of their efficiencies and abilities. They can organise themselves in a dynamic manner with that of a lower memory overhead and a requirement of a lower bandwidth than the protocols that are table driven. But as there are some more bottlenecks in their pioneering versions of the routing protocols there is more research work done for rectifying these problems. For instance, there are many on-demand routing protocols like the Associativity Based Routing (ABR), the Dynamic Source Routing (DSR) and the Ad hoc On-demand Distance Vector (AODV) that makes use of a single route for every data session. So a new route discovery is initiated in case the active route has been broken. The Single path on-demand routing protocols are discussed and examined in the past but recently the research topic for the MANET is a multipath on-demand routing protocols.

The Minimizing of the number of hops is not the objective of the routing algorithm any more but an optimization of the multiple parameters like the packet error rate, the energy consumption, the bandwidth, the routing overhead, the route setup, the route repair speed and the possibility of the establishment of parallel routes and so on. Another critical issue has been power constrained and the developing of routing protocols for the MANETs is an extensive research area in the last few years and particularly in an energy efficient routing which is an important criteria in the MANETs as the mobile nodes that are powered by the batteries having limited capacity. The mobile node and its power failure will affect the nodes and also its ability to forward packets for the others and so an overall lifetime of the network. For this, there are many efforts that are devoted to the development of the energy aware protocols of routing [4].

A Multipath routing is used for incorporating a high level of reliability in the process of packet delivery in the ad-hoc network. But in case of battery constrained networks like that of the MANETs the multipath routing by means of duplicating packets is not considered affordable. The approach further incorporates dynamicity as well as an enhanced security in the process of routing by means of using the multiple paths for transmitting a single message than using one path for a whole message [5]. The process of identification of the multiple paths that use the SA has been performed in two different phases. The first one makes use of the FF for identifying the multiple paths and the second phase makes use of the SA for identifying many of the best paths from the set of the paths that are identified by the FF. On the initiation of transmission, the message will be obtained and also divided as nr packets. Every nr packet will be transmitted by using packets. Every nr packet has to be transmitted using a different route to that of the destination.

The AOMDV will extend the AODV for providing many multiple paths and each Route Reply (RREP) will be considered by that of the source node and the multiple paths will be discovered in a single route discovery. An intermediate node will maintain multipath entries in that of their respective routing tables. Each node will maintain a hop count for the destination and the advertised hop count will be defined as "Maximum hop count for all the paths". The Route advertisements of this destination are sent for using the hop count. Another path to this destination has been accepted by the node in case the hop count is found to be less than that of the hop count that is advertised for this destination. But this will not consider the stability or even the energy metrics of the nodes at the time of route discovery [6].

The approaches that are metaheuristic have been developed for solving problems that are complicated like that of the flow shop scheduling, the high dimensional function and its optimization, the reliability and the other problems of engineering. In the 50's the nature evolution had been idealized as a technology of optimization and this called for a new approach which was [7], the Genetic Algorithms (GAs). Once this was done there were several other methods that appeared like the Evolutionary Strategy (ES), the Ant Colony Optimization (ACO), the Probability Based Incremental Learning (PBIL), the big bang-big crunch algorithm, the Harmony Search (HS), the Charged System Search (CSS), the artificial physics optimization, the Bat Algorithm (BA), the Animal Migration Optimization (AMO), the Krill Herd (KH), the Differential Evolution (DE), the Particle Swarm Optimization (PSO), the Stud GA (SGA), the Cuckoo Search (CS), the Artificial Plant Optimization Algorithm (APOA), the Biogeography Based Optimization (BBO), and finally the FF algorithm method.

Here in this work a hybrid optimized with that of the FF-SA and multi-path routing in the MANETs has been proposed. The rest of the investigation has been organized as followed. The Section 2 will discuss related work, Section 3 will explain methods used in this work, Section 4 will discuss experimental results and section 5 will conclude the work.

2. Related works

Sarkar and Datta [8] presented a secure as well as energy efficient multipath routing protocol that was stochastic and based on the MANET Markov chain. This routing protocol computed multiple paths that existed between the source-destination pairs and will select a path that is energy efficient and stochastic from the paths for forwarding data packets. Additionally, the protocol will also secure the data flow within the network as the packets that have been forwarded using random paths from that of the source node to their destination nodes. The data flow paths that are random will make this difficult in terms of being able to jam, to intercept and also hijack the data packets as this will need the attacker to be able to listen to the possible paths from the source to the destination.

Sun et al., [9] made a proposal for a Multipath Optimized Link State Routing (MOLSR) protocol, which was constraint of delay in the multipath routing protocol for the wireless multimedia and their ad hoc networks. This protocol initially detects and also analyses the link delay in the nodes and collects the delay information as that of a routing metric by a HELLO message and also a topology control message. After this by means of using an improved multipath algorithm called the Dijkstra for the path selection, this protocol can gain a minimal delay path from that of the source node to the remaining nodes. Lastly, when a route is launched, there are several node-disjoints or the link disjoint multi-paths that are built using the computation of route.

Bheemalingaiah et al., [10] made a proposal of a Power-aware Node-disjoint Multipath Source Routing (PNDMSR) for implementing and analysing the performance of Multipath Dynamic Source Routing (MDSR) by means of using several quantitative metrics of performance like the routing control overhead, the throughput, the packet delivery ratio, the packet loss and finally the efficiency of energy by changing several parameters like the mobility of the node, the pause time, the data rate and the load. The objective of PNDMSR is the choosing of the energy aware node-disjoint multipath from the source to the destination by means of optimizing the overheads and using the cost of the node and increasing the network lifetime.

Turky et al., [11] made a proposal for one more multi-population memetic algorithm for an optimization for the Dynamic Shortest Path Routing (DSPR) problem in the MANETs. However, for handling this dynamic environment and at the same time maintaining diversity continues to be a major issue. So the multi-population memetic algorithm has been designed with four parts to balance between the exploitation and the exploration of the search space to maintain them better. They also include a GA part that will focus mainly on the exploring of search spaces which is a local search component for searching in and around the local area and a multi-population mechanism that is meant for maintaining the diversity by means of allocating each sub-population to a different search area along with an external archive that will be sued for preserving their current best solutions.

Chatterjee and Das [12] made a proposal for an enhanced version of the DSR scheme that is based on the ACO algorithm. Likewise, the authors can also calculate the level of pheromone of a route based on the hops in the route, the congestion in the path and the end to end path and its reliability. This route has a very high performance for that of the delivery of data packet. The authors further proposed another novel pheromone decay technique for the maintenance of the route. The results of simulation show that this ACO based Enhanced DSR (E-Ant-DSR) have outperformed the original DSR and also the other algorithms that are based on ACO.

Karthikeyan and Baskar [13] made a proposal of an algorithm called Ensemble of Immigrant Strategies with Genetic Algorithm (EISGA) that optimizes the objectives that are combined with that of the network lifetime and the delay in solving the problem of multicast routing. The strategies of the immigrant will be the specific operators of replacement that are designed for problems of optimization that have been naturally suited for that of multicast routing. The sequence and also the topological coding along with genetic operators like the energy mutation, the topology crossover and the node mutation have been employed in the EISGA. Their results endorse that this algorithm improves the GA and its performance to solve the routing problems in multicast efficiently.

Kalaiselvi and Radhakrishnan [14] made a presentation of a QoS Routing (QoSR) that was based on one Differentially Guided Krill Herd (DGKH) algorithm in the MANET. The QoSR being a Non-deterministic Polynomial (NP) having immense challenges in the determination of an optimum path which will simultaneously satisfy various constraints in that of the MANETs, in which the topology will constantly vary. There are many algorithms used for this purpose and the work now proposes an algorithm that is based on krill herd called the DGKH in which the krill individuals do not update their position compared with the one to one but use the information from different krill individuals and complete searches. Robinson and Rajaram [15] made a proposal for an Energy-aware Multipath routing scheme that was based on the Particle Swarm Optimization (EMPSO) using Continuous Time Recurrent Neural Network (CTRNN) for solving the problems of optimization. The CTRNN could find optimal loop free paths for solving the link disjoint paths in the MANET. This CTRNN has been used as a technique for optimum path selection which can produce an optimal set of paths between that of the source and the destination. In case of the CTRNN, the PSO method has been used primly for training Recurrent Neural Network (RNN). This proposed scheme makes use of the measures of reliability like the cost of transmission, the energy factor and the ratio of optimal traffic among the source as well as the destination for increasing the performance of routing.

3. Methodology

The Energy aware routing in that of the MANET has been of great importance and the objective of the protocols of energy aware routing is to reduce the energy consumption in case of packets. Here in this section, the FF algorithm, the SA routing algorithm and also the proposed FF-SA routing algorithm have been discussed.

3.1. Firefly (FF) algorithm

The FF algorithm is a meta-heuristic that was developed by Yang for solving problems in optimization. This is an emerging algorithm exploiting the bioluminescence behaviour of the fireflies in nature. The FF in that of the search space will communicate with the other fireflies that influence the selection of mate. The implementation of this FF algorithm for the network and its optimization for determining an optimal path from that of the source determine a path that is optimal from the source to the destination in a single source single destination graph that is presented in the sections that follow [16].
The FF swarm in nature will exhibit a social behaviour using collective intelligence for performing certain essential activities like the recognition of species, foraging, mating and defence mechanism. The light pattern made by the FF will signal the swarm with the information on the species, their location and attractiveness. Two of the important properties of this flashing light of FF are as below:

- The Brightness of fireflies are proportional to their attractiveness
- The Brightness and the attractiveness of the pair of fireflies will be inversely proportional to that of the distance between them.

Such properties are found to be responsible for the firefly and its visibility leading to the communication among them. A swarm of fireflies will be place in the source node s initially with a random brightness B^0. The choice of the next node from the candidate neighbour set will lead to the determination of the shortest route based in the measure of attractiveness [17]. The FF moving through a link (i, j) has been based on three parameters which are, the brightness, the attractiveness and the fitness function. The brightness is estimated as per (1).

$$B_f = B_f^0 e^{-\gamma \psi_{ij}^2} \quad (1)$$

In which, ψ_{ij} is the fitness function that is estimated by FF for the subsequent move and γ is the absorption coefficient of the light. The Attractiveness is estimated by FF for determining the next position and its desirability (2):

$$At_{ij} = \psi_{ij} + B_f + \alpha(rand - 0.5) \quad (2)$$

In which, α is the Randomization parameter, $rand$ is the Random number (0, 1). Once the transition is complete the brightness of every FF will be updated on the basis of the solution of the FF that is corresponding. The node having a maximum attractiveness will be chosen by the FF and the process is repeated till such time all fireflies in the swarm will reach the destination node. By means of tuning the size of the swarm and the parameters of brightness of this algorithm there are more diversified solutions that are obtained from that of a feasible region. Every FF in the swarm will yield a sub-optimal path that leads the FF from the source to the node of destination.

3.2. Simulated annealing (SA) routing algorithm

Normally the algorithms of multipath routing will face challenges of how the volume of traffic is to be distributed. On the basis of the feedback of the traffic measurements made real-time, this is designed in a simple and also efficient algorithm.
The SA [18] is a metaheuristic method applied to the problems of combinatorial optimization. It derives this form the analogous natural phenomena of the annealing of solids that will be accomplished by means of heating a solid and letting it cool down. Every step in the process of SA will replace the present solution by using a random solution with a probability depending on the difference between that of the corresponding values on global parameter T (the temperature). Here the T is decreased gradually during the process for reaching a steady state or a thermal equilibrium.
The Basic SA:

$s = Generate\_Initial\_Solution()$
$T = T\_0$
$WHILE\ termination\ conditions\ not\ met$
$s1 = Pick\_At\_Random(N(s))$
$IF\ f(s1) < f(s)$
$s = s1$
$ELSE$
$Accept\ s1\ as\ new\ solution\ with\ probability\ p(T, s1, s)$
$ENDIF$
$Update(T)$
$ENDWHILE$

In this proposed algorithm, an SA approach has been used for solving the problem of multipath routing. A basic concept in the proposed algorithm will be to proportionally load traffic for each route based on adaptability. For transmission of packets a relay node on the basis of PC information is chosen. From the view point of node i, the probability of neighbour node k (SPk) is (3):

$$SP_k = \frac{TC_k}{\sum_{j=1}^{n} TC_j}$$

$$Where \quad (3)$$

$$TC_k = 1 - \frac{(PC_j + L\_P_{ij})}{\sum_{j=1}^{n}(PC_j + L\_P_{ij})}$$

In which n denotes the total neighbour nodes. On the basis of the roulette wheel function of the SP values there is a next relay node that is selected on a temporary basis. The probability of the node k's selection will be the SP_k. So, it can make the adaptable nodes be chosen [19]. Additionally, for avoiding a local solution a Boltzmann Probability (BP) has been adopted and BP is as (4):

$$BP = \exp\left(-\frac{N_{pc} - C_{pc}}{T(t)}\right) \quad (4)$$

In which N_{pc} denotes the SP value of the selected node and C_{pc} denotes the SP value of the node previously connected. In (4), the actual difference between the N_{pc} and the C_{pc} (i.e., $N_{pc} - C_{pc}$) will mean the alteration of path adaptability. T will be the parameter for controlling the BP value. Speaking metaphorically, time t's temperature will be the system and as a process of annealing the T will be decreased based on a cooling schedule. Initially, the temperature will be high to accept any changes to the decision. As time passes the Tvalue will decreases until such time the stopping condition has been met. Here, T (t) value will be set to a current ratio of the packet amount to the total amount of routing packet.

At the time of routing decision, two cases are observed.

i) In case the N_{pc} value is found to be higher than C_{pc} (i.e., $N_{pc} - C_{pc} \geq 0$), the newly chosen neighbour node will replace its current relay node.

ii) In case the N_{pc} value is lower than C_{pc} value (which is $N_{pc} - C_{pc} < 0$), the newly chosen neighbour node will not be eligible for replacing the current relay node. But this node can still be used for avoiding local optima. It is still analogous to that of the acceptance of uphill move for reaching a pint that is optimal and here this will be a random number X that is generated, in which X will be within the range of $\{0 \cdots 1\}$.

a) In case the X is below the BP (which means $X <$ BP), then the newly chosen neighbour node will replace the present relay node.

b) Else, this current routing route will not be changed.

On the basis of this SA approach the individual nodes of the proposed scheme for making routing decisions to choose the next node and this hop by hop selection process is repeated till the packet reaches its destination node. So this algorithm has self-adaptability for that of the network dynamics.

3.3. Proposed FF-SA routing algorithm

The work gives a new technique for solving problems of optimization and this technique is a combination of both the FF and the SA [20]. The FF algorithm is the one that is population oriented proving to be weak in a local search. As stated earlier, this includes a neighbour search process. This process will lead to a high local search for this method. By combining both algorithms the search space is searched globally as well as locally. In the method presented, n is a primary population of the fireflies that is generated and the brightness level for every FF has been computed. In the next step every FF will move towards the FF that has the highest attractiveness. Here, the SA algorithm for that of the local search will be used for the generated solutions and the overall structure of this method is as per [21]:

Step 1. The Primary initialization of FF algorithm parameters like primary population N_{Pop}, and the maximum repetitions, with the attraction coefficient.

Step 2. The Primary initialization of parameters of SA algorithms like the number of repetitions along with the primary temperature (T).

Step 3. The generation of N_{Pop} fireflies (the primary solution).

Step 4. For every pair of the fireflies (or solutions) follow the steps below:

Step 4.1. In case the attractiveness of the FF i is higher than the FF j (or in case the fitness function i is found to be better than its fitness function j), this FF i will move toward FF j that is based on the equation below (5):

$$\Delta x_i = \beta_0 e^{-\gamma r_{ij}^2}(x_j^t - x_i^t) + \alpha \varepsilon_i \quad (5)$$

Step 4.2. Change attractiveness level relating to the distance.

Step 4.3. For each of the generated solution x:

Step 4.3.1. Finding of the neighbours of x.

Step 4.3.2. In case the energy is decreased $\Delta E < 0$, then accept the solution, else accept it if $\exp(-\Delta E / T)$.

Step 4.3.3. In case the balance has not been reached, the needs of temperature will be decreased and a shift will be made to the step 4.3.1.

Step 4.4. In case the condition of termination is not met, go to step 4.

The flowchart for the hybrid FF algorithm with the SA is shown in Fig. 1:

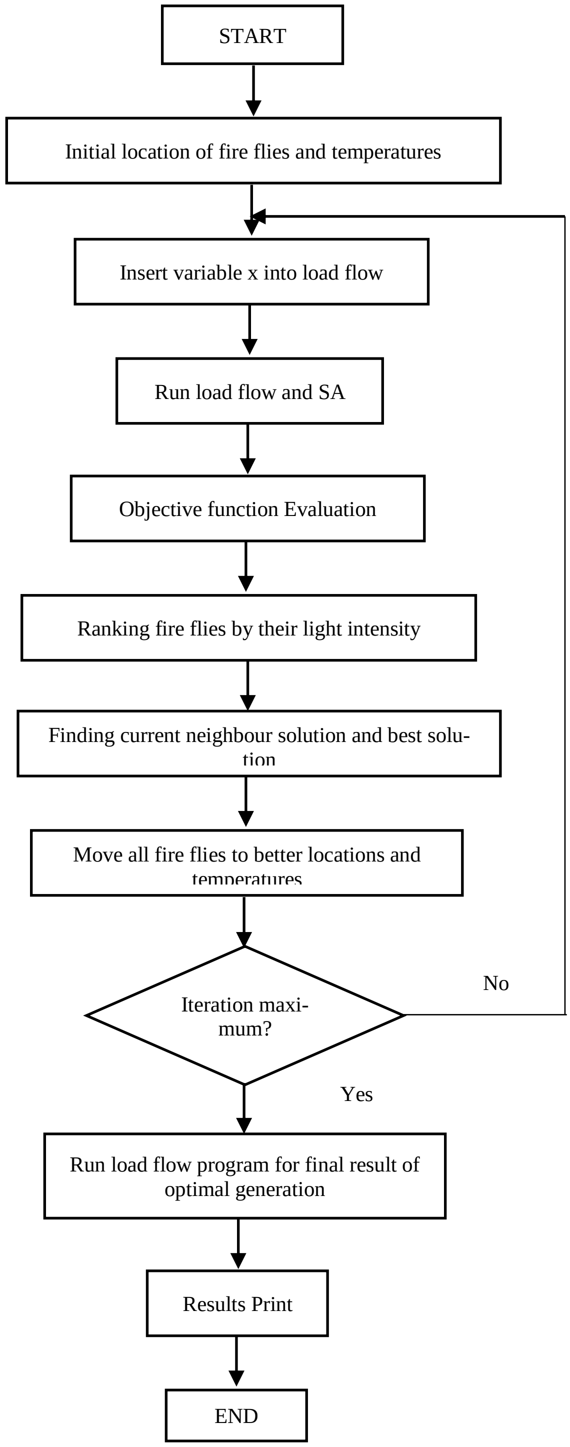

Fig. 1: Flowchart for Proposed FF-SA.

4. Results and discussion

The proposed SA-FF-AOMDV is simulated to evaluate Packet Delivery Ratio (PDR), average end to end delay, average number of hops to sink and remaining energy in network after 900 second. The performance of SA-FF-AOMDV is compared with SA-AOMDV. Simulation is conducted using varying number of nodes (25, 50, 75, and 100) and network size is 1200 sq m. The transmission range of node is 250 m and the traffic type is constant bit rate. Tables 1 to 4 and Figures 2 to 5 in this work explains result value and graph respectively for PDR, average end to end delay, average number of hops to sink and remaining energy in network after 900 second.

Table 1: Packet Delivery Ratio

Number of nodes	SA-AOMDV	FF-SA AOMDV
25	0.8316	0.9406
50	0.8238	0.8692
75	0.7982	0.873
100	0.769	0.8368

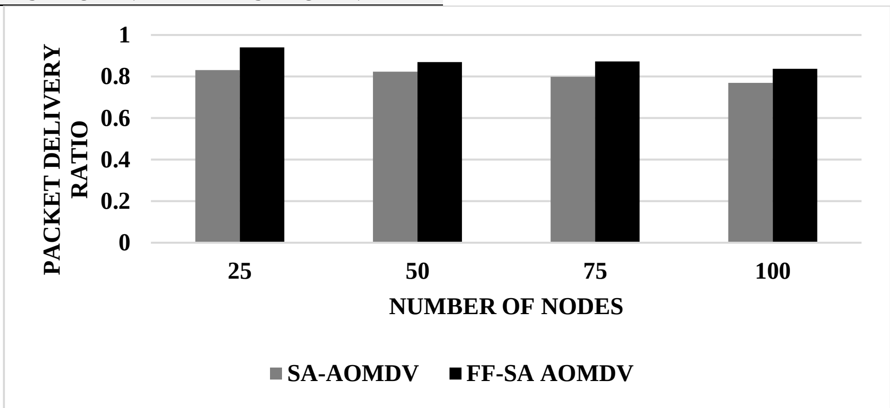

Fig. 2: Packet Delivery Ratio.

From the table 1 and Fig. 2, it can be observed that the FF-SA AOMDV has higher PDR by 12.3% for 25 number of nodes, by 5.36% for 50 number of nodes, by 8.95% for 75 number of nodes and by 8.44% for 100 number of nodes when compared with SA-AOMDV.

Table 2: Average End to End Delay

Number of nodes	SA-AOMDV	FF-SA AOMDV
25	0.0013	0.000976
50	0.0014	0.001159
75	0.0014	0.001357
100	0.0018	0.001349

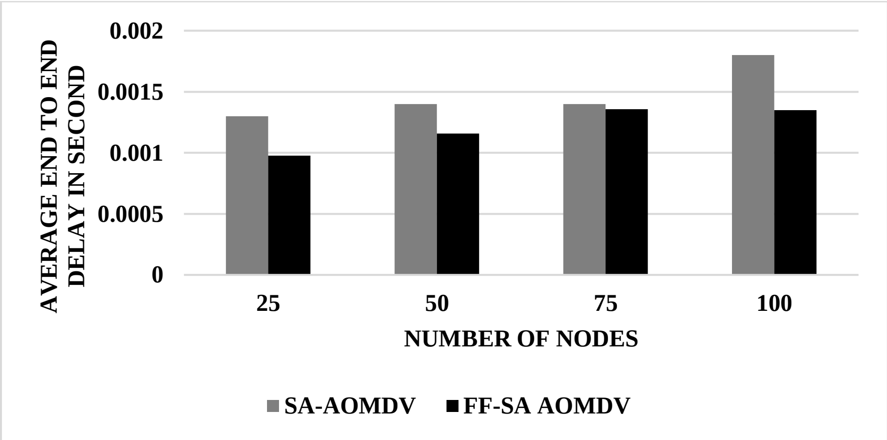

Fig. 3: Average End to End Delay.

From the table 2 and Fig. 3, it can be observed that the FF-SA AOMDV has lower average end to end delay by 28.47% for 25 number of nodes, by 18.83% for 50 number of nodes, by 3.11% for 75 number of nodes and by 28.64% for 100 number of nodes when compared with SA-AOMDV.

Table 3: Average Number of Hops to Sink

Number of nodes	SA-AOMDV	FF-SA AOMDV
25	3.8777	3.68
50	5.839	4.69
75	6.0269	4.75
100	6.0803	4.97

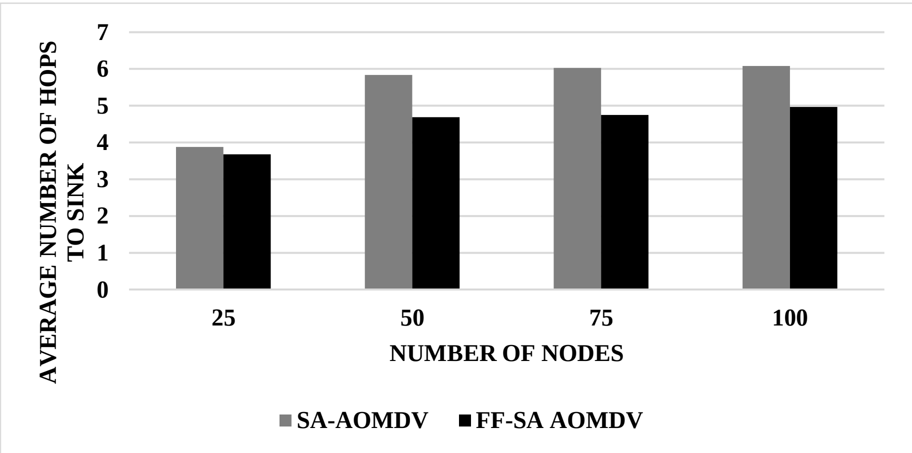

Fig. 4: Average Number of Hops to Sink.

From the table 3 and Fig. 4, it can be observed that the FF-SA AOMDV has lower average number of hops to sink by 5.23% for 25 number of nodes, by 21.82% for 50 number of nodes, by 23.69% for 75 number of nodes and by 20.09% for 100 number of nodes when compared with SA-AOMDV.

Table 4: Remaining Energy in Network after 900 Second

Number of nodes	SA-AOMDV	FF-SA AOMDV
25	4793.92	4820.5
50	9341.48	9689.83
75	13754.82	14474.25
100	18145.61	19170.54

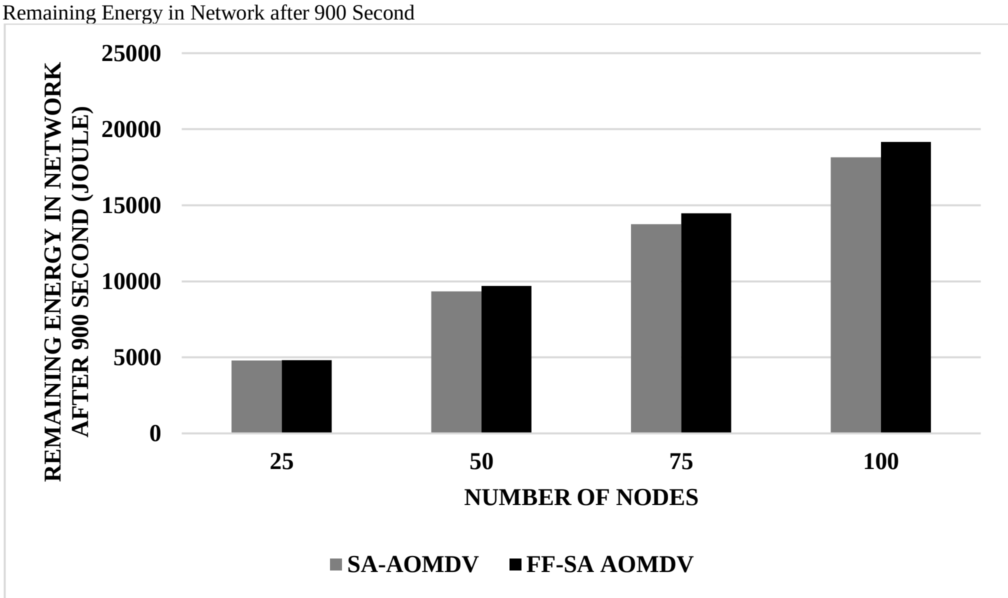

Fig. 5: Remaining Energy in Network after 900 Second.

From the table 4 and Fig. 5, it can be observed that the FF-SA AOMDV has higher remaining energy in network after 900 second by 0.55% for 25 number of nodes, by 3.66% for 50 number of nodes, by 5.09% for 75 number of nodes and by 5.49% for 100 number of nodes when compared with SA-AOMDV.

5. Conclusion

The MANETs have been treated as an emerging field in wireless communication. Routing is one major issue here and there are different protocols observed to solve these issues. In this work, a new hybrid algorithm that is based on the SA algorithm for improve the FF algorithm and its functionality is proposed for improving routing. The FF algorithm has demonstrated a huge potential for the global search it proving to be modest in its local search. So the local search ability of SA algorithm has been incorporated. The results prove that this FF-SA AOMDV has a higher PDR by about 12.3% for 25 number of nodes, by about 5.36% for 50 number of nodes, by about 8.95% for 75 number of nodes and finally by about 8.44% for 100 number of nodes when being compared with the SA-AOMDV.

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