

## A MANET ROUTING PROTOCOL FOR IOT BASED ON LINK STABILITY, BANDWIDTH, ENERGY AND TRUST

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### ABSTRACT

The Mobile Ad hoc Networks (MANETs) is defined as a wireless mobile node system that has dynamic and self-organizing network topologies and does not require communication infrastructure. Routing is a key challenge in ad hoc networks because of its characteristics, such as the absence of centralized authority and temporary topology. In MANET, it is quite vital to take into account the battery capacity of the nodes and link stability at the same time. A lot of research has been done nowadays for network lifespan prolongation as well as energy efficiency. Along with the establishment of several routes between a source node and a destination node, the multipath routing algorithm also spreads the traffic load along various routes. In a specific path, it is able to diminish the congestion of traffic. Hence, route resilience whilst ensuring data transmission reliability is offered by multipath routing algorithms. This work has proposed a multipath routing scheme which is based on Ad hoc On-demand Multipath Distance Vector Routing (AOMDV) Protocol through utilizing Evolutionary Algorithms (EA) and the FireFly (FF) algorithm. This powerful routing scheme is capable of detecting efficient solutions for the MANET routing problem. The proposed FF-AOMDV is a probabilistic metaheuristic algorithm that is also capable of the quality-aware best path routing. The FF-AOMDV's simulation outcomes demonstrate its superior performance over EA-AOMDV, AODV, and AOMDV.

**Keywords:** Mobile Ad hoc Networks (MANETs), Energy, Multi-Path Routing, Ad hoc On-demand Multipath Distance Vector Routing (AOMDV) Protocol, Evolutionary Algorithms (EA), and FireFly (FF) algorithm.

### 1 INTRODUCTION

A mobile node collection, which is connected by means of wireless links for forming an infrastructure-less network without any central administrator, is referred to as a Mobile Ad hoc Network (MANET). Data acquisition, emergency, search rescue, and military are the MANET's areas of application. The topology of the network dynamically changes since the wireless mobile nodes can arbitrarily traverse. On the basis of the network situation, these mobile nodes can serve as the intermediate router, the receiver, and the sender. All nodes comprise of a limited battery power that diminishes with time [1]. The MANET's key characteristics are, topology which is dynamic in nature because of all nodes' mobility, constrained resources (battery lifetime, computation power, bandwidth, and so on), frequent link breakages because of mobile nodes, multihop radio communication, self-configuration, swift deployment, and operation without a central coordinator. Thus, the MANET's routing protocol has key issues like it should have minimum collision, QoS provision, use resources optimally, have optimal and loop-free routes, be easy to compute and maintain, be adaptive to the frequent topology change, and be fully distributed [2].

Detecting a path between communicating nodes in the MANET's is a challenge. This network type is characterized by limited bandwidth, multihop, node heterogeneity, energy restriction, dynamic topology, and

absence of centralized infrastructure. Routing in MANET signifies the detection of a path between a source and a destination where there will be packet forwarding. This is quite an arduous process due to the MANET's energy usage, frequent topology changes that are a result of node mobility, limited bandwidth, and dynamic features. The routing must also be adaptive. Hybrid, reactive, and proactive are the three key routing protocol categories [3].

The multipath routing approaches are introduced for detection of the numerous routes between source-destination pairs. A source-destination pair's many paths are advantageous in various aspects such as longer lifespan of a network, higher bandwidth utilization, smaller end-to-end delay, higher throughput, and so on. It offers protection from route failures and aids in network congestion reduction. It also balances the network load through moving the traffic via multiple paths. Multipath routing's mechanism of path discovery mechanism is akin to MANET's single path routing. Disjoint paths are often chosen to move the traffic forward between source and destinations (s-d). Node-disjoint and link-disjoint are the two multipath types. The routes constitute paths that do not have any common node, except the source-destination (s-d), in more than one constituent path in the node-disjoint approach. For a provided s-d pair, the link-disjoint route set constitutes paths which are not commonly linked except for the constituent s-d path. During a single route discovery attempt, there is computation of many paths between an s-d pair in the MANET multipath on-demand routing protocols. Only when there is a failure of every path between an s-d pair, there is an initiation of a new route discovery operation [4].

Three distinct messages: Route Error (RERR), Route Reply (RREP), and Route Request (RREQ), are utilized by the reactive routing discovery-based Ad-hoc On-Demand Distance Vector Routing (AODV) protocol. Moreover, freedom of loops is guaranteed every time through destination sequence number usage. RREQ's limited flooding with ring expansion aids in the finding of novel routes by every source node in the AODV, and by means of RREP, there is also acquisition of a route to its destination. There is expansion of the AODV by the AOMDV protocol as a multipath routing protocol. Here, numerous distinct routes from multiple RREPs are retained by the source node. But, AOMDV's election of static routes is not able to deal with the network's dynamic change like the biased traffic's production of extreme congestion [5].

In MANET, swarm optimization techniques are employed for identifying the best and optimal solution from the potential outcomes. The application of distinct optimization techniques in MANET offers better results and high performance. These techniques primarily targets on optimization approaches that makes the network more effective, reliable, and without any original link loss during transition of data. With these optimization techniques, the finding of eligible solutions from every outcome will be easier. Many optimization approaches are employed for the detection of best and optimal solution. For optimization, bio-inspired algorithms are the algorithm category, which is akin to nature performance. The benefits of these algorithms aid in the resolution of diverse problems: 1) Mathematical approaches do not have to be followed to arrive at a solution. 2) The results are accurate and are produced very quickly [6].

This work proposes the EA with AOMDV and FF with the AOMDV algorithm for MANET routing protocols. The associated literary works are described in Section Two. The several approaches utilized in this work are detailed in Section Three. Experimental results are outlined in Section Four, while the work is brought to a close in Section Five.

## RELATED WORKS

The performance of a MANET is good only when there is cooperation in the mobile node behaviour in packet routing. For the reduction of malicious node hazards, and enhancement of network security, Alkhamisi et

al. [7] put forward an extension of the AOMDV routing protocol, which is termed the Integrated Incentive and Trust-based optimal path identification in AOMDV (IIT-AOMDV) for MANET. In this protocol, there is integration of the Intrusion Detection System (IDS) with the Bayesian Network (BN) based trust and payment model. The BN's empirical first-hand and second-hand trust information is employed by the IDS. It depends on Cuckoo Search (CS) algorithm for mapping trust value and Quality of Service (QoS) into one fitness metric that is adjusted as per the malicious nodes' presence. Simulation results demonstrate that, when compared to the AOMDV integrated with IDS (AID), the IIT-AOMDV enhances throughput by 16.6%, and accuracy of detection by 20%.

This problem's earlier works had constraints like low potentiality for packet delivery and not having flexibility in the network model for QoS delivery. Robinson et al. [8] proposed the Fault-Tolerant Disjoint Multipath Distance Vector Routing Algorithm (FD-AOMDV), which can speed through the path discovery phase with less delay. It is able to detect disjoint paths such that there is a considerable decrease in routing overloads. The scalability can be maximized by the FD-AOMDV through routing overload minimization during establishment of the latest route. Also, due to the node mobility in MANETs, any consequent link breakages will result in routing overload enlargement and the active path's disconnection. Simulation results of the proposed work confirm that there is routing overload reduction, reduction of packet delivery ratio, and decrease in end-to-end delay when comparison is made on the Network Simulator 2 (NS-2) with ZD-AOMDV and AOMDV.

Soni et al. [9] recommended DREAM Multipath Routing (DMR) based on the hybrid location of MANETs. Through maintenance of mobile nodes' location information, the DREAM protocol boosts the multiple routes' routing performance. There is decrease in the overhead in this protocol through packet flood forwarding in the MANET. Additionally, network delay is diminished. Compared to conventional AOMDV routing, the proposed DMR's performance is better. The DREAM keeps the information about the nodes' location and the speed of nodal mobility. There is evaluation of the nodal motion's anticipated potentiality, and there is also minimization of the routing packet flooding. The flooding of package happens at the destination's intended location. The number of nodes' position changes continuously and at each node, there is working of the DREAM. Every nodes' location information is stored by each node in the network's neighbourhood. The proposed hybrid DMR protocol, in a dynamic network, offers better data transmission, and also boosts the performance of routing.

Prakasi & Varalakshmi [10] put forward a data mining method for the route selection process from source to destination, referred to as Decision Tree based Routing Protocol (DTRP). This protocol picks the one hop neighbours depending on parameters like Link Expiration Time, node lifetime, trip\_time, and speed. Hence, the route discovery mechanism's performance is boosted through picking stable one-hop neighbours along the path so as to arrive at the destination. In comparison to other existing routing protocols, simulation outcomes of the proposed DTRP routing protocol demonstrates that there is route lifetime increase, which in turn, diminishes data loss, and end-to-end delay, thus, increasing network throughput.

In the ad hoc network, for the provision of more effective optimal routing, an Optimized Adaptive Multipath AODV Protocol (OAM-AODV) was put forward by Deepa et al. [11]. This protocol would avoid the frequent occurrence of link breakages and would also offer optimal path election. This protocol tracks the elected optimal path, predicts the link breakage chances, switches over to an alternate path, proceeds with data transfer from the sender node towards the receiver node, and increases the throughput. This protocol would also diminish the route discovery numbers through use of alternative routes which are chosen from the many routes, and diminish the control overhead numbers. Also, it would minimize the packet transmission's time delay through

beginning the transmission of data right away up on detecting the first path, and afterwards proceeding towards the optimal route which is based on the criterion set for the node's energy, link's strength of signal, hop count, and continuation of transmission. The ratio of packet drop can be decreased through switching to an alternative better optimal path prior to the occurrence of link breakage. This is done through unicasting of the MONITOR message in order to monitor each path's criterion value. The network simulator NS-2 is utilized for carrying out the simulations. The outcomes of these simulation clearly depict the proposed protocol's efficient performance in comparison to the existing AODV protocol.

For QoS, the multipath routing protocol's evaluation was done by Thiagarajan et al. [12]. The AOMDV has enhanced methods for better data delivery. These methods can maintain the QoS with regards to factors such as MANET bandwidth, end-to-end delay, and hop count. There is exploration of the evolutionary computation schemes for routing optimization in this work. The QoS's discovery in a multi-constrained network is a complex problem which is resolved optimally through heuristic algorithm utilization. In these type of challenging set ups, there is usage of the Grammatical Evolution (GE) which is especially employed for intrusion detection programs. There is application of the GE scheme (which is natural evolution-motivated) for detection of MANET's common threats. In MANETs, results show that the proposed AOMDV-QoS schemes accomplish the QoS requisites with high reliability and minimum delay.

For message transmission to many nodes, an efficient routing scheme is multicast routing. These schemes necessitate the fulfilment of many QoS guarantees. Singh et al. [13] presented the Genetic oriented QoS Multicast Routing (GA-QMR) algorithm. In comparison to two other algorithms, this algorithm can effectively detect optimal multicast tree which fulfils multiple QoS parameters. It also has the capability to simultaneously explore various paths from a node, chose the best path depending on quality of parameter, and attain global convergence. Bandwidth, rate of packet success, jitter, packet loss rate, end-to-end delay, and so on, must be fulfilled by the routes.

A power-aware secure routing protocol which took into consideration a reputation model was introduced by Srinadh & Satyanarayana [14]. For a secure path's the establishment from initial node to destination there is development of Krill Herd based Grasshopper Optimization Algorithm (KH-GOA), together with the reputation model and power. The reputation model constitutes reputation parameters, that are inclusive of reputation amongst neighbours, previous records, node's actual capability, and node mobility. For each node, the reputation factors are taken into consideration, together with the proposed KH-GOA algorithm, that is an integration of Krill Herd (KH) and Grasshopper Optimization Algorithm (GOA), for establishment of a secured path starting from the initiating node towards the destination. Multi-objective functions like delay, distance, power, and reputation, are employed by the proposed KH-GOA based routing protocol. The proposed KH-GOA's performance analysis offers better power of value 27.313W, better throughput of value 0.670, better delay of value 0.114, and better detection rate of value 0.734ms.

## METHODOLOGY

It is hard to do MANET routing due to its dynamic nature. There may be network resource loss because of node failures and breakages of link. The fundamental issue in MANETs is the optimal path election between any two nodes. Various schemes like AODV routing, and Dynamic Source Routing (DSR) has been proposed for data packet routing in ad-hoc network. However, for choosing paths, shortest path or minimum hop count is the



major metric utilized by these traditional routing protocols [15]. Multipath routing protocol utilizing AOMDV, EA-AOMDV algorithm, and FF-AOMDV algorithm methods are discussed in this section.

### 3.1 Ad-hoc On-Demand Distance Vector (AODV) Protocol

As a reactive routing protocol, the AODV protocol was designed with the objective of MANET utilization. This protocol detects a route towards a destination at the time when a node prefers to perform packet transmission towards that destination. The source node will maintain these routes till they are needed. The route discovery process is dependent on the route information which is kept (in a route table entry form) in every intermediate node along the route. There is routing table for each node with fields such as lifetime, active neighbours, number of hops, next hop, destination sequence number, and destination. Many control packets are utilized by AODV such as Route Request packet (RREQ) for broadcasting of a node what is required by a route to another node, unicasting of the Routing Reply message (RREP) back towards the source of the RREQ, and delivery of Route Error message (RERR) for link loss notification to other nodes. Active neighbours are found by utilizing HELLO messages. The freshness of routes towards the destination can be found by utilizing the sequence numbers. Upon unavailability of route for the destination [16], throughout the network there will be RREQ packet flooding.

RREQ consists of source address and request ID. Every time, it is incremented when a new RREQ is delivered by the source node, and it has a unique identification. Upon receipt of a RREQ packet, every node will check the request ID and the source address. If the node already has a RREQ with the similar parameter pair, there is discarding of the packet of the new RREQ. Else, with a RREP packet, the RREQ is either broadcast (forwarded) or unicast (replied): upon receipt of a RREP packet, there is route establishment. Many RREP packets having diverse routes can be attained by a source node. The routing entries are updated only when RREP has a greater sequence number, that is, latest information. During the network transmission of RREQ packet, the reverse path to the source is noted by all nodes. This path is traversed by the RREP packet upon detection of the destination node.

AODV's benefits are: 1) AODV's feasibility for VANET due to its dynamic nature. 2) This protocol is essentially utilized for multicasting of packets and unicast. AODV's drawbacks are: 1) Broadcast medium requirement [17]: The algorithm necessitates/expects that the broadcast medium's nodes can identify each other's broadcasts. 2) Since there is no initial knowledge about the route, the request packet will traverse in a network from one node to another node for detection of the route information on demand. There is formation of a reverse path as it also keeps the addresses of every nodes through which it passes. Hence, there is occurrence of the overhead on bandwidth. 3) There is a lack of an effective method for maintenance of routes as the routing information which is constantly got on demand that also comprises of common traffic information, that may not be reusable. 4) AODV does not have high throughput routing metric assistance: AODV's design is for the assistance of the shortest hop count metric that has a preference for links which are long and have low bandwidth links over links which are short and have high bandwidth. 5) Since this protocol is reactive, there is no route discovery till initiation of the flow. Thus, large network such as mesh have high route discovery latency.

### 3.2 Adhoc on-Demand Multipath Distance Vector Routing (AOMDV) Protocol

There is initiation of a route discovery process by the AODV protocol throughout the network by means of a Route REQuest (RREQ) towards the destination. Upon a non-duplicate RREQ receipt, the intermediate node will record the earlier hop, and will also check for a novel and valid route entry towards the destination. A Route

REPLY (RREP) and a unique sequence number is delivered by the node. Upon update of the route information, there is propagation of the route reply, and extra RREPs are got if the RREP has found either a larger destination sequence number (fresher) or a shorter route. In ad hoc networks which are highly dynamic, for the purpose of removing occurrence of frequent failure of links and disconnection of routes, from a unipath path on-demand routing protocol AODV, there is development of the AOMDV [18].

Multiple paths are detected by the AOMDV protocol. This constitutes the below two stages:

There is establishment of a route update and it will sustain at every node, multiple loop-free paths.

Link-disjointed paths are detected by a distributed protocol.

Link-disjoint or node-disjoint routes between source and destination are found by the AOMDV protocol. Packet collisions, traffic congestions, node failures, node mobility, etc. can cause link failures. For node-disjoint route detection, every node will not reject duplicate RREQs right away. Each RREQ will find a node-disjoint path which arrives from the source's different neighbour as the nodes are not able to broadcast duplicate RREQs. The same node cannot be traversed by any two RREQs that arrive at an intermediate node through the source's different neighbour. For getting multiple link-disjoint routes, RREP is sent by the destination for the RREQs' duplication regardless of their initial hop. For guaranteeing link-disjointness in the RREP's initial hop, the destination only responds to RREQs which arrive through neighbours that are unique. Reverse paths are followed by the RREPs, which are node-disjoint and hence, after the initial hop, link-disjoint. At an intermediate node, there is intersection of each RREP. By traversing an alternative reverse path towards the source, there is also guarantee of link-disjointness.

Multipath routing's intention is to seek multiple routes to a host in order to avoid active attacks. This may have many reasons as it diminishes the end-to-end delay at the time of a transfer between two nodes, prior to disappearance of the link which is used by them. AOMDV protocol's [19] benefits are: 1) Establishment of routes on demand. 2) Creation of loop free nodes. 3) Maintenance of connectivity. 4) Rapid and effective recovery from failures. AOMDV utilization's drawback is, having more message overheads during route discovery as a result of increased flooding. Being a multipath routing protocol, reply of destination to the multiple RREQs are those outcomes in a longer overhead packets which respond to heavy control overhead caused by one RREQ packet.

### 3.3 Evolutionary Algorithms (EAs) Based AOMDV Protocol

For the solution of Non-deterministic Polynomial (NP)-complete problems, there is application of Evolutionary Algorithms (EAs) which are renowned iterative metaheuristics (that is, approximate optimization techniques). EAs generally operate on a set of tentative solutions to the problem (termed as population), that at the same time evolve in the direction of (hopefully) better solutions. The performance of this process of evolution is done through the application of certain stochastic operators (often termed as evolutionary operators) to the solutions (termed as individuals), with the intention of replicating the process of natural evolution. The individual's evaluation is done for quantification of the solution's quality they denote (survival of the fittest individuals for the succeeding generations is due to the technique of replacement). There is iteration of EAs on the candidate solution set till fulfilment of the termination condition (often, after a number of iterations are carried out or the optimal solution is detected). In every iteration, there is evolution of solutions by use of certain evolutionary operators like mutation, recombination (or crossover), and parent selection. Usually, diverse families of EAs vary on the evolutionary operators which are used in the evolution [20].

Conventionally, the EA's preliminary existing families were Genetic Programming (GP), Genetic Algorithms (GAs), Evolutionary Programming (EP), and Evolution Strategies (ESs) and. The preliminary design of GAs was for combinatorial optimization problems with binary representations (even though GAs are also presently utilized for other continuous and combinatorial optimization problems), solutions are evolved by them through iterative application of operators like mutation, recombination, and selection. Unlike GAs, rather than a solution population, one single solution is worked on by ESs for resolution of real-valued variables, and the evolutionary process is just applied with the selection and mutation operators. GP algorithms operate on a tree-shaped individual (that is, program) population rather than binary character strings which are conventionally employed in GAs or real-valued variable strings which are conventionally employed in ES. Although EP is akin to the GP, there is a fixed structure of the program to be optimized [21].

These days, there is growth of the field of EAs and its evolution. This is evidenced by recent emergence of the number of novel families like Estimation of Distribution Algorithms (EDAs), Differential Evolution (DE), Ant Colony Optimization (ACO), or Particle Swarm Optimization (PSO). For optimization of continuous problems, both DE and PSO are very effective algorithms. The swarm-inspired PSO follows the motion of the leader (for example, fish or bird swarms), whilst solutions are evolved by the DE through application of certain changes which follow simple formulae on the basis of operations which are geometric in nature, utilizing the information about the population's other solutions. As constructive-based EAs, ACO algorithms are often employed on combinatorial problems. These algorithms are inspired by the ant's behaviour when it seeks food sources. ACO begins with the creation of unoccupied solutions and value assignment to all variables on the basis of one-by-one. Despite the stochastic assignment of these values, there is also consideration of the solution quality of the different assignments caused earlier. Ultimately, EDAs evaluates the variables assignments' distribution in the population's solutions after each iteration. Depending on the evaluated distribution, there is random generation of the next population of solutions.

Just like the AOMDV's procedure of route finding, the EA-AOMDV protocol has the same procedure, except for the intermediate node delay flooding a RREQ being inversely proportional to their residual energy capacity. The time delay for the flooded RREQ which was produced by the EA-based multipath routing protocol, suggested and chose many routes which has the overall minimum time delay amongst the candidate routes as follows. The EA-based multipath's intermediate node will wait for the time that is inversely proportional to its capacity of residual energy for delaying the RREQ packet. There is discarding by intermediate nodes of the lately arrived RREQ packets that have similar destination sequence number and source node for the maintenance of the same sequence number's multiple paths [22].

EA-based multipath routing's route maintenance is an extension of route maintenance in AOMDV. A RERR is generated or forwarded by a node towards a destination when there is breakage of the last path to the destination. An optimization to salvage is also included in EA-based multipath routing. There is forwarding of packets over links that have failed through their re-forwarding over alternate paths by mutation and crossover. It is essential to maintain established/discovered routes for two key benefits: accomplishment of network stability, and the reduction of excess overhead that is needed in discovering network. EA-based multipath routing always initiates the exchange of data and gives new route by crossover and mutation, whenever there is RERR. There is production of the correct solution by crossover in order to detect better solutions.

### 3.4 Proposed Fire Fly (FF) Algorithm with AOMDV (FF-AOMDV)

Author (Yang 2008, Yang 2009) development of the FF algorithm depends on the flashing characteristics of idealized firefly behaviour. The below three rules can idealize the flashing characteristics for the sake of simplicity [23]:

- Every fireflies are unisex such that sex is not a factor when an individual firefly has an attraction to other fireflies.
- Attractiveness has direct proportion to the brightness. Hence, for any two flashing fireflies, the less bright firefly is attracted to the brighter firefly. Also, as the distance increases, both the attractiveness and brightness also decreases. There is random movement of the firefly, if none of the fireflies are brighter compared to a certain firefly.
- A firefly's light intensity or brightness is determined or affected by the optimized objective function's landscape.

FF algorithm's two critical challenges are formulation of the attractiveness and the variation of light intensity. For simplicity's sake of, there is always an assumption that a FF's attractiveness is decided by its light intensity or brightness that corresponds with the encoded objective function. In maximum optimization problems' simplest cases, a FF's brightness  $I$  at a certain location  $x$  is elected as  $I(x) \propto f(x)$ . The relativity of attractiveness  $\beta$  must be decided by the other fireflies, or noted in the beholder's eyes. Hence, the attractiveness  $\beta$  should change with the distance  $r_{ij}$  between FF  $i$  and FF  $j$ . As light intensity reduces with the distance from its source, also there is light absorption in the media, thus, it must permit variation of the attractiveness with the absorption degree.

As per the law of inverse squares [24], Equation (1) provides the evaluation of light intensity ( $I(r)$ ) at a distance  $r$  from a light source ( $I_s$ ):

$$I(r) = I_s / r^2 \quad (1)$$

In an environment, there is absorption of light at a constant light absorption coefficient ( $\gamma$ )  $\in [0, \infty]$ . Hence, there is formation of the equation in Gaussian according to Equation (2):

$$\beta(r) = \beta_0 e^{-\gamma r^2} \quad (2)$$

Here,  $\beta(r)$  denotes a FF's attractiveness at  $r$  distance, and  $\beta_0$  denotes attractiveness when  $r = 0$ .

If  $i$  and  $j$  are assumed to denote two fireflies and their respective positions are denoted as  $X_i(x_i, y_i)$  and  $X_j(x_j, y_j)$ . The distance ( $r_{ij}$ ) between two fireflies is evaluated depending on Euclidean according to Equation (3):

$$r_{ij} = \|X_i - X_j\| = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (3)$$

Therefore, the new position ( $X_i$ ) of the less brighter FF  $i$  and motion to the more attractive FF  $j$  is evaluated according to Equation (4):

$$X_i = X_i + \beta_0 e^{-\gamma r_{ij}^2} (X_j - X_i) + \alpha \epsilon_i \quad (4)$$

In this equation,  $\epsilon_i$  denotes the random variable vector and Randomization parameter ( $\alpha$ )  $\in [0, 1]$ .

The FF algorithm's pseudo-code:



*Objective function  $f(x)$ ,  $x = (x_1, \dots, x_4)^T$*   
*Generate initial population of fireflies  $x_i (i = 1, 2, \dots, n)$*   
*Light intensity  $I_i$  at  $x_i$  is determined by  $f(x_i)$*   
*Define light absorption coefficient  $\gamma$*   
*While ( $t > \text{MaxGeneration}$ )*  
     *for  $i = 1:n$  all  $n$  fireflies*  
         *for  $j = 1:i$  all  $n$  fireflies*  
             *if ( $I_j > I_i$ ), Move firefly  $i$  towards  $j$  in  $d$ -dimension;*  
         *endif*  
         *Attractiveness varies with distance  $r$  via  $\exp[-\gamma r]$*   
         *Evaluate new solution and update light intensity*  
     *end for  $j$*   
     *end for  $i$*   
     *Rank the fireflies and find the current best*  
*end while*  
*Post process results and visualization*

This work deploys a novel multipath routing protocol referred to as the FF-AOMDV routing protocol [25]. This protocol combines Fitness Function with the AOMDV protocol. When the RREQ is broadcast by the source node in a normal scenario, there is detection of more than one route towards the destination, and without knowledge about the quality of the routes, there is forwarding of data packets. Through this algorithm's implementation in this same scenario, there will be complete difference in the election of routes. Upon broadcast and receipt of a RREQ, the source node has three information for detection of the most optimized and shortest route that uses the least amount energy. The conventional AOMDV utilizes RREQs for multiple path construction. The energy is not considered during path election. The proposed protocol considers residual energy and the transmission power of nodes in the election of paths for maximization of the network lifespan.

The FF-AOMDV algorithm's critical parameter is the discount factor [26]. It makes use of the variable discount factor, that is decided by the available node bandwidth on the route, the stability of link, and the count of hops. There is discount of the information when it passes through the node. It is also discounted in accordance with the bandwidth utilization and the link stability. This guarantees that the route has attained the more stable, shorter route with ample bandwidth. The local used bandwidth BW is evaluated using (5):

$$BW(\text{bps}) = \frac{n \times S_B \times 8}{T} \quad (5)$$

In this formula,  $n$  denotes number of packets sent and received by a node.  $S_B$  denotes the packet's size in bytes, and  $T$  denotes the time period.

## RESULTS AND DISCUSSION

An energy model [27] was based on the Lucent 2Mb/s WaveLAN 802.11 LAN card. For performance evaluation, transmission energy (1.4W), receiving energy (1.0W), listening/Idle energy (0.83W), and sleeping energy (0.043W) were used. It assume that energy consumption in the idle mode is ignored and each node operates in a non-promiscuous mode. Simulation result shows that when pause time is 0 second, mobile nodes always

move during the simulation time, and when pause time is 900 seconds, data is exchanged between mobile nodes at a fixed location. Table 1 shows the simulation parameters.

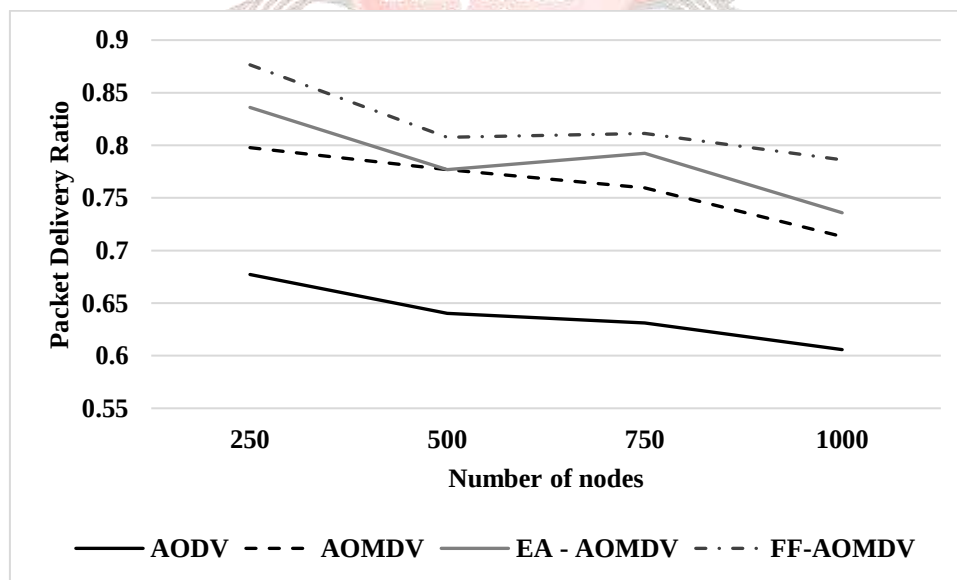
**Table 1 Simulation Parameters**

|                            |                        |
|----------------------------|------------------------|
| Number of nodes            | 250, 500, 750 and 1000 |
| Transmission range of node | 250 m                  |
| network size               | 1200 sq m              |
| Traffic type               | Constant bit rate      |

In this section, the AODV, AOMDV, EA-AOMDV and FF-AOMDV methods are used. Experiments are carried out using 250 to 1000 number of nodes. The Packet Delivery Ratio (PDR), average end to end delay, average number of hops to sink and remaining energy in the network as shown in tables 2 to 5 and figures 1 to 4.

**Table 2 Packet Delivery Ratio for FF-AOMDV**

| Number of nodes | AODV   | AOMDV  | EA - AOMDV | FF-AOMDV |
|-----------------|--------|--------|------------|----------|
| 250             | 0.6772 | 0.7978 | 0.836      | 0.8765   |
| 500             | 0.6404 | 0.7769 | 0.7769     | 0.8077   |
| 750             | 0.6312 | 0.7595 | 0.7923     | 0.8113   |
| 1000            | 0.6058 | 0.7133 | 0.7359     | 0.7862   |

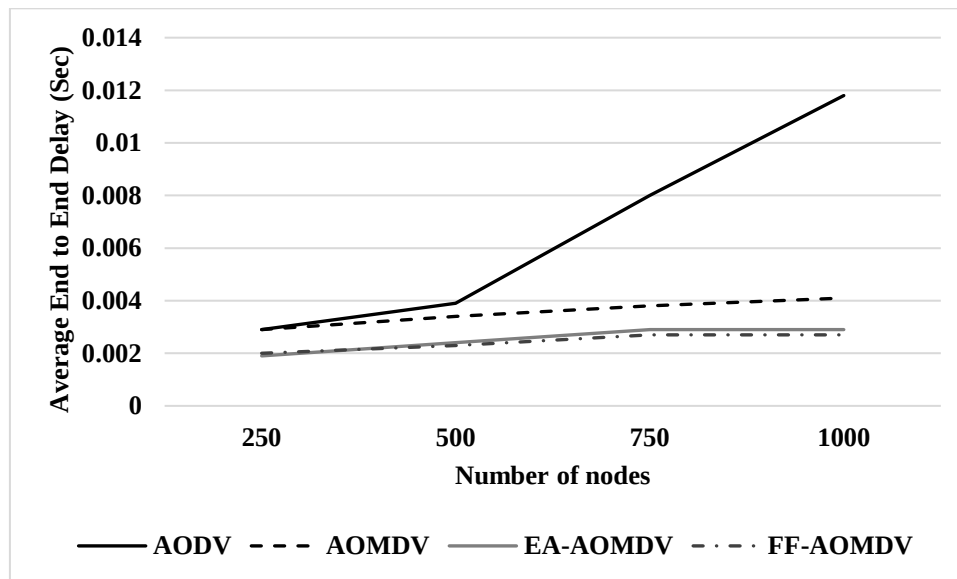


**Figure 1 Packet Delivery Ratio for FF-AOMDV**

From the figure 1, it can be observed that the FF-AOMDV has higher average PDR by 25.65%, 9.4% & 4.72% for 250 number of nodes, by 23.1%, 3.88% & 3.88% for 500 number of nodes, by 24.97%, 6.59% & 2.36% for 750 number of nodes and by 25.91%, 9.72% & 6.61% for 1000 number of nodes when compared with AODV, AOMDV and EA-AOMDV respectively.

**Table 3 Average End to End Delay for FF-AOMDV**

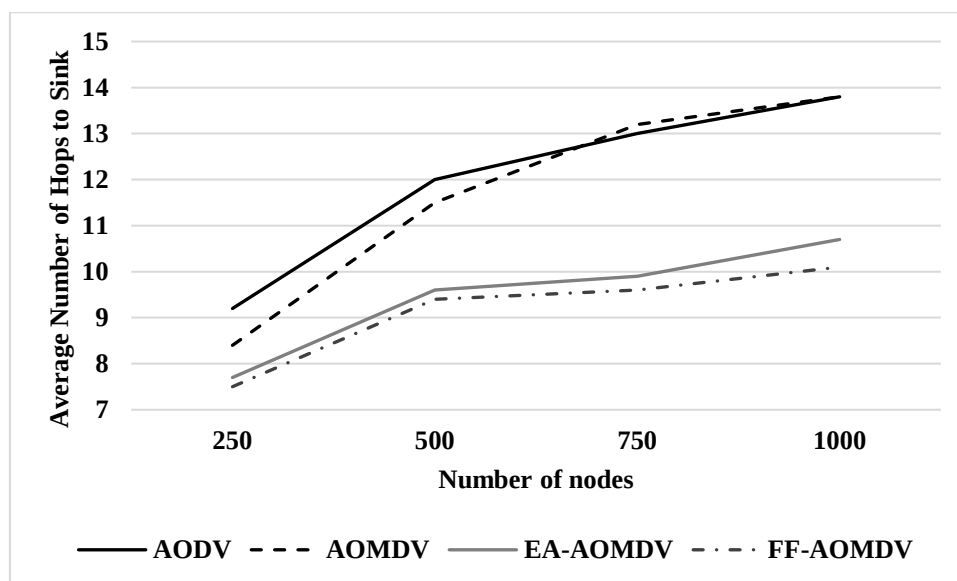
| Number of nodes | AODV   | AOMDV  | EA-AOMDV | FF-AOMDV |
|-----------------|--------|--------|----------|----------|
| 250             | 0.0029 | 0.0029 | 0.0019   | 0.002    |
| 500             | 0.0039 | 0.0034 | 0.0024   | 0.0023   |
| 750             | 0.008  | 0.0038 | 0.0029   | 0.0027   |
| 1000            | 0.0118 | 0.0041 | 0.0029   | 0.0027   |

**Figure 2 Average End to End Delay for FF-AOMDV**

From the figure 2, it can be observed that the FF-AOMDV has lower average end to end delay by 36.73%, 36.73% & 5.12% for 250 number of nodes, by 51.61%, 38.59% & 4.25% for 500 number of nodes, by 99.06%, 33.84% & 7.14% for 750 number of nodes and by 125.51%, 41.17% & 7.14% for 1000 number of nodes when compared with AODV, AOMDV and EA-AOMDV respectively.

**Table 4 Average Number of Hops to Sink for FF-AOMDV**

| Number of nodes | AODV | AOMDV | EA-AOMDV | FF-AOMDV |
|-----------------|------|-------|----------|----------|
| 250             | 9.2  | 8.4   | 7.7      | 7.5      |
| 500             | 12   | 11.5  | 9.6      | 9.4      |
| 750             | 13   | 13.2  | 9.9      | 9.6      |
| 1000            | 13.8 | 13.8  | 10.7     | 10.1     |

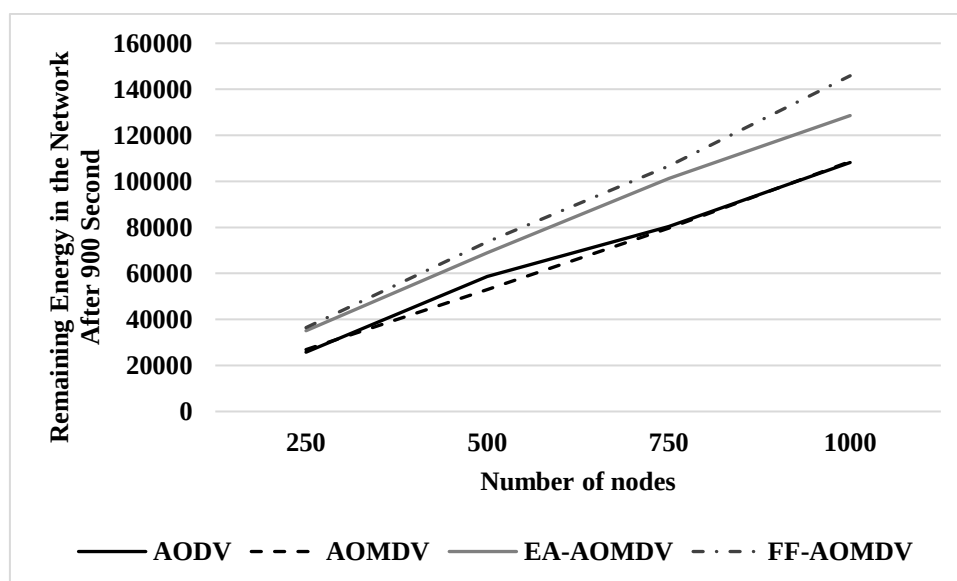


**Figure 3 Average Number of Hops to Sink for FF-AOMDV**

From the figure 3, it can be observed that the FF-AOMDV has lower average number of hops to sink by 20.35%, 11.32% & 2.63% for 250 number of nodes, by 24.29%, 20.09% & 2.1% for 500 number of nodes, by 30.08%, 31.57% & 3.07% for 750 number of nodes and by 30.96%, 30.96% & 5.76% for 1000 number of nodes when compared with AODV, AOMDV and EA-AOMDV respectively.

**Table 5 Remaining Energy in the Network after 900 Second for FF-AOMDV**

| Number of nodes | AODV    | AOMDV    | EA-AOMDV | FF-AOMDV |
|-----------------|---------|----------|----------|----------|
| 250             | 25752.4 | 26883.6  | 35079.5  | 36430    |
| 500             | 58633.7 | 52939.3  | 68965.1  | 73630.2  |
| 750             | 80338.7 | 79605.7  | 101283.4 | 106708.1 |
| 1000            | 108193  | 108621.5 | 128598   | 145878.8 |



**Figure 4 Remaining Energy in the Network after 900 Second for FF-AOMDV**



From the figure 4, it can be observed that the FF-AOMDV has higher remaining energy in the network after 900 second by 34.34%, 30.15% & 3.77% for 250 number of nodes, by 22.67%, 32.69% & 6.54% for 500 number of nodes, by 28.19%, 29.09% & 5.21% for 750 number of nodes and by 29.66%, 29.27% & 12.59% for 1000 number of nodes when compared with AODV, AOMDV and EA-AOMDV respectively.

## CONCLUSION

The definition of MANET is an autonomous collection of mobile nodes which communicate across comparably bandwidth-constrained wireless links. Limited bandwidth and frequency link changes make it quite challenging for communication in MANET. The design of routing protocols makes the provision of reliability very critical. Self-starting, loop free, dynamic, multi-hop routing is given by AODV protocol. This implies that there is broadcast of the control packets only when required, thus, eliminating the requirement for routing updates' periodic broadcast. A novel mechanism is proposed in this work for route selection by use of AOMDV protocol with EA and FF algorithm for the enhancement of MANET's quality aware best path routing. For the computation of multiple loop-free and link disjoint paths, the extension of the AODV protocol, AOMDV protocol is used. Fire Fly Algorithm (FF) is a nature-inspired algorithm that traces its roots to the light intensity attraction process of nature's fireflies. This algorithm is employed for the detection of best path from the supply to the destination for energy usage reduction in multipath routing by use of the AOMDV protocol. Various mobile multi-hop optimization problems have the successful application of Evolutionary Algorithms (EAs). The key idea is the EA's integration into the simulation framework which serves as an optimization engine for the detection of the most optimal design variables for a provided optimization problem. Experimental results demonstrate that, 250 number of nodes, the FF-AOMDV has higher average PDR by 25.65% compared to AODV, by 9.4% compared to AOMDV, and by 4.72% compared to EA-AOMDV. For 500 number of nodes, the FF-AOMDV has higher average PDR by 23.1% compared to AODV, by 3.88% compared to AOMDV, and by 3.88% compared to EA-AOMDV. For 750 number of nodes, the FF-AOMDV has higher average PDR by 24.97% compared to AODV, by 6.59% compared to AOMDV, and by 2.36% compared to EA-AOMDV. For 1000 number of nodes, the FF-AOMDV has higher average PDR by 25.91% compared to AODV, by 9.72% compared to AOMDV, and by 6.61% compared to EA-AOMDV.

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