Mutation Based Hybrid Routing Algorithm for Mobile Ad-hoc Networks

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Abstract--- **Mobile Adhoc NETworks (MANETs) usually present challenges such as a highly dynamic topology due to node mobility, route rediscovery process, and packet loss. This leads to low throughput, a lot of energy consumption, delay and low packet delivery ratio. In order to ensure that the route is not rediscovered over and over, multipath routing protocols such as Adhoc Multipath Distance Vector (AOMDV) is used in order to utilize the alternate routes. However, nodes that have low residual energy can die and add to the problem of disconnection of network and route rediscovery. This paper proposes a multipath routing algorithm based on AOMDV and genetic mutation. It takes into account residual energy, hop count, congestion and received signal strength for primary route selection. For secondary path selection it uses residual energy, hop count, congestion and received signal strength together with mutation. The simulation results show that the proposed algorithm gives better performance results compared to AOMDV by 11% for residual energy, 45% throughput, 3% packet delivery ratio, and 63% less delay.**

Key words: *Mobile Ad – Hoc Networks; AODV; AOMDV; Ant – AODV; Genetic Mutation; Residual energy; Packet Delivery Ratio; Throughput; End – to – end delay*

I. INTRODUCTION

MANET is a collection of mobile nodes that have routing capabilities via wireless links. In this autonomous setup, each node can be a router and can communicate with neighbouring nodes within its transmission range[1]. One prominent attribute about MANET is that nodes can change locations dynamically and this causes the topology to change dynamically as well. Other features of a MANET include automatic self-configuration, self-maintenance, lack of fixed infrastructure or centralized administration[2]. There have been several standard technologies that support MANETs, like, IEEE 802.15.4, ultrawideband, IEEE 802.15.3, IEEE 802.11 and Bluetooth[3]. Due the features MANETs have, they are finding popular applications in coal mining networks [4], military, emergency communications[5], as well as, 5G wide area coverage and ultra-dense network scenes[6]. Routing protocols are the key aspect of enhancing network performance and ensuring that communication is taking place[7], at the same utilizing network resources as much as possible. One of the major challenges in MANETs is having a routing protocol that is dynamic[2] and can sustain the route (s) efficiently during transmission with better performance and less overhead.

Routing protocols can be categorized into either proactive (table-driven), reactive (on demand) and hybrid [2], [8]–[10]. Proactive protocols search for routes before the need to transmit and maintain those routes through periodic updates e.g., Destination-Sequenced Distance-vector (DSDV) and Optimized Link State Routing (OLSR) protocols. With reactive protocols, when there is a need to transmit, a node applies a route discovery mechanism and creates connections for a route to the destination e.g., Dynamic Source Routing (DSR) and Ad Hoc On Demand Distance Vector (AODV) protocols. Hybrid routing protocols combine the best attributes of both proactive and reactive protocols e.g., Zone Routing Protocol (ZRP).

Reactive routing protocols have challenges in high mobility environments and since they use single path, it becomes prone to route breakage and rediscovery, thus, degrading the performance of a MANET[2], due to consuming of network resources. In order to improve the single path challenges, various multipath routing mechanisms have been developed to replace the single path mechanisms[11]– [18]. These mechanisms focus on energy awareness, greedy forwarding, genetic mutation, dynamic source routing, receiver – based route discovery, and concurrent transmission.

AOMDV mainly uses the hop count metric to determine the most optimal routes, then it transmits packets through the route with the minimum hop count[15]. Taking into consideration that energy consumption, congestion and bandwidth wastage are caused by not having node and link disjointedness[16], it is an important idea to put them into account together with node residual energy, as well as received signal strength. After multiple routes have been identified based on the above metrics, a fitness function based on Genetic Algorithm can be applied on the routes in order to optimize the best routes from source to destination.

This paper proposes a routing algorithm based on node residual energy, hop count, congestion, and received signal strength; with the routes having link and node disjointedness and finally the routes are optimized through a genetic mutation operator. The performance of the algorithm is considered on Packet Delivery Ratio (PDR), Residual Energy, Delay and Throughput compared against node speed and number of nodes used in the simulation.

II. RELATED WORKS

AOMDV as an advancement of AODV has the capability of searching for multiple paths which are loop – free and have link disjointedness. This enables the reduction of route discovery process since there is a pool of already existing routes which can be used either as back – up routes or for load balancing. This is why AOMDV as a multipath routing algorithm provides the benefit of reducing the end – to – end delay and resource wastage i.e., energy and bandwidth. Multipath routing in MANETs is mostly supported by AOMDV mechanism[15]. When a node needs to transmit, it will have to first check whether there exists a route between itself and the destination in its routing list[16]. If the route is not available, a route request is initiated and after routes have been found, route selection is executed based on minimum hop count. Multipath routing algorithms bring about the benefits of fault tolerance, load balancing and bandwidth aggregation [19]; through the use of multiple routes, where information can be divided into several streams and routes used as back – up after the primary route has failed. This is towards the goal of fulfilling Quality of Service (QoS).

Genetic algorithm simulates the natural process of survival for the fittest [20], by finding the optimum route for packet transmission within a specified time so as to satisfy feasibility and quality of service. According to [7], genetic algorithm is an artificial intelligence Mechanism with powerful search ability for route planning, task allocation, etc; that is why it becomes a popular solution in a resource constrained scenario like a MANET.

[21] implemented an adaptive MANET multipath routing algorithm based on simulated annealing approach, whereby, performance metrics included remaining energy, network throughput, packet loss probability and traffic load distribution. It worked by estimating current link status through distance and remaining energy, then proportionally loading traffic to each route according to its adaptability. The algorithm did not however put into consideration end – to – end delay, which is an important factor in the overall performance of a MANET. [22] proposed an energy efficient multipath routing algorithm based on AOMDV with fitness function (FF – AOMDV), whereby the fitness function finds the most optimum route from source node to destination node so as to reduce energy consumed in multipath routing. In order to improve network lifetime, the algorithm did not consider bandwidth, which is an important resource in prolonging network lifetime. An energy efficient congestion control for multipath routing algorithm was developed by [23], whereby a weight distribution vector is obtained as a near – optimal solution, then congestion windows are adjusted based on the acquired vector to schedule packets over each route. The algorithm puts into consideration energy efficiency, round – trip time and path loss rate so that it is possible to adjust the increment of the congestion window when an acknowledgement is received. However, the algorithm did not consider different factors such as delay and packet delivery, which are also important resource factors. [24] formulated a genetic based routing design, however, it was only based on hop count in getting the optimum route. A Mobility Aware Routing Algorithm was designed by [2], whereby, it allows mobile nodes to rebroadcast or discard received broadcasted messages based on node speed, distance between nodes, and residual energy of the nodes, during route request and route reply processes, in order to reduce link breakage and broadcast storm problems. The algorithm did not, however, factor in link quality and routing loads, which are important performance metrics and can adversely affect energy consumption and increase congestion, which can affect the overall network performance in terms of lifetime and throughput. [25] came up with a new crossover operator to design a hybrid genetic algorithm. A multipath routing protocol using genetic algorithm that uses a fitness function of shortest route, maximum residual energy, and less data traffic was implemented by [15], with the use of TCP Congestion Control Enhancement for Random Loss (TCP CERL) in the fitness function for optimization. Although the protocol showed improved performance, it introduced increased end – to – end delay and routing overhead. [26] proposed a Genetic Algorithm based – Location Aided Routing (GALAR), which adds the transmitting node location information to the packet and selecting the transmitting node to carry the packets to their destination. The algorithm did not, however, consider the energy levels of nodes in the selection criterion and this contributes to the reduction of network

lifetime. [4] introduced a Physarum – inspired optimization model in the routing process to predict the congestion and availability of the link and is used to calculate the conductivity among neighbours and recalculate the flow value to find an optimal route for data transmission. The downside to this algorithm is that it is single path. [27] proposed an enhanced technique which combined AODV and Ant Colony Optimization (ACO), whereby, before a node sends data packets it will have to find a route to the destination. In this case the biological analogy of ants spreading out to search for food and when they find the food source, they deposit pheromone on their way back so that others can be aware of that path. This analogy is applied in the protocol whereby RREQ messages are broadcast throughout the network and they go collecting information about the paths discovered like end – to – end, congestion along the route, residual energy along the route and length of the route. After receiving RREQ message, the destination calculates the pheromone count of the route using the parameter measures provided by the RREQ and sends back the RREP. The route with the highest pheromone will be selected for transmission. The challenge with this scheme is that it a single path reactionary routing protocol and it would be prone to failure due to mobility and since it is a single path routing algorithm, a route search would be initiated in order to update the new route again and that uses resources like power and bandwidth as well as causing delay.

The motivation in this study is to design a solution that has a mechanism covering all these challenges. The proposed algorithm is focused on selecting multiple routes for transferring data in MANET that are link disjointed, short (hop count), residual energy is higher, less congestion, and minimum delay; then mutation operation is applied to get the most optimal routes.

III. PROPOSED ROUTING ALGORITHM

Multipath routing algorithms that have been designed come up with multiple routes whereby traffic load is split and transmitted through two or more routes simultaneously for load balancing, or traffic is sent through one route, and the other routes are used as a backup in case of route-link breakage. In this paper we propose a new multipath routing algorithm for optimum route selection based on node residual energy, congestion, hop count and delay; with genetic mutation, to ensure that the best primary route is selected and also the best secondary route(s) is availed for backup.

The algorithm modifies the routing table for the Route Request (RREQ) and Route Reply (RREP) packet structures to have an added field known as the Link Status (LS). When the RREQ is initiated, the LS is set at 0 and the value is added as packet is propagated over the network on intermediate nodes. When it reaches the destination, the packet's LS field determines the connectivity level of that route. When the destination node receives the RREQ packet, among the multiple RREQs received, then it sends back the RREP through the paths that have been discovered to the source. When nodes receive RREQ for a destination, there would be two ways to respond; one is that the receiver is the destination itself and it can increment the destination sequence number itself. The second response is that the particular node is an intermediary and it has already saved the sequence number that was generated by the destination node when it received the route, so it will simply copy the earlier learnt sequence number and does not generate a new one.

During path selection when nodes are forwarding the route request to the destination, the nearest node is not always preferable because of factors such as congestion and residual energy not reaching threshold and bandwidth constraints. The enhanced AOMDV uses the LS value for selecting the next hop. For instance, if a node s has a link to node d, the link LS for the link LSsd is calculated as follows;

$$LS_{sd} = \frac{Rn_{sd} \times En_d}{Cn_d \times Hn_{sd}} \qquad \textbf{(1)}$$

Equation 1: calculating the Link Status Metric

Where Rn_{sd} is the received signal strength at node d from node s,

En_d is the residual energy of the node d,

Cn_d is the congestion in node d,

Hn_{sd} is the number of hops that the route request has traversed from the original node to node d via node s.

This will be used to determine the next hop that gives the best value.

Received Signal Strength Metric (RSSM)

This metric is used for each link to determine the reliability of the link to tell whether the link can break during transmission or not. Received Signal Strength (RSS_{ix}) from neighbour node I at a distance x can be expressed as;

$$RSS_{ix} = \frac{G_e \times G_t \times S_t}{(4\pi \times {}^{x}/_{2})^2} \qquad \textbf{(2)}$$

Equation 2: Calculating Received Signal Strength Metric

Where G_t is transmitting antenna gain,

S_t is utmost transmission power of transmitting antenna,

λ is the wavelength used in the MANET.

From that received signal strength, a Threshold (T_d) is calculated in the neighbouring node j as given by [28] as follows;

$$T_d = \frac{G_r \times G_t \times S_t}{4 \times \pi^{0.9054^R}/\lambda}$$

Where G_r is receiving antenna gain, and R is the range of the antenna. Depending on the threshold value (T_d), RSSM of the link (s, d) is calculated. The value of Received Signal Strength Metric at node j for the link (s, d) is 0 if RSS_{sd} is less than T_d or is equal to

$(1 – T_d/RSS_{sd})$ if RSS_{sd} is greater than or equal to T_s.

Congestion Metric (CM)

This can be determined by the buffer occupancy [29] and the TCP Congestion Control Enhancement for Random Loss (TCP CERL) method [30]. TCP CERL uses the Bandwidth (BW) and the Round-Trip Time (RTT) to get the Queue Length (L) as shown in the following equation:

$$L = (RTT - T)BW \quad \textbf{(3)}$$

Equation 3: Calculating the Congestion Metric

Where T is the smallest RTT observed by the sender

L is updated with the latest RTT measurement every time a new RTT value is received.

In order to determine the congestion status of a particular link, TCP CERL sets a dynamic queue length of N based on: $N = A*L_{max}$

Where L_{max} would be the largest value of L detected by the sender and A would be a constant between 0 and 1. If L>N then it would mean that packets will be dropped at the particular node because there would be traffic congestion.

The number of packets in the buffer of each node forms the queue length and this queue length keeps on changing as a number of packets keep on entering and leaving the node. It is;

Buffer - which is the number of packets in a node = Packets sent – Packets dropped

Congestion Metric N = λt

N = total number of packets arriving in a node in a specified period of time

λ = the rate at which the packets arrive

t = time taken for a certain number of packets to arrive

According to [29], the queue length is used to determine the congestion in a node. So, when the queue buffer is full to capacity the next incoming packets will be dropped till the queue has space.

Residual Energy Metric (REM)

An energy model is used to represent the energy levels of nodes in the network[27]. At the start a node has initial energy and it loses some amount of energy for every packet transmitted or received, hence, the node energy keeps on decreasing and what remains after every transmission or receipt of a packet is the residual energy. When the residual energy is too low to transmit a packet towards destination, transmission will not be successful and it is calculated as follows [27];

$$Ei^{res}(t) = E_i^0 - C_t \quad \textbf{(4)}$$

Equation 4:Calculating the Residual Energy Metric

Where Ei^{res} (t) is the residual energy at time t

E_i^0 is the initial energy at the node i

C_t is the energy consumption of the node i until time t

Hop count Metric (HCM)

This metric calculates the number of hops a packet has to go through to get to a destination d from a source s, which is incremented by 1 (one) when a packet proceeds to the next hop.

The best route will be achieved by summing up the LS of each of the routes discovered between source S and destination D as shown below;

$$\sum_S^D LS \quad \textbf{(5)}$$

In the mutation process, the initial population will be created during route request and route reply. The routes which have been identified as either the primary route or secondary routes form the chromosomes. The LS value of each route will be the genes (in DNA) which will be used to select the best route via mutation algorithm, thus, saving on route re – discovery and resource wastage. This can be exemplified as follows;

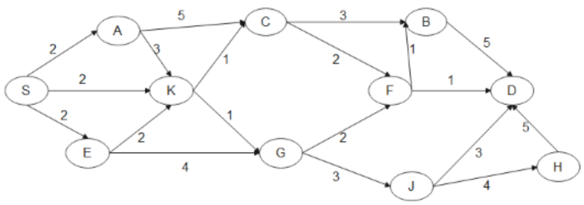

Figure 1:MANET

In figure 1 above, all the links have been shown with their corresponding LS. Using AOMDV, the possible routes discovered are;

Table 1: Discovered Routes

	Route	**Link Status**
1	S – A – K – C – F – B – D	14
2	S – K – C – F – F – B – D	11
3	S – E – K – C – F – B – D	13
4	S – E – K – C – F – D	8
5	S – E – G – F – D	9
6	S – E – G – J – D	12
7	S – E – G – J – H – D	18
8	S – A – C – B – D	15

From the above table 1, the primary route will be 7, because it has the best link status value of 18. It will be selected for transmission. In case the selected route breaks, routes 1, 3, 6, and 8 will be the population for applying mutation algorithm in order to get the next best route for transmitting. Roulette wheel selection is used because an individual is picked depending on the percentage of contribution to the total population fitness, a string is selected for mating to form the next generation. In order to evaluate the fitness f(x) of the selected routes, the formula

$$f\,(x) = x^2, \tag{6}$$

x being the LS of the routes selected

Evaluating the fitness of each link

$$P_x = {f_x}\Big/{\frac{f_x}{\sum_{f=1}^{n} f_x}} \tag{7}$$

f_x is the fitness for string x in the population
P_x is the probability of string x being selected
n is the number of individuals in the population
n*p is the expected count

The parent selection will be carried out as shown in table 2 below;

Table 2:Evaluating the fitness of each link

Route	**LS(fx)**	**Binary**	$f_x = x^2$	P_x	**Expected Count**
1	14	1110	196	0.27	1.08
3	13	1101	169	0.23	0.92
6	12	1100	144	0.20	0.8
8	15	1111	225	0.31	1.24
SUM			734	1.00	4.04

As the algorithm moves on to the next stage of applying crossover operator, the least favourable route 6 will be removed from this step and replaced with the most favourable one 8 in the mating pool of parents. The crossover point will be on the third binary digit and the new off springs will look like the ones shown in the table below;

Route	**Mating pool**	**Crossover point**	**Offspring after crossover**	**n value**	**Fitness**
1	1110	3	1111	15	225
3	1101	3	1100	12	144
8	1111	3	1111	15	225
8	1111	3	1111	15	225
SUM					819

The last stage is applying the mutation operator to each child after crossover. The bits will be changed from 0 to 1 or vice versa at randomly chosen potions for randomly selected routes. In this case since applying a mutation operator may not get us a better route than the existing route 8 or the newly generated route 1 (S – A – C – F – B – D). The best route favoured still is 8 because of the number of hops to the destination.

Proposed Algorithm pseudocode

//Source with the intention to transmit checks for a path to the destination. If a path exists, transmission takes place. If the path doesn't exist, route discovery is initiated by broadcasting a RREQ packet.

Begin:

```
        if (hub A has route to Sink B) then
        for each RREQ packets send do
        <GAOMDV_Compute_link_status>
        // received signal strength multiplied by the residual energy of the node
        New_RSS = RSSM * REM
        //Output is divided by the congestion (CM) in the node and the number of hops (HCM) the route request has traversed from the source.
        Traversed_Hops = New_RSS/CM
        end if
```

//If the link status is okay (meaning the node can be used in routing) a reverse entry is made. If the link status is not okay broadcast of the RREQ packet continues.

```
if (link_status == active) then
for each RREQ packets send do
<GAOMDV_Initiate_Reverse_Entry>
else
<GAOMDV_Broadcast_Packets>
end if
```

//If the node is not the destination and the link status is okay, add the ID in the route and broadcast the RREQ. This process continues until you reach the destination.

```
if (! Sink B and link_status == active) then
add Route_ID and Broadcast RREQ
while (Sink B == true) then
<GAOMDV_Broadcast>
end while
end if
```

//Once at the destination a RREP is generated containing the route list and sent back to the source. once the source is found transmission begins. If it's not found the RREP is broadcast.

```
if (RREP in Destination) then
<GAOMDV_generate_routelist>
else
RREP_Broadcast
end if
```

//Route Repair

```
if(route_fails) then
<GAOMDV_check_another_route>
if(route_exists) then
<GAOMDV_send_packets>
else
<GAOMDV_perform_local_repair AND Generate_RREP with new_route_list>
end if
end if
```

//If the local repair time has ended, initialize the mutation algorithm based on the secondary routes and transmit the packet.

```
if (local_repair_time > 0) then
```

//GAOMDV Initiate Mutation Algorithm and Retransmit Packets

```
Foreach (all_given_secondary_routes) do
While (P (Probability That Node Will Mutate)) do
Crossover (Given from fittest routes)
Mutation (mutate from children's routes)
NodeFitness(Select the fittest route)
End
Foreach (N (set of fittest routes selected)) do
If (N (set of fittest routes selected) > 0) then
<Transmit packet towards destination>
End
End
End
```

The new algorithm is represented in the flowchart showed in figure 2 below, and works in the following order;

i. *Source with the intention to transmit checks for a path to the destination. If a path exists, transmission takes place. If the path doesn't exist, route discovery is initiated by broadcasting a RREQ packet.*
ii. *Intermediate node receives the RREQ packet and calculates the link status.*
    - *Check the received signal strength (RSSM) multiplied by the residual energy (REM) of the node*
    - *Output is divided by the congestion (CM) in the node and the number of hops (HCM) the route request has traversed from the source.*
iii. *If the link status is okay (meaning the node can be used in routing) a reverse entry is made. If the link status is not okay broadcast of the RREQ packet continues.*
iv. *If the node is not the destination and the link status is okay, add the ID in the route and broadcast the RREQ. This process continues until you reach the destination.*
v. *Once at the destination a RREP is generated containing the route list and sent back to the source. once the source is found transmission begins. If it's not found the RREP is broadcast.*
vi. *During transmission if a route fails, check if another route exists. If it exists send the packets through that route.*
vii. *If the route doesn't exist, perform a local repair and broadcast the local repair packet to the intermediate nodes to perform the route repair and generate a RREP with a new routing list. Send the RREP to the originator of the repair packet and make a forward entry.*
viii. *If path to destination doesn't exist send the RREP packet to the originator of the repair packet as long as it is within the local repair time. If path to destination exists, transmit the packets*
ix. *If the local repair time has ended, initialize the mutation algorithm and transmit the packet.*
    - *Mutation will be performed on the secondary routes using Received Signal Strength (RSSM), Residual Energy (REM), Congestion (CM), Hop Count (HCM) and Link Status (LS) as the genes (in DNA) which will be used to select the best route.*

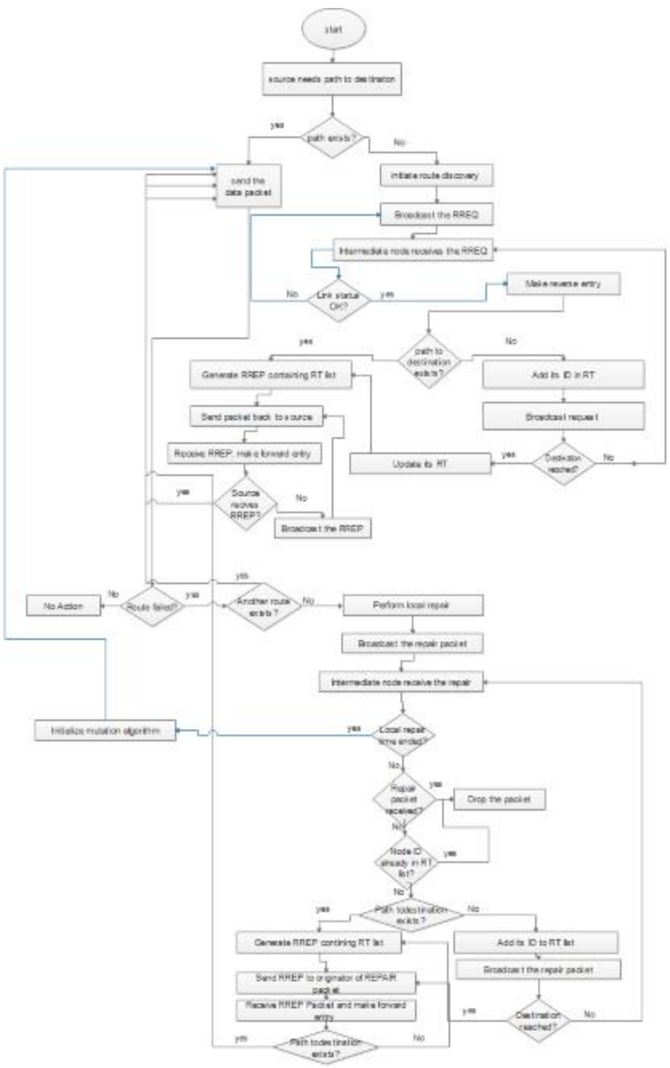

Figure 2:Mutation Based Hybrid Routing Algorithm

IV. EXPERIMENTAL RESULTS AND DISCUSSION

Simulation

Simulator: NS2.35
Language: C++ , TCL and Python
Operating system: Linux

Table 3:Simulation Parameters

Simulator	NS2
Simulation nodes	70
Interface type	Phy/wireless/phy
Channel	Wireless channel
MAC type	802.11
Queue type	Queue/DropTall/PriQueue
Queue length	201 packets
Antenna type	Omni antenna
Propagation type	TwoRay ground
Size of packet	512
Protocol/algorithm	AODV
Traffic	TCP
Initial energy	100 J
Compared protocols	AODV, AOMDV, Ant-AODV, GAOMDV

Experimental Results and Discussion

The results are posted after running each simulation 10 times then finding an average of the outputs.

Throughput

The performance analysis of throughput for AODV, AOMDV, Ant-AODV and the proposed Enhanced GAOMDV is shown in considering 70 nodes and varying the node speeds.

Table 4: Throughput against number of nodes

Node Speed	**AVG Throughput AODV**	**AVG Throughput - AOMDV**	**AVG Throughput - Ant AODV**	**AVG Throughput Enhanced GAOMDV**
0.5 Ms	154.212	282.784	291.068	363.129
1.5 Ms	150.328	275.328	279.048	359.664
2.5 Ms	134.094	256.407	264.132	347.505
3.5 Ms	122.226	196.808	266.616	341.200
4.5Ms	118.760	188.941	251.739	336.950

Table 4 above shows that there is a 46% better performance for the proposed protocol against AOMDV and a 29 % better performance against Ant – AODV when it comes to throughput.

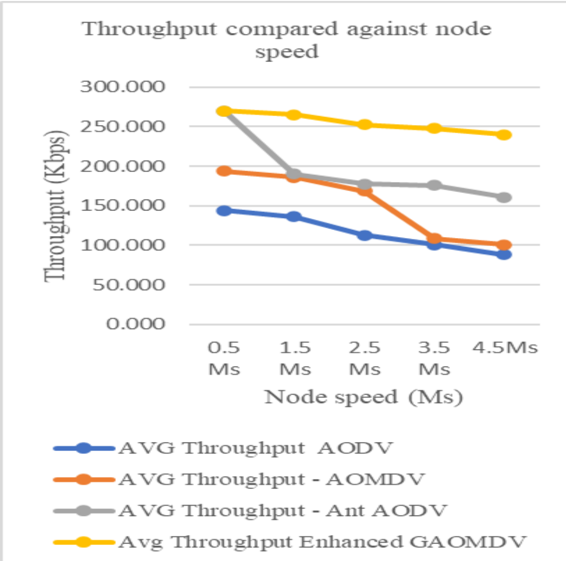

Figure 3 : Comparison of AODV, AOMDV, Ant-AODV and proposed Enhanced GAOMDV for throughput with speed

From the figure 3 and table 4 above, As the speed of nodes increases Throughput reduces as a result of loss of connectivity and degradation of routes. The proposed protocol outperforms the other protocols. This is because of the route selection novel method which puts in to consideration the received signal strength, residual energy, congestion, and link status metrics. The protocol enables the ability to select best which are sustained for long period of time due to the novel routing metric taken into account and mutation. It will also be sending data packets through a route that has the highest average of residual energy and the shortest distance to the destination thereby ensuring more life or route sustainability.

Figure 4 below compares throughput against the number of nodes where ENHANCED GAOMDV outperforms AODV and AOMDV as the number of nodes is increased from 10, 20, 30, 40, 50, 60, and 70 nodes, since with the increase of the number of nodes there is a likelihood of having more stable routes and alternatives except for AODV. This shows that the proposed protocol adapts to topological change better when the number of nodes increases beyond 30 nodes. The general trend of throughput decreasing as the number of nodes increases is due to the MAC sublayer protocol for Wi-Fi which increases the chances of collisions in the network.

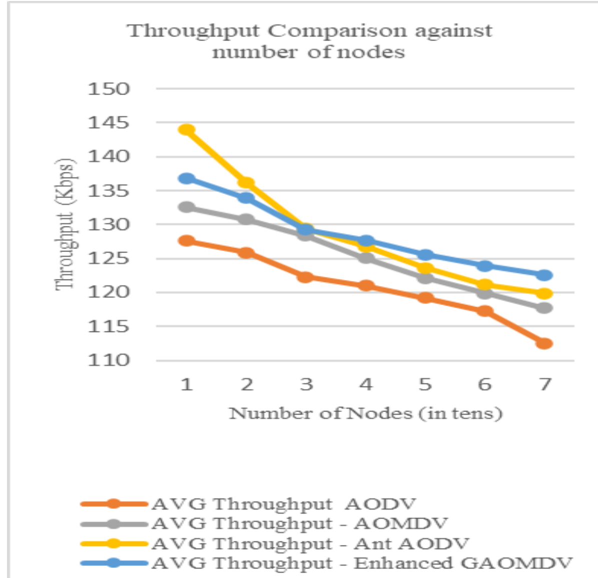

Figure 4:Comparison of Throughput against number of nodes

Packet Delivery Ratio

The PDR impact is being shown in figures 5 and 6 whereby when there is an increase in the number of nodes or an increase in in node speed, there is an effect as shown below.

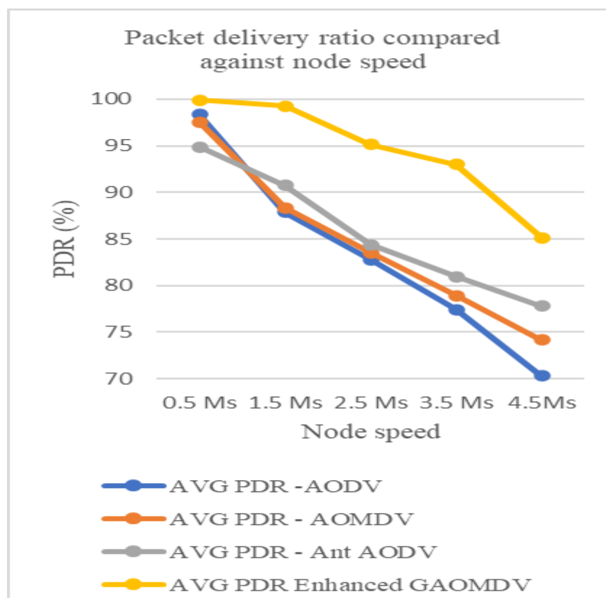

Figure 5: Comparison of PDR against node speed

As the speed of the nodes increases the PDR drops for all the protocols. This is due to the fact that with increase in speed, node mobility increases which in turn affects the topology. Frequent topological changes mean that packet drop rate increases. The proposed enhanced GAOMDV has outperformed the other three protocols. Here enhanced GAOMDV has outperformed the other protocols meaning that there is a reduced number of retransmissions required because of either node mobility or congestions.

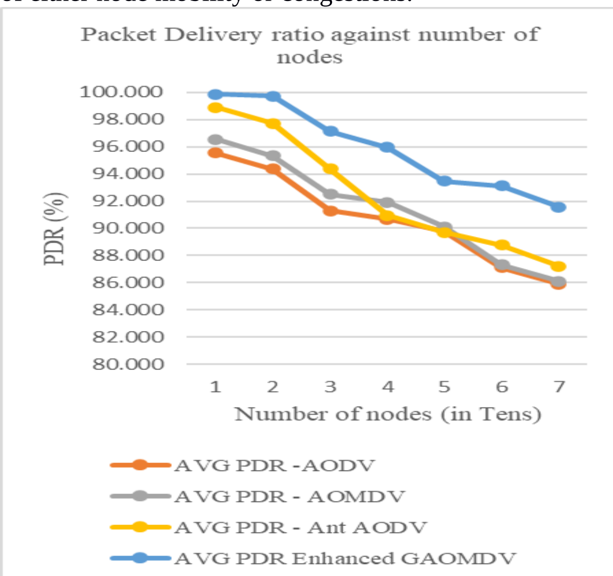

Figure 6:PDR compared against number of nodes

From the figure 6 above, in regard to the tested protocols, Enhanced GAOMDV has been able to outperform them, with a 3% better performance than AOMDV and Ant – AODV, as shown in table 5 below. As the number of nodes increases from 10, 20, 30, 40, 50, 60, and 70, the PDR is on the inverse. This is attributed to the fact that as the number of nodes increases, congestion would be more likely to occur hence packet drop rate increasing.

Table 5:PDR compared to number of nodes

No. Of Nodes	AVG PDR AODV	AVG PDR - AOMDV	AVG PDR - Ant AODV	AVG PDR Enhanced GAOMDV
10	92.534	92.496	91.545	95.474
20	89.734	89.896	90.545	93.874
30	87.334	87.496	87.745	93.074
40	84.934	87.296	86.745	89.074
50	82.534	84.696	85.945	86.2744
60	80.334	83.096	83.545	83.4744
70	77.734	80.296	80.197	81.6744

Residual energy

The energy model in ns2 had the initial energy set at 100. Since one of the main goals of the routing algorithm is to reduce energy consumption, or be energy efficient, the results for residual energy are shown below against speed and number of nodes.

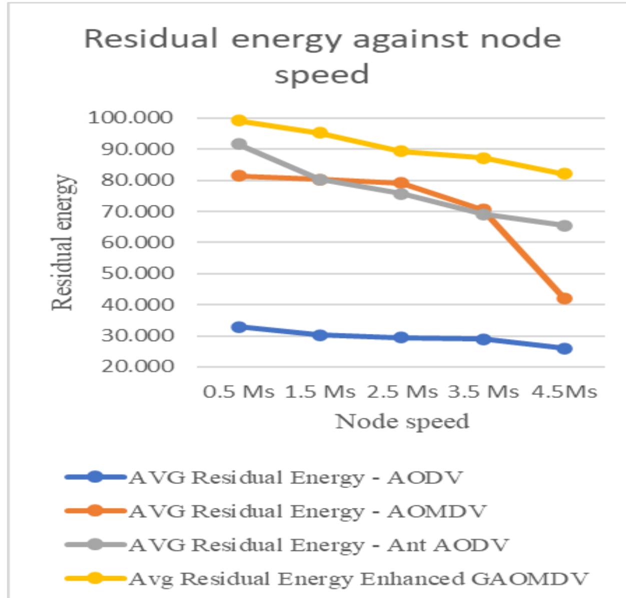

Figure 7: Residual Energy compared against node speed

From the figure 7 above, Enhanced GAOMDV protocol performed better in comparison to the other protocols that were simulated. From table 7 below, the proposed protocol has a 12% better energy consumption than AOMDV and 7% better than Ant – AODV. This is a good indicator that the proposed protocol is able to increase the network lifetime since, cumulatively, the nodes do not consume a lot of energy bot with increasing speed of node movement as well as increasing number of nodes.

Table 6:Residual energy against node speed

Node Speed	AVG Residual Energy - AODV	AVG Residual Energy - AOMDV	AVG Residual Energy - Ant AODV	Avg Residual Energy Enhanced GAOMDV
0.5 Ms	100.000	100.000	100.000	100.000
1.5 Ms	95.179	90.619	94.369	98.050
2.5 Ms	92.468	86.790	90.619	96.947
3.5 Ms	89.229	80.603	86.746	95.160
4.5Ms	85.515	75.168	80.026	93.168

Table 7:Residual energy against number of nodes

Number Of Nodes	AVG Residual Energy - AODV	AVG Residual Energy - AOMDV	AVG Residual Energy - Ant AODV	Avg Residual Energy Enhanced GAOMDV
10	100.0000	100.0000	100.0000	100.0000
20	90.3335	93.3090	95.8390	99.2830
30	86.6032	90.5090	93.8390	95.8830
40	80.1684	86.9090	90.8390	92.6830
50	74.4684	80.3090	87.2388	90.0828
60	60.4645	76.7090	84.8388	88.0828
70	55.4457	60.1090	70.8388	82.4828

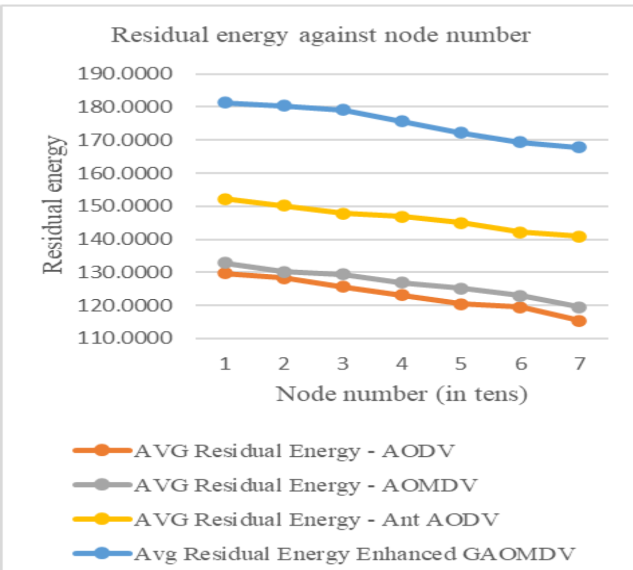

Figure 8: Average residual energy compared to number of nodes

From the figure 8 above, at a constant speed of 4.5 Ms and the number of nodes growing from 10 to 70, Enhanced GAOMDV protocol outperforms the other three protocols it compares with due to the fact that after the initial route search, the proposed protocol is able to optimally maintain the route and reduce routing updates which is the main goal of this protocol.

Average end – to – end delay

The analysis here is for comparing the average end – end – to – end delay for the number of hops for AODV and AOMDV. [30] proposes using distance and energy protocols under consideration. Conventionally, hop count has been used as the metric for evaluating distance [27] and the best route would be the one with the least metrics hence the processing time becomes longer. The proposed protocol uses hop count, residual energy, congestion, and bandwidth.

Figure 9 Average end- to - end delay compared against node speed

From the figure 9 above, the proposed protocol has a remarkably lower delay in comparison to the three protocols it is compared with. As the node speed increased, the average end – to – end delay increased for all the protocols.

In figure 10 below, the proposed protocol, enhanced GAOMDV performs well in comparison with the compared protocols AOMDV, AODV, and Ant AODV. This is because when there is reduced number of route updates then it means the time taken for transmission is less as compared to the other protocols.

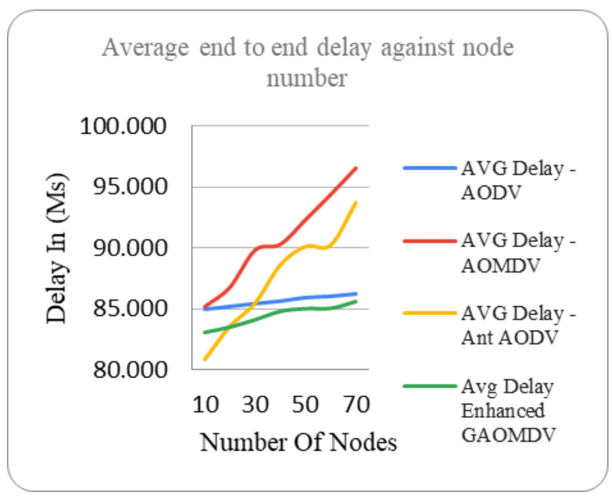

Figure 10: End - to - end delay compared against number of nodes

V. CONCLUSION

This paper addresses the problem of routing in MANETs. The performance of the proposed protocol has been compared with two other reactive protocols, one single path and the other multipath. The simulation results were evaluated in terms of packet delivery ration, throughput, end – to – end delay and bandwidth.

The proposed algorithm has made an integration of the AODV and AOMDV mechanisms as the basis for routing and then the Genetic Algorithm (GA) for optimization and minimizing routing updates. This has been made possible by avoiding routes which are congested or have less residual energy. This in a way may affect the route selection process in that not just the shortest route is selected but the fittest. The proposed protocol has outperformed the other protocols in terms of Throughput, PDR, Residual energy, and End – to – end delay; both in terms of node speed and number of nodes.

More research can go into the algorithm being used with data streaming communications (multimedia) traffic due to delay/jitter variations. This is because if a communication is moving from a point a to b in a multi-hop environment, different packets will take different durations due to transmission delay, propagation delay and processing delays, hence, it becomes difficult for streaming data.

Future research may focus on looking into the performance of this protocol in regard to position of the nodes, when sources and destinations are close to each other or when they are far apart in the simulation scenario and determine whether the performance is affected based on the same metrics.

VI. DATA AVAILABILITY

Research data and summarised findings can be found at http://dx.doi.org/10.17632/3hdc7rxxnn.1

REFERENCES

[1] R. Chandren Muniyandi, M. K. Hasan, M. R. Hammoodi, and A. Maroosi, “An Improved Harmony Search Algorithm for Proactive Routing Protocol in VANET,” *Journal of Advanced Transportation*, vol. 2021, 2021, doi: 10.1155/2021/6641857.

[2] C. Z. Sirmollo and M. A. Bitew, “Mobility-Aware Routing Algorithm for Mobile Ad Hoc Networks,” *Wireless Communications and Mobile Computing*, vol. 2021, 2021, doi: 10.1155/2021/6672297.

[3] M. Ahmad *et al.*, “Cluster Optimization in Mobile Ad Hoc Networks Based on Memetic Algorithm: MemeHoc,” *Complexity*, vol. 2020, 2020, doi: 10.1155/2020/2528189.

[4] H. Jiang, X. Liu, S. Xiao, C. Tang, and W. Chen, “Physarum-Inspired Autonomous Optimized Routing Protocol for Coal Mine MANET,” *Wireless Communications and Mobile Computing*, vol. 2020, 2020, doi: 10.1155/2020/8816718.

[5] M. M. A. Alkadhmi, O. N. Uçan, and M. Ilyas, “An Efficient and Reliable Routing Method for Hybrid Mobile Ad Hoc Networks Using Deep Reinforcement Learning,” *Applied Bionics and Biomechanics*, vol. 2020, 2020, doi: 10.1155/2020/8888904.

[6] Y. Liu, Y. Li, Y. Zhao, and C. Zhang, “Research on mac protocols in cluster-based ad hoc networks,” *Wireless Communications and Mobile Computing*, vol. 2021, 2021, doi: 10.1155/2021/5513469.

[7] X. Wei, H. Yang, and W. Huang, “A Genetic-Algorithm-Based Optimization Routing for FANETs,” *Frontiers in Neurorobotics*, vol. 15, Jun. 2021, doi: 10.3389/fnbot.2021.697624.

[8] T. Melodia, H. Kulhandjian, L. C. Kuo, and E. Demirors, “Advances in Underwater Acoustic Networking,” in *Mobile Ad Hoc Networking: Cutting Edge Directions: Second Edition*, John Wiley and Sons, 2013, pp. 804–852. doi: 10.1002/9781118511305.ch23.

[9] M. Natkaniec, “Ad Hoc Mobile Wireless Networks: Principles, Protocols, and Applications (Sarkar, S. K. et al.; 2008) [Book Review],” *IEEE Communications Magazine*, vol. 47, no. 5, pp. 12–14, May 2009, doi: 10.1109/mcom.2009.4939268.

[10] M. Ilyas, “THE HANDBOOK OF AD HOC WIRELESS NETWORKS,” 2003.

[11] A. Genta, D. K. Lobiyal, and J. H. Abawajy, “Energy efficient multipath routing algorithm for wireless multimedia sensor network,” *Sensors (Switzerland)*, vol. 19, no. 17, Sep. 2019, doi: 10.3390/s19173642.

[12] M. Zarei and M. Soltanaghaei, “A Gray System Theory Based Multi-Path Routing Method for Improving Network Lifetime in Internet of Things Systems,” 2020, doi: 10.20944/preprints202001.0304.v1.

[13] A. Al-Nahari and M. M. Mohamad, “Receiver-based ad hoc on demand multipath routing protocol for mobile ad hoc networks,” *PLoS ONE*, vol. 11, no. 6, Jun. 2016, doi: 10.1371/journal.pone.0156670.

[14] N. Shrivastava and A. Motwani, “A Modification to DSR using Multipath Technique,” *International Journal of Computer Applications*, vol. 92, no. 11, pp. 24–28, Apr. 2014, doi: 10.5120/16053-5236.

[15] A. Bhardwaj and H. El-Ocla, “Multipath routing protocol using genetic algorithm in mobile ad hoc networks,” *IEEE Access*, vol. 8, pp. 177534–177548, 2020, doi: 10.1109/ACCESS.2020.3027043.

[16] D. G. Zhang *et al.*, “A Multi-Path Routing Protocol Based on Link Lifetime and Energy Consumption Prediction for Mobile Edge Computing,” *IEEE Access*, vol. 8, pp. 69058–69071, 2020, doi: 10.1109/ACCESS.2020.2986078.

[17] A. Abdelkader Aouiz *et al.*, “AOMDV Protocol Using Nodes Energy Variation,” *International Journal Network*

Protocols and Algorithms, vol. 10, no. 2, pp. 73–94, 2018, doi: 10.5296/npa.v10i2.13322ï.

[18] S. Wang, “Multipath Routing Based on Genetic Algorithm in Wireless Sensor Networks,” *Mathematical Problems in Engineering*, vol. 2021, 2021, doi: 10.1155/2021/4815711.

[19] J. Seetaram and P. S. Kumar, “An energy aware Genetic Algorithm Multipath Distance Vector Protocol for efficient routing,” *Proceedings of the 2016 IEEE International Conference on Wireless Communications, Signal Processing and Networking, WiSPNET 2016*, pp. 1975–1980, 2016, doi: 10.1109/WiSPNET.2016.7566488.

[20] A. Biradar and R. C. Thool, “Reliable genetic algorithm based intelligent routing for MANET,” *2014 World Congress on Computer Applications and Information Systems, WCCAIS 2014*, 2014, doi: 10.1109/WCCAIS.2014.6916649.

[21] S. Kim, “Adaptive MANET multipath routing algorithm based on the simulated annealing approach,” *Scientific World Journal*, vol. 2014, 2014, doi: 10.1155/2014/872526.

[22] A. Taha, R. Alsaqour, M. Uddin, M. Abdelhaq, and T. Saba, “Energy Efficient Multipath Routing Protocol for Mobile Ad-Hoc Network Using the Fitness Function,” *IEEE Access*, vol. 5, pp. 10369–10381, 2017, doi: 10.1109/ACCESS.2017.2707537.

[23] W. Wang, X. Wang, and D. Wang, “Energy Efficient Congestion Control for Multipath TCP in Heterogeneous Networks,” *IEEE Access*, vol. 6, pp. 2889–2898, Dec. 2017, doi: 10.1109/ACCESS.2017.2785849.

[24] X. Sun, J. Wang, W. Wu, and W. Liu, “Genetic algorithm for optimizing routing design and fleet allocation of freeway service overlapping patrol,” *Sustainability (Switzerland)*, vol. 10, no. 11, Nov. 2018, doi: 10.3390/su10114120.

[25] M. Ye, Y. Wang, C. Dai, and X. Wang, “A Hybrid Genetic Algorithm for the Minimum Exposure Path Problem of Wireless Sensor Networks Based on a Numerical Functional Extreme Model,” *IEEE Transactions on Vehicular Technology*, vol. 65, no. 10, pp. 8644–8657, Oct. 2016, doi: 10.1109/TVT.2015.2508504.

[26] R. Alsaqour, S. Kamal, M. Abdelhaq, and Y. al Jeroudi, “Genetic Algorithm Routing Protocol for Mobile Ad Hoc Network,” *Computers, Materials and Continua*, vol. 68, no. 1, pp. 941–960, Mar. 2021, doi: 10.32604/cmc.2021.015921.

[27] D. Sarkar, S. Choudhury, and A. Majumder, “Enhanced-Ant-AODV for optimal route selection in mobile ad-hoc network,” *Journal of King Saud University - Computer and Information Sciences*, 2018, doi: 10.1016/j.jksuci.2018.08.013.

[28] S. Chatterjee and S. Das, “Ant colony optimization based enhanced dynamic source routing algorithm for mobile Ad-hoc network,” *Information Sciences*, vol. 295, pp. 67–90, 2015, doi: 10.1016/j.ins.2014.09.039.

[29] S. Patel, P. Gupta, and G. Singh, “Performance measure of drop tail and RED algorithm,” *ICECT 2010 - Proceedings of the 2010 2nd International Conference on Electronic Computer Technology*, no. August 2018, pp. 35–38, 2010, doi: 10.1109/ICECTECH.2010.5479996.

[30] A. Bhardwaj and H. El-ocla, “Multipath Routing Protocol Using Genetic Algorithm in Mobile Ad Hoc Networks,” vol. 8, 2020, doi: 10.1109/ACCESS.2020.3027043.