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Original Article

Fuzzy Based Priority Ad Hoc on Demand Multipath Distance Vector Stable Routing Protocol

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Abstract *- Mobile ad-hoc networks are the most uncertain type of network. Uncertainty occurs due to the mobile nature of the nodes; continuous consumption of energy and bandwidth results in an unpredictable state of nodes. In this situation, making an efficient, reliable and stable route selection is a challenging task and an open research problem aiming to provide continuous and consistent transfer of data among the source and the destination node. Multipath routing protocol ensures reliable communication by providing multiple paths between source and destination nodes. Choosing the best one among different alternative paths is the problem addressed by this paper. For this purpose, fuzzy logic (multi-valued logic) has been used. Fuzzy logic is a soft computing technique that is able to make precise and accurate decisions in multivariable, uncertain and imprecise situations. Here, firstly Multipath Priority Based Route Discovery Mechanism (MPRDM) has been used to generate multiple paths between the two nodes participating in the communication. MPRDM calculates the individual priority value for every RREP packet and assigns it to the different obtained routes. Further, in this paper, fuzzy logic has been used for designing fuzzy route selection controller for the Fuzzy Logic Based Stable Route Selection mechanism (FLSRSM), which calculates the stability value of different routes based on priority value, average mobility and residual energy along the paths FLSRSM is able to make a selection of best stable path based on the highest value of stability metric. This mechanism has been used to propose fuzzy-based priority ad-hoc on-demand multipath distance vector stable routing protocol (FPAOMDV) that provide stability reliability and selects the route that has a sufficient amount of energy to hold continuous data transfer. In Simulation results on NS2, the proposed protocol outperforms other compared routing protocols in terms of delay, throughput, PDR and overhead.*

Keywords - *Fuzzy Logic, Multi-path, Networks, Priority, Soft Computing, Route Discovery, Stability.*

I. INTRODUCTION

Ad-hoc networks are highly dynamic, mobile and unpredictable types of networks. Due to the continuous movement of nodes, there is an excessive requirement of resources, i.e., Energy and Bandwidth. One of the severe issues to deal with in mobile ad-hoc networks is the continued consumption of energy of nodes with time. Maintaining a sufficient amount of energy at each and every node of the network is a prerequisite for consistent communication among the nodes of the network; thus, carrying out routing in MANET is a challenging task. Quality of service (QoS)[1] ensures healthy communication among the nodes of the network. It is a way of transferring data from one node to another in an efficient way.

Nowadays, routing not only concentrates on transferring data from the source node to the destination node, but also it is highly responsible for the transfer of the data in a most secure, reliable and stable way. Earlier, Uni-path[2] routing was used, which discovers only a single path between two particular nodes that are participating in the communication. In the recent era of research, Multi-path routing [3] is the first choice of the researcher, which is kept in mind while developing a routing protocol. MANETs are no doubt self-configurable and self-organizing type of networks, these two characteristic makes them highly deployable [4], but its mobile environment is always a critical and prime factor that is always kept in mind while developing any routing protocol. In order to ensure reliability and load balancing, multi-path routing [5] are the most successful routing protocol among all types of routing protocols[6]–[8], so far studied. Apart from this, multipath routing reduces delay, maximises the lifetime of the network and reduces overhead by decreasing the number of dead nodes in the network [9].

Numbers of multipath routing protocols are available in the literature[10] [11], depending on the issues or services to be provided to the host. Priority has been considered as a critical parameter for developing Multipath Priority Based Route Discovery Mechanism (MPRDM). Priority is an assigned integer value to an entity that is able to make a decision regarding the order of preference for its utilization. Here the calculated priority value is utilized for assigning the order of preferences given to the generated multiple routes. Fuzzy logic [12] is an intelligent decision-making technique that helps in making an efficient decision for effective node and route selection when a number of network constraints are to be considered. In this paper, Multi-Path Priority-based Route Discovery Mechanism (MPRDM) [13] has been used, which is extended by using fuzzy logic on output obtained by the route discovery mechanism. MPRDM calculates the total priority value at the source node for every received RREP packet. This priority value is used in assigning priority to the multiple paths. To be more precise in route or path selection, further, a novel approach using fuzzy logic-based decision-making technique[14] has been developed, which makes a precise and accurate decision for the most un-precise and uncertain Mobile Ad-hoc Networks. Fuzzy logic based Stable Route Selection Mechanism (FLSRSM) makes use of priority value, residual energy, and mobility along with 27 constructed Fuzzy IF-THEN rules which are able to make an effective and efficient decision in multiple variable situations. Fuzzy route selection controller has been designed in MATLAB using Fuzzy Toolbox. It calculates stability as an output parameter which is used by source node for making stable route selection among multiple available paths. Higher the value of stability parameter more will be the stability of path. Both mechanisms (i.e., MPRDM and FLSRM) have been combined to propose a novel routing protocol named as fuzzy based priority ad-hoc on demand multipath distance vector stable routing protocol (FPAOMDV). Comparison of results with other routing protocols obtained from NS-2 simulations shows a promising path for further improvement and research.

The main contributions of the proposed work include the following aspects:

1) Fuzzy logic based reactive, multipath and stable ad hoc on-demand distance vector routing protocol has been proposed using the concept prioritizing routes for highly dynamic mobile ad hoc networks, which aims to design a multipath routing protocol that uses the fuzzy logic-based process to find the most stable route between any source and the destination pair.
2) Fuzzy Logic Process uses Priority of route, Mobility and Residual Energy as the input parameter for finding the most stable route. This ensures minimal delays in transmitting the packet from source to destination.
3) The energy factor also adds to the reliability of the routes. The node's failure due to limited energy life may lead to failure at the transmitting nodes and thus result in the high rate of dropped packets. So, all these factors have been cumulatively using the fuzzy logic process to control the uncertainties in the network.
4) A comprehensive analysis of the proposed FPAOMDV has been conducted that considers four different scenarios. A series of NS-2 simulations have been done to evaluate the performance of the proposed work on four metrics (i.e., PDR, delay, throughput and overhead).

The paper has been organized in the sections as follows: Section II defines the problem. Section III cover the literature related to multipath routing protocols and fuzzy-based routing protocols so far studied. Section IV presented the proposed fuzzy-based priority ad hoc on-demand multipath distance vector stable routing protocol. Section V describes the simulation environment and set-up used on NS-2.4. Section VI did the performance evaluation of the proposed protocol based on four scenarios and compared the simulation results with other routing protocols. Section VII concludes the work.

II. PROBLEM DEFINITION

Representation of Mobile Ad-hoc Networks (MANETs) can be compared with the data structure Graph. In Graph G (V, E), V represents a number of nodes, and E represents the unidirectional links. MANETs is a most uncertain network because of its dynamic topology. As the nodes are mobile in nature, links or paths among nodes are unstable, so in order to ensure reliability now, day's research mainly focuses on multipath routing. In this uncertain and dynamic environment, making a decision regarding the selection of optimal paths among several available paths is the problem to be addressed. For this purpose, intelligent soft computing technique (i.e., fuzzy logic) has been used. Fuzzy logic is a multi-valued computational, logical technique that is capable of handling multiple parameters at the same time along with the vagueness and impreciseness in the input parameters. For the selection of the best stable path among possible available paths, the proposed mechanism has considered priority value, average mobility and residual energy along the generated paths, which is used as fuzzy input criteria to the fuzzy logic system in order to calculate the value of stability metric as shown in figure 1 which will further select the best stable path among various generated paths.

M (i) represents the average mobility of nodes along path i, represented by eq. (1). T.E.(n) represents the total initial energy at node n, and C.E.(n) represent the consumed energy by node n, hence residual energy (r.e. (n)) at node n and residual energy (R.E.) along path i can be represented by eq. (2) and (3).

$$\text{Avg. M(i)} = \frac{\sum_{j=1}^{n} \text{m(j)}}{\text{n}} \tag{1}$$

$$r.e.(n) = T.E.(n) - C.E.(n) \tag{2}$$

$$R.E.(i) = \sum_{i=1}^{n} r.e.(i) \tag{3}$$

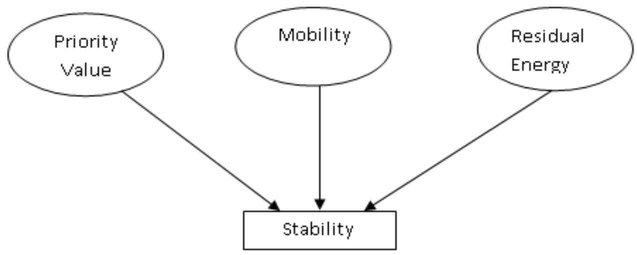

Fig.1 Fuzzy based Route selection System

III. RELATED WORKS

A. Overview of Routing Protocols

To route a packet from a source node to a destination node successfully is the main and core task of routing protocols. Routing protocols specify certain rules which govern healthy communications among the nodes of networks. There are two phases that are common to every routing protocol, i.e., route discovery and route maintenance.

Route discovery is carried out with the help of route request (RREQ) packets and route reply (RREP) packets. RREQ packets are broadcasted in the neighbour with a one-hop distance. They are further broadcasted by the intermediate node till they reach their destination node, which generates an RREP packet corresponding to the received RREQ packet and sends it to the source node following the reverse path. Source node receives the RREP and creates a path between the two nodes for further communication. This is the common mechanism that is followed by every routing protocol in Mobile Ad-hoc Networks (MANETs). There is a number of issues that occur due to the mobile environment of nodes [15], due to which work in this field is continuously getting focused and new developments are coming out day by day. To ensure continuous connectivity in a dynamic environment, multipath routing protocols are more preferred as compared to uni-path routing protocols. The next section will focus on the literature studied in the field of multipath routing.

B. Multipath Routing Protocols

Mobile nodes are battery-operated, hence require a sufficient amount of energy to remain active in a mobile ad-hoc network. That's why providing an energy-efficient routing protocol in MANETs is a key area of research and is more focused on by researchers nowadays. Shinde et al. developed a Power-Aware Load Balancing Multipath Routing Protocol[16], which performs energy-efficient routing along with balancing the traffic load on multiple available paths. There are several other issues that may occur due to the blind distribution of the network traffic, such as an increase in the number of dead nodes in the network. In order to decrease the number of dead nodes in the network, continuous work is going on in the field of MANETs towards multipath routing protocols. Alghamdi presented a load balancing approach for ad-hoc on-demand multipath distance vector routing (LBAOMDV)[17], which efficiently makes use of available node energy and bandwidth in a balanced way to utilize multiple discovered paths for data transfer hence reducing overutilization of specific nodes of the networks. Due to limited energy availability in wireless nodes of a network, the conservation of nodes energy is a prime issue to work on. Max-Min-Path Energy Efficient Routing Algorithm [18] is one of the energy-efficient routing mechanisms proposed by ponnuswamy that is able to enhance network lifetime. This technique is successful in minimizing the energy cost in the the the multipath communication. The residual energy of the node is referred to as the remaining energy of the node, which is available for further transmission of a data packet. Liu et al. developed MMRE-AOMDV[19] that calculates the residual energy of nodes of the network and then compares them to find the minimum residual energy of nodes in order to select the node that possesses the highest minimum residual energy for communication. Further, Banerjee and Chowdhury extended this protocol by focussing on a much deeper concept than residual energy and developed ERL-AOMDV[20]. They work on an expected residual lifetime of nodes and try to approximate the completion time of a communication session. Both of the above techniques work in electing optimal routes in multipath routing protocols. Apart from finding multiple routes between source and destination, multipath routing protocol also provides scalability and fault tolerance. A multipath routing protocol is successful in increasing the lifetime of the network. In this field, a fault-tolerant and scalable multipath routing protocol FTSMR [21], was developed by jayalakhsmi which makes use of the Dijkstra algorithm in the creation of multiple paths and implementing route recovery and loop detection to improve the quality of services. HyphaNet [22], a bio-inspired routing algorithm, has been introduced for MANET, which is inspired by the survival of fungi with limited resources in the environment. Simulation results obtained for HyphaNet performs best in low traffic situation but lacks performance good in high traffic scenarios. HyphaNet is further compared with AODV and performs much better than AODV but in comparison to SARA, which is a ACO based routing protocol results are not much better.

Multipath routing protocols are continuously gaining importance due to the reliability offered by them to the ad hoc networks. Further, the efficiency of multipath routing protocols can be enhanced by applying appropriate decision making and intelligent techniques such as fuzzy logic. The next section will discuss some related work of fuzzy logic in mobile ad-hoc networks.

C. Fuzzy Logic Based Routing Protocols.

Fuzzy logic has been applied over priority-based congestion control protocol for wireless body area networks. A two-input and single output fuzzy-based system [23] has been developed by pasandideh et al., which dynamically estimates the Max. Drop Probability (Max_P) by fuzzification of the average queue size and average changed queue size. Further, if the congestion indicator value is greater than the set threshold value, then implicit congestion notification is sent, and transmission is controlled as per requirement. This protocol achieves high performance in terms of packet loss, end to end delay and energy.

Multipath routing protocol based on fuzzy controller system has been designed by pi et al. for mobile ad-hoc networks. The aim of the FMRM [24] algorithm is to develop a fuzzy controller which can reduce the cost of route construction. Multipath routing protocols are capable of providing various alternative paths. In order to have proper utilization of multiple routes, several other requirements pose hindrances. In order to deal with the uncertain, unexpected behaviour of nodes and the mobile environment fuzzy controller has been used. FMRM system calculates the priority index of each packet. For this purpose, expiry time, data rate and queue length of nodes associated with packets have been fuzzified. This approach works towards reducing overhead and increasing the packet delivery ratio.

QoS trust-based model based on uncertain fuzzy rules [25] has been designed, which selects the nodes which are cooperative and capable of handling route requests for a longer period of time. Capability, here measured by considering energy, bandwidth, link stability and cooperativeness, is measured in terms of reliability and quality. Based on these two factors fuzzy expert system applies fuzzy rules in order to calculate the node trust value. The destination node will be going to send a packet on the route with a higher trust value. Since the fuzzy logic-based quality of service model (FQTM) is taking mobility and energy of nodes into consideration, it has contributed significantly by improving packet end to end delay and throughput.

In Mobile Ad-hoc Networks, due to unpredictable and uncertain environments, it is very difficult to find a safe, secure and shortest route. For this purpose, fuzzy logic based reliable and real-time routing protocol [26] has been proposed by ghasemnezad et al., which is going to optimize the efficiency of the routing protocol by using fuzzy logic rules on bandwidth, amount of energy of the battery, no. of hops and degree of dynamicity of nodes. The Fuzzifier system is going to fuzzify the input parameters in order to obtain the optimised route as an output. Results of simulation prove the efficiency of this protocol in terms of improved packet delivery rate, average end to end delay and throughput.

For uninterrupted communication among nodes, energy-efficient stable routing using QoS [27] has been developed by Palaniappan et al., which calculates the link reliability by applying the fuzzy IF-THEN logic rules on the metrics such as link expiry time, link reliable time, link packet error rate and link signal strength. This link reliability metric further calculates the route selection probability. This approach helps in improving the packet delivery ratio and decreasing energy consumption. Some of the recent research in the field of fuzzy logic has been highlighted in table 1.

Table. 1 Fuzzy Logic-based Routing Protocols

S.No.	Routing Algorithm	Multi-Path support	Problem Addressed	Fuzzy Input Criteria	Calculated Output Parameter	Performance Metrics Affected	Limitation Observed
1.	Fuzzy logic based Reliable routing protocol[26]	No	To reduce routing overhead in selecting a stable path	Bandwidth, Battery Energy, no. of Hops, Degree of dynamicity of nodes	Link Stability	Improves PDR, Throughput, Reduces Avg. End to end delay.	No support for multipath routing. Effect on Energy consumption on a network has not been discussed
2.	A Fuzzy Priority-based Scheme in Wireless Body Network[23]	No	To optimize the energy consumption of sensor nodes installed in the patient body by developing a congestion control protocol	Avg. Queue size, Avg. queue size changes	Max_P (Maximum drop probability)	Reduced Packet Loss Ratio, Packet Loss Probability and end to end ratio.	Energy consumption of the proposed protocol does not give appreciable results with the comparable protocol (i.e. PCP & PHTCCP)
3.	An energy-efficient fuzzy-based Routing with Constant threshold in Wireless Sensor Network[28]	No	To improve network lifetime by lessening cluster head selection and transmitted messages in each round	The remaining energy, no. of nodes, a distance of each node for select cluster head	Selecting a cluster head.	Reduces the number of sent messages, Improves network performance by avoiding clustering in all rounds.	Reducing energy consumption to a certain level. Not suitable for a variable mobile environment.
4.	Fuzzy Rule-based Approach for design and analysis of a Trust-based Secure Routing Protocol for MANETs (TBSRPM)	No	To find stable and trusted routes in the highly dynamic MANETs where the shortest route does not guarantee an optimal route	Trust value of nodes, throughput	Encryption action requires	None	Simulation analysis of the proposed work not done Further, it has not been compared with any existing protocol.

	[29]						
5.	Neuro-Fuzzy based cluster formation protocol (FBCFP)[30]	No	To address the issue of fastest nodes energy depletion, which leads to a reduction in nodes performance and increase in delay.	The current Energy level of CH, a distance of CH from sink node, changes area between nodes of a cluster, CH mobility and degree of CH.	Member choice	Avg. Energy Consumption, improved Enhanced network lifetime, Better PDR and reduced delivery ratio	Proposed work assumed that all the nodes are trustful nodes which are not always possible
6.	Fuzzy logic based emergency vehicle Routing[31]	Yes	Reducing the travel time of an emergency vehicle to increase the chances of casualty survival	**Sensor Data Parameters** Sound, co_2, co, temperature difference **Crowdsource Data** Congestion rating, congestion duration.	Congestion Estimate	Generating Aware congestion routes	Strong Network connectivity to sensor node is a challenging issue Trust factors for the data collected from the different sources need to evaluate in order to authenticate the data

In this paper, the efficiency of multipath routing protocols has been enhanced by applying fuzzy Logic decision making on Multipath Priority-based Route Discovery Mechanism. For this purpose, a fuzzy controller for route selection has been designed in the next section.

IV. PROPOSED FUZZY-BASED PRIORITY AD HOC ON DEMAND MULTIPATH DISTANCE VECTOR STABLE ROUTING PROTOCOL (FPAOMDV).

The aim of the proposed work is to develop a decision-making mechanism using fuzzy logic [32], [33] that is able to select a stable path among available alternative paths. For this purpose, a fuzzy route selection controller has been designed and discussed in the following section. Our proposed protocol improves in terms of PDR, delay, throughput and network overhead in a high traffic situation.

A. *Fuzzy Inference System*

A fuzzy logic controller is a decision-maker that is able to handle multiple imprecise variables information in a precise way. Generally, a fuzzy system consists of Input Parameters, Output parameters, Fuzzy IF-THEN rules, Fuzzifier and Defuzzifier. In this paper, a fuzzy logic-based stable route selection algorithm has been designed. The structure of the fuzzy-based proposed system is shown in figure 2. Here three input parameters, namely priority value, residual energy and mobility, have been used for effective decision making based on 27 constructed IF-THEN rules. Fuzzifier will take crisp input values and convert them into fuzzy input. For this purpose, membership functions and linguistic variables have been used. Defuzzifier converts fuzzy output back to the crisp form. Defuzzification is just a reverse process of fuzzification. Finally, a stable route is selected based on the stability parameter, which is the final output of the fuzzy logic controller system.

a) Input Parameters

***1) Priority Value*:** Priority is a finite integer value assigned to an entity that can be exploited to decide the order of preference for selection among various existing entities (i.e., nodes and paths) in Mobile Ad-hoc Networks. Multipath routing protocols provide a reliable way of routing. Multiple paths between source and destination nodes are generated by applying MPRDM in the route discovery process. Multiple paths thus generated needs some mechanism of selection so that an efficient path can be utilized for further transmission of a data packet. Here priority value assigned to the RREP packets at source Node by using multipath priority-based route discovery mechanism can act as deciding factor for selection of stable route among multiple generated routes. Figure 3 shows the membership function plotted for priority value.

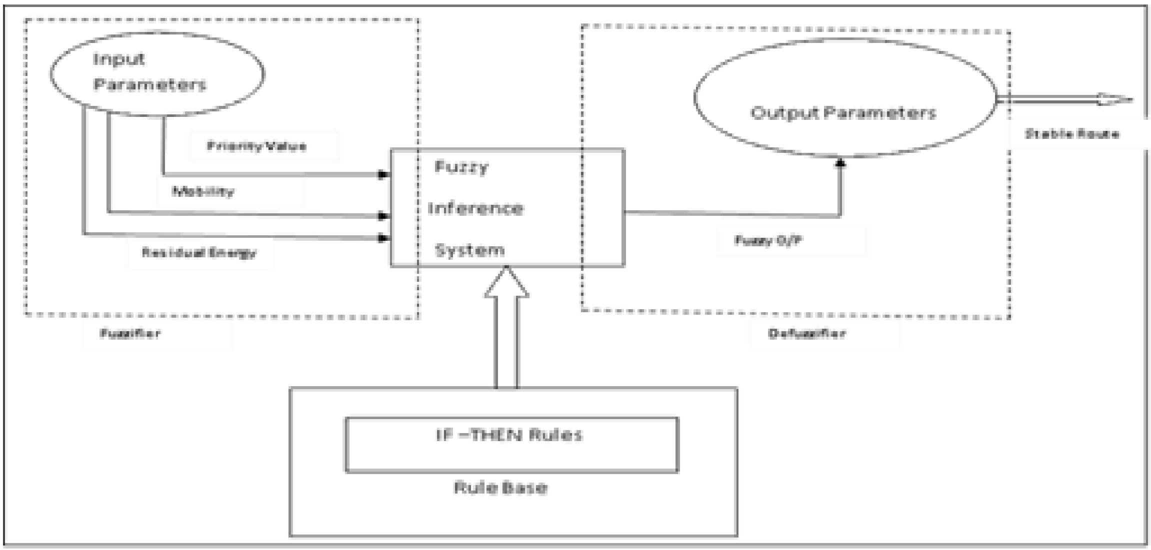

Fig. 2 Fuzzy Route Selection Controller

2) Average Mobility: Mobile Ad-hoc Networks deal with mobile nodes. Nodes keep on changing their position in different directions with respect to time. This dynamic nature of nodes makes this network most uncertain and unpredictable in terms of topology. Mobility thus plays a crucial role in selecting any route for data transmission. Average mobility is calculated along a route taking a ratio of the mobility value of individual nodes to the total no. of nodes along that path. Figure 4 shows the membership function plotted for mobility

$$Avg.M(i) = \frac{\sum_{j=1}^{n} m(j)}{n}$$

Where m(j) is the Mobility value of individual nodes along path i and n is the number of nodes along path i.

***3) Residual Energy*: ** Nodes in Mobile Ad-hoc Networks are battery operated. Energy is being consumed continuously. A node must have a sufficient amount of energy so that it can remain active and live for the longest period of time. Residual Energy **(r.e.)** of node n is the difference between the total energy**(T.E.(n))** of node n and the current energy**(C.E.(n))** of node n. Residual Energy **(R.E.(i))** along path i is the sum of the residual energy (r.e.) of nodes along that path. Figure 5 shows the membership function plotted for residual energy

$$r.e.(n) = T.E.(n) - C.E.(n)$$

$$R.E.(i) = \sum_{i=1}^{n} r.e.(i)$$

b) Output Parameter

1) Stability: Shortest route is not necessarily an optimal path for data transmission. In high mobility, the environment path must be stable so that it can remain active for the longest period of time. Stability is an output Parameter of the FPAOMDV, which is able to make an optimal selection of routes among multiple generated routes. Linguistic variables for stability are shown in table 3, and the membership function plot for stability is shown in figure 6.

$$ST(i) \propto P(i) * R.E.(i)/M(i) \qquad (4)$$

c) Fuzzification

Fuzzification is a process of conversion of Crisp input values (i.e., Priority value, Avg. Mobility, Residual Energy) fed to the fuzzy inference system into the fuzzy input. The membership function is used to map the crisp input values to the real fuzzy values ranging between 0 and 1. Here trapezoidal membership function is used for mapping priority value, residual energy, mobility and stability into their corresponding fuzzy set. Linguistic values such as high, very high, low, very low, medium etc., are used for the representation of fuzzy input values of a fuzzy set, as shown in table 2.

$$P_i \rightarrow \mu_{P_i}(P) \qquad (5)$$

$$M_i \rightarrow \mu_{M_i}(M) \qquad (6)$$

$$R.E_i \rightarrow \mu_{R.E_i}(R.E) \qquad (7)$$

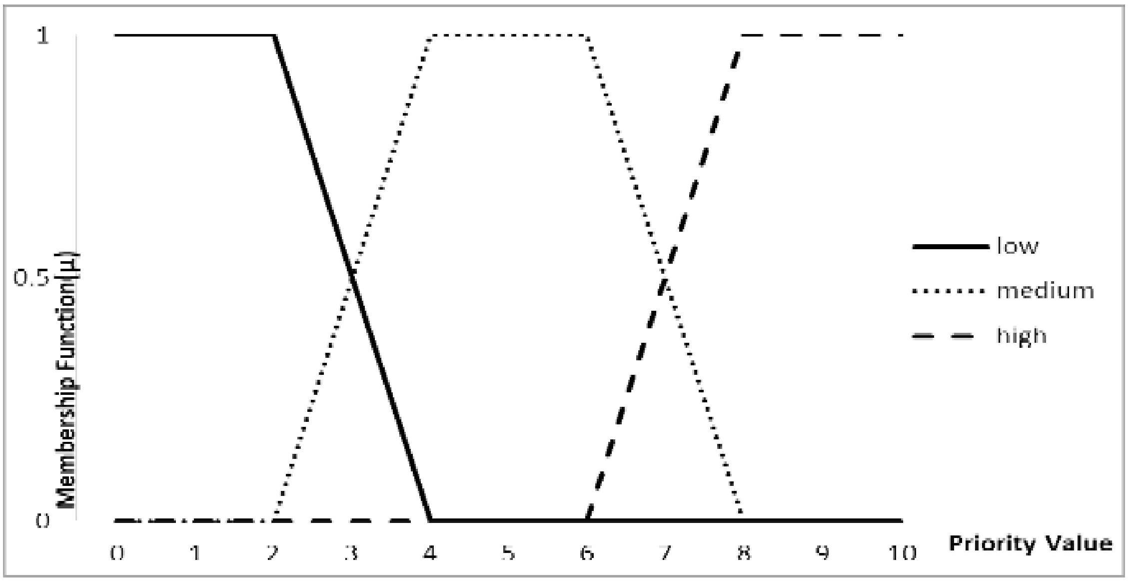

Fig.3 Membership Function Plotted for Priority Value

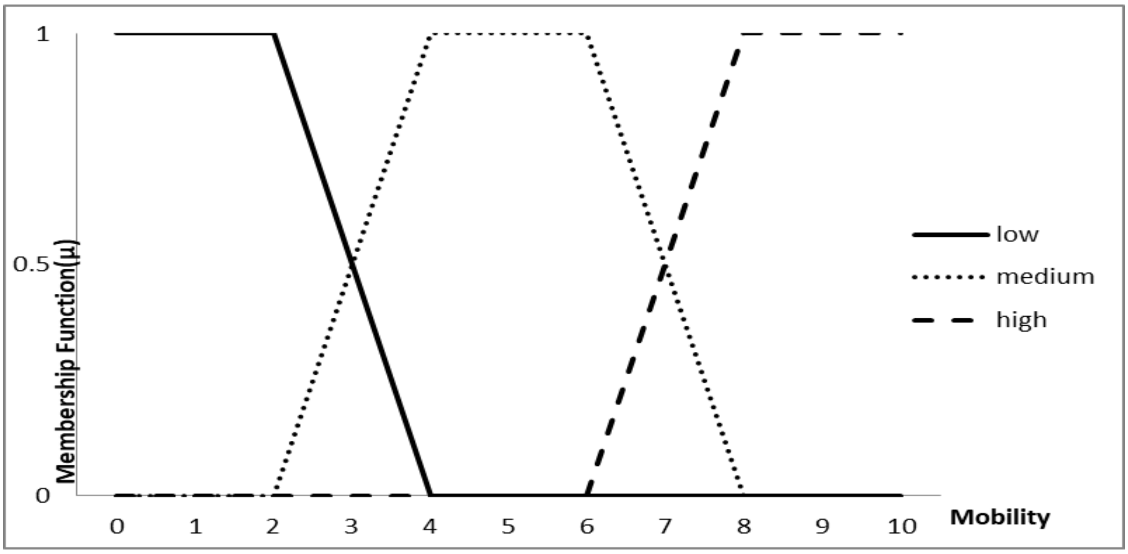

Fig. 4 Membership Function Plotted for Mobility

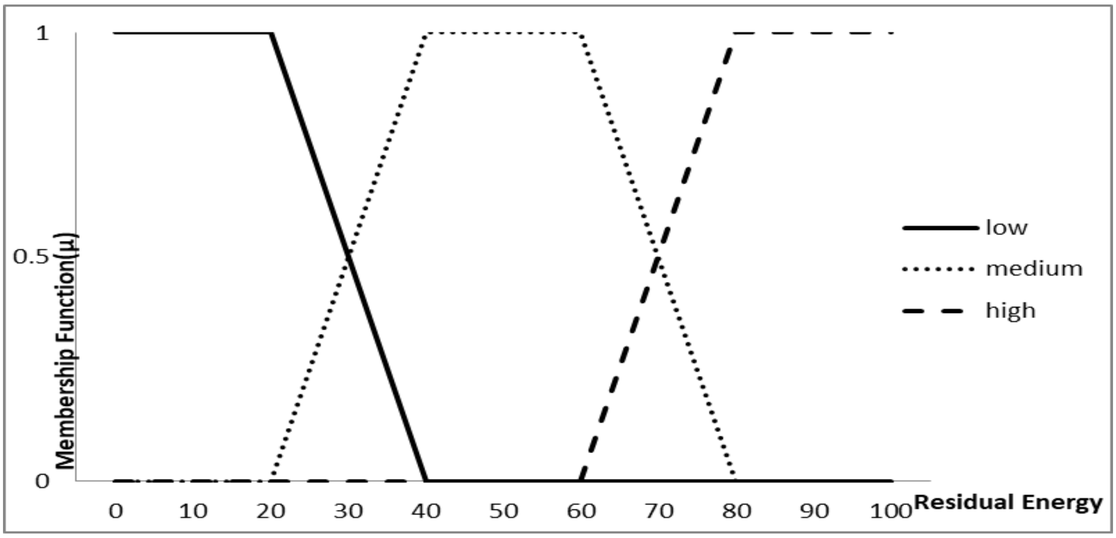

Fig. 5 Membership Function Plotted for Residual Energy

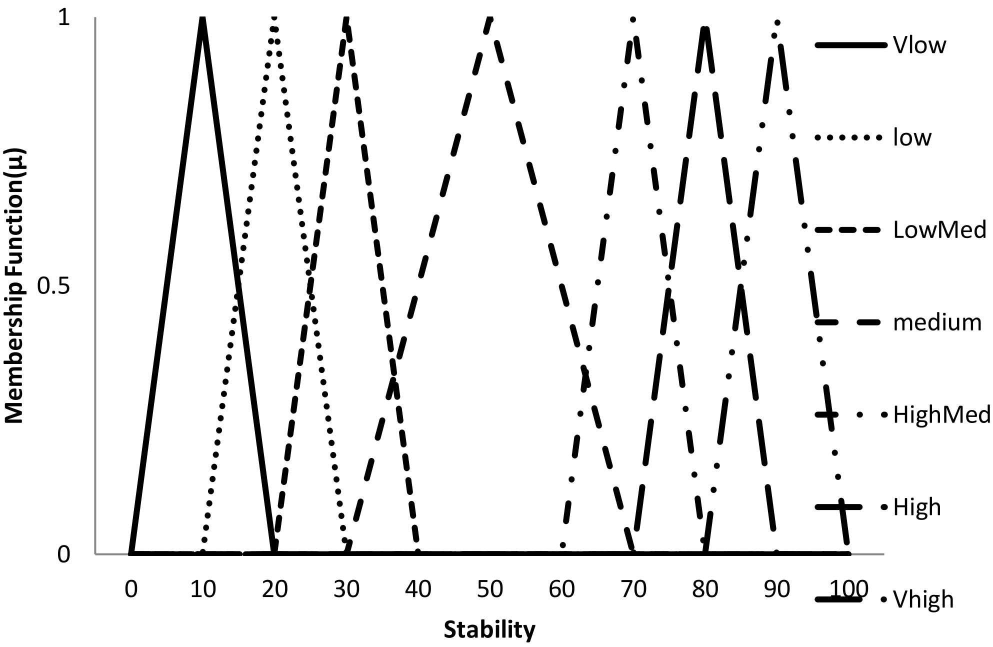

Fig. 6 Membership Function Plotted for Stability

Table. 2 Input Parameters Membership Functions

INPUT	MEMBERSHIP FUNCTION		
Priority Value	Low	Medium	High
Residual Energy	Low	Medium	High
Avg.Mobility	Low	Medium	High

Table 3. Output Parameter Membership Function

OUTPUT	MEMBERSHIP FUNCTION
Stability	VLow, low, LowMedium, Medium, HighMedium, High, VHigh

d) Fuzzy Rules

Fuzzy rules are the IF-THEN rules constructed for effective decision making. For three input parameters, three linguistic variables have been used; therefore, 3^3=27 fuzzy rule sets have been constructed, as shown in table 4.

Stability is calculated by applying a fuzzy rule based on the three input parameters.

- **The rule for Maximum Stability Value:**
  IF (Priority Value is high) AND (Residual Energy is high) AND (Mobility is LOW) THEN (Stability is very high).
- **The rule for Minimum Stability Value:**
  IF (Priority Value is low) AND (Residual Energy is low) AND (Mobility is high) THEN (Stability is very low).

e) Defuzzification:

Defuzzification is the reverse process of fuzzification. Here the fuzzy output is converted back to the crisp real-world values. For this purpose, the centroid method has been used.

$$\mathbf{STi}\,\big(\mu(\mathbf{COG})\big) = \frac{\sum_{i=1}^{n} \mu(xi) * X(ci)}{\sum_{i=1}^{n} \mu(xi)} \quad (8)$$

X(ci): CenterPoint of Output Linguistic Term (X_i).
μ(COG): Membership Function of Output Linguistic Term.
μ(xi): Membership Function value of Linguistic Input Term

Table 4. Logical Rule Sets

Priority Value	Residual Energy	Mobility	Stability
Low	Low	Low	Low
High	High	Low	VHigh
Low	High	Low	LowMed
High	Low	Low	LowMed
Low	Medium	Low	HighMed
Medium	Low	Low	LowMed
Medium	Medium	Low	HighMed
Medium	High	Low	HighMed

High	Medium	Low	High
Low	Low	Medium	Low
High	High	Medium	High
Low	High	Medium	HighMed
High	Low	Medium	LowMed
Medium	Low	Medium	Low
Low	Medium	Medium	Low
Medium	High	Medium	HighMed
High	Medium	Medium	HighMed
Medium	Medium	Medium	Medium
Low	Medium	High	Low
Medium	Low	High	Low
Medium	Medium	High	LowMed
Low	Low	High	Verylow
Low	High	High	Low
High	Low	High	Low
High	High	High	High
Medium	High	High	HighMed
High	Medium	High	HighMed

B. Route Discovery

Multipath routing maintains reliability in routing packets from source node to destination node. To develop a multipath routing protocol, some factors need to be considered, such as energy and mobility. Energy is one of the constraints of the MANETs whose depletion can lead to a path failure. Here one more factor, i.e., priority, has been introduced, which will be able to prioritize paths based on cumulative energy, Max._E. And Min._E. Available along paths, here, MPRDM has been used. After prioritizing the multiple paths, further to enhance the efficiency of routing protocol, a novel routing protocol FPAOMDV, based on intelligent fuzzy-based decision making, has been introduced. This protocol has used Multipath priority-based route discovery mechanism, and fuzzy logic based multipath stable route selection mechanism as described in algorithm 1, and pictorial representation of the process is shown with the help of flowchart in figure 13. Source node will initiate and flood RREQ packets, and destination node will reply with corresponding RREP packet towards source node on the reverse path. The whole process of sending RREQ and generating the RREP packet will be done using MPRDM. Now, based on assigned priorities source node calculates the total priority value. Now fuzzy route selection controller will initiate FMSRSM and apply fuzzy rules on every generated path with a priority value, residual energy and mobility as input parameters. Source calculates stability value of each path by applying equation 4, and then path with the highest value of stability parameter will be selected for further transmission of packets. Intermediate nodes will update their routing table whenever update messages or control messages arrive. This protocol is able to select a stable path that considers dynamic factors such as energy and mobility, which changes within a short span of time. A protocol has the advantage of getting information on the life of a path in advance, prior to starting communication, which will further help in increasing the lifetime of the network. The working of the protocol has been illustrated with the help of an example.

Algorithm 1: Algorithm for Fuzzy based Multipath Stable Route Selection Mechanism (FMSRSM)

Input: *Source Node(S) receives multiple* ***RREP*** *packets using MPRDM*

Output: *Selection of Stable Route based on Stability metric.*

Begin

Source Node Calculates Total Priority Value (P_i), Avg. Mobility (M_i), Residual Energy ($R.E._i$) *along path i.*
P_i obtained from MPRDM. M_i and $R.E._i$ are calculated as follows:

$$r.e.(n) = T.E.(n) - C.E.(n)$$

r.e is the residual energy at node n calculated by subtracting current node energy from total energy value at node n

$$R.E.(i) = \sum_{i=1}^{n} r.e.(i)$$

$$Avg.M(i) = \frac{\sum_{j=1}^{n} m(j)}{n}$$

Where m(j) is the Mobility value of individual nodes along path i and n is the number of nodes along path i.

Fuzzification of P_i, M_i & $R.E_i$.

$$P_i \rightarrow \mu_{P_i}(P)$$
$$M_i \rightarrow \mu_{M_i}(M)$$
$$R.E_i \rightarrow \mu_{R.E_i}(R.E)$$

Compute *Stability (ST)*

$$ST(i) \propto P(i) * R.E.(i)/M(i)$$

Defuzzification using the Centroid method.

$$\boldsymbol{ST(i)}\ (\mu(\boldsymbol{COG})) = \frac{\sum_{i=1}^{n} \mu(\boldsymbol{xi}) * \boldsymbol{X(ci)}}{\sum_{i=1}^{n} \mu(\boldsymbol{xi})}$$

X(ci): CenterPoint of Output Linguistic Term (X_i).
μ(COG): Membership Function of Output Linguistic Term.
μ(xi): Membership Function value of Input Linguistic Term.

Source Node(S) selects path having the highest value of *Stability* metric (ST)
Source Node(S) sends data packets along the most stable selected route.

End

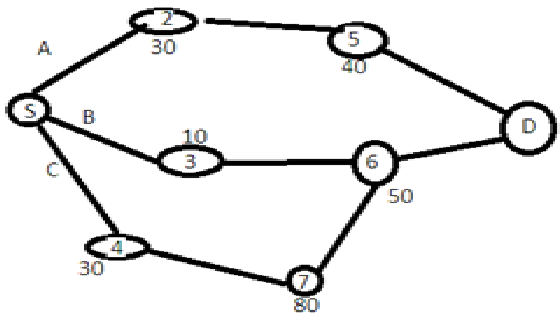

Fig. 7 Network of Nodes

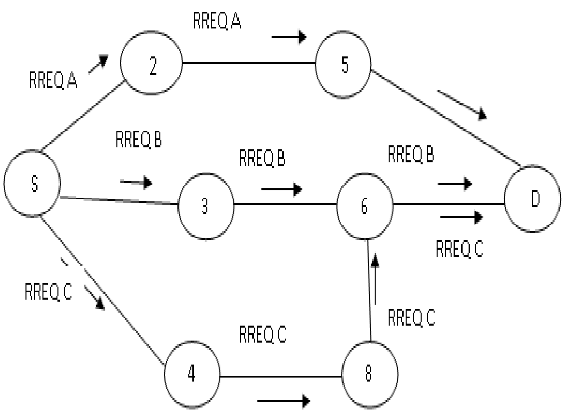

Fig. 8 Forwarding RREQs

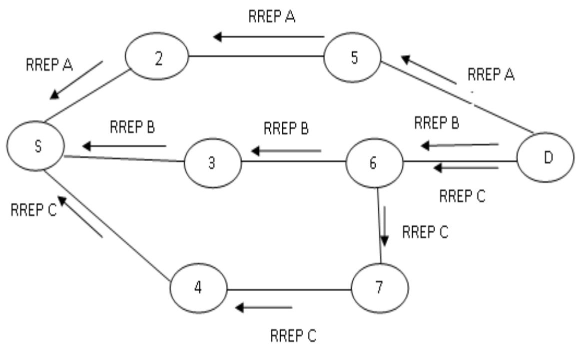

Fig. 9 Destination Sending RREPs along Reverse Path

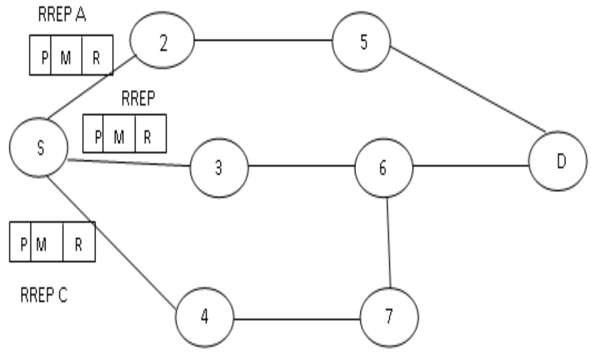

Fig. 10 Source Node calculating Priority using MPRDM

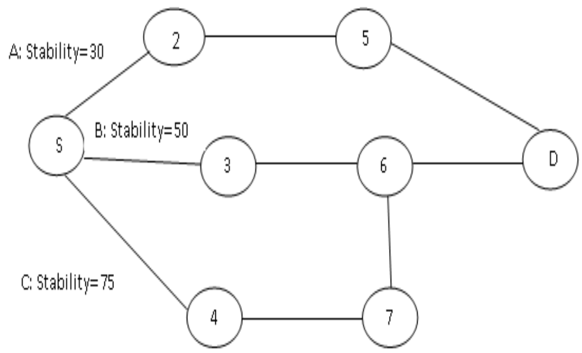

Fig. 11 Source Node Calculating Stability using FLSRSM

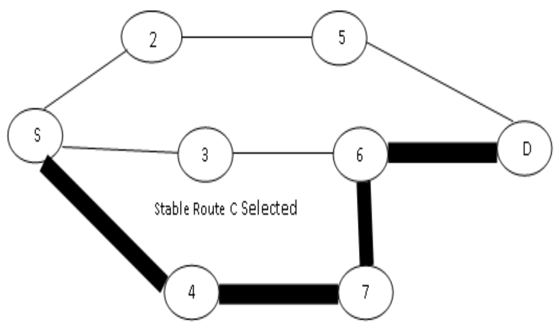

Fig. 12 Stable Route C Selected

Table 5. Calculation of Stability Value of Routes

RREP Packets	Route	Total priority Value	Mobility	Residual Energy	Stability	Stable Route is C
RREP(A)	A	6	2	20	30	
RREP(B)	B	4	5	60	50	
RREP(C)	C	8	8	70	75	

Figure 7 shows a network of nodes, where S is a source node and D is a destination node. The current Energy value has been mentioned along with every node. Multipath priority-based route discovery mechanism will initiate route discovery process by forwarding RREQ packet as shown in figure 8. Multiple route replies will be received by the source node corresponding to the RREQ packet reached at the destination node, as shown in figure 9. Source Node will calculate the total priority value individually for every RREP packet using MPRDM and insert it in the RREP packet along with avg. Mobility and residual energy of that path as shown in figure 10. Fuzzy based decision-making process will be going to calculate stability value as per algorithm 1, as shown in figure11. Route C with the highest stability value has been selected, as shown in figure 12. Table 5 calculates the stability parameter value corresponding to every RREP packet.

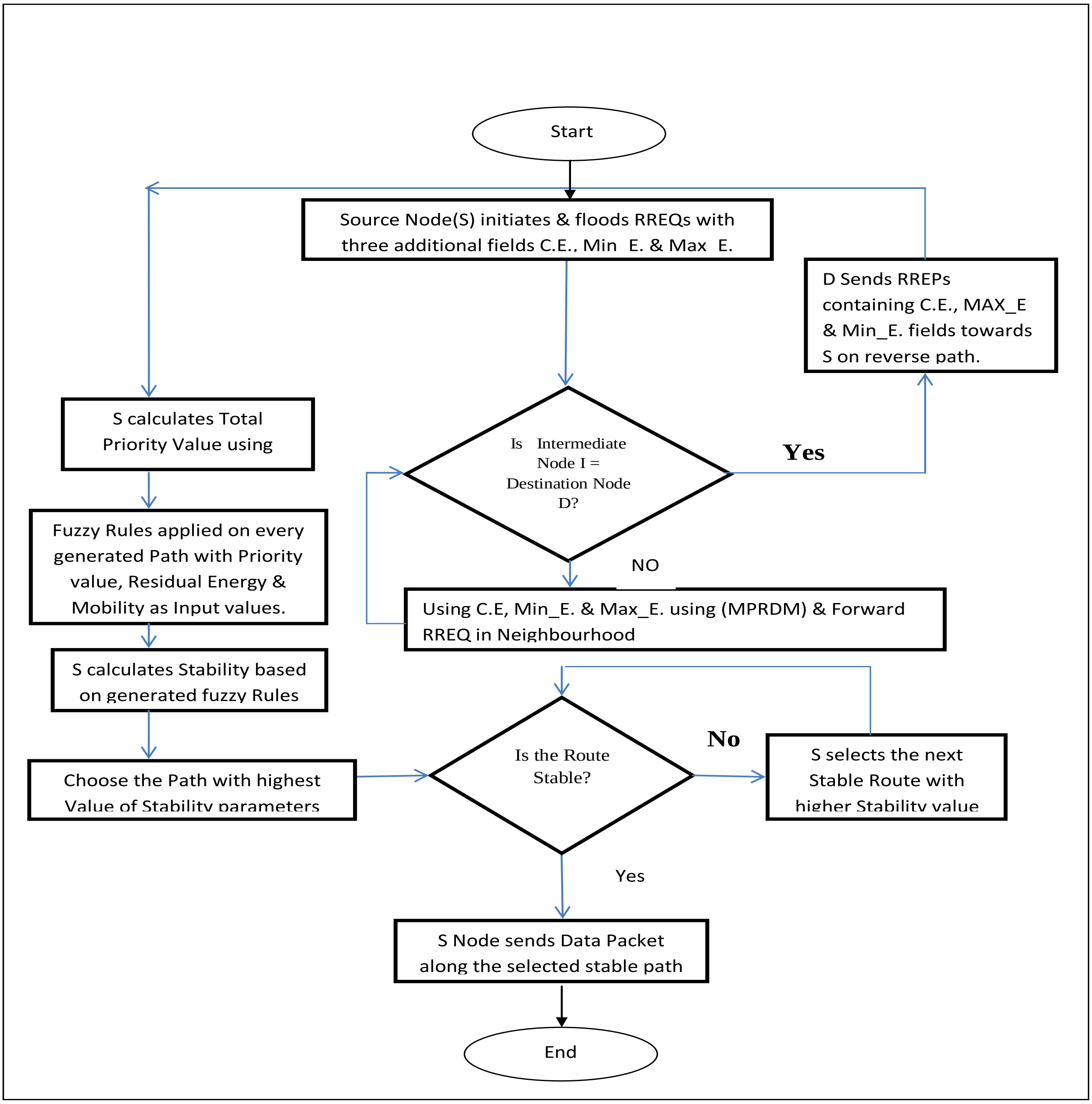

Fig. 13 Flowchart of Fuzzy Logic Based Stable Route Selection Mechanism

C. Route Maintenance

The dynamic nature of MANETs may lead to the failure of a certain path with time. There can be many other reasons for the failure of paths, such as the low energy level of nodes along that path which results in node failure. MANETs require a continuous update of the information in the database stored at all the nodes of the network. This updation of information is done in the route maintenance phase. If the residual energy of the path is not sufficient to hold further communication among nodes, then nodes along that path will update their routing table and send RERR message to the source node so that FPAOMDV can use an alternate path for further communication or it has an option to start route discovery again in case of unavailability of alternate paths.

V. SIMULATION ENVIRONMENT AND SET UP

FPAOMDV simulation has been performed using MATLAB 2014a and NS-2.34 software packages[34, p. 2]. Fuzzification, defuzzification and fuzzy decision-making rules generation has been done on MATLAB fuzzy toolbox. Network simulation of mobile nodes for routing protocols has been performed on an open-source discrete event Network Simulator 2.34; hence the performance of FPAOMDV has been compared with HyphaNet, AODV, and SARA. AODV is well known classical routing protocol for MANETs whereas, SARA is an ACO based routing protocol, and HyphaNet is a bio-inspired routing protocol for fungi networks. Four scenarios have been studied and tested using CBR traffic type with variation in Pause time, connections, packets size and packet transmission rate.

A. Performance Metrics

Performance metrics are used to analyze the performance of the routing protocol. In a view to analyzing FPAOMDV performance in comparison to AODV, SARA and HyphaNet following metrics were considered.

1) Throughput: Throughput is commonly termed as transfer rate. It is expressed in kbps. It gives the measure of the average amount of data received by the destination nodes per unit of time.
2) End to End Delay: End to end delay is used to calculate the total amount of time taken for transmission, propagation and receiving of a data packet from sender to receiver nodes. It is generally expressed in seconds (s).
3) Packet Delivery Ratio (PDR): PDR is the ratio of the total number of packets successfully received at the destination node to the total number of a packet sent from the source node to the destination node in MANETs.

$$PDR = \frac{No.of\ Data\ Packets\ Sucessfully\ Received\ at\ the\ Destination}{No,of\ Data\ Packet\ Originated\ from\ Source} \quad (9)$$

4) Network Overhead: Network overhead or routing overhead is a measure of the efficiency of the system. It is expressed as

$$Overhead = \frac{No.of\ Control\ Packets}{No,of\ Data\ Packet\ Packets + No.of\ Control\ Packets} \quad (10)$$

More the number of control packets used by the routing algorithm, more routing overhead will be added to the network

B. Scenario 1

In this scenario, as shown in table 6, CBR traffic type is simulated over 20 connections. The area of simulation is 1000*1000 m^2. Connections are sending packets of 64-byte size with a packet transmission rate of 4 packet/s. A network has 100 nodes where a random waypoint model is used to generate nodes mobility. Speed is being defined with the interval [0-20] m/s. Simulation has been performed for 180s with a set of pauses [0, 15, 30, 60, 120, 240] s.

Table 6. Scenario 1 Modelling Parameters

Traffic Type	CBR
#Connections	20
Packet Size	64 byte
Speed	0-20 m/s
Packet Transmission Rate	4 Packet/Second
#Nodes	100
Mobility Model	Random way Point Model
Network Topology	1000*1000
Simulation Time	180 s
Antenna	Omnidirectional
Pause Time	0,15,30,60,120,240

C. Scenario 2

Table 7. Scenario 2 Modelling Parameters

Traffic Type	CBR
#Connections	10,20,40
Speed	0-20 m/s
Packet Size	64 byte
Pause Time	0
Packet Transmission Rate	4 Packet/Second
Simulation Time	180 s
#Nodes	100
Network Topology	1000*1000
Antenna	Omnidirectional
Mobility Model	Random way Point Model

Under this scenario shown in table 7 number of connections have been varied with CBR traffic pattern at zero pause time that is sending 64-byte packet size at a rate of 4 packet/seconds. 100 nodes with varying speed [0-20] m/s have been studied for 10, 20, and 40 numbers of connections for 180 s simulation time.

D. Scenario 3

Scenario 3, as shown in table 8, uses a random waypoint model having 100 nodes with CBR traffic of 20 connections. Here the 64-byte size of packets has been transmitted at different packet rates: 1, 2, 4 and 8 packets/second. The system runs for 180 s with zero pause time.

Table 8. Scenario 3 Modelling Parameters

Traffic Type	CBR
#Connections	20
Speed	0-20 m/s
Pause Time	0
Packet Size	64 byte
Simulation Time	180 s
Packet Transmission Rate	1,2,4 and 8 Packet/Second
#Nodes	100
Network Topology	1000*1000
Antenna	Omnidirectional
Mobility Model	Random way Point Model

E. Scenario 4

Scenario 4, as per table 9, considers simulations with 20 CBR traffic connections. Here the size of packets has been varied as 64, 512, 1024 bytes at a packet transmission rate of 2 packets/second. Speed of the nodes has been taken in the interval [0-20] m/s. RWP model uses pause time and simulation set up runs for 180 seconds.

Table 9. Scenario 1 Modelling Parameters

Traffic Type	CBR
#Connections	20
Speed	0-20 m/s
Packet Size	64, 512,1024 bytes
Pause Time	0
Packet Transmission Rate	2 Packet/Second
Simulation Time	180 s
#Nodes	100
Network Topology	1000*1000
Antenna	Omnidirectional
Mobility Model	Random way Point Model

VI. SIMULATION RESULTS AND ANALYSIS.

A. Performance Evaluation based on Scenario 1.

The effect of using the multipath routing along with the assignment of priorities to various paths on the basis of energies is visible in the delays, as with the increase in the pause time, the delays almost remain constant without any significant increase. The delays of FPAOMDV are significantly low as compared to other protocols (i.e. AODV, SARA and HyphaNet), as seen in figure 15. The reason for lower delays as compared to other protocols is attributed to the changes in the priorities of paths according to their availability and energies. This results in the availability of the best

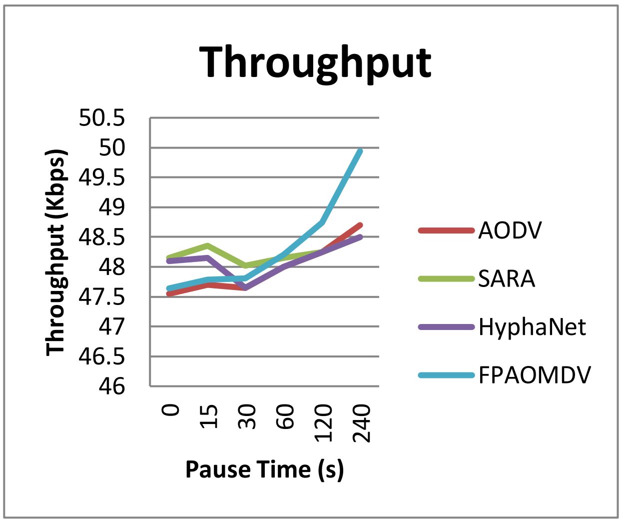

Fig. 14 Throughput Performance in scenario 1

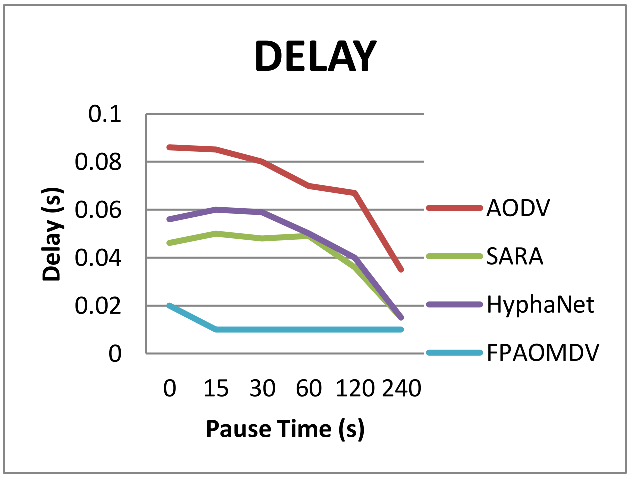

Fig. 15 Delay Performances in Scenario1

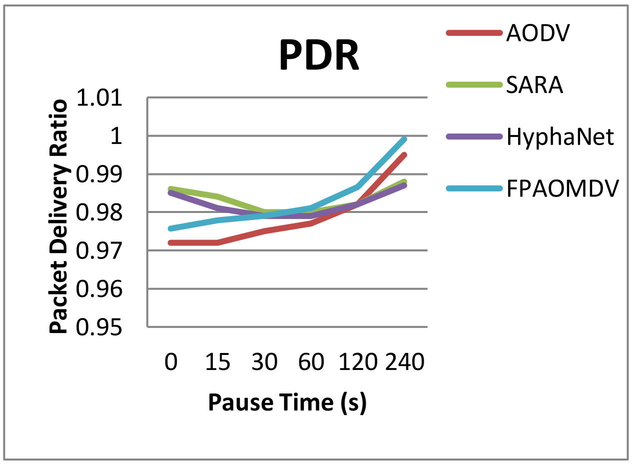

Fig. 16 PDR Performances in Scenario1

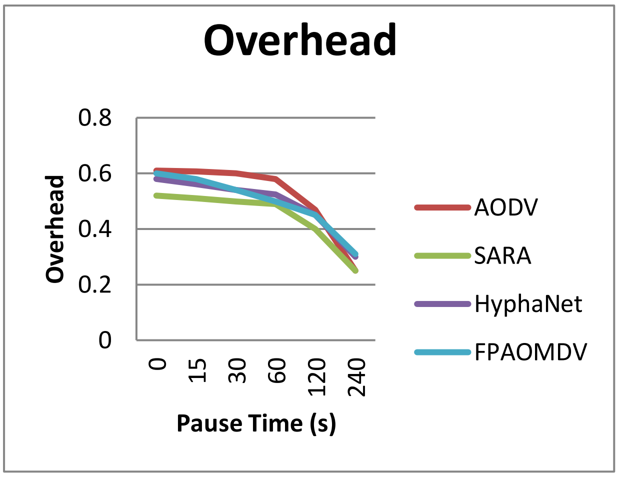

Fig. 17 Overhead Performance in Scenario 1

Path for transmission. At the same time, FPAOMDV does not compromise on either the Packet delivery ratio or the throughput.

Figure 14 and 16 clearly shows that the throughput and packet delivery ratio increases more in the case of FPAOMDV as compared to other protocols. However, for obtaining better results in terms of Delay, Packet delivery ratio and Throughput, FPAOMDV makes use of a greater number of control packets. These control packets help in maintaining up to date topological information. The greater number of control packets results in a slight increase in FPAOMDV overhead, as in figure 17. However, this increase in overhead can be compromised for obtaining better results in terms of other metrics.

B. Performance Evaluation based on Scenario 2

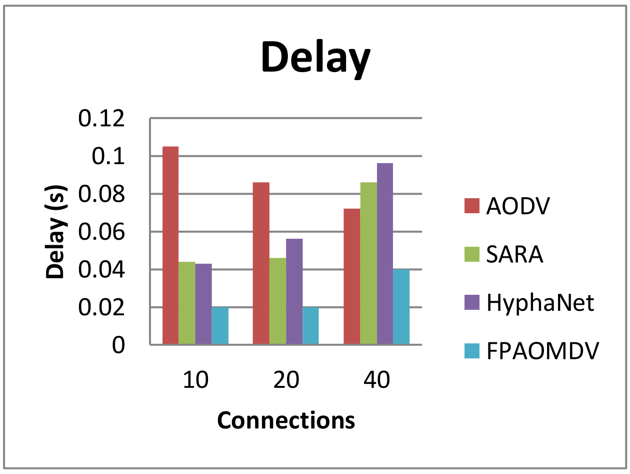

Fig. 18 Delay Performances in Scenario 2

A number of connections represent the load conditions of the network. A small number of connections represents the low load conditions and a large number of connections signify the high load conditions. With an increase in the number of connections in the network, the topological information stored on the nodes increases; this results in the availability of more paths with a node to some other node. This further leads to lower delays (figure 18), better Packet Delivery Ratio (figure 19) and greater throughput (figure 20).

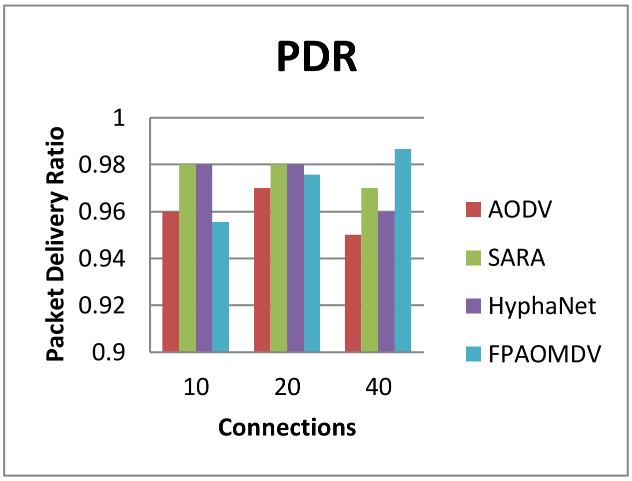

Fig. 19 PDR Performances in Scenario 2

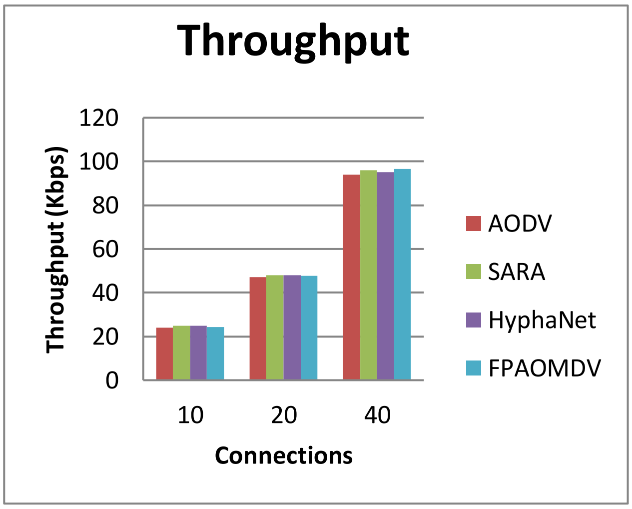

Fig. 20 Throughput Performance in scenario

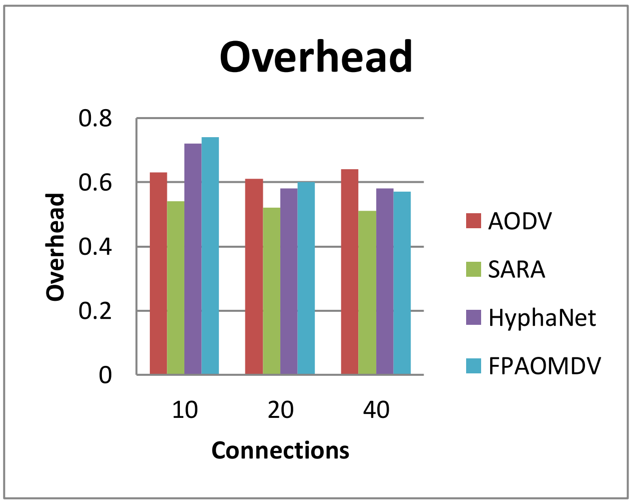

Fig. 21 Overhead Performance in scenario

The lower overhead (figure 21) and better results in terms of Packet delivery, delays, and throughput signify the suitability of FPAOMDV for high load conditions.

C. Performance Evaluation based on Scenario 3

The lower data rates resemble the suitability of protocol for lower bandwidth usage, and the higher data rates signify the suitability of protocol for applications having high bandwidth requirements. With the increase in the number of packets transmitted per second, the performance of FPAOMDV increases and hence making it more suitable for high bandwidth requirements based applications. Figure 22 e 25 shows the result

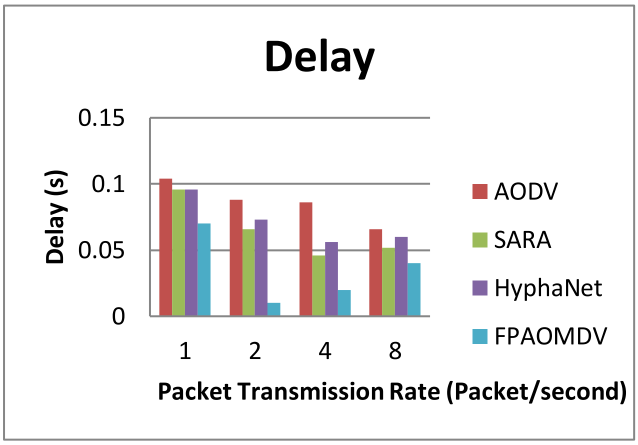

Fig. 22 Delay Performances in Scenario 3

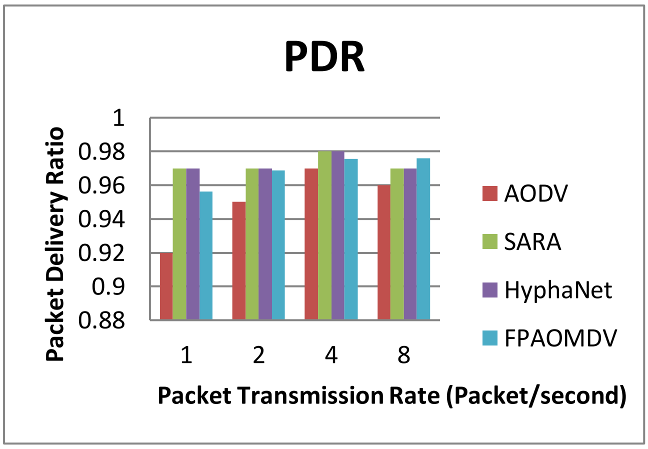

Fig. 23 PDR Performances in Scenario 3

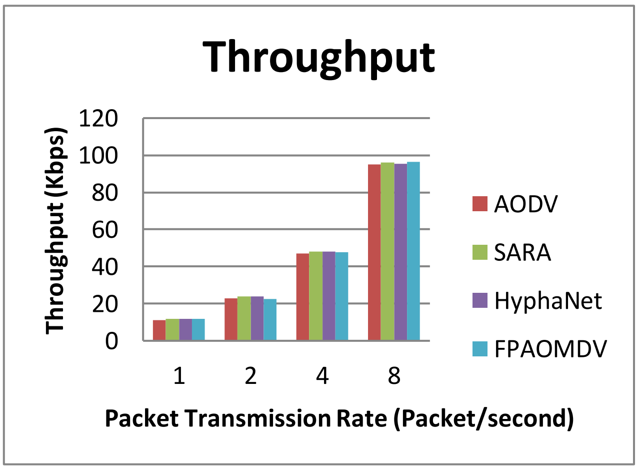

Fig. 24 Throughput Performance in Scenario 3

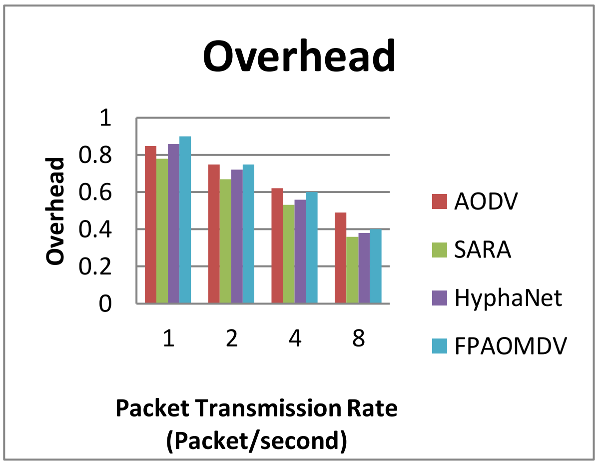

Fig. 25 Overhead Performance in Scenario 3

D. Performance Evaluation based on Scenario 4

With variations in packets sizes, the protocol continues to deliver well in terms of delays. This is attributed to the process of prioritizing the routes followed by FPAOMDV. At the same time, FPAOMDV provides marginally better results in terms of other metrics like Packet delivery ratio and throughput by using slightly more number control packets in a few cases as compared to other protocols. However, this slightly increased overhead is expected to maintain an updated state of multiple paths and their updated priorities. Priority-based generation of multiple paths considers the energy factor along with every generated path, which is able to provide high energy stable paths for high sized packets, which results in less number of route breakage. Further, the intelligent fuzzy-based decision making discovers stable routes, which decrease route failure hence resulting in less overhead when packet size increases. When packet size increases, route breakage is frequent due to available low energy routes that result in a high frequency of route discovery. Figure 26 e 29 shows the results.

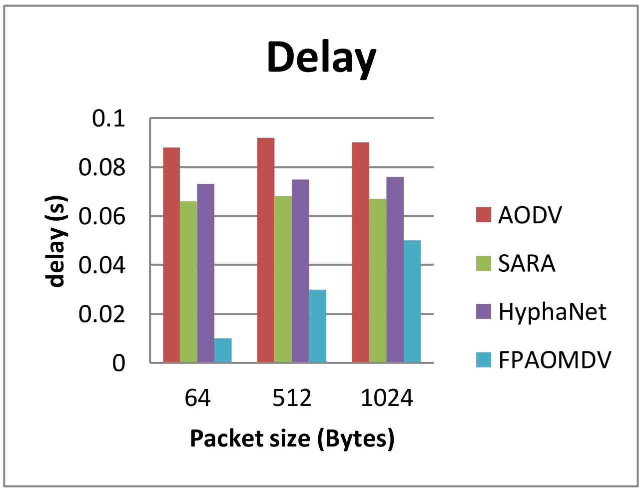

Fig. 26 Delay Performance in Scenario 4

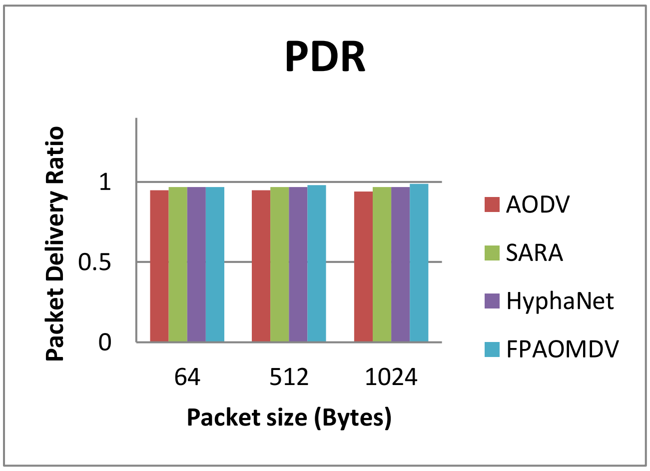

Fig. 27 PDR Performance in Scenario 4

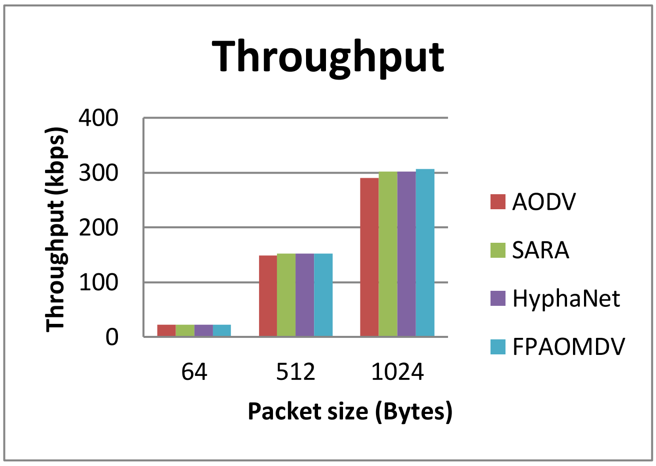

Fig. 28 Throughput Performance in Scenario 4

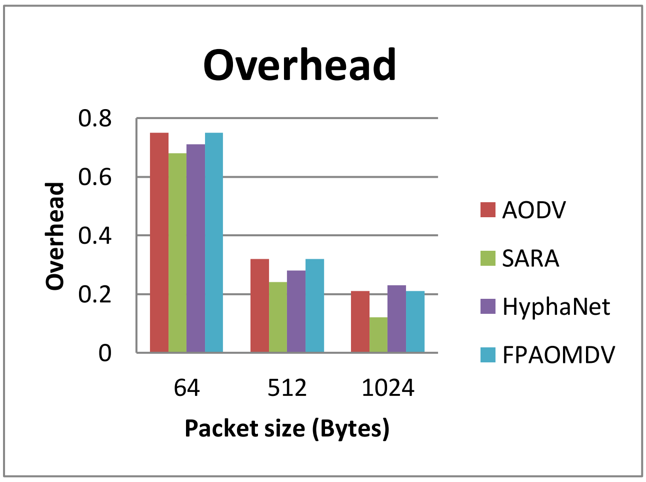

Fig. 29 Overhead Performance in Scenario 4

VII. CONCLUSION

The efficiency of the routing protocol is estimated by the quality of service provided by the protocol for transmitting the data packets between a pair of nodes. Multi-path routing protocols are the most reliable and efficient routing protocols that exist to date. The various factors, such as the availability of more than one path load distribution, adds to the benefits of multipath routing. Encouraged by the benefits of the multipath routing protocols in the mobile environment, Multi-path Priority-based Route Discovery Mechanism has been used, which calculates and assigns the priority to the multiple routes between a pair of nodes. This priority value of routes, along with calculated average mobility and residual energy along a path, is used as an input to fuzzy route selection controller, which is used for the development of fuzzy-based priority ad-hoc on-demand multipath distance vector stable routing protocol (FPAOMDV). The simulation of a protocol using the network simulator proved the efficiency and effectiveness of the protocol in controlling various uncertainties of the Mobile Ad Hoc Networks. It rightly provides stability and reliability and selects the route that has a sufficient amount of energy to hold continuous data transfer. Performance evaluation of the FPAOMDV with other routing protocols on NS-2.4 based on four scenarios outperforms in terms of PDR, delay, throughput and overhead in high traffic situations, therefore, resulting in an overall increase in the total lifetime of the network. However, there is definitely a scope of work that can be done to decrease the overhead by further limiting the number of control packets. But, an unforeseen decrease in the number of control packets is also a limiting factor in getting the true benefits of multipath routing. This opens up an area for further investigation and research by inculcating more uncertainties of the mobile networks.

VIII. DECLARATION

For conducting this research work, no financial assistance has been taken and further, it is stated that the authors of this paper have no conflict of interest.

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