Fuzzy Based Priority Ad Hoc on Demand Multipath Distance Vector Stable Routing protocol (FPAOMDV)

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Research Article

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Abstract-Mobile ad-hoc networks are the most uncertain type of networks. Uncertainty occurs due to the mobile nature of the nodes, continuous consumption of energy and bandwidth results in 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 data transfer between source and destination node. Multipath routing protocol ensures reliable communication by providing multiple paths between source and destination nodes. To choose 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 which is able to make precise and accurate decision in multi variable, uncertain and imprecise situation. 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 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 Fuzzy Logic Based Stable Route Selection mechanism (FLSRSM) which calculates stability value of different routes based on priority value, average mobility and residual energy along the paths FLSRSM is able to make 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 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, Priority, Route Discovery, Routing, Stability.

1. Introduction

Ad-hoc networks are the highly dynamic, mobile and unpredictable type 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 in mobile ad-hoc networks is continuous consumption of energy of nodes with time. Maintaining sufficient amount of energy at each and every nodes of network is a prerequisite for consistent communication among nodes of network, thus to carry out routing in MANET is a challenging task. Quality of service (QoS)[1] ensures healthy communication among the nodes of network. It is way of transferring data from one node to other in an efficient way.

Now a days, routing not only concentrates on transferring data from source node to destination node, but also it is highly responsible for the transfer of data in a most secure, reliable and stable way. Earlier Uni-path[2] routing was used which discovers only single path between two particular nodes, who are participating in the communication. In recent era of research, Multi-path routing [3] is the first choice of 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 which is always keep 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 have studied. A part from this multipath routing reduces delay, maximizing 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 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 integer value that is assigned to an entity which can decide the order of preference given to it. Here priority is utilized for assigning the order of preferences given to the generated multiple routes. Fuzzy logic [12] is an intelligent decision making technique which helps in making efficient decision for effective node and route selection when number of network constraints 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 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 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 is able to make 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 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 the 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. As, the nodes failures due to limited energy life may lead to failure at the transmitting nodes and thus resulting the high rate of dropped packets. So all these factor 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 considering 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 Rest of the paper has been organized as follows: Section 2 defines the problem. Section 3 cover the literature related to multipath routing protocols and fuzzy based routing protocols so far studied Section 4 presented the proposed fuzzy based priority ad hoc on demand multipath distance vector stable routing protocol. Section 5 describes the simulation environment and set up used on NS 2.4. Section 6 done the performance evaluation of proposed protocol based on four scenarios and compared the simulation results with other routing protocols. Section 7 concludes the work.

2. Problem Definition

A Mobile Ad-hoc Network can be represented as graph G (V, E) where V represents number of nodes and E represents the unidirectional links. Mobile ad-hoc network 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 a day's research mainly focuses on multi path routing. In this uncertain and dynamic environment, to make a decision regarding selection of optimal path 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 which is capable of handling multiple parameters at same time along with the vagueness and impreciseness in the input parameters. For the selection of 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 stability 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 the 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).

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

$$r.e.(n) = T.E.(n) - C.E.(n) \quad (2)$$

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

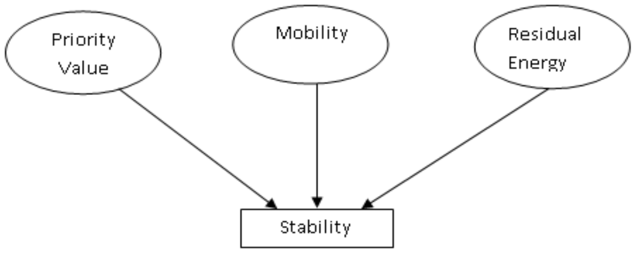

Figure 1 Fuzzy based Route selection System

3. Related Works

3.1. Overview of Routing Protocols

To route a packet from source node to 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 which are common to every routing protocols 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 one hop distance. They are further broadcasted by the intermediate node till they reach their destination node, which generates RREP packet corresponding to the received RREQ packet and send 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 which is followed by every routing protocol in Mobile Ad-hoc Networks (MANETs). There are number of issues which occur due to 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 dynamic environment multipath routing protocols are more preferred as compared to uni-path routing protocols. Next section will focus on the literature studied in the field of multipath routing.

3.2. Multipath Routing Protocols

Mobile nodes are battery operated, hence require sufficient amount of energy to remain active in mobile ad-hoc network that's why providing an energy efficient routing protocol in MANETs is a key area of research and is more focussed by the researchers now a days. 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 network traffic such as increase in number of dead nodes in network. In order to decrease the number of dead nodes in network, continuous work is going on in 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 reduces over utilization of specific nodes of networks. Due to limited energy availability in wireless nodes of a network, 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 mechanism proposed by ponnuswamy that is able to enhance network lifetime. This technique is successful in minimizing the energy cost in multipath communication. Residual energy of node is referred as the remaining energy of node which is available for further transmission of 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 possess highest minimum residual energy for communication. Further banerjee and chowdhury extended this protocol by focussing on much deeper concept than residual energy and developed ERL-AOMDV[20]. They work on 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 route in multipath routing protocols. Apart from finding multiple routes between source and destination, multipath routing protocol also provides scalability and fault tolerance. Multipath routing protocol is successful in increasing the lifetime of network. In this field a fault tolerant and scalable multipath routing protocol FTSMR [21] was developed by jayalakhsmi which makes use of dijkstra algorithm in 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 environment. Simulation results obtained for hyphaNet performs best in low traffic situation but lacks to perform 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. Next section will discuss some related work of fuzzy logic in mobile ad-hoc networks.

3.3. Fuzzy Logic Based Routing Protocols.

Fuzzy logic has been applied over priority based congestion control protocol for wireless body area network. 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 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. Aim of FMRM [24] algorithm is to develop a fuzzy controller which can reduce the cost of route construction. Multipath routing protocols are capable in 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 mobile environment fuzzy controller has been used. FMRM system calculates priority index of each packet. For the purpose, expiry time, data rate and queue length of nodes associated with packet has been fuzzified. This approach works towards reducing overhead and increases 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 in handling route request for the 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. Destination node will be going to send packet on the route with higher trust value. Since fuzzy logic based quality of service model (FQTM) is taking mobility and energy of nodes in to consideration, it has contributed significantly by improving packet end to end delay and throughput.

In Mobile Ad-hoc Networks, due to unpredictable and uncertain environment, 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 routing protocol by using fuzzy logic rules on bandwidth, amount of energy of battery, no. of hops and degree of dynamicity of nodes. Fuzzifier system is going to fuzzify the input parameters in order to obtain the optimize 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

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 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 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 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 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	Remaining energy, no. of nodes, distance of each nodes for select cluster head	Selecting a cluster head.	Reduces number of sent messages , Improves network performance by avoiding clustering in all rounds.	Reducing the energy consumption to certain level. Not suitable for variable mobile environment.
4.	Fuzzy Rule based Approach for design and analysis of a Trust based Secure Routing Protocol for MANETs (TBSRPM) [29]	No	To find stable and trusted routes in the highly dynamic MANETs where 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.
5.	Neuro-Fuzzy based cluster formation protocol (FBCFP)[30]	No	To addressed the issue of fastest nodes energy depletion which leads to reduction in nodes performance and increase in delay.	Current Energy level of CH, distance of CH from sink node, changes area between nodes of 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 is 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 **Crowed source Data** Congestion rating, congestionduration, congestion estimate		Generating congestion Aware routes	Strong Network connectivity to sensor node is a challenging issue Trust factor for the data collected from different source need to evaluate in order to authenticate the data

link reliability metric further calculates the route selection probability. This approach helps in improving packet delivery ratio and decreasing the energy consumption. Some of the recent research in the field of fuzzy logic has been highlighted in the table 1.

In this paper, efficiency of multipath routing protocols has been enhanced by applying fuzzy logic decision making on Multipath Priority based Route Discovery Mechanism. Routing in Mobile ad-hoc networks is carried by the routing protocols. Initially route discovery mechanism floods the network with RREQ packets. Due to mobility of nodes in mobile ad-hoc networks, routing protocol do not consider quality of service (QoS) as an important factor for routing. In order to achieve reliability, multi-path routing can be used as an alternative. In this paper priority factor has been exploited during the route discovery process to build the multi-path routing protocol. Fuzzy logic has been applied over Multi-path priority based route discovery mechanism (MPRDM). For this purpose fuzzy controller for route selection has been designed in next section.

4. Proposed Fuzzy based Priority Ad Hoc On demand Multipath Distance Vector Stable Routing Protocol (FPAOMDV).

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 path. For this purpose 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 high traffic situation.

4.1 Fuzzy Inference System.

Fuzzy logic controller is a decision maker that is able to handle multiple imprecise variables information in a precise way. Generally fuzzy system consists of Input Parameters, Output parameters, Fuzzy IF-THEN rules, Fuzzifier and Defuzzifier. In this paper, fuzzy logic based stable route selection algorithm has been designed. Structure of fuzzy based proposed system has been 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, stable route is selected based on stability parameter which is the final output of fuzzy logic controller system.

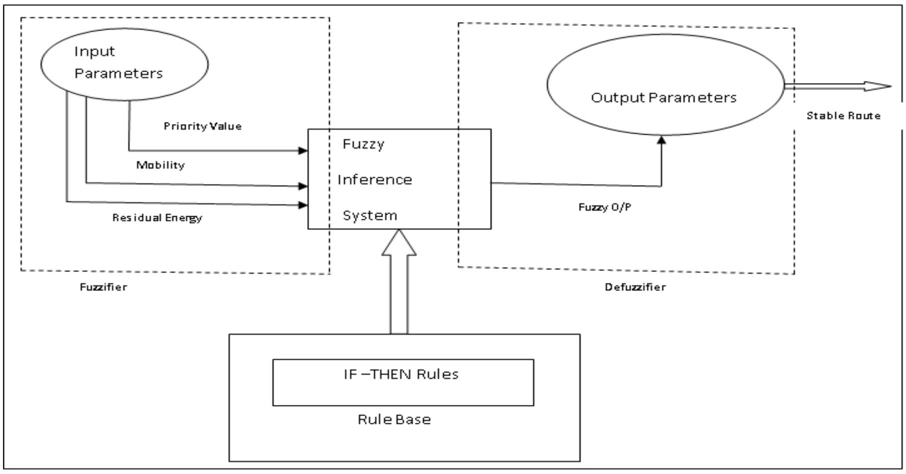

Figure 2 Fuzzy Route Selection Controller

a) Input Parameters

- **Priority Value:** Priority is a finite integer value assigned to an entity which 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 provides reliable way of routing. Multiple paths between source and destination nodes are generated by applying MPRDM in route discovery process. Multiple paths thus generated needs some mechanism of selection so that efficient path can be utilized for further transmission of data packet. Here priority value assigned to the RREP packets at source Node by using multi path priority based route discovery mechanism, can act as deciding factor for selection of stable route among multiple generated routes. Figure 3 shows membership function plotted for priority value.

- **Average Mobility:** Mobile Ad-hoc Networks deals 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 ratio of the mobility value of individual nodes to the total no. of nodes along that path. Figure 4 shows membership function plotted for mobility

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

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

- **Residual Energy:** Nodes in Mobile Ad-hoc Networks are battery operated. Energy is being consumed continuously. Node must have 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 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 membership function plotted for residual energy

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

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

b) Output Parameter

- **Stability:** Shortest route is not necessarily an optimal path for the data transmission. In high mobility environment path must be stable one 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 route among multiple generated routes. Linguistic variables for stability shown in table 3 and membership function plot for stability is shown in figure 6.

$$\boldsymbol{ST(i) \propto P(i) * R.E.(i)/M(i)} \quad (4)$$

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 in to the fuzzy input. 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 in to their corresponding fuzzy set. Linguistic variables such as high, very high, low, very low, medium etc. are used for representation of fuzzy input values of fuzzy set as shown in table 2.

$$\boldsymbol{P_i \rightarrow \mu_{P_i}(P)} \quad \textbf{(5)}$$
$$\boldsymbol{M_i \rightarrow \mu_{M_i}(M)} \quad \textbf{(6)}$$
$$\boldsymbol{R.E_i \rightarrow \mu_{R.E_i}(R.E)} \quad \textbf{(7)}$$

Table 2 Input Parameters Membership Functions

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

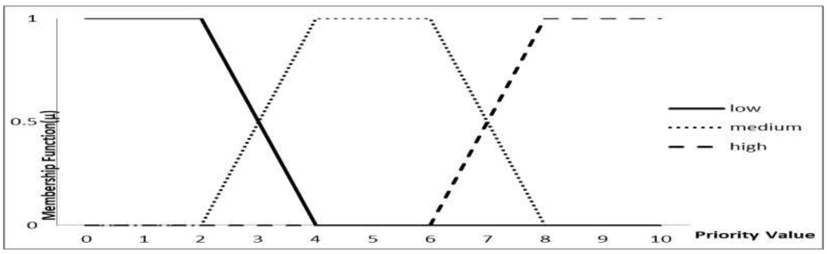

Figure 3 Membership Function Plotted For Priority Value

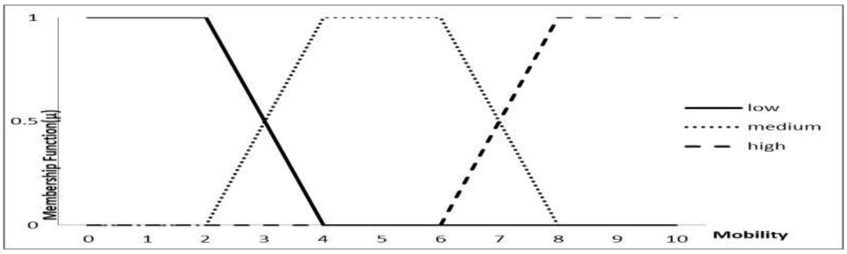

Figure 4 Membership Function Plotted For Mobility

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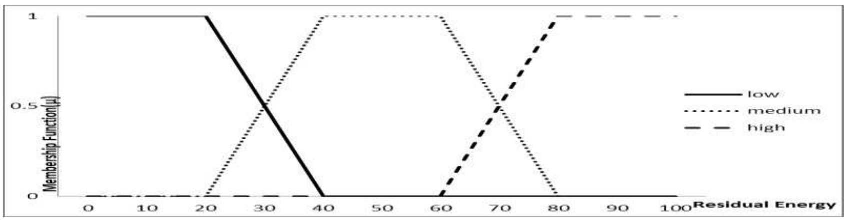

Figure 5 Membership Function Plotted For Residual Energy.

Table 3 Output Parameters Membership Function

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

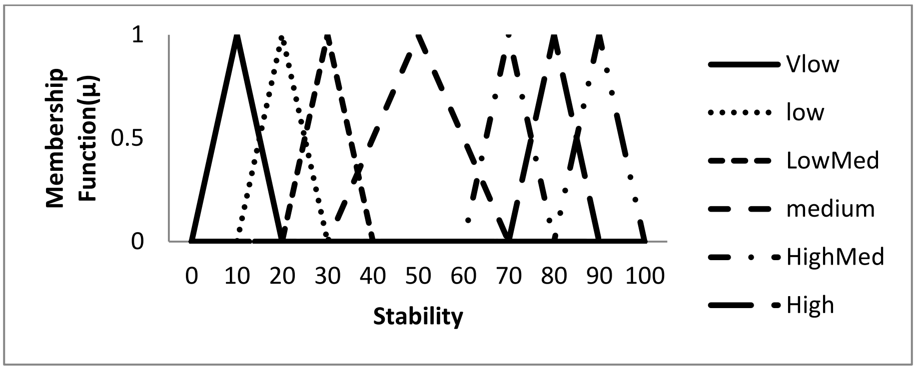

Figure 6 Membership Function Plotted For Stability

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 set have been constructed as shown in table 4. Stability is calculated by applying fuzzy rule base on the three input parameters.

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

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

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

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, centroid method has been used.

$$\mathbf{STi}\left(\boldsymbol{\mu}(\mathbf{COG})\right) = \frac{\sum_{i=1}^{n} \mu(xi) * X(ci)}{\sum_{i=1}^{n} \mu(xi)} \tag{8}$$

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.

4.2 Route Discovery

Multipath routing maintains reliability in routing in routing packets from source node to destination node. To develop a multipath routing protocol some factors need to considered such as energy and mobility. Energy is one of the constraints of the MANETs whose depletion can leads to path failure. Here one more factor i.e. priority has been introduced which will be able to prioritized 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 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 reverse path. Whole process of sending RREQ and generating RREP packet will be done using MPRDM. Now based on assigned priorities source node calculates total priority value. Now FMSRSM will initiate and apply fuzzy rules on every generated path with priority value, residual energy and mobility as input parameters.

Source calculates stability value of each path by applying equation 14, and then path with 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 which considers dynamic factors such as energy and mobility which changes with a short span of time. Protocol has an advantage of getting information of lifetime of a path in advance, prior to start communication, which further helps in increasing the lifetime of network. Working of protocol has been illustrated with the help of example.

Algorithm 1: Algorithm for Fuzzy based Multipath Stable Route Selection Mechanism

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 number of nodes along path i.

Fuzzification of P_i,M_i & R.E$_i$.

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

Compute *Stability (ST)*

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

***Defuzzification* using Centroid method.**

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

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

End

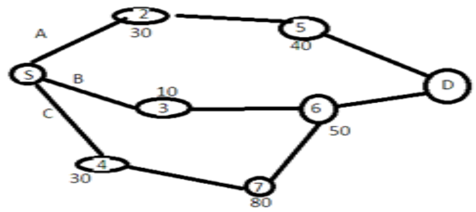

Figure 7 Network of Nodes

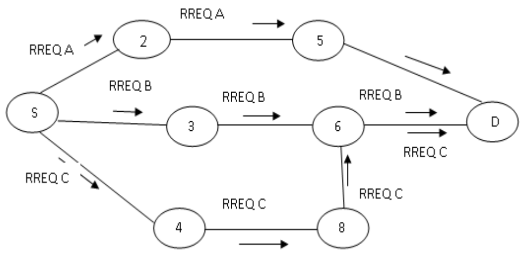

Figure 8 Forwarding RREQs

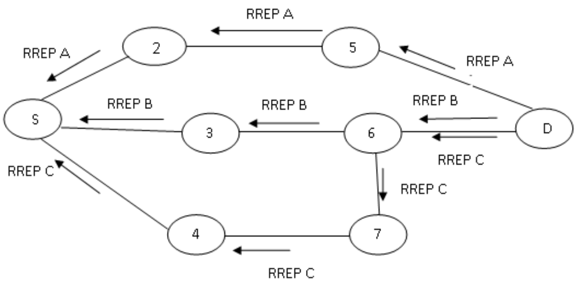

Figure 9 Destination Sending RREPs along Reverse Path

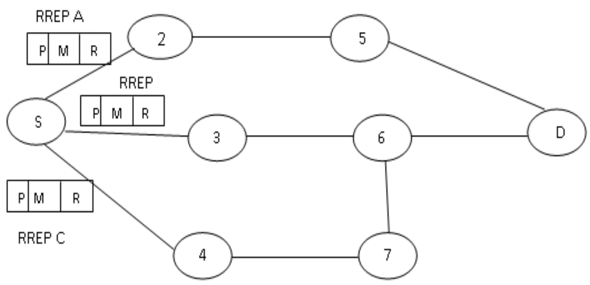

Figure 10 Source Node calculating Priority using MPRDM

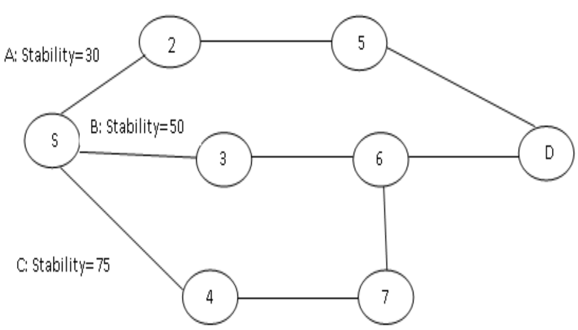

Figure 11 Source Node Calculating Stability using FLSRSM

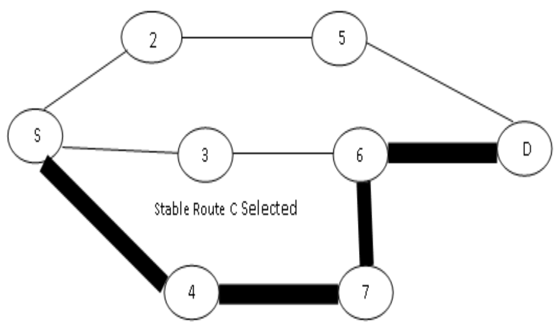

Figure 12 Stable Route C Selected

Figure 7 shows network of nodes, where S is a source node and D is a destination node. Current Energy value has been mentioned along every node. Multipath priority based route discovery mechanism will initiate route discovery process by forwarding RREQ packet as shown in figure 8. Multiple route reply will be received by source node corresponding to the RREQ packet reached at the destination node as shown in figure 9. Source Node will calculate 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 highest stability value has been selected as shown in figure12.Table 5 calculates the stability parameter value corresponding to every RREP packet.

Table 5 Calculation of Stable Routes

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

4.2 Route Maintenance

Dynamic nature of mobile ad hoc networks may leads to failure of certain path with time. There can be many other reasons for failure of paths such as low energy level of nodes along that path which results in node failure. MANETs require 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 alternate path for further communication or it has option to start route discovery again in case of unavailability of alternate paths.

5. 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 ACI 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.

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

a) 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.
b) End to End Delay: End to end delay used to calculate the total amount of time taken for transmission, propagation and receiving of data packet from sender to receiver nodes. It is generally expressed in seconds (s).
c) 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 packet sent from source node to the destination node in MANETs.

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

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

$$: Overhead = \frac{No.of\ Control\ Packets}{No,of\ Data\ Packet\ Packets + No.of\ Control\ Packets} \tag{10}$$

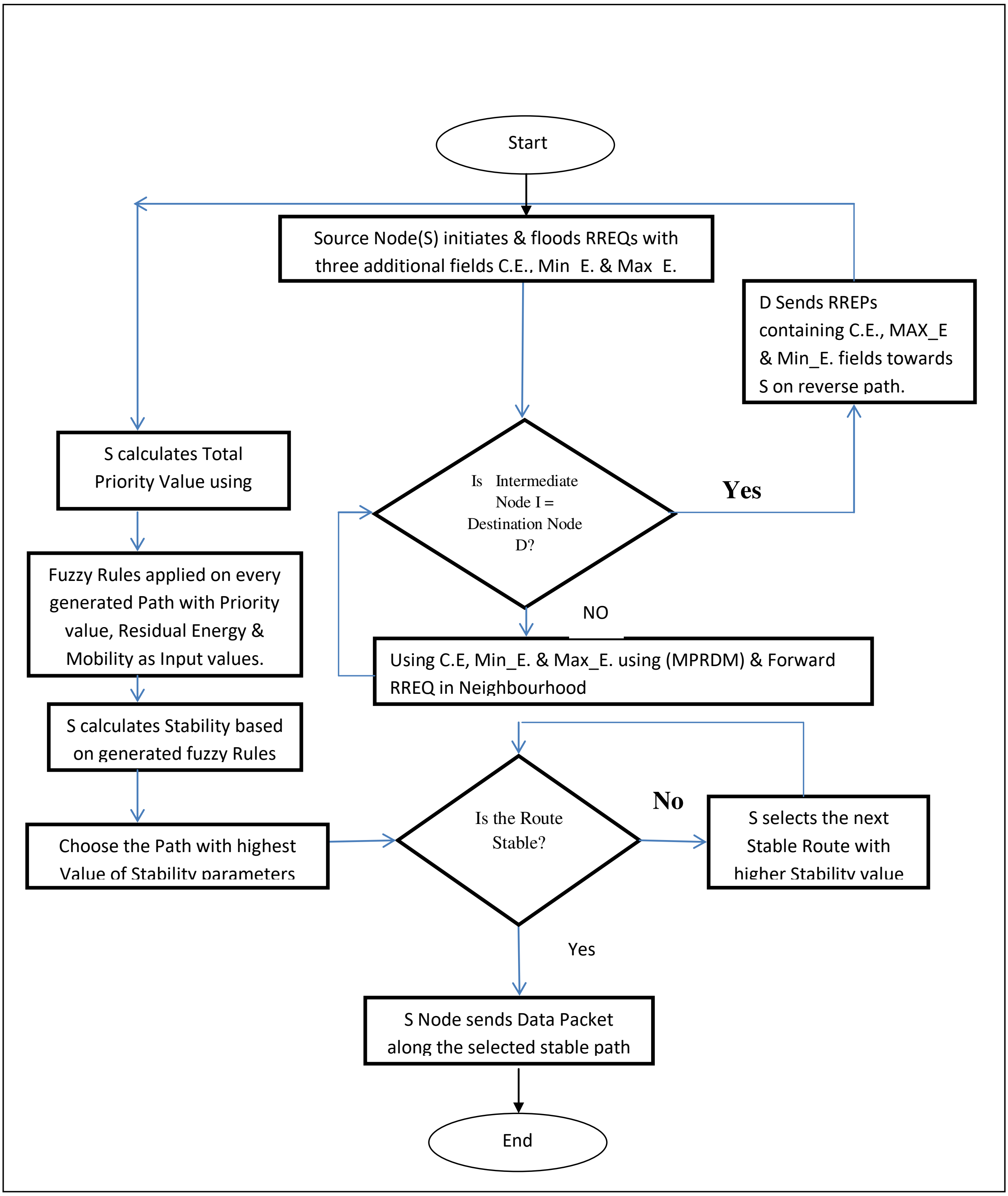

Figure 13 Flowchart Of Fuzzy Logic Based Stable Route Selection Mechanism

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

5.2 Scenario 1

In this scenario as shown in table 6 CBR traffic type is simulated over 20 connections. Area of simulation is 1000*1000 m^2. Connections are sending packets of 64 byte size with packet transmission rate of 4 packet/s. Network having 100 nodes where, random way point model is used to generate nodes mobility. Speed is being defined with interval [0-20] m/s. simulation has been performed for 180s with 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
Packet Transmission Rate	4 Packet/Second
#Nodes	100
Network Topology	1000*1000
Antenna	Omnidirectional
Speed	0-20 m/s
Pause Time	0,15,30,60,120,240
Simulation Time	180 s
Mobility Model	Random way Point Model

5.3 Scenario 2

Table 7 Scenario 2 Modelling Parameters

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

5.3 Scenario 3

Table 8 Scenario 3 Modelling Parameters

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

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

5.4 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 byte at packet transmission rate of 2 packet/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
Packet Size	64, 512,1024 bytes
Packet Transmission Rate	2 Packet/Second
#Nodes	100
Network Topology	1000*1000
Antenna	Omnidirectional
Speed	0-20 m/s
Pause Time	0
Simulation Time	180 s
Mobility Model	Random way Point Model

6. Simulation results and Analysis.

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

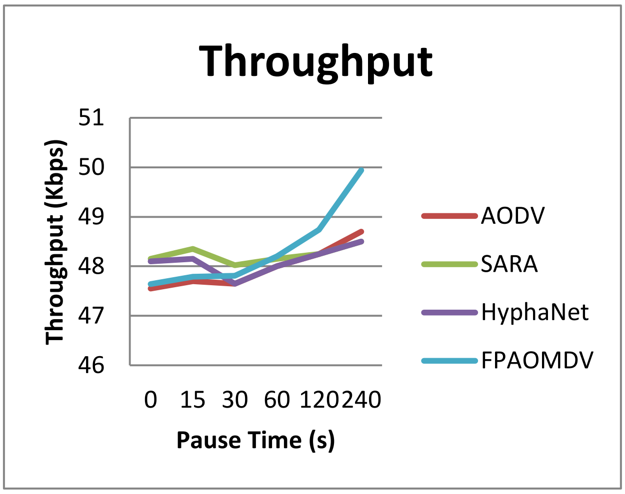

Figure 14 Throughput Performance in scenario 1

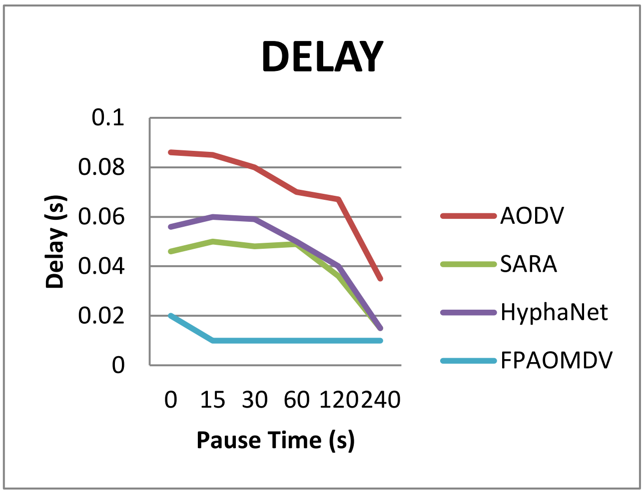

Figure 15 Delay Performance in Scenario

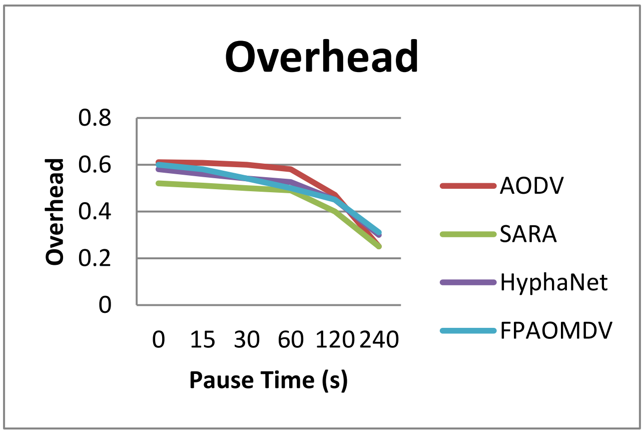

Figure 16 PDR Performance in scenario 1

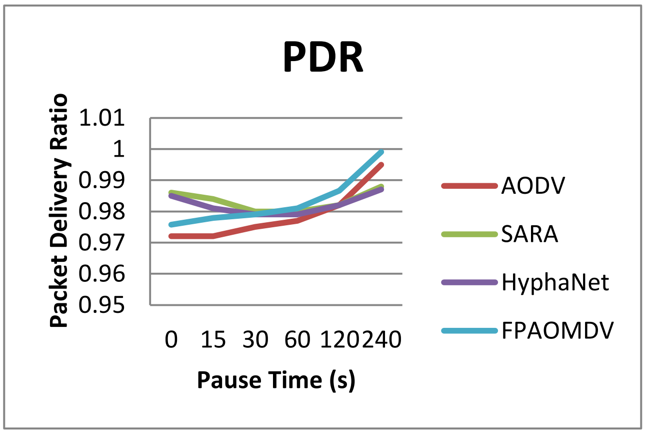

Figure 17 Overhead performance in Scenario 1

Figure 14 and 16 clearly shows the throughput and packet delivery ratio increases more in 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 greater number of control packets. These control packets helps in maintaining up to date topological information. The greater number of control packets results in 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.

6.2 Performance Evaluation based on Scenario 2

Number of connection represents the load conditions of the network. Small number of connections represents the low load conditions and large number of connections signifies the high load conditions. With increase in the number of connection in the network, the topological information stored on the nodes increases; this results in the availability of more number of 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).The lower overhead (figure 21) and better results in terms of Packet delivery, delays and throughput signifies the suitability of FPAOMDV for high load conditions.

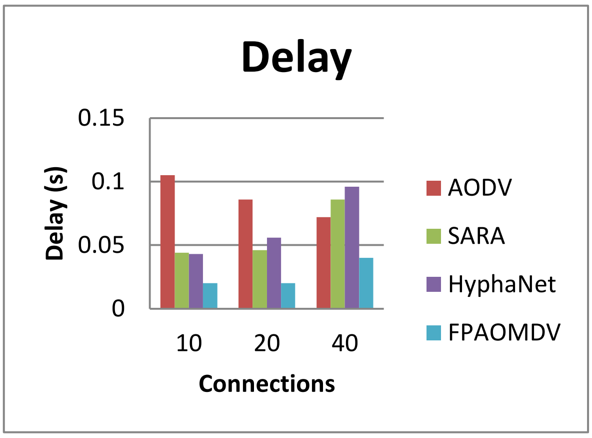

Figure 18 Delay Performance in Scenario 2

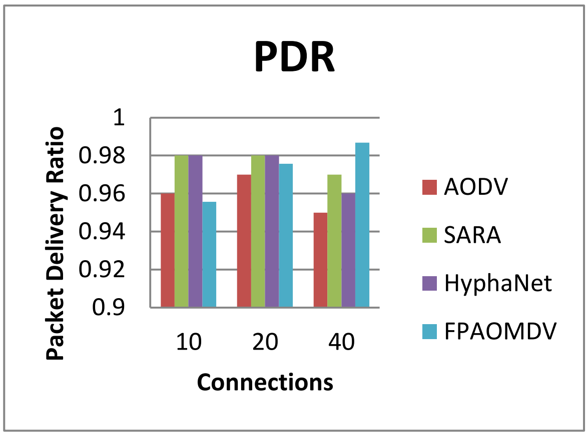

Figure 19 PDR Performance in Scenario 2

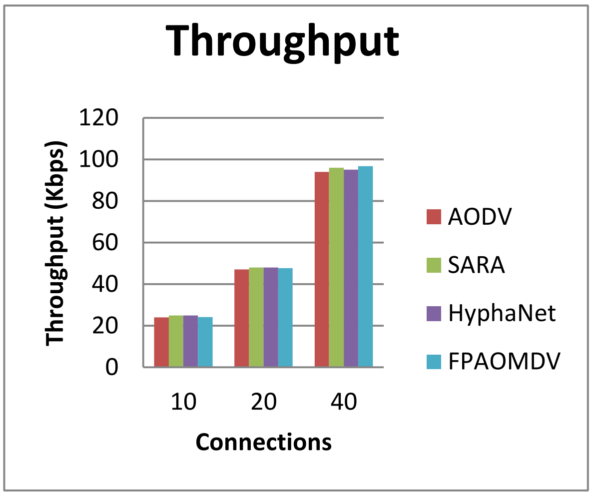

Figure 20 Throughput Performance in Scenario 2

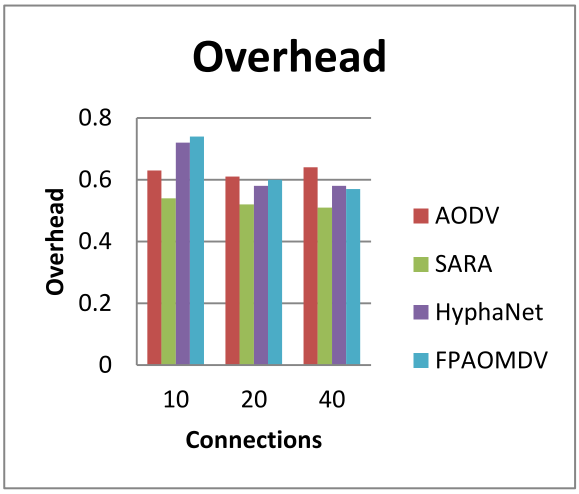

Figure 21 Overhead performance in scenario 2

6.3 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 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

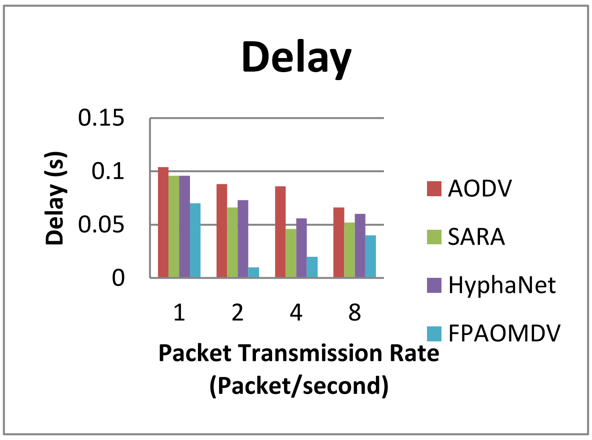

Figure 22 Delay Performance in Scenario 3

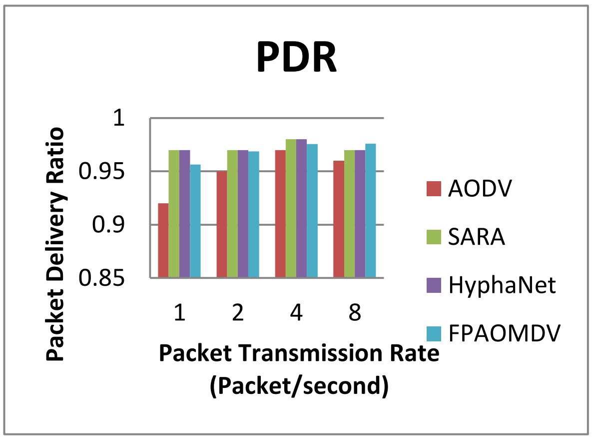

Figure 23 PDR Performance in Scenario 3

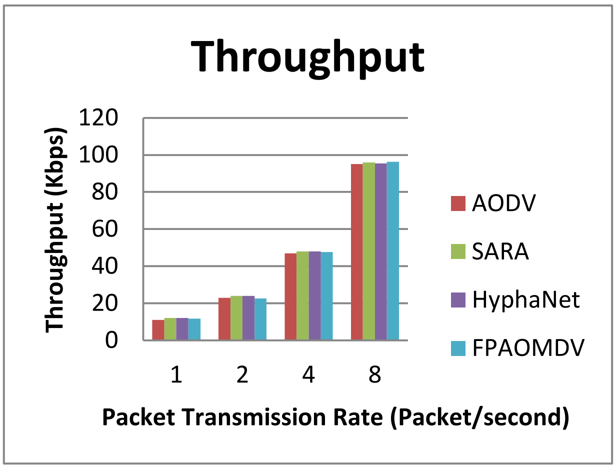

Figure 24 Throughput Performance in Scenario 3

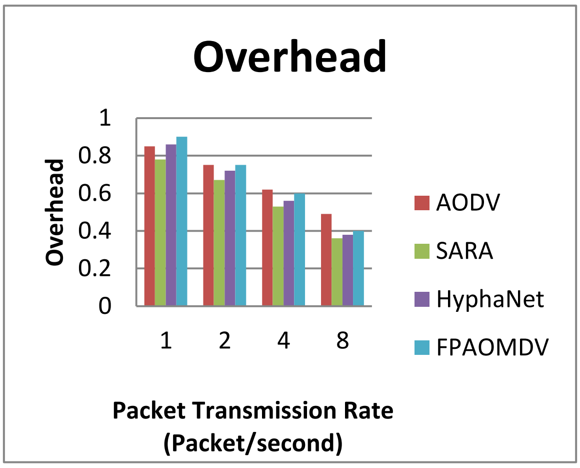

Figure 25 Overhead Performance in Scenario 3

6.4 Performance Evaluation based on Scenario 4

With variations in packets sizes, 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 of control packets in few cases as c ompared 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 decreases route failure hence results in less overhead when packet size increases. When packet size increases, route breakage is frequent due to available low energy routes that results in high frequency of route discovery. Figure 26 e 29 shows the results.

7. Conclusion.

Efficiency of 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 till date. The various factors such as availability of more than one path, load distribution adds to the benefits of multipath routing.

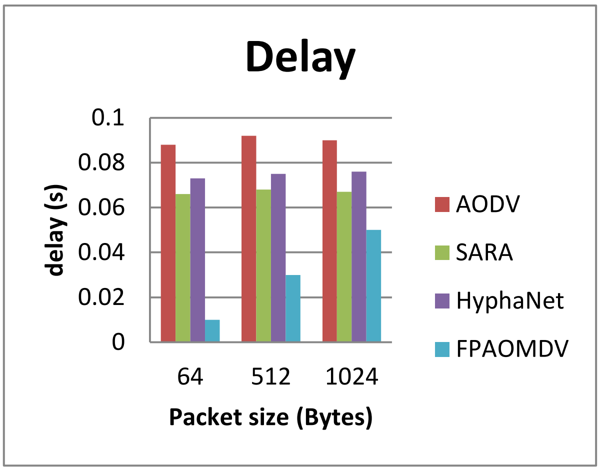

Figure 26 Delay Performance in Scenario 4

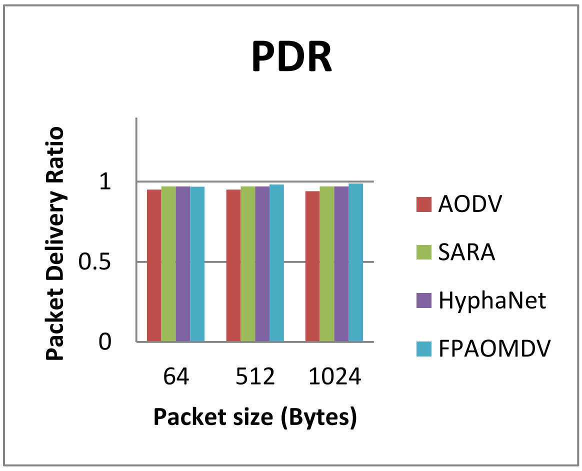

Figure 27 PDR Performance in Scenario 4

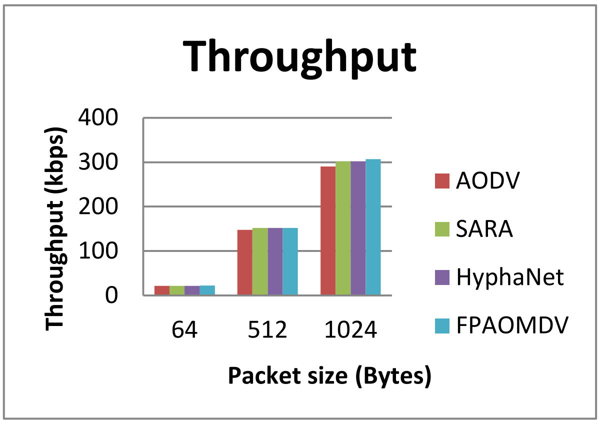

Figure 28 Throughput Performance in Scenario 4

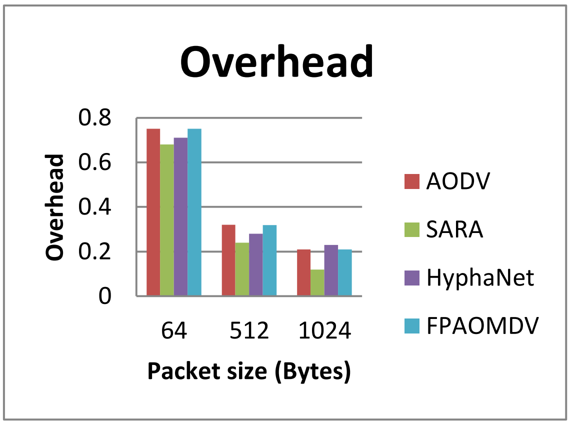

Figure 29 Overhead Performance in Scenario 4

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 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 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 scenario outperforms in terms of PDR, delay, throughput and overhead in high traffic situations therefore, results in an overall increase in the total lifetime of 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.

Declaration

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Acknowledgements

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Figures

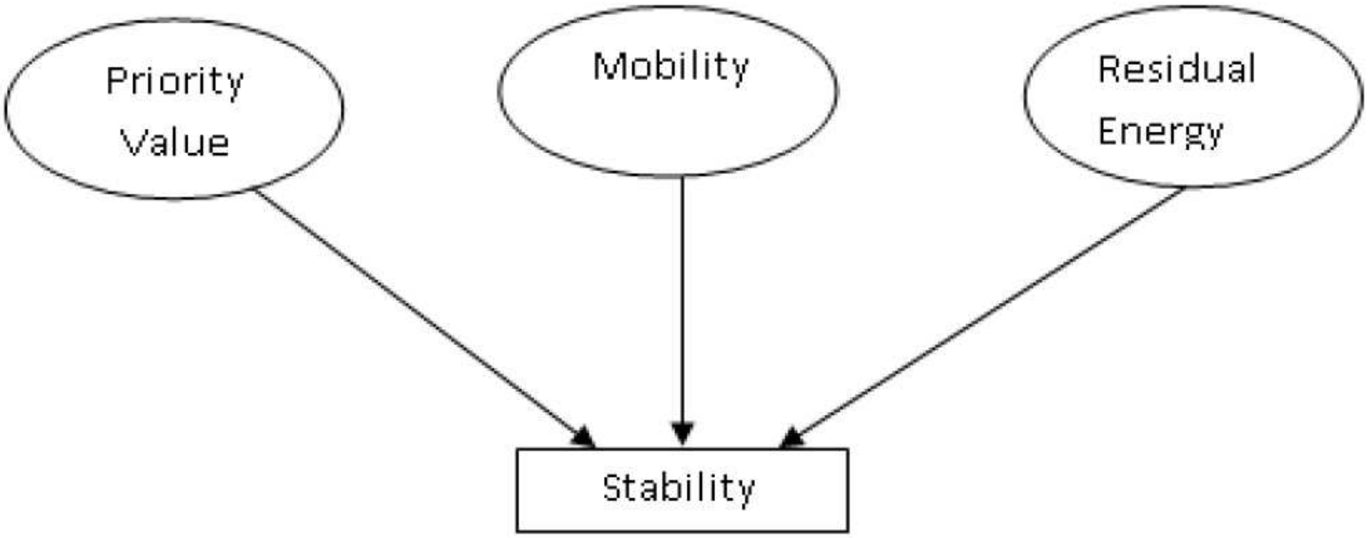

Figure 1

Fuzzy based Route selection System

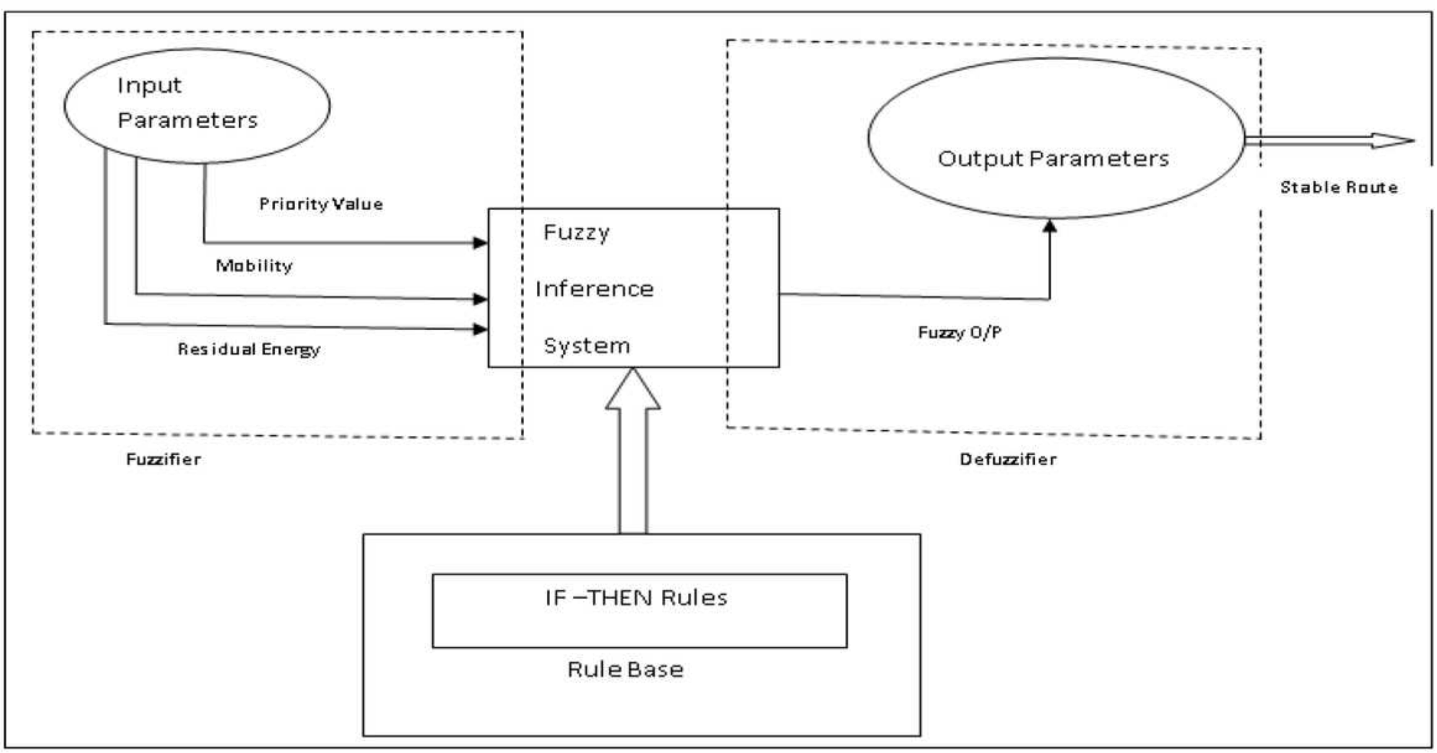

Figure 2

Fuzzy Route Selection Controller

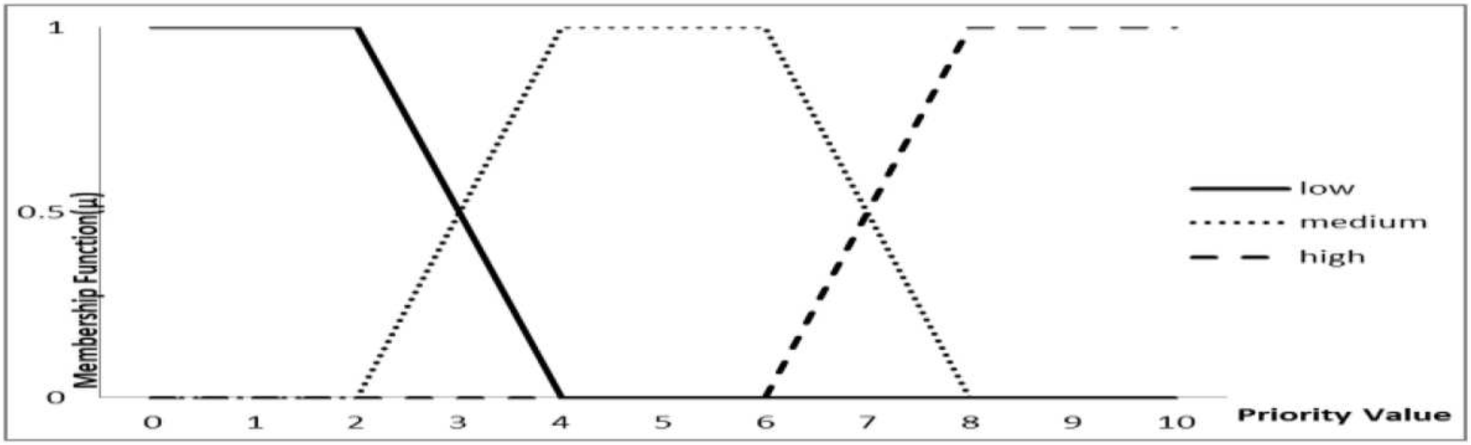

Figure 3

Membership Function Plotted For Priority Value

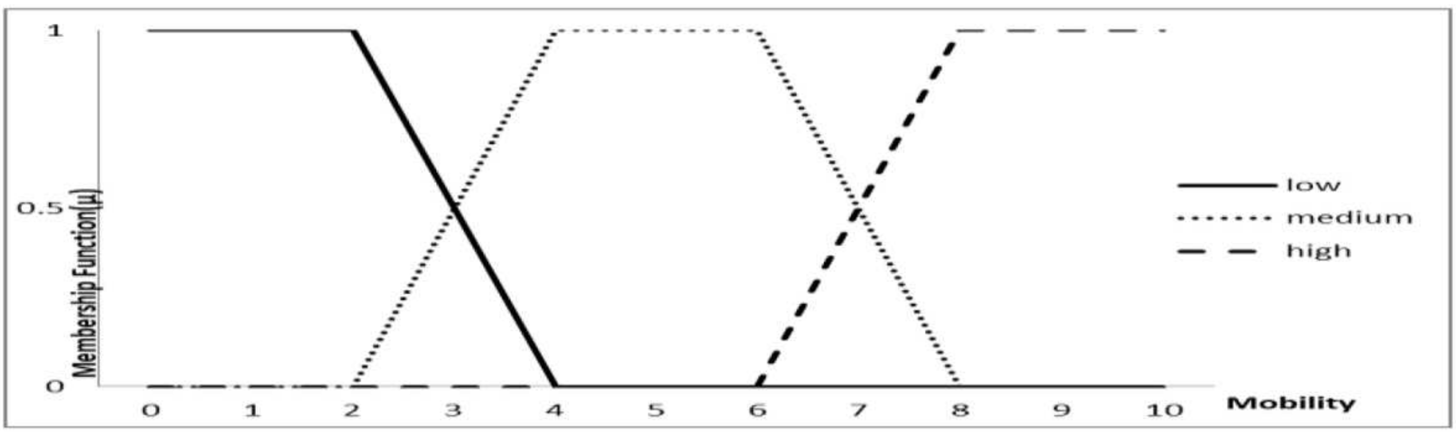

Figure 4

Membership Function Plotted For Mobility

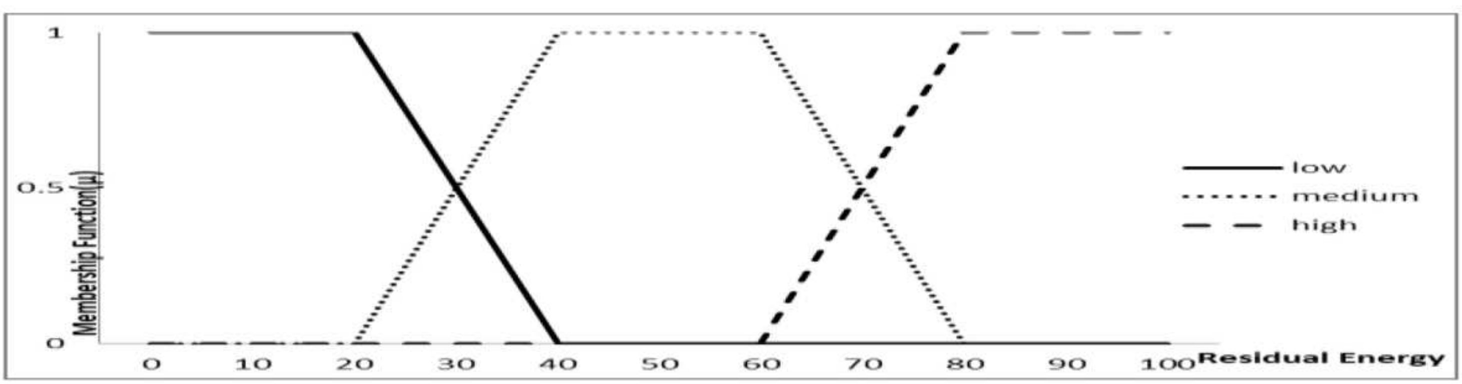

Figure 5

Membership Function Plotted For Residual Energy.

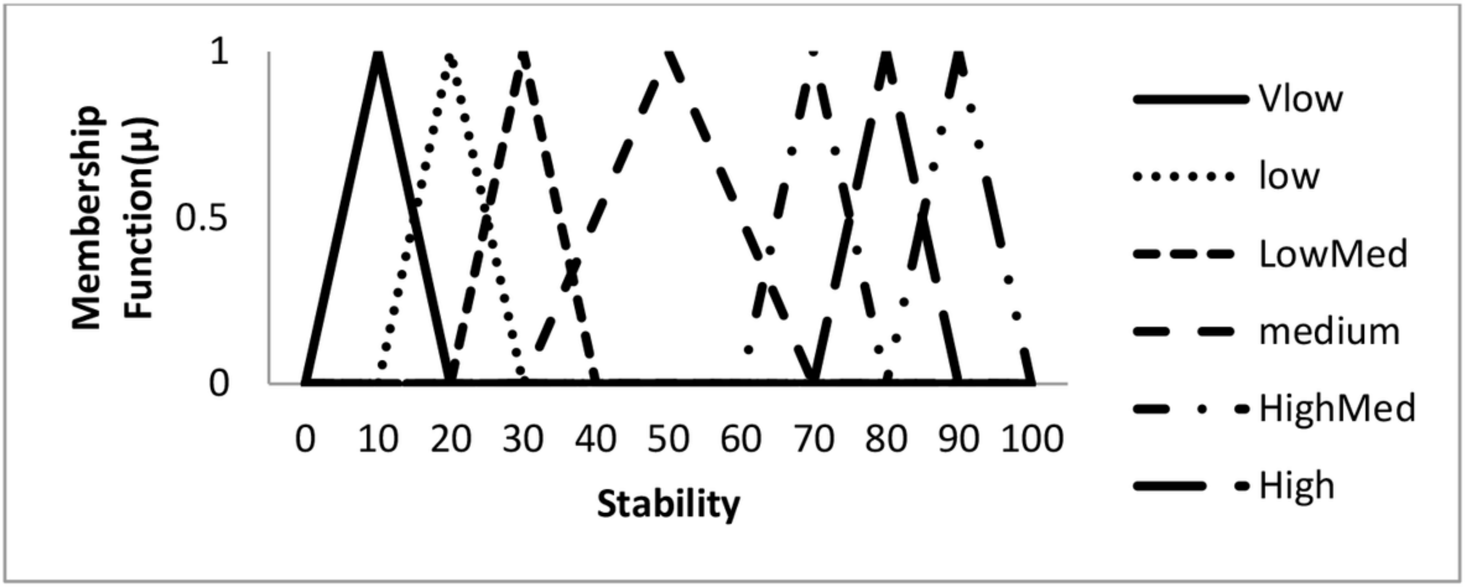

Figure 6

Membership Function Plotted For Stability

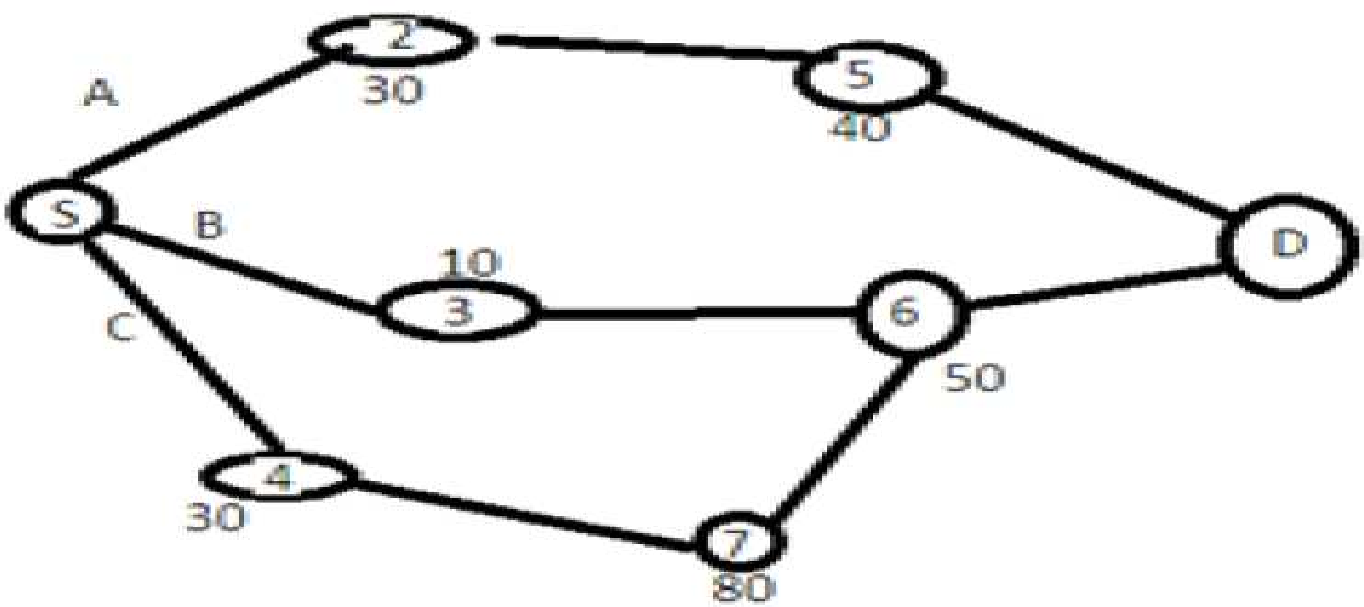

Figure 7

Network of Nodes

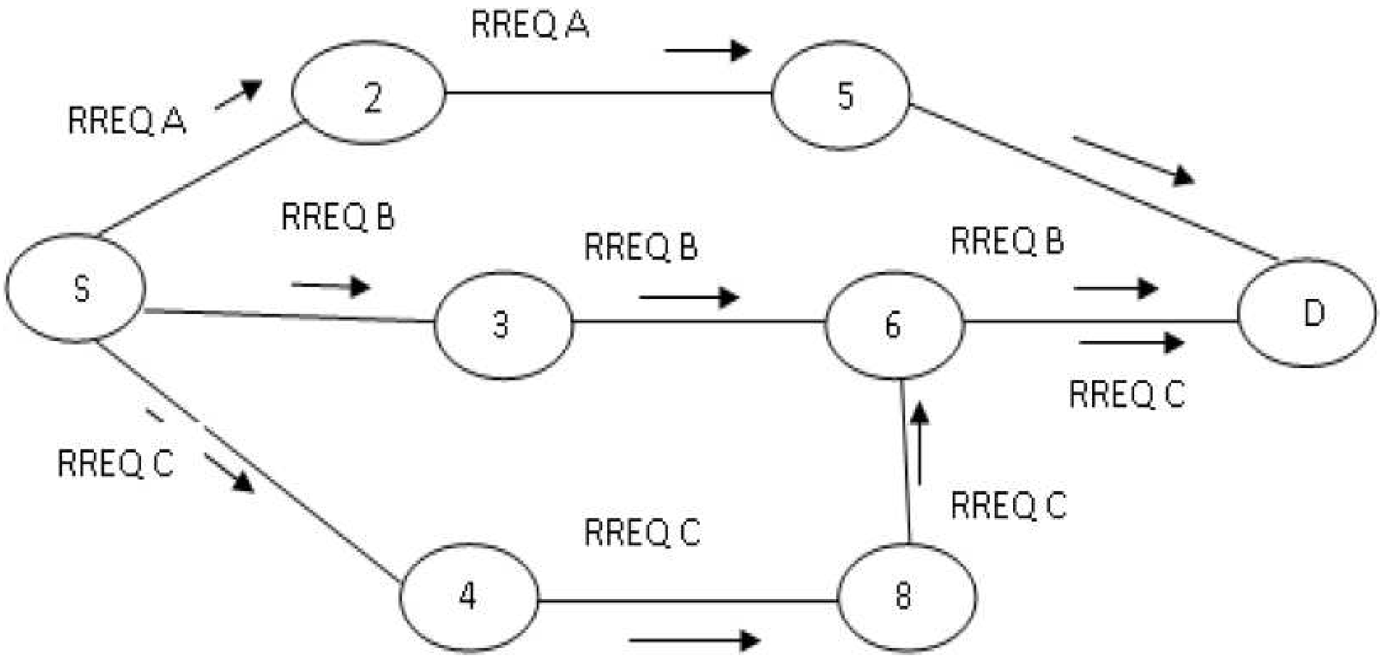

Figure 8

Forwarding RREQs

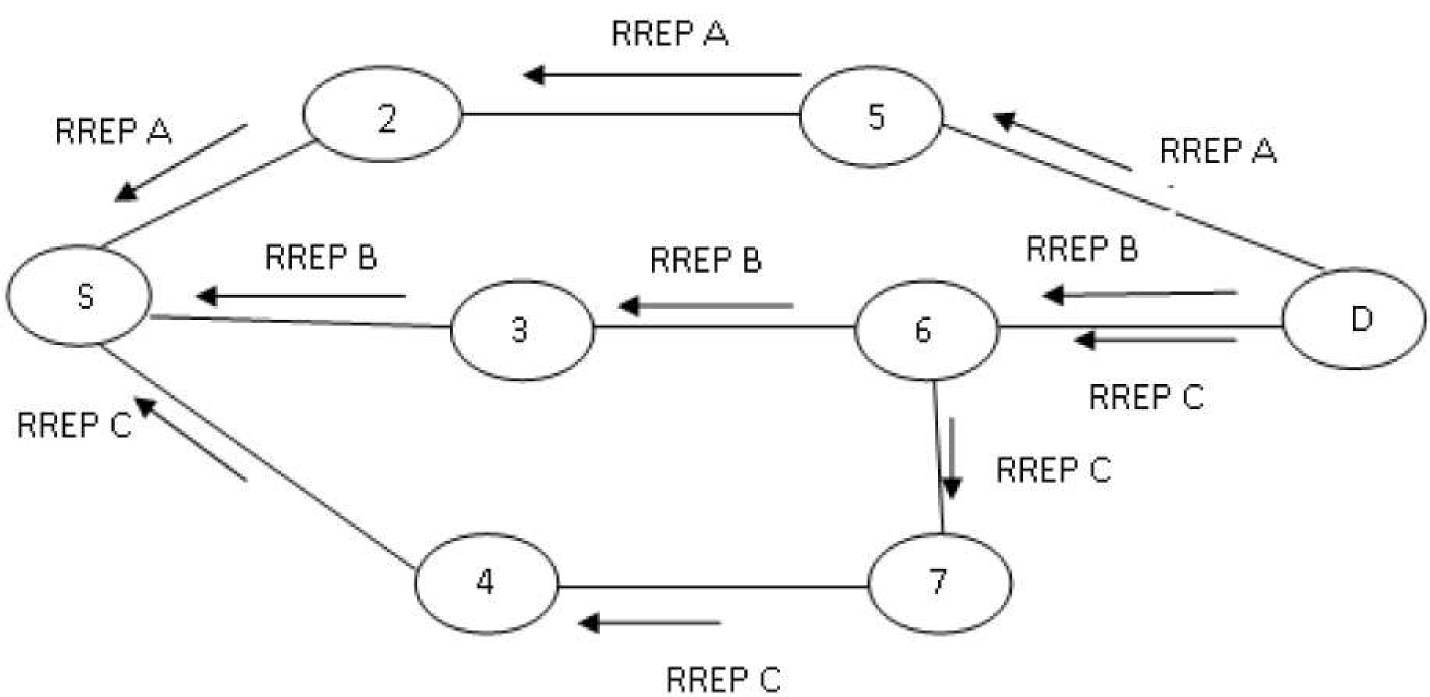

Figure 9

Destination Sending RREPs along Reverse Path

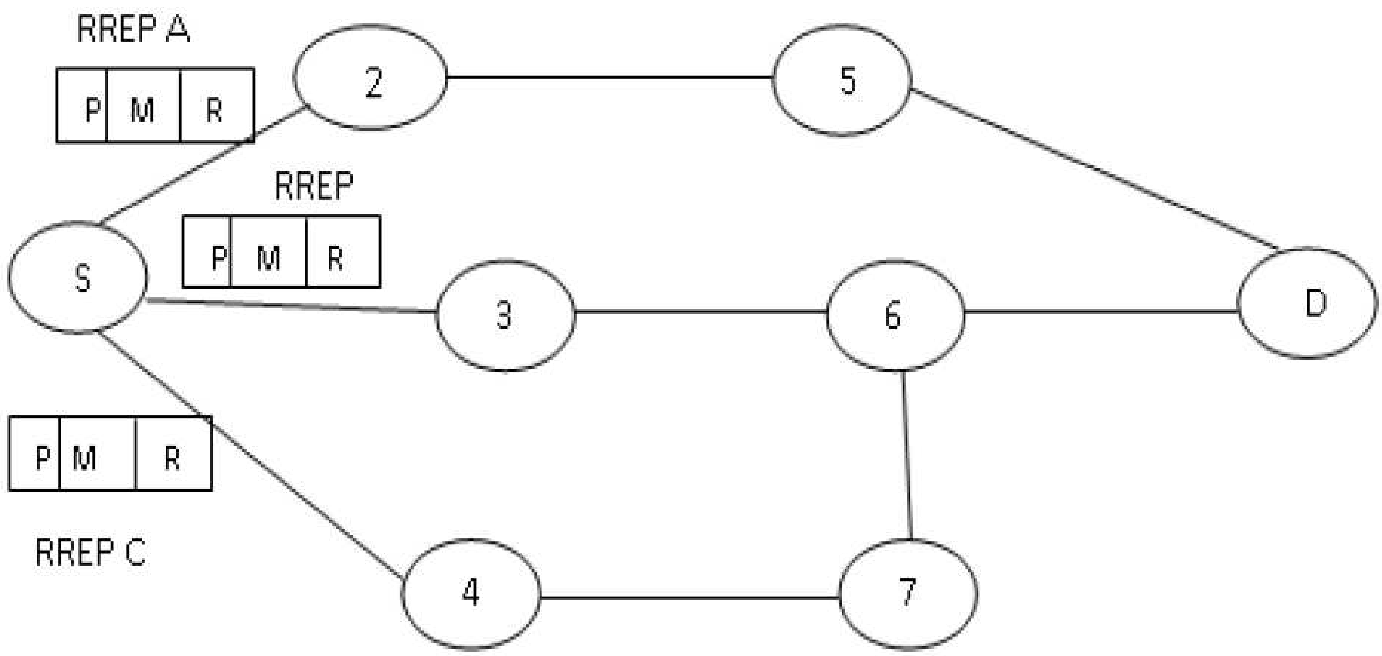

Figure 10

Source Node calculating Priority using MPRDM

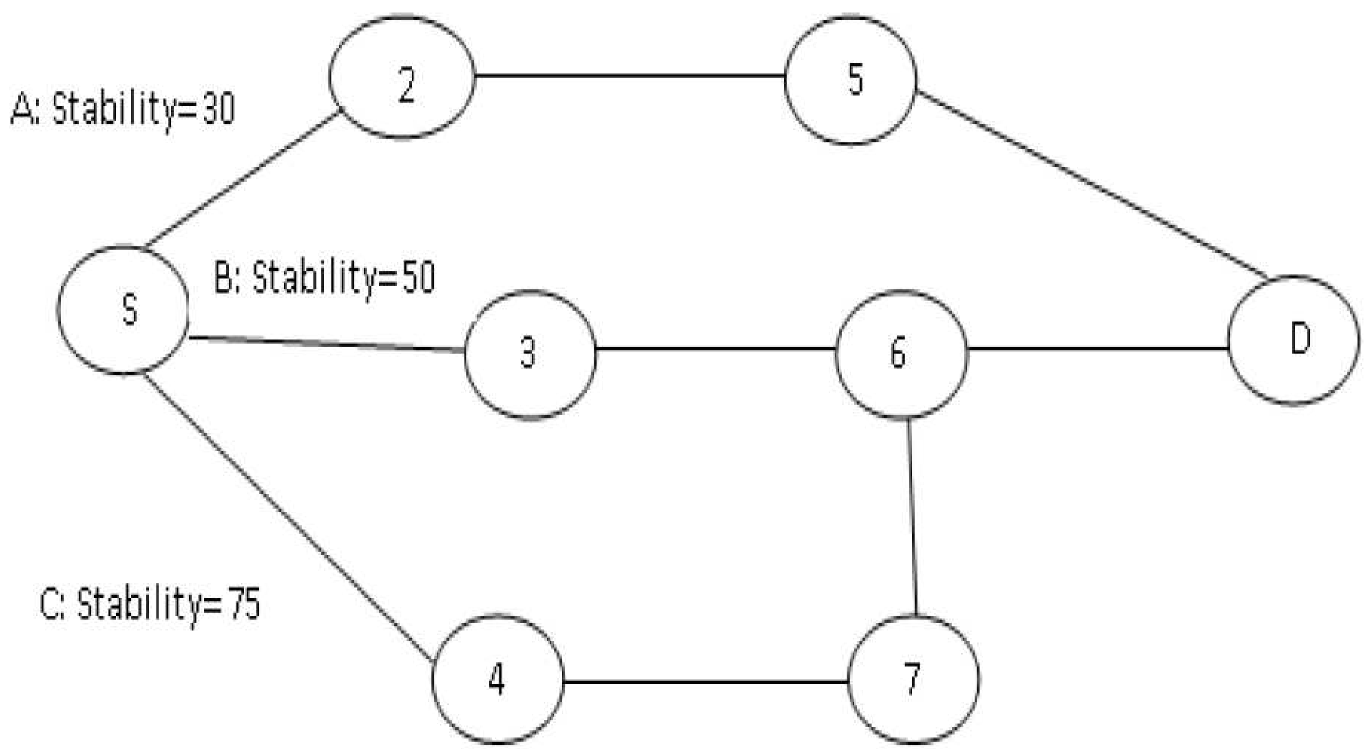

Figure 11

Source Node Calculating Stability using FLSRSM

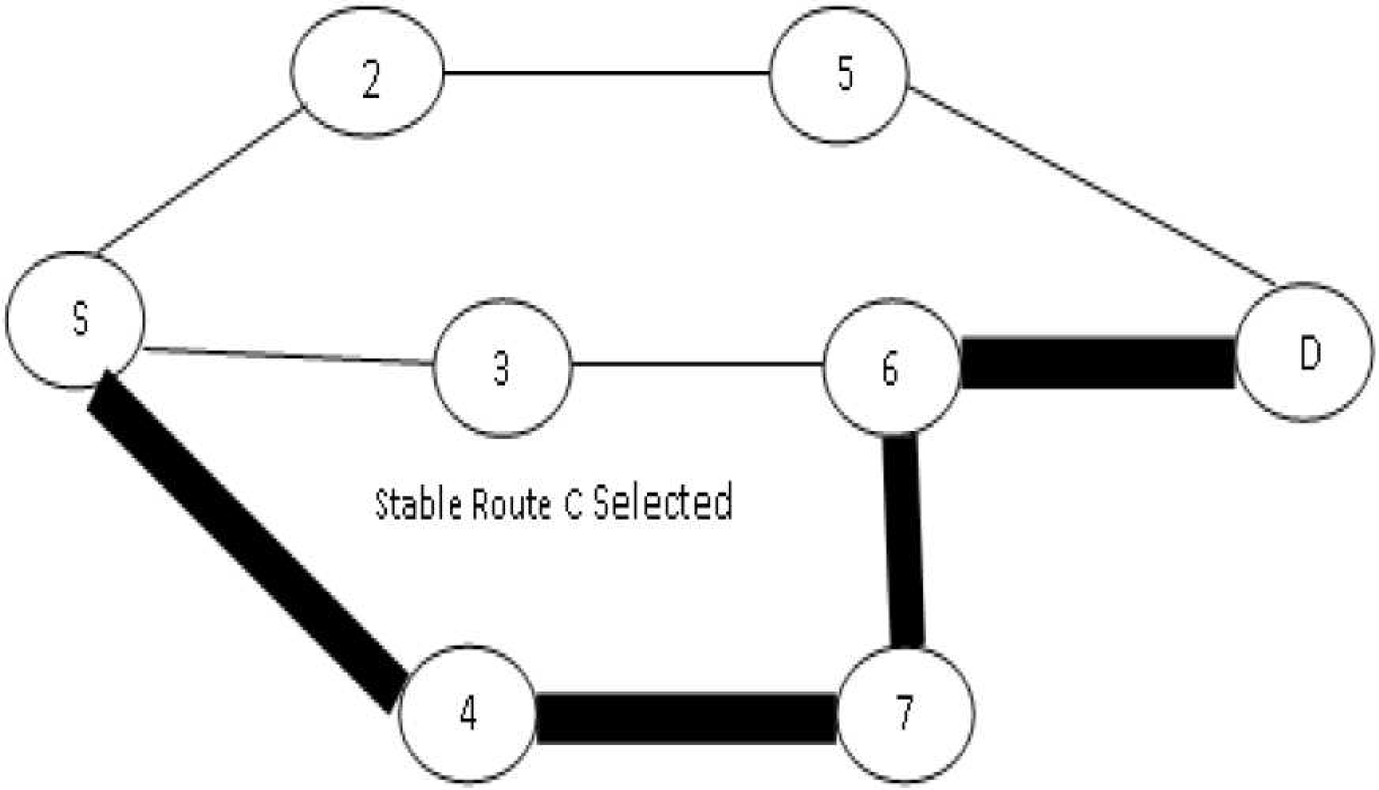

Figure 12

Stable Route C Selected

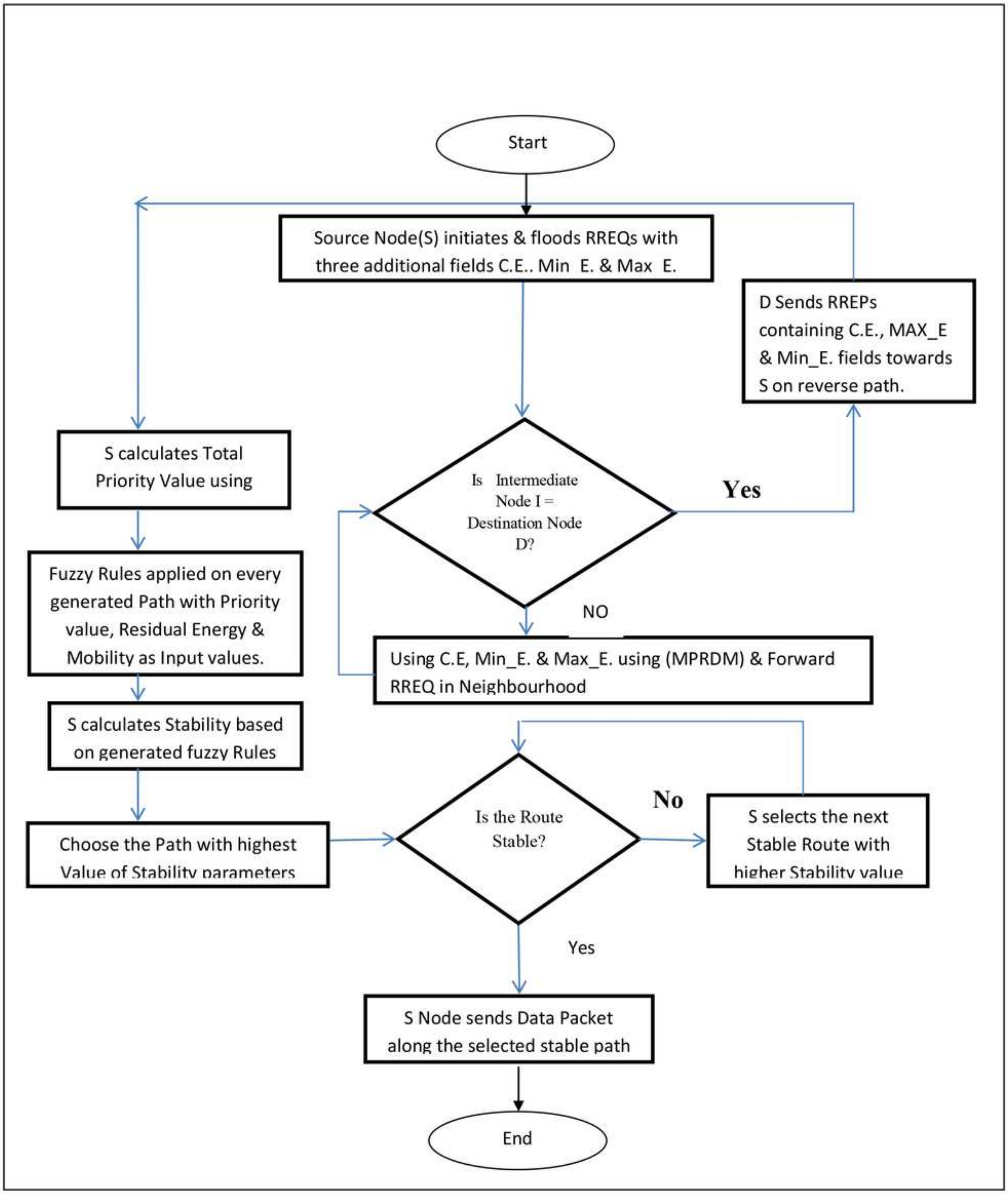

Figure 13

Flowchart Of Fuzzy Logic Based Stable Route Selection Mechanism

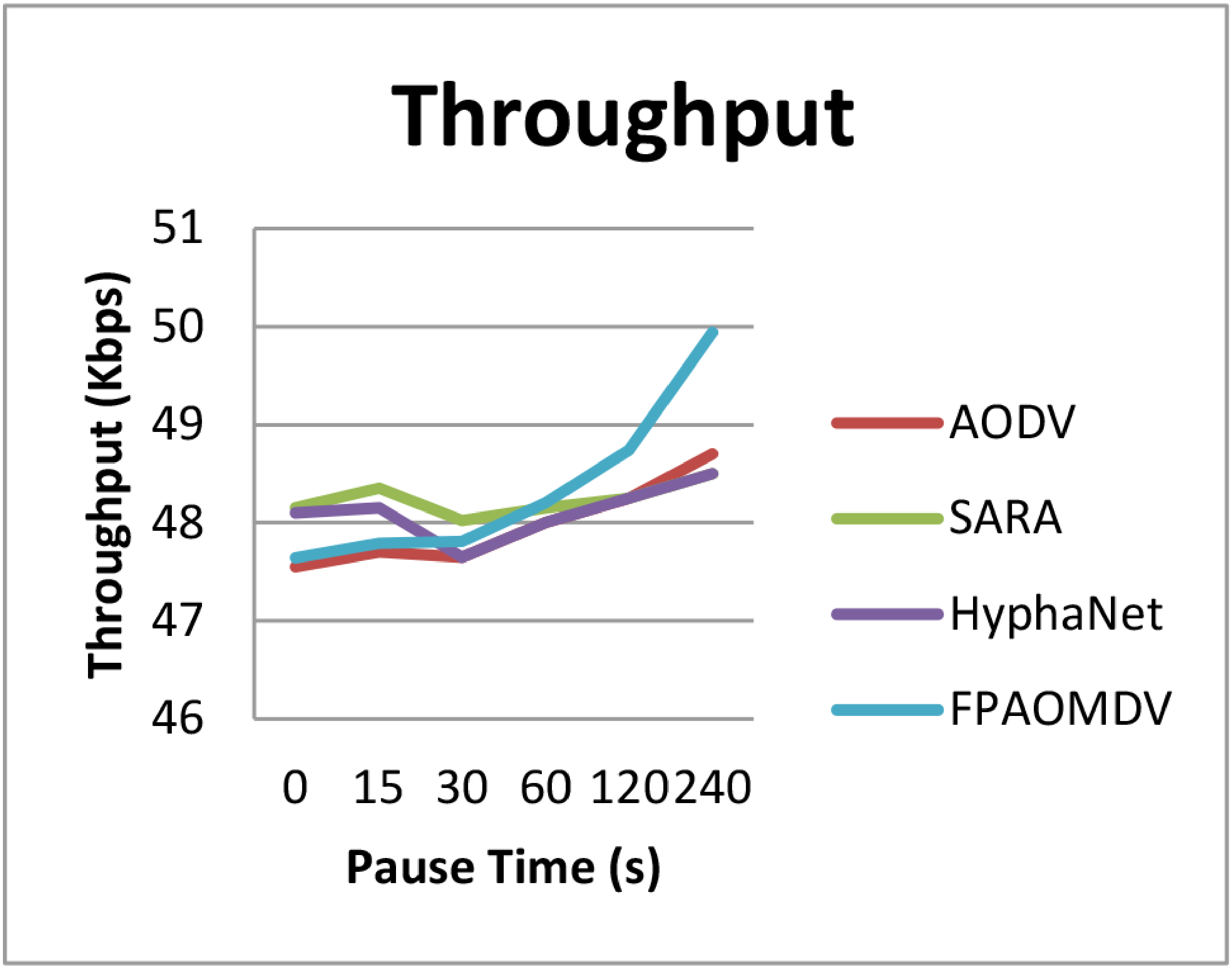

Figure 14

Throughput Performance in scenario 1

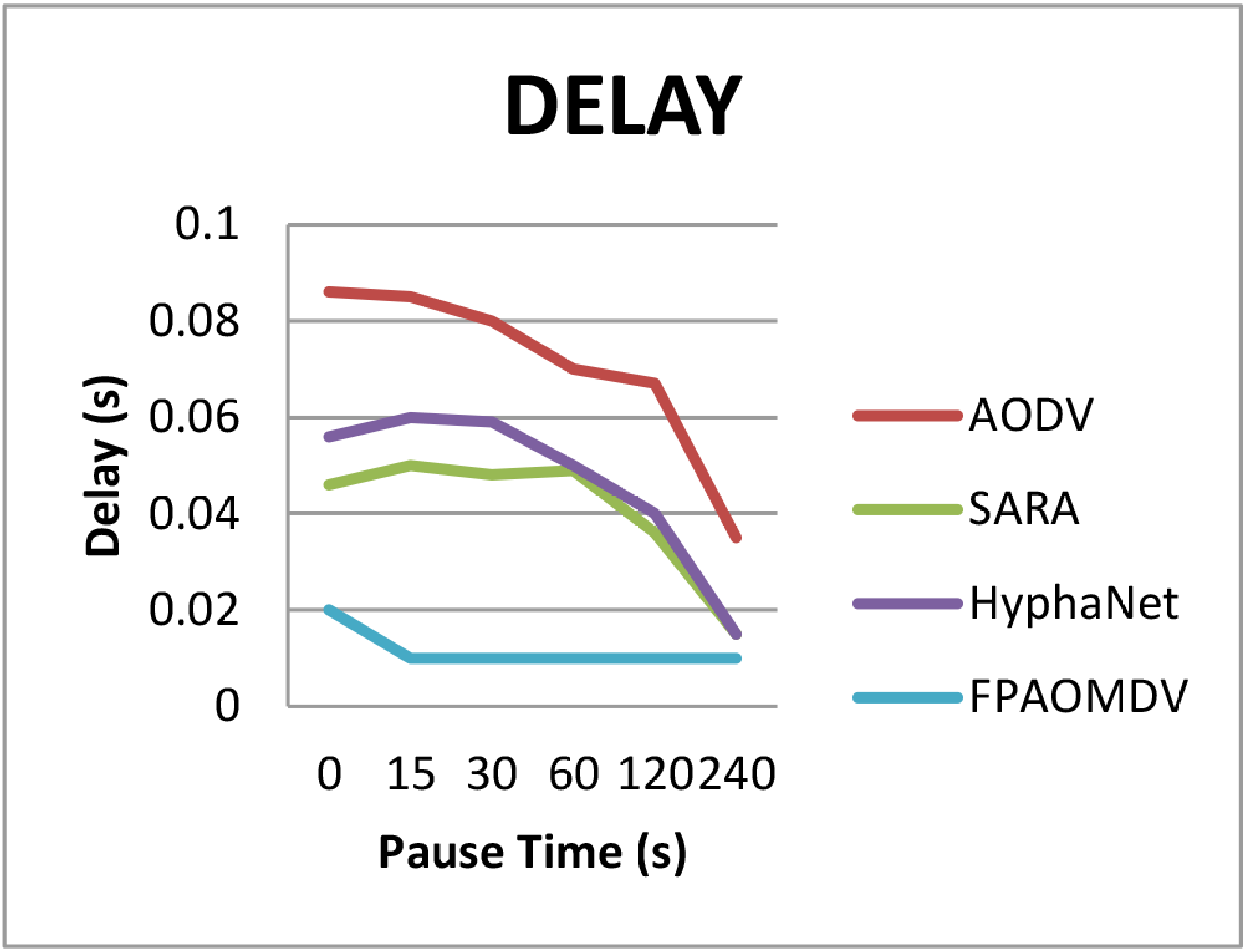

Figure 15

Delay Performance in Scenario

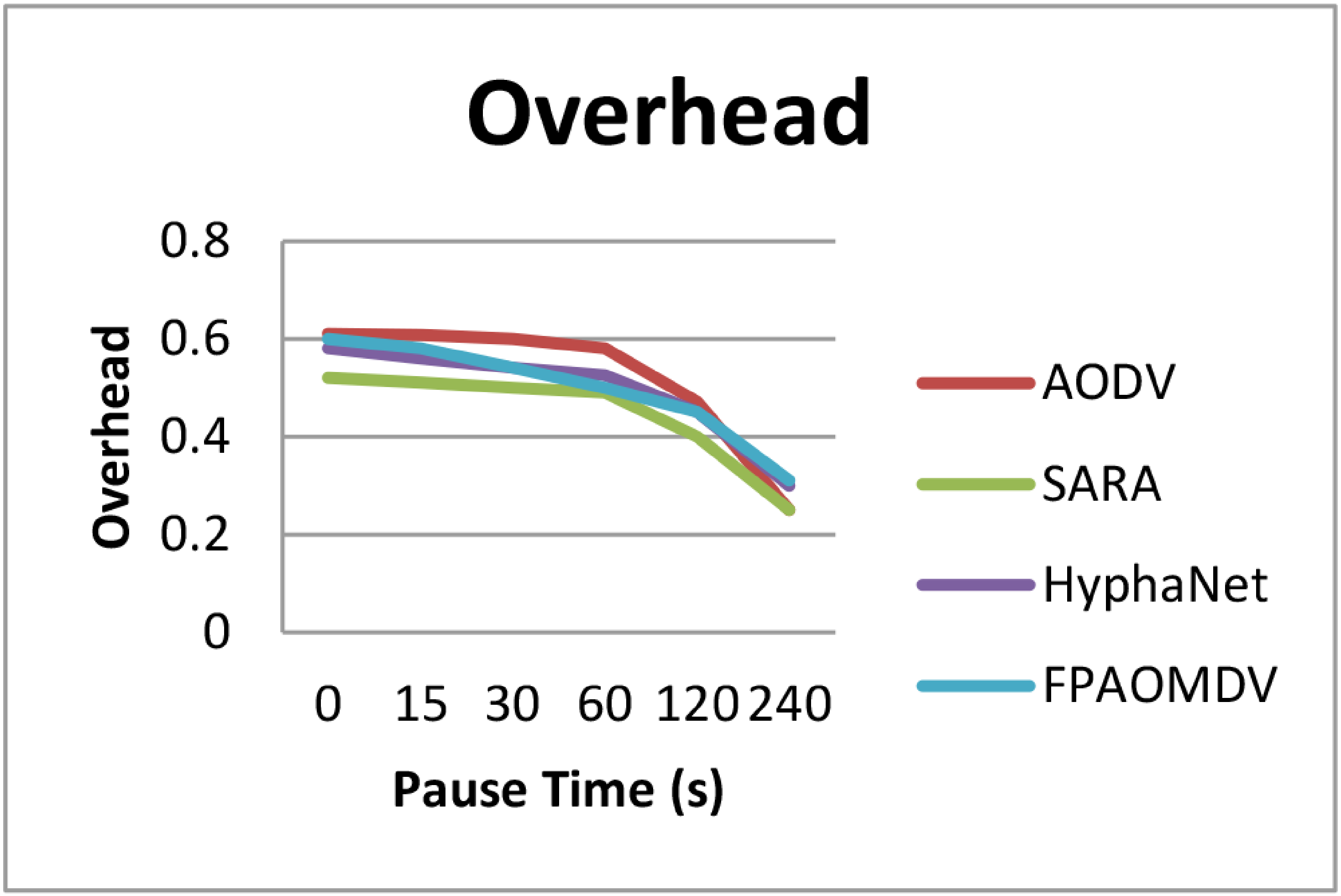

Figure 16

PDR Performance in scenario 1

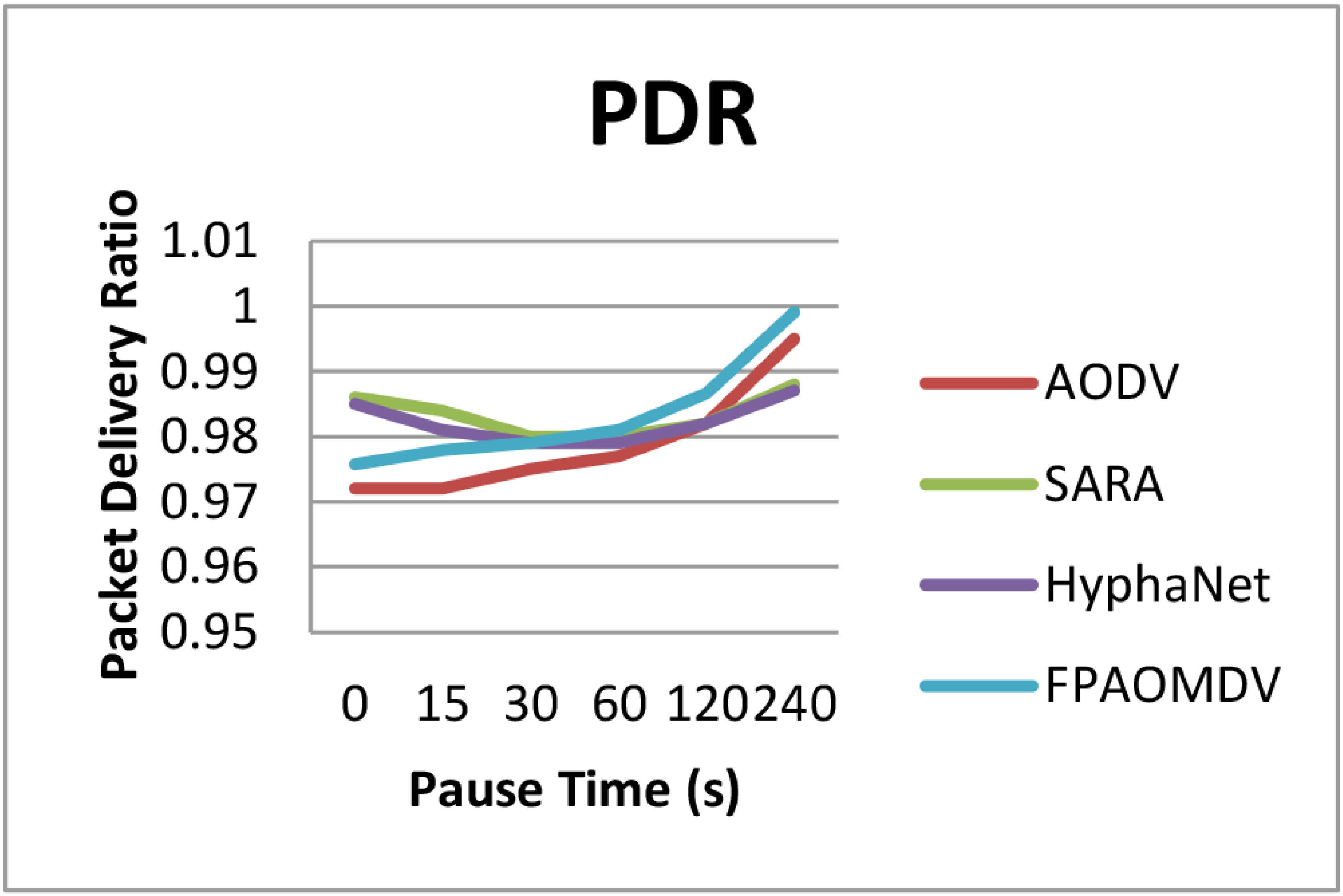

Figure 17

Overhead performance in Scenario 1

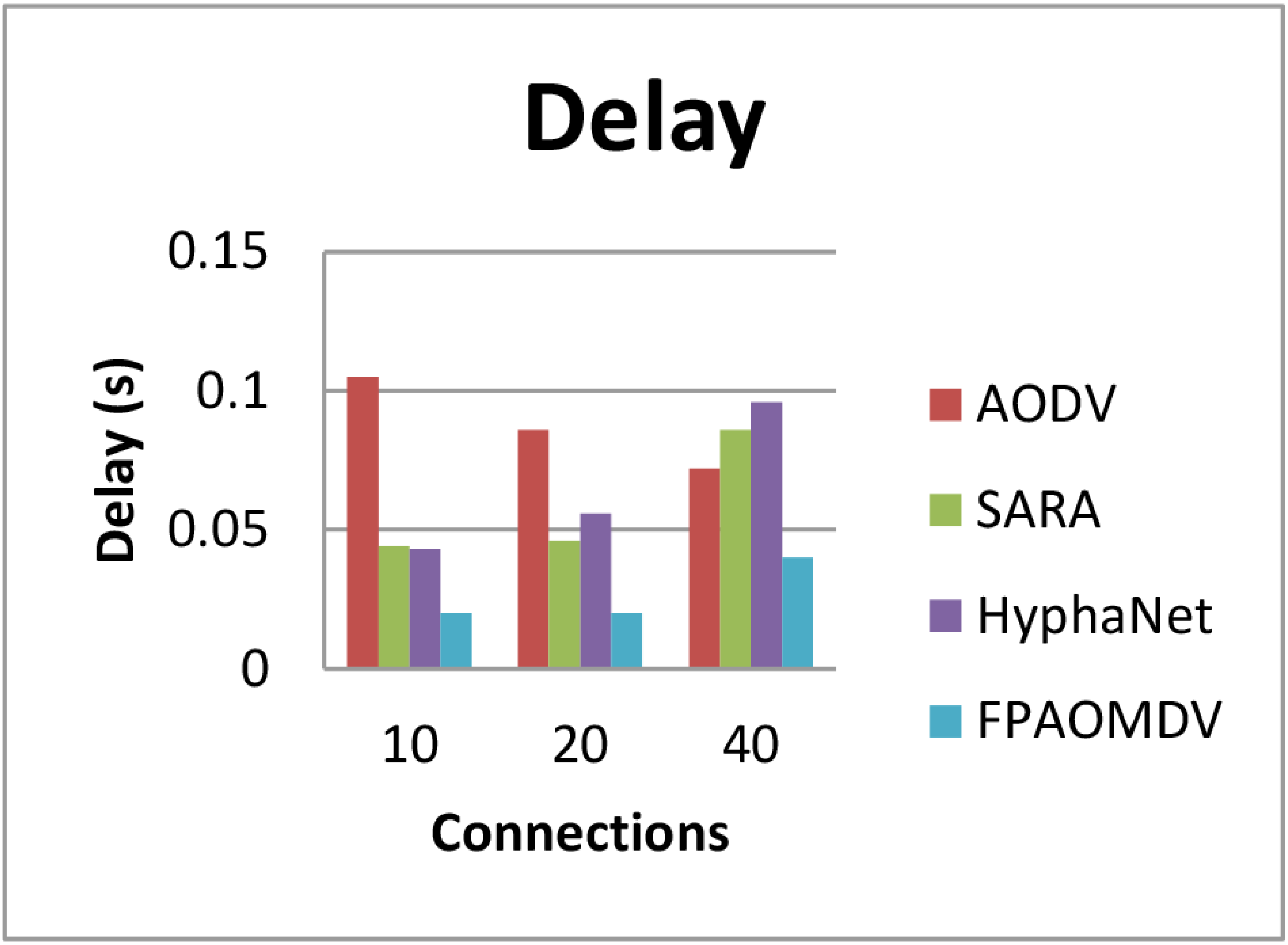

Figure 18

Delay Performance in Scenario 2

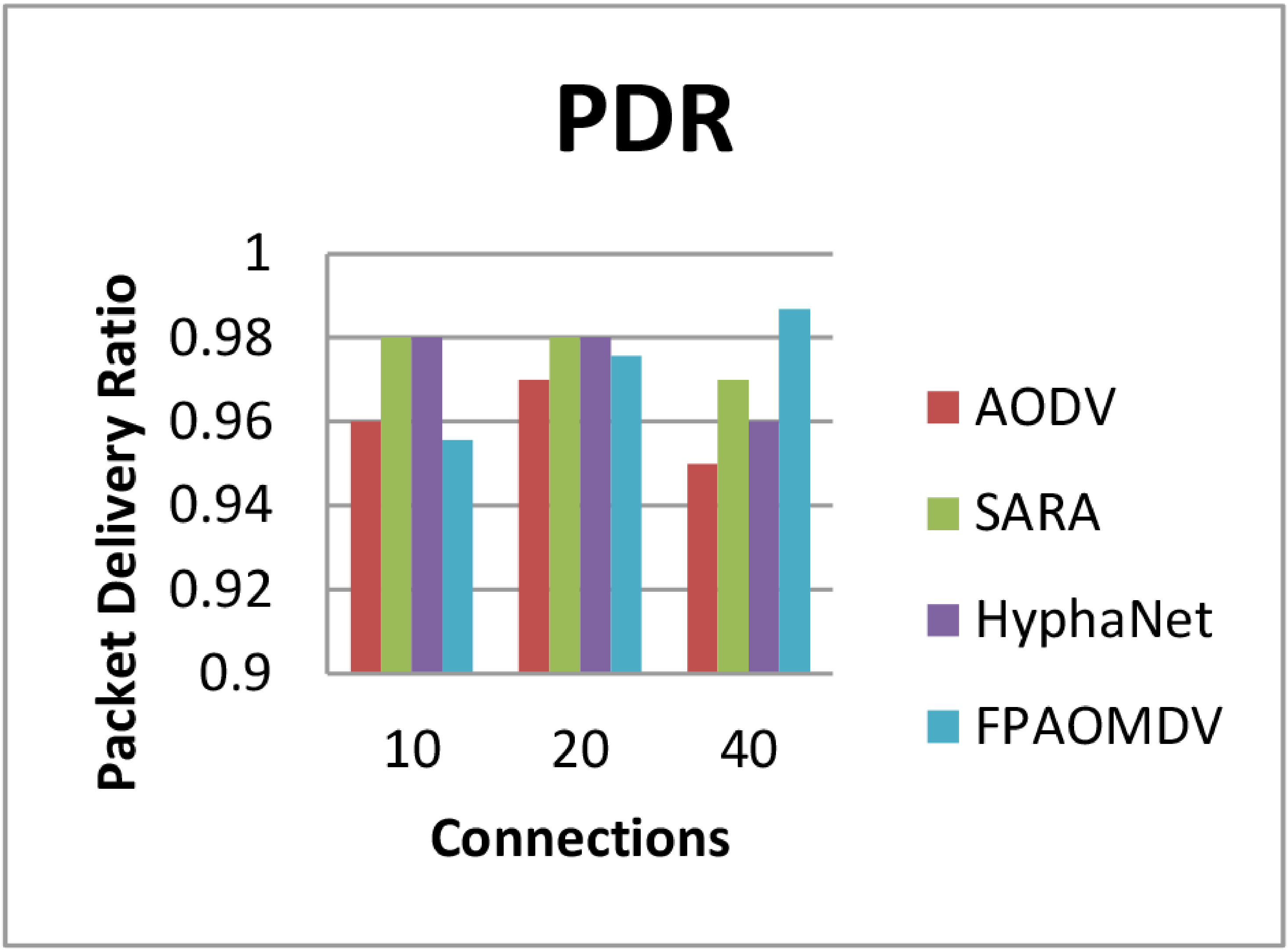

Figure 19

PDR Performance in Scenario 2

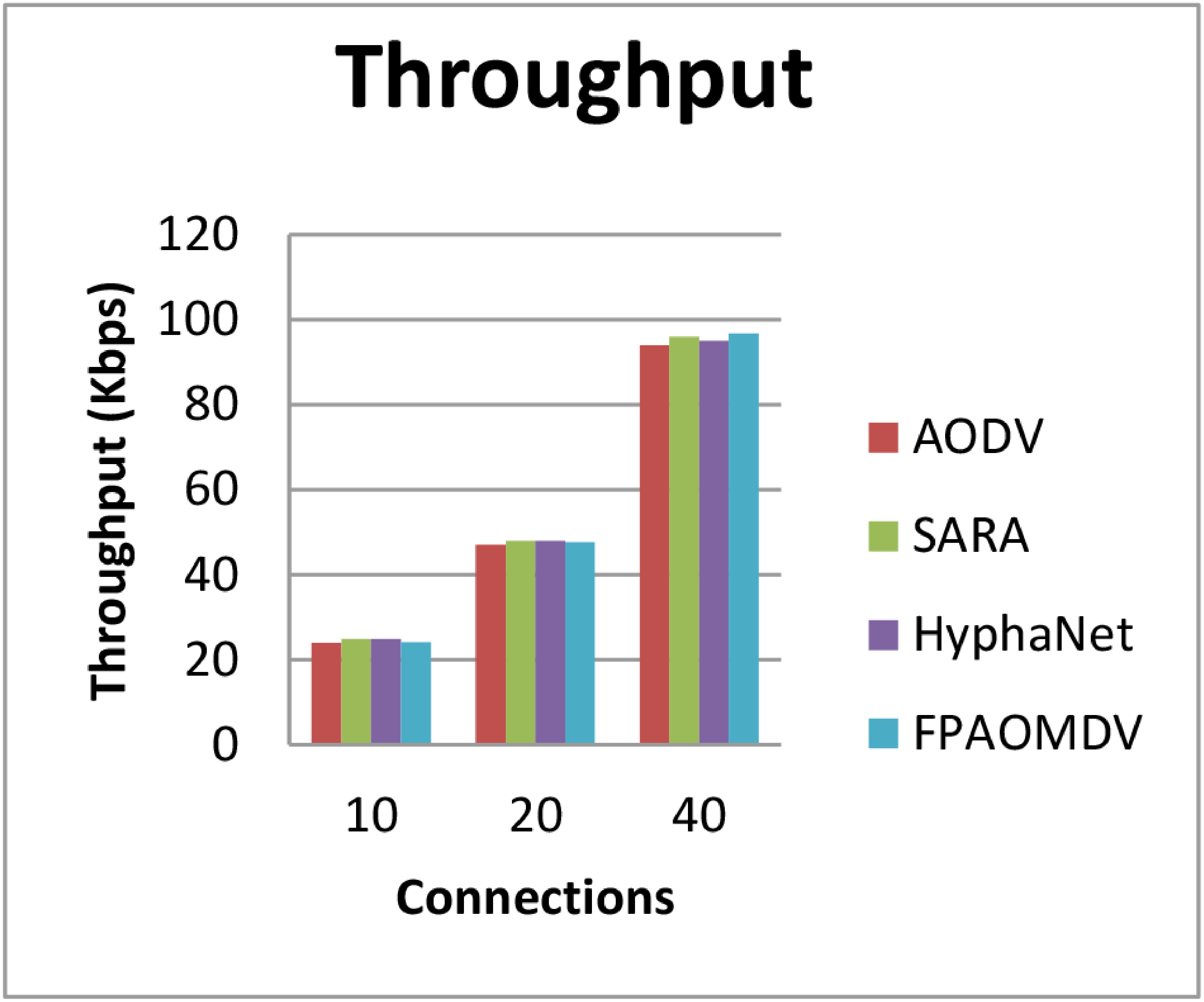

Figure 20

Throughput Performance in Scenario 2

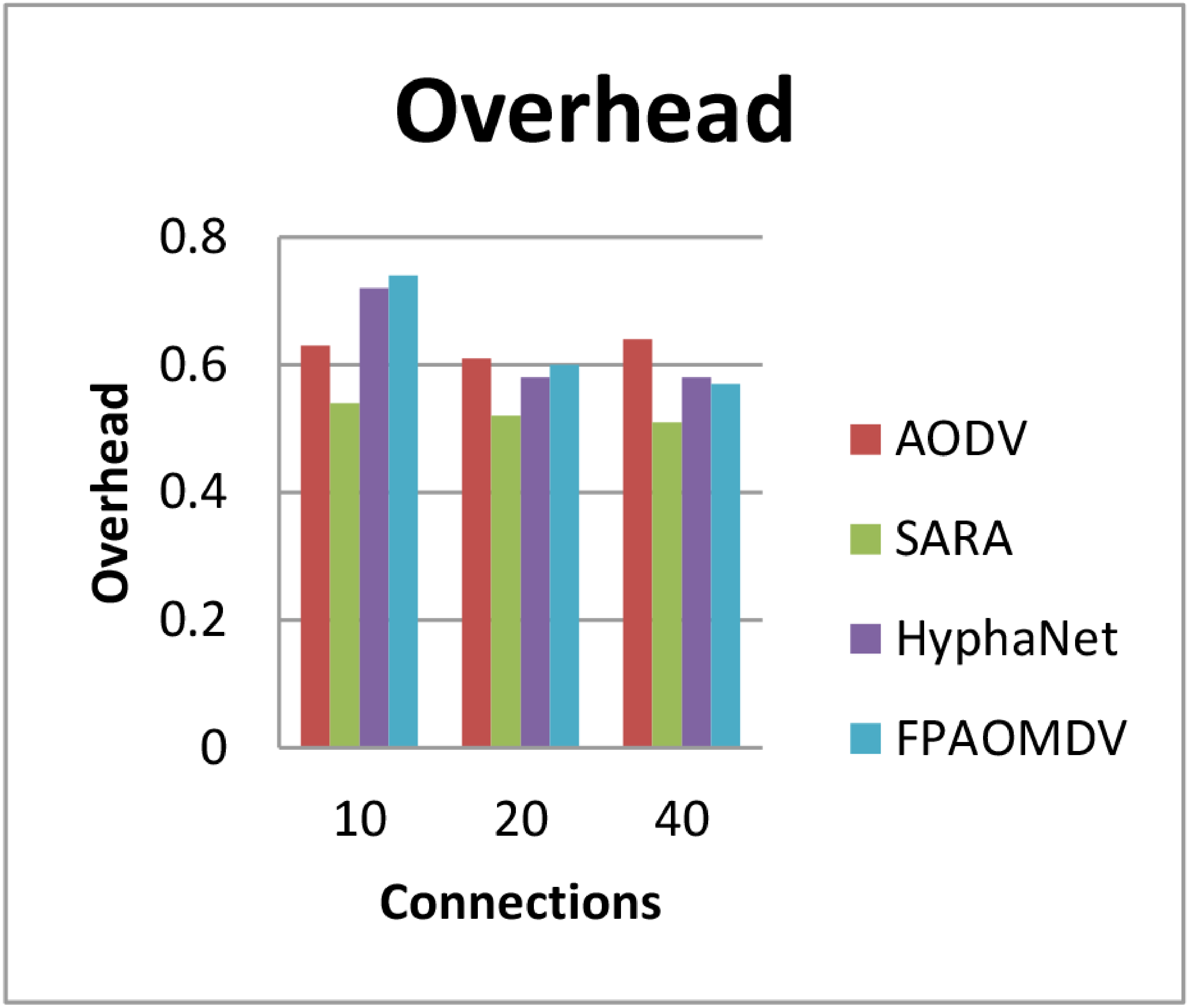

Figure 21

Overhead performance in scenario 2

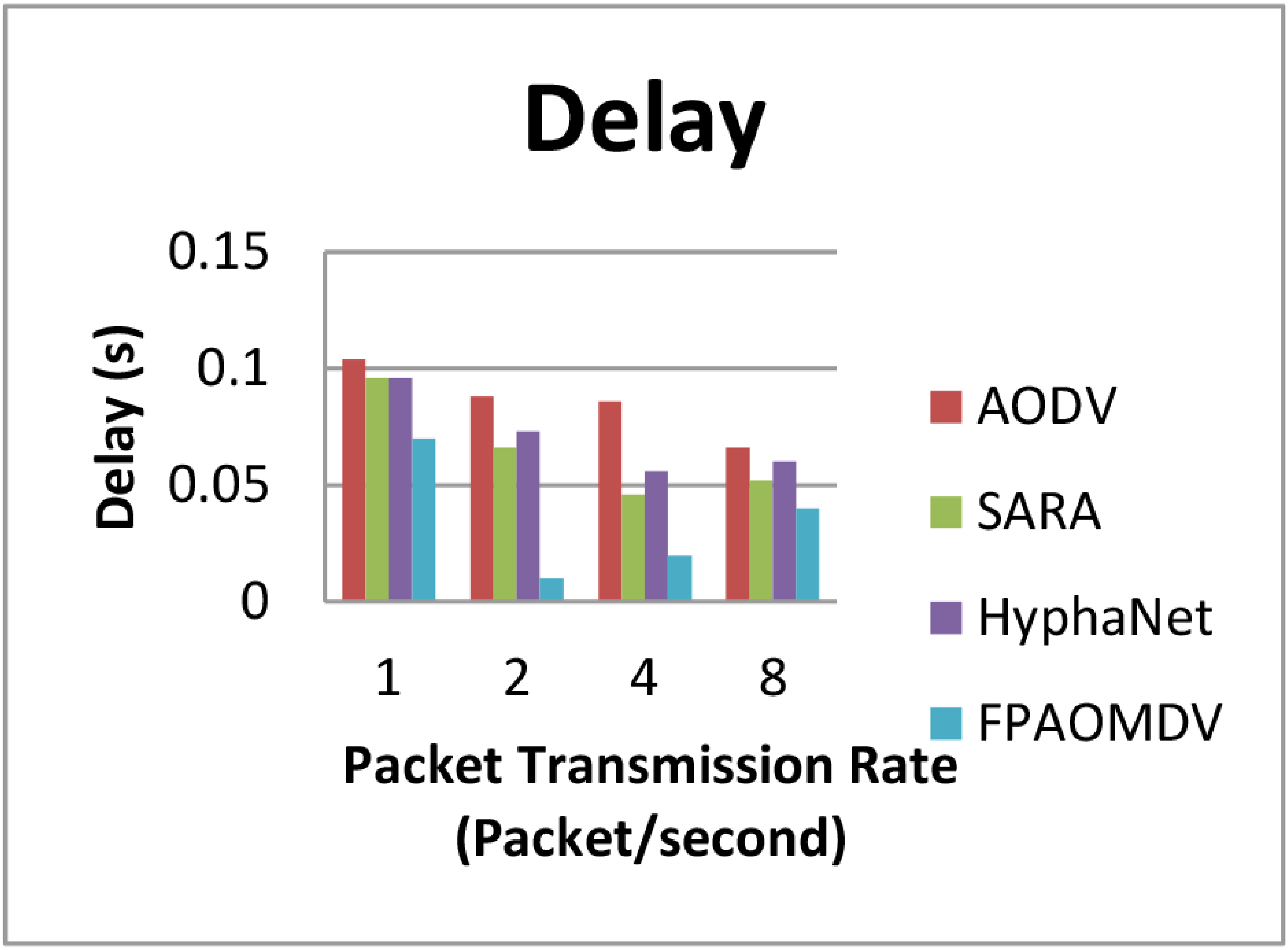

Figure 22

Delay Performance in Scenario 3

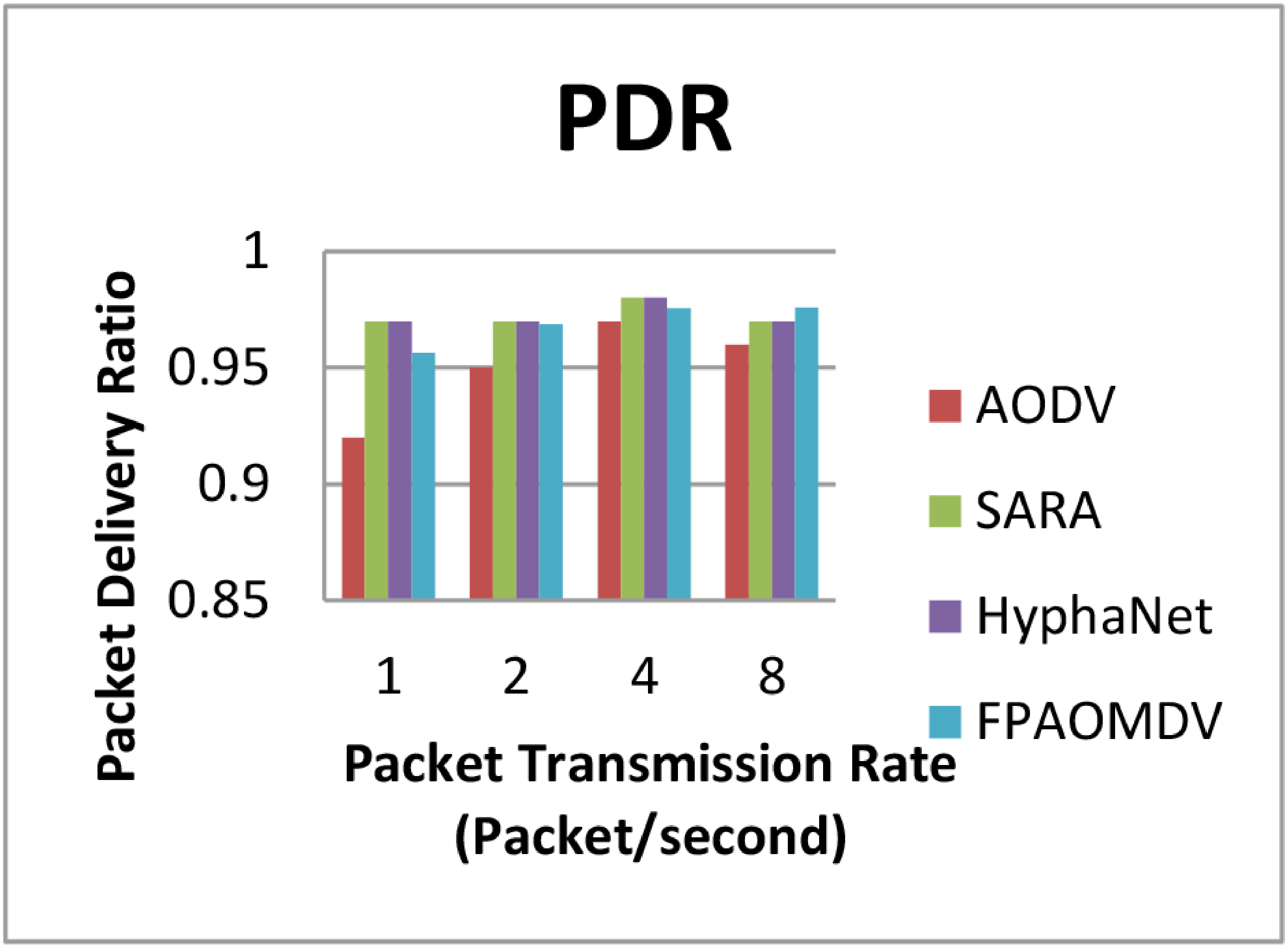

Figure 23

PDR Performance in Scenario 3

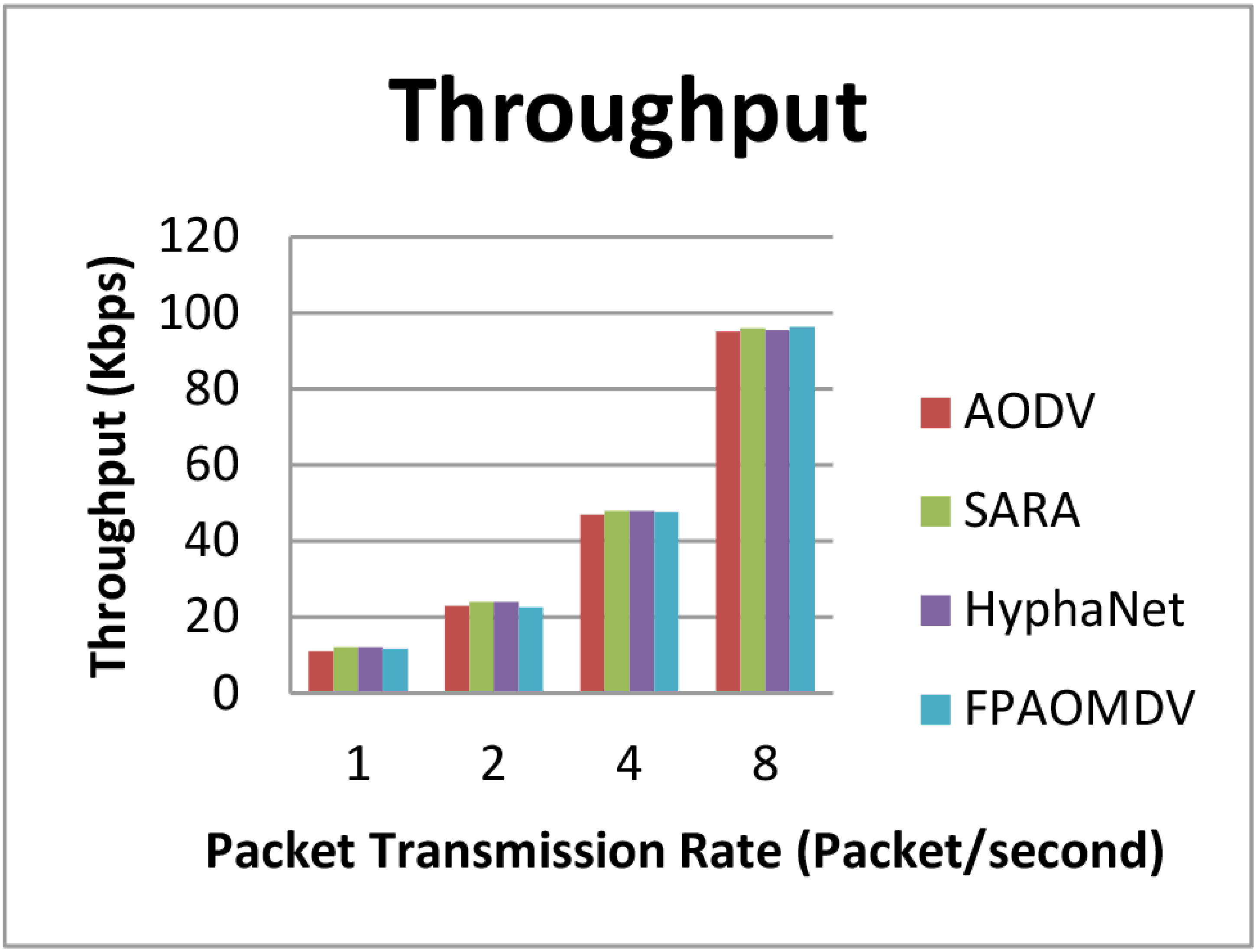

Figure 24

Throughput Performance in Scenario 3

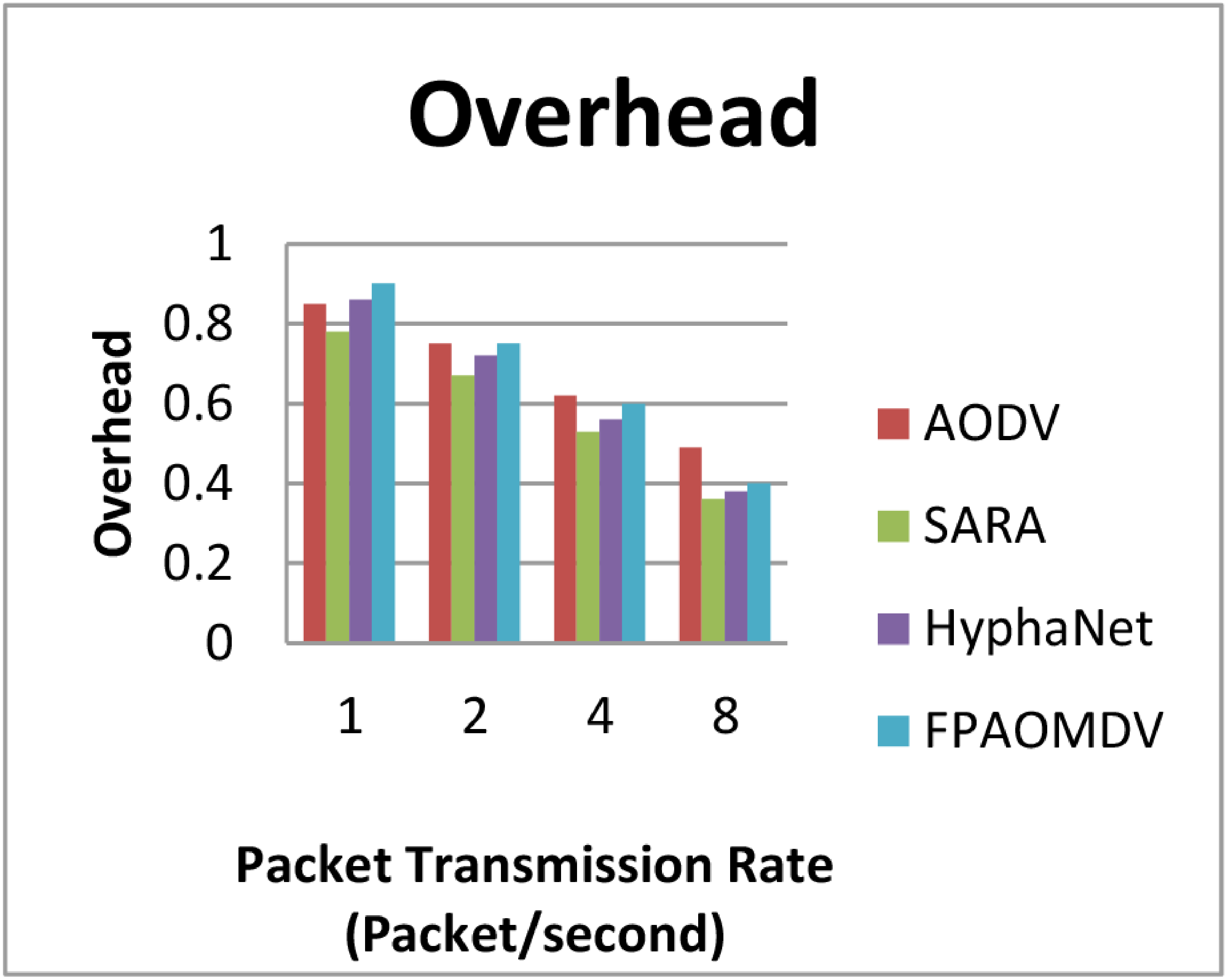

Figure 25

Overhead Performance in Scenario 3

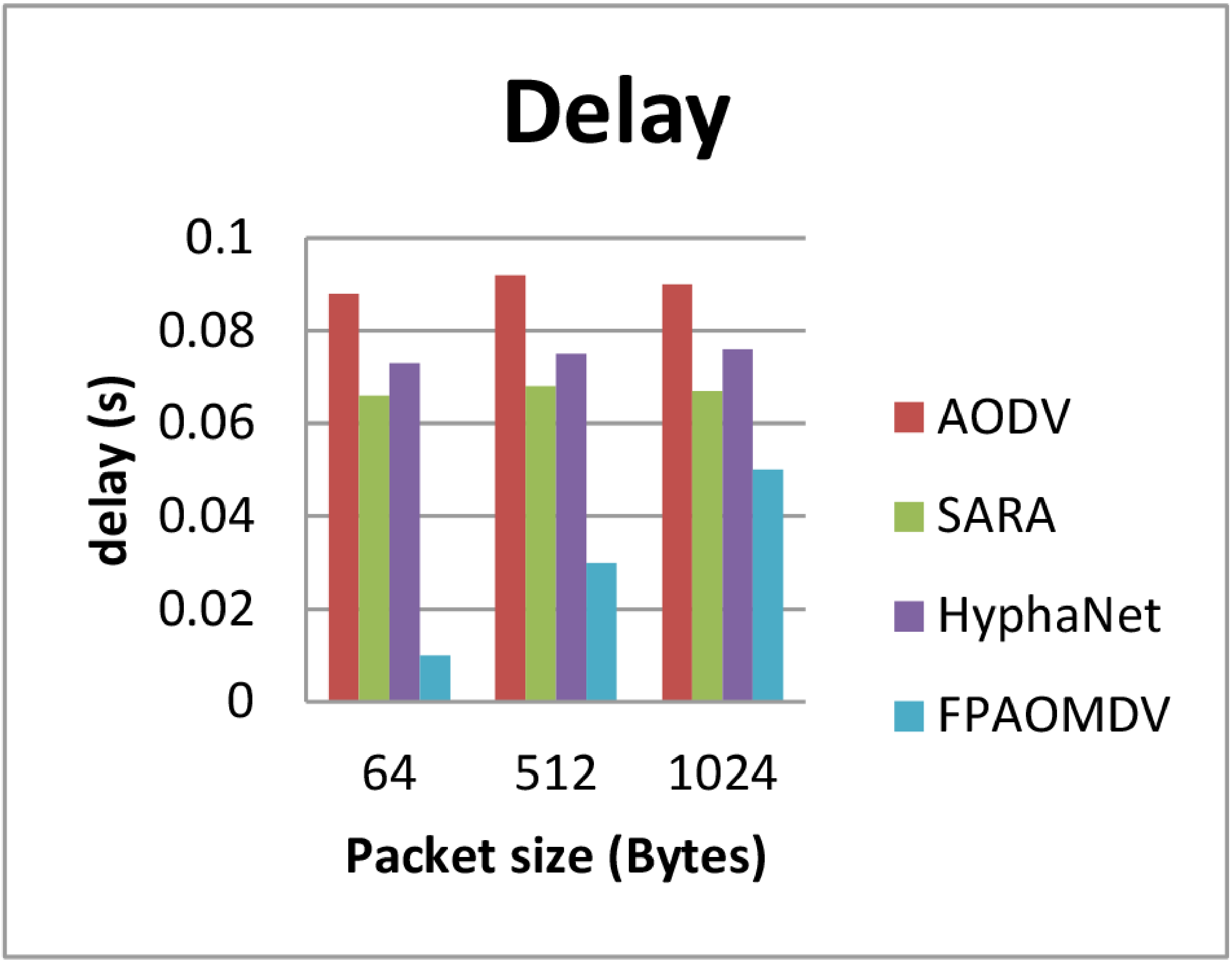

Figure 26

Delay Performance in Scenario 4

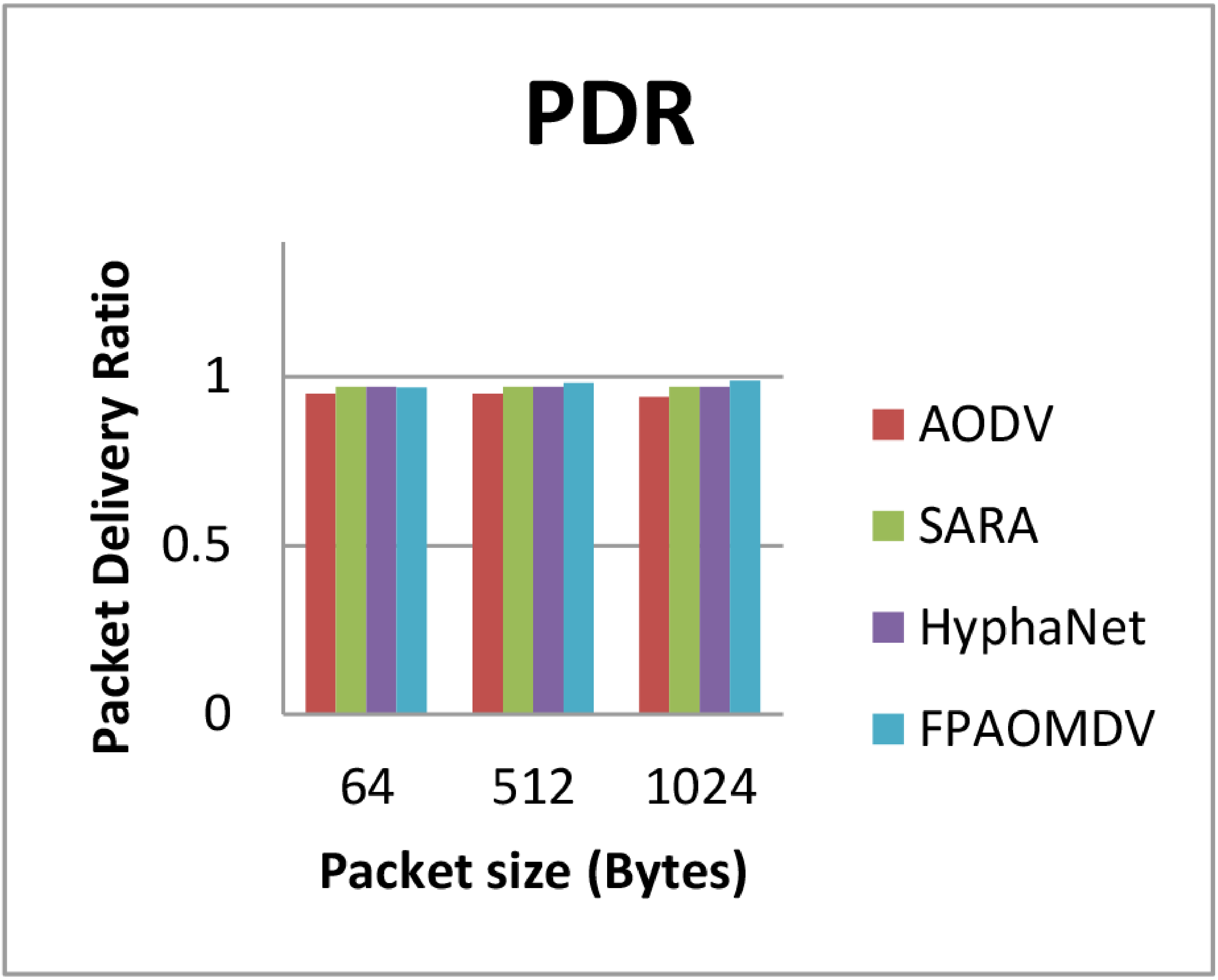

Figure 27

PDR Performance in Scenario 4

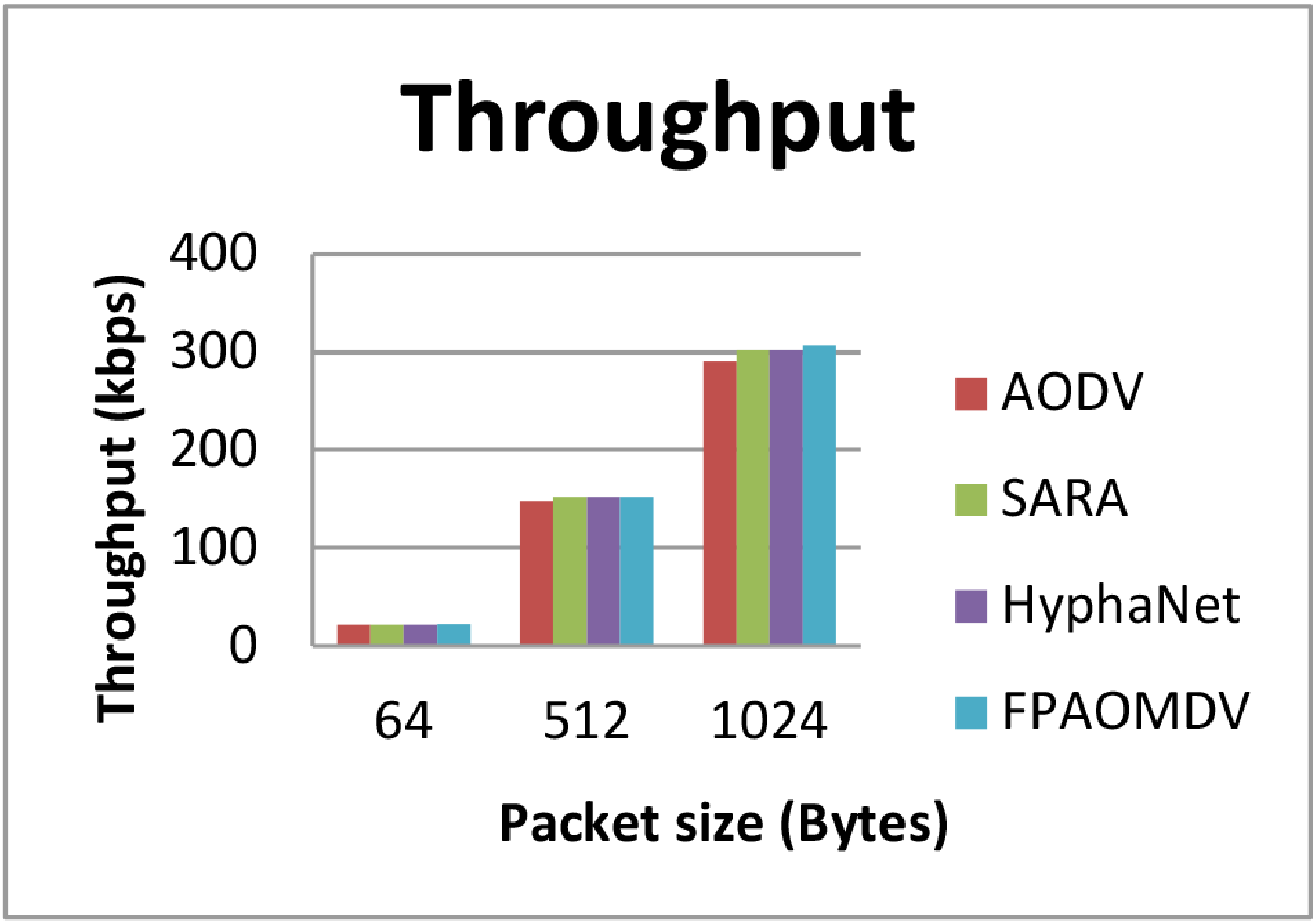

Figure 28

Throughput Performance in Scenario 4

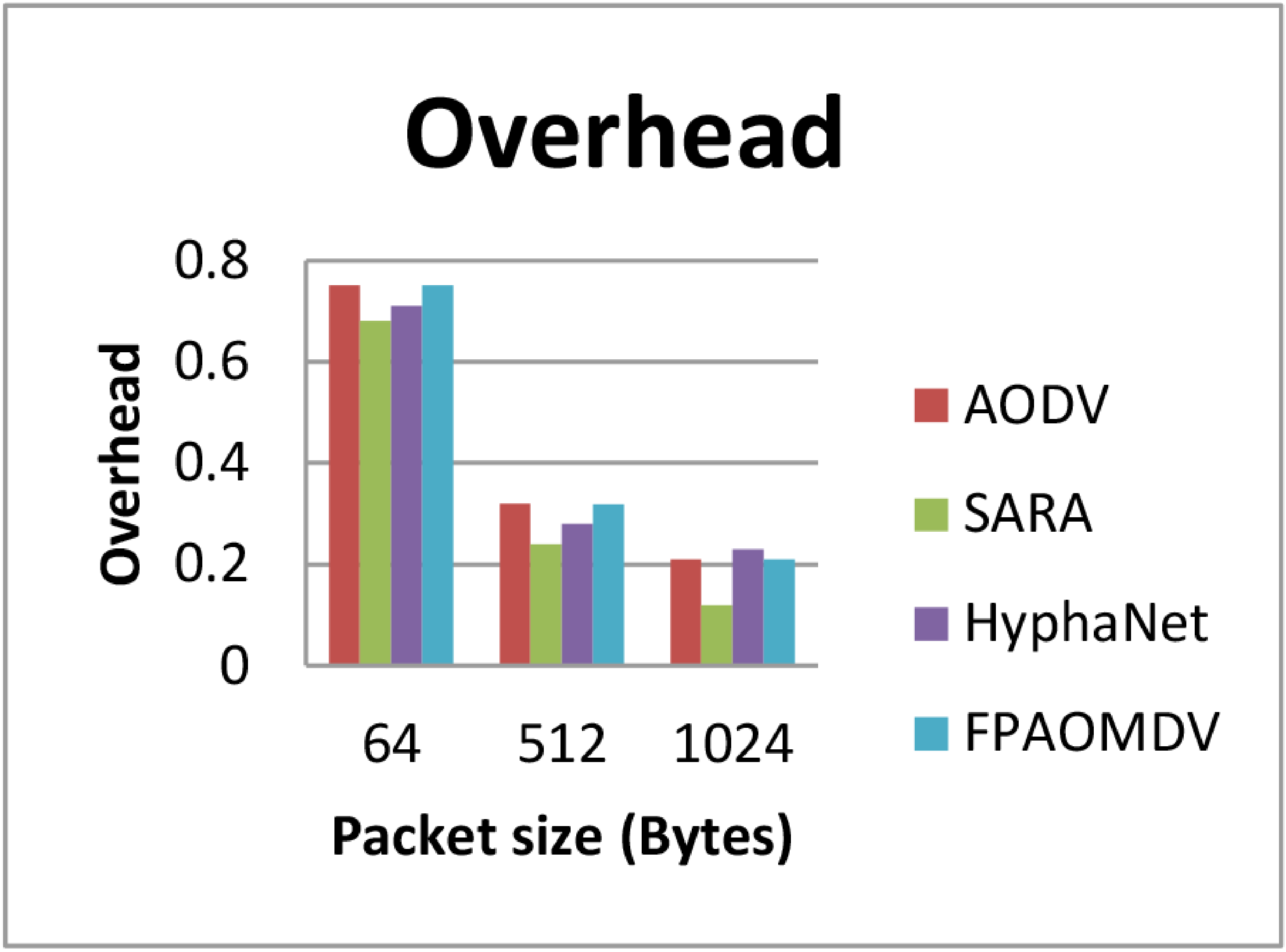

Figure 29

Overhead Performance in Scenario 4