Evaluation of Multipath Based Protocols in Wireless Networks

Pushpender Sarao

School of Computer Science and Engineering, Lovely Professional University, Phagwara (Punjab)-144411, India
Email: drpushpendersarao@gmail.com

***Abstract*—In wireless communications, it is very tedious task to achieve the best performance without losing any data and time. It is also a challenging work to select an appropriate routing protocol in different network scenarios in respect of several performance parameters. In this research work reactive and proactive routing protocols are evaluated by considering six performance parameters. Especially multipath-based routing protocols have been compared. Network scenarios are generated by varying the pause time, network size, simulation time, speed, number of nodes, network connections, and packet size. Performance parameters are considered as throughput, packet delivery ratio, average end to end delay, total dropped packets, jitter, and total received packets. Experimental work is conducted on network simulator NS-2.35 and results are tabulated for analytical discussion purpose. In most of the cases simulation results clearly indicate that, Ad-hoc on Demand Multi-path Distance Vector (AOMDV) and Destination Sequenced Distance Vector (DSDV) routing protocols shows excellence performance. In some cases, Multi-path Dynamic Address Routing Techniques (M-DART) routing protocol works well as compared to Ad hoc on Demand Distance Vector (AODV) and DSDV.**

***Keywords*—network topology, node density, throughput, network connections, jitter, pause time, delay**

I. Introduction

Wireless ad-hoc networks are infrastructure less, having low installation cost, ad hoc in nature, without centralized administration, used for short term communications like military operations. During data transmission, performance of wireless ad-hoc networks [1] is degraded due to poor efficiency of routing protocols in respect of different network scenarios. So many routing protocols have been used in past and present scenario for data transmission. Higher performance is desired by all the network users. But, to achieve this target is not so easy task; because in different network conditions and performance parameters, each and every routing protocol presents a totally different result. We cannot say which one is appropriate for better results. For that purpose existing routing protocols have been enhanced by researchers to extend their efficiency in different network scenarios [2–4].

Routing protocols are classified into three categories in to ad-hoc networks: proactive [5], reactive [6, 7], and hybrid routing protocols [8, 9]. Multi-path Dynamic Address Routing Techniques (M-DART), Destination Sequenced Distance Vector (DSDV) [10] are proactive routing protocols while Ad hoc on Demand Distance Vector (AODV), Ad-hoc on Demand Multi-path Distance Vector (AOMDV) [11], Dynamic Source Routing (DSR) [12] comes under reactive category. Zone Routing Protocol (ZRP) [13] and Two Zone Routing Protocol (TZRP) [14] are examples of the hybrid routing protocols.

M-DART: Dynamic Address Routing Techniques (DART) protocol have been further extended with some advanced features for example Table Elimination DART (ET-DART) and Multi-path DART (M-DART) routing protocols. To reduce the complexity of DART, connectedness feature is added in ET-DART [15]. Multi-path Dynamic Address Routing (M-DART) is an enhancement of DART (Dynamic Address Routing) protocol and follows the distance vector concept. It is a proactive multi-path routing protocol. M-DART was designed for scalable networks [16]. M-DART works on the basis of Distributed Hash Table (DHT). Performance of M-DART is better than DART routing protocol due to its coordination and communication free features in scalable networks. M-DART can identify all the possible and available routes between source node and the destination node. Energy consumption and delay is lower than Ad-hoc on Demand Distance Vector Routing Protocol (AOMDV) in scalable networks. Also in terms of throughput, M-DART outperforms as compared to AOMDV [17].

Destination Sequenced Distance Vector (DSDV) routing protocol is a proactive protocol. Dynamic Source Routing (DSR) is a reactive (on demand) protocol. Overhead messages is reduced in DSR, Ad hoc on Demand Distance Vector (AODV) [18], and On Demand Multi-path Distance Vector (AOMDV) routing protocol. To discover a new route, the above reactive routing protocols consumes more time as compared to proactive routing protocol.

In different network conditions, every routing protocol is not producing the desired performance results. Existing routing protocols are working well in one network scenario; but it may be possible that they will not produce better results in other network conditions. Efficiency may be degraded in terms of performance metrics such as

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throughput, packet delivery ratio, average end to end delay, and jitter.

In literature, so many enhancements of routing protocols have been proposed by researchers [19–21], but still there is a space to further enhancement. Therefore, to design a new routing protocol [22], efficiency evaluation of existing routing protocols is required. Also further investigation of their features and services, comparative analysis work is to be desired by the researchers. In this paper, a comparative investigation work has been carried out for reactive as well as proactive routing protocols. Here, objective is to prepare a background for enhancement of existing routing protocols in specified network scenarios.

The rest of this work is organized as follows: Section II revealed the literature work performed by several researchers in past. Proposed work with methodology and simulation setup is presented in Section III. After conducting the experimental work, detailed discussions for the results has been performed in Section IV. Section V presents the conclusions for this work.

II. Related Work

Sarao proposed an evaluation work for AODV, AOMDV, DSR, and DSDV routing protocols [23]. Total 31 mobile nodes were simulated on network simulator NS-2.35 based on performance parameters (throughput, end to end delay, normalized routing load). Four network scenarios were generated by varying the connections, pause time, simulation time, and speed. It was declared that AOMDV routing protocol has better results as compared to AODV, DSDV, and DSR routing protocols. Boukerche [24] presented the performance analysis of AODV, Preemptive AODV (PAODV), Cluster Based Routing Protocol (CBRP), DSR, and DSDV routing protocols. Node mobility, network size, network load based three scenarios were applied for comparative study on the platform of NS-2. Three performance parameters (throughput, average end to end delay, normalized routing overhead) were evaluated based on nodes and number of network connections. It was declared that PAODV works little better than AODV routing protocol.

Based on vehicle velocity and density, AODV, AOMDV, DSDV, and DSR routing protocols have been analysed in vehicular ad hoc network. By varying the speed (60–100 km/h) and nodes (100, 150, 200, 250, 300), performance metrics were analysed. It has been observed that in Vehicle Ad hoc Network (VANET) environment, velocity and density of vehicles will degrade the performance of AODV, AOMDV, DSDV, and DSR routing protocols [25]. Enhancement of AODV has been presented by Trivedi [26]. Also, a comparison work was carried out for AODV, AOMDV, DSR, and proposed protocol. Based on performance metrics such as packet dropped ratio, average end to end delays, normalized routing load, existing and proposed protocol were evaluated. By varying the number of nodes, network connections, different network scenarios were generated. In respect of end to end delay, normalized routing overhead, dropped ratio, performance of proposed algorithm was declared better than AODV, AOMDV, and DSR routing protocol. Also in respect of link failure and overhead, proposed protocol O-AODV works well.

Fahad Taha AL-Dhief presented an evaluation work for AODV, DSR, and DSDV routing protocols. To evaluate the performance of AODV, DSR, and DSDV performance metrics such as packet delivery ratio, average throughput, average End-to-End (E2E) delay, packet loss are used. Simulation work was conducted on network simulator NS-2.35 for 160 s in 600 m × 600 m network size. By varying the number of nodes (10–50 nodes) packet delivery ratio, throughput, packet loss has been observed. It has declared that DSDV produced better performance results with respect to packet delivery ratio and packet loss [27]. AODV, AOMDV, DSR, and DSDV routing protocols have been analysed based on Cluster Based Routing (CBR) and File Transfer Protocol (FTP) traffic [28]. Simulation work was carried out on NS-2.35 by varying the nodes (from 50 to 150 nodes). Packet delivery ratio and end to end delay were considered as performance metrics. Simulation results were recorded for 200 s in 1000 m × 1000 m network size. Network scenarios were generated by varying the speed and nodes. AODV protocol was recommended in terms of packet delivery ratio and packet loss ratio while AOMDV declared as best suitable protocol in terms of packet delivery ratio and end to end delay. In mobile ad hoc network environment, Velmurugan Thambusamy and Navitha Srinivasan investigated AODV and Temporally Ordered Routing Algorithm (TORA) routing protocols [29]. Authors considered performance metrics such as Packet Delivery Ratio (PDR), throughput, E2E delay and routing overhead. Total 75 mobile nodes have been simulated at network simulator NS-2.35 in 500 m × 500 m network size environment. By varying the simulation time, packet size, and mobility, three different network scenarios were generated. It is suggested to use mobility model only in small and medium sized networks. AODV routing protocol declared as best suitable protocol for Mobile ad hoc network (MANET) as compared to TORA routing protocol.

Kong and Cui [30] presented evaluation work for AODV, DSR, and DSDV routing protocols in MNAET at the platform of network simulator 2.35. Evaluation parameters were considered such as E2E delay, PDR, normalized routing load in the network. Using the mobility model and traffic model, protocols were simulated in different network scenarios. Network scenarios were generated by varying the sending rate pause time. After simulation work carried out for 50 mobile nodes with maximum speed 20 m/s. it was concluded that DSR and AODV performs better results as compared to DSDV routing protocol in terms of PDR. While in other case, AODV works well as compared to DSR and DSDV in terms of average delay.

Singh *et al.* proposed a comparative study for M-DART and AOMDV routing protocols [31]. To investigate the performance of both protocols, evaluation parameters were considered such as average throughput, packet delivery ratio, average end to end delay and average energy consumption. By varying the simulation time and number of nodes, performance of M-DART and AOMDV has been analysed. M-DART routing protocol was declared as best suitable protocol in terms of energy consumption. Because of better scalability, M-DART presents better performance results in terms of throughput and end to end delay. AODV, AOMDV, DSR, and DSDV routing protocols have been analysed with move and without move conditions in mobile ad hoc networks. Quantitative performance parameters were considered such as average throughput, packet delivery ratio, average E2E delay, and packet dropped ratio. With move and without move situations, simulation work was carried out on network simulator NS-2. In without move condition, AODV protocol presents better results as compared to DSR and AOMDV in terms of average throughput. AODV and DSR works well with better results in terms of packet delivery ratio, average E2E delay, and total dropped packets. In with move condition, AODV and DSR are preferably better than AOMDV routing protocol [32].

Performance of Routing Protocol for Low-Power and Lossy Networks (RPL) has been evaluated in [33] with static and mobile ad hoc networks. The simulation and implementation work was carried out in Cooja network simulator. It was observed that number of sending nodes, mobility of nodes, and numbers of sink nodes are such parameters which directly affect the performance of RPL routing protocol. Total 15–30 nodes were simulated for 1800 s and it was identified that Hop Count (HC), Expected Transmission Count (ETX), and power consumption values are highest in dense networks while packet delivery ratio and Transmit Duty Cycle (TDC) are very low. Also it has been declared that RPL works well as the number of sink nodes are increased.

Kondakci has presented the routing efficiency in infrastructure less networks in terms of traffic. Also a reference model is proposed in respect of routing algorithm named as sink-oriented Collaborative Routing Algorithm (SOCRA), in order to conduct routing process evaluation in an infrastructure less network [34]. For experimental work, Python/scapy, and Nmap/nping have been used for packet generator while MATLab was used to generate an infrastructure less network scenario for simulation purpose. Throughput based comparison work was carried out for flooded nodes and SOCRA scheme based nodes. It was observed that throughput is better in SOCRA based routing as compared to flooded nodes. It was suggested that for fast data transmission, better power sustainability, and higher mobility, SOCRA is a best option to create a collaborative network topologies. Tan *et al.* [35] have been evaluated four routing protocols AODV, DSR, Optimized Link State Routing (OLSR), Geographic Routing Protocol (GRP) in Unmanned Aerial Vehicle (UAV) communication networks. The performance parameters were considered such as throughput, network delay, data packets dropped, and total packets received. The experimental work was conducted on OPNET 14.5 network simulator. By varying the node density and speed, all above protocols were compared and analysed. Route discovery and route maintenance processes were also presented in detail. It was declared that none of the above protocols has optimal efficiency in terms of throughput, delay, data packets received, and total packets dropped. Sharma and Chaudhary [36] proposed an enhancement for AODV in terms of end to end delay in Vehicle Ad hoc Network (VANET). Also a comparative experimental work was carried out for AODV and proposed algorithm named Temporary Modified AODV (TM-AODV) on SUMO and network simulator NS-2. By varying the number of nodes and considering the evaluation parameters such as throughput and end to end delay, performance analysis work was conducted. It was observed that in VANET environment, TM-AODV shows better performance results in terms of end to end delay as compared to AODV routing protocol.

Various routing protocols have been surveyed and analysed in Unmanned Aerial Vehicle (UAV) based vehicular ad-hoc network [37]. Classification, advantages, and disadvantages of routing protocols have been presented. Also, a comparative study has been conducted and summarised in table. Reactive routing based protocols are classified as: Delay Constrained UAV-aided Vanet Routing Protocol (DCUVP), Connectivity-based Traffic Density Aware Routing for UAV-aided Vanet (CRUV), Ground-air Co-operative Routing Protocol (GACP), Routing Protocol for UAV-aided-Vanet Backbone Network (RPUBN), while hybrid routing protocols are classified as: an intersection UAV-assisted Vanet Routing Protocol (UVAR), Zone-based Routing Protocol for UAV-aided Vanet (ZRPUV), an intersection UAV-assisted VANET Routing protocol (UVAR) in UAV based VANET. In some existing protocols, delay and energy performance is not considered, while in other protocols, incoming vehicles and mobility concept was missing. Areas of application, a particular protocol is recommended. In Ref. [38], Al-Zahraniproposed the optimized and enhancement of routing protocols in multi-hop wireless networks. Efficiency of four flooding techniques have been performed using six routing protocols based on energy and time consumption, efficiency of flooding techniques have been evaluated using some mathematical models that are applicable on routing protocols. Optimization and enhancement work was conducted on network simulator NS-2. Fifty nodes were simulated for 900 s in network area of 1000 m × 1000 m. performance parameters such as end to end delay, normalized routing load, and throughput were considered for evaluation of enhanced work. It was concluded that normalized routing load plays a great role in reducing the overhead and delay for all data communication process. Zhang *et al.* presented link life time and energy based Ad hoc On-demand Multi-path Distance Vector (AOMDV) routing prot0col [39]. In mobile edge computing, energy grading strategy concept has been applied to enhance the AOMDV routing protocol. By varying the simulation time and speed of nodes, network scenarios were generated. Also, a comparison and evaluation work was carried out for AOMDV, Link Lifetime and Energy Consumption Prediction AOMDV (LLECP-AOMDV), Ad hoc On-demand Multi-path Routing with Lifetime Maximization (AOMR-LM), Fitness Function-AOMDV (FF-AOMDV) 1000 m × 1000 m size network topology. For efficiency evaluation, performance parameters were considered such as packet delivery rate, average end to end delay, and energy consumption. It was claimed that proposed routing protocol shows better results in terms of end to end delay, energy consumption, and delivery rate of data packets.

In Ref. [40], AODV, AOMDV, and DSDV routing protocols have been evaluated in mobile ad-hoc networks. Performance evaluation parameters were considered such as routing overhead, delay, throughput, packet loss, and Packet Delivery Ratio (PDR). Implementation work was carried out on network simulator NS-2 in 1000 m × 1000 m network size for 200 s. By varying the number of nodes (25–200 nodes), all the above protocols were analysed. It was observed that AOMDV routing protocol works well as compared to AODV and DSDV in terms of packet delivery ratio and packet loss. AODV presents better results in terms of throughput while DSDV works well in terms of delay. A comparative study for AODV and DSR routing protocols has been presented in ad-hoc networks. By varying the number of nodes (10 nodes to 510 nodes) performance evaluation work was carried out for 60 min at network simulator NS-2. Evaluation parameters were considered such as packet loss, energy consumption, throughput, packet delivery fraction, and average end to end delay. AODV routing protocol was highly recommended as compared to DSR routing protocol in terms of throughput and energy consumption [41].

Mohsin and Woods [42] have investigated the efficiency of AODV, AOMDV, DSR, and DSDV routing protocols in ship ad hoc networks environment. In network size 400 × 300 km, simulation work was conducted for all above protocols on network simulator version NS-2.35 for 80 s. Performance metrics were considered such as end to end delay, packet delivery ratio, and throughput. From the experimental work, it was concluded that out of four above protocols, no one has desired performance in ship ad hoc networks. Due to its multipath route discovery feature, AOMDV shows better results as compared to AODV, DSR, and DSDV routing protocols. Five routing protocols AODV, DSR, DSDV, ZRP, and TORA have been compared and analyzed on the basis of performance metrics such as jitter, throughput, average E2E delay, and total dropped packets [43]. Merits and demerits of all the above protocols are also presented as per applications of area. By varying the number of nodes, network scenario has been generated. ZRP protocol is recommended for higher number of nodes in terms of jitter and total dropped packets while DSDV is preferable in terms of average end to end delay. Gao *et al.* [44] presented vehicle to vehicle reliable data transmission and route optimization techniques by considering the Road Side Units (RSUs) in VANET. By analysing the problem and issues in moving vehicles and network connectivity, and enhanced greedy algorithm has been applied for reliable routing. Hybrid Network Routing (HNR) for vehicular ad hoc network has been proposed to achieve the best PDR in terms of number of nodes and wireless transmission ranges. HNR is designed on the basis of Manhattan mobility model. To improve the transmission process, HNR uses the Road Side Units (RSUs). HNR mostly uses the wired transmission in hybrid networks. HNR reduces the number of hops in routing process to achieve the better performance in terms of large number of nodes (node densities). In terms of PDR, delay, and number of hops, HNR shows better results.

Using common Random Point Group Mobility Model (RPGM), three routing protocols namely AODV, DSR, and DSDV have been investigated in terms of performance metrics such as average delay, and average throughput [45]. Performance analysis and comparison work was carried out in single group and multiple group environments by varying the pause time, mobility, and connection ratio. In multiple group environments, at constant connection ratio, AODV presents better results as compared to DSR routing protocol while in single group environment, DSDV outperforms DSR and AODV in terms of average throughput.

III. Proposed Work: Methodology and Simulation Setup

The proposed research work has been conducted for AODV, AOMDV, DSR, DSDV, and M-DART routing protocols.

For simulation work, we have used network simulator NS-2.35 on UBUNTU 16.4 operating system. Before simulation work, we wrote a number of Tcl scripts in respect of required wireless scenarios for maximum 30 movable nodes. After executing the Tcl scripts on network simulator NS-2.35, trace files have been generated. Performance parameters are calculated with the help of trace files and awk scripts.

Simulation work was carried out in seven different network scenarios for maximum 50 s simulation time. These seven network scenarios are listed as below:

1) Varying the no. of connections
2) Varying the network size
3) Varying the packet size
4) Varying the pause time
5) Varying the simulation time
6) Varying the speed
7) Varying the node density

- **Scenario-I:**

In this scenario, maximum 30 nodes (with traffic type CBR, UDP) were simulated (in 512 m × 468 m network topology) for 50 s simulation time. All nodes were settled with 0s pause time and 40 m/s maximum speed. Varying the network connections from 5 to 30 connections with packet size 512 bytes, routing protocols were evaluated.

- **Scenario-II:**

Varying the network size 100 m × 100 m to 1000 m × 1000 m, simulation set up was prepared with 30 maximum connections. All other parameters were kept as same as in Scenario-I.

- **Scenario-III:**

Varying the packet size from 256 bytes to 4500 bytes (with 30 network connections, 40 m/s maximum speed, 0 s pause time, and 512 m × 468 m network topology size), network scenario was generated. Simulation work carried out at network simulator NS-2.35 for 50 s simulation time. All other parameters were kept same as in Scenario-I and Scenario-II.

- **Scenario-IV:**

At different values of pause times (40 s, 60 s, 80 s, 100 s, 120 s, 140 s, and 160 s), (having 160 m/s maximum speed, 512 bytes packet size, 30 network connections with UDP, CBR traffic), simulation work was carried out for 30 mobile nodes. Total duration of simulation was kept as 50 s. All other parameters like antenna type, channel type, network topology (512 m × 468 m), network interface type etc. were kept same as in Scenario-III.

- **Scenario-V:**

Five routing protocols (AODV, AOMDV, DSR, DSDV, and M-DART) were simulated by varying the simulation time from 20 s to 200 s (with 60 m/s maximum speed). Parameters like network size, pause time, maximum connections, and pause time etc. were settled as same as in Scenario-IV.

- **Scenario-VI:**

Varying the speed of mobile nodes from 20 m/s to 160 m/s, network scenario was created. Remaining other parameters were kept as same as in Scenario-V.

TABLE I. SCENARIO I TO VII PARAMETERS

	Scenario-I: Connections	**Scenario-II: Network Size**	**Scenario-III: Packet Size**	**Scenario-IV: Pause time**	**Scenario-V: Simulation time**	**Scenario-VI: Speed**	**Scenario-VII: Nodes**
Parameter	Value	Value	Value	Value	Value	Value	Value
NS-2 Version	2.35	2.35	2.35	2.35	2.35	2.35	2.35
Channel type	Wireless Channel	Wireless Channel	Wireless Channel	Wireless Channel	Wireless Channel	Wireless Channel	Wireless Channel
Radio propagation model	Two Ray Ground	Two Ray Ground	Two Ray Ground	Two Ray Ground	Two Ray Ground	Two Ray Ground	Two Ray Ground
Network interface type	WirelessPhy	WirelessPhy	WirelessPhy	WirelessPhy	WirelessPhy	WirelessPhy	WirelessPhy
MAC type	Mac/802.11	Mac/802.11	Mac/802.11	Mac/802.11	Mac/802.11	Mac/802.11	Mac/802.11
Interface queue type	PriQueue	PriQueue	PriQueue	PriQueue	PriQueue	PriQueue	PriQueue
Link layer type	LL	LL	LL	LL	LL	LL	LL
Antenna model	Omni Antenna	Omni Antenna	Omni Antenna	Omni Antenna	Omni Antenna	Omni Antenna	Omin Antenna
Max. packets in queue (queue length)	50	50	50	50	50	50	50
No. of mobile nodes	30	30	30	30	30	30	5, 10, 15, 20, 25, 30
Traffic type	UDP, CBR	UDP, CBR	UDP, CBR	UDP, CBR	UDP, CBR	UDP, CBR	UDP, CBR
Routing protocol	AODV, AOMDV, DSR, DSDV, M-DART	AODV, AOMDV, DSR, DSDV, M-DART	AODV, AOMDV, DSR, DSDV, M-DART	AODV, AOMDV, DSR, DSDV, M-DART	AODV, AOMDV, DSR, DSDV, M-DART	AODV, AOMDV, DSR, DSDV, M-DART	AODV, AOMDV, DSR, DSDV, M-DART
Network topology size (x × y)	512 m × 468 m	100 m×100 m, 200 m × 200 m, 300 m × 300 m, 400 m × 400 m, 500 m × 500 m, 600 m × 600 m, 700 m × 700 m, 800 m × 800 m, 900 m × 900 m, 1000 m × 1000 m	512 m × 468 m	512 m × 468 m	512 m × 468 m	512 m × 468 m	512 m × 568 m
Simulation time	50 s	50 s	50 s	50 s	20 s, 40 s, 60 s, 80 s, 100 s, 120 s, 140 s, 160 s, 180 s, 200 s	50 s	50 s
Pause time	0 s	0 s	0 s	40 s, 60 s, 80 s, 100 s, 120s, 140 s, 160 s	0 s	0 s	0 s
Max. speed	40 m/s	40 m/s	40 m/s	40 m/s	40 m/s	20 m/s, 40 m/s, 60 m/s, 80 m/s, 100 m/s, 120 m/s, 140 m/s, 160 m/s	40 m/s
Max. no. of connections	5, 10, 15, 20, 25, 30	30	30	30	30	30	4
Packet size	512 bytes	512 bytes	256, 512, 1024, 2048, 3072, 4096, 4500 bytes	512 bytes	512 bytes	512 bytes	512 bytes

- **Scenario-VII:**

This scenario was generated by varying the number of mobile nodes (5–30 nodes) with network size 512 m × 568 m (having 50 s simulation time, 0 s pause time. Different routing protocols were simulated with different node densities. Keeping the 50 queue length, Maximum speed for all nodes was decided as 40 m/s. All parameters were decided as same as in Scenario-VI.

In seven different network scenarios, efficiency of routing protocols (AODV, AOMDV, DSR, DSDV, and M-DART) have been investigated with respect to six performance parameters (received packets, packet delivery ratio, average end to end delay, throughput, total dropped packets, and jitter).

If we set the pause time as zero, then it means nodes are moving continuously.

Performance metrics: The below list shows the performance metrics for the simulation.

1) Throughput
2) Total Dropped packets
3) Total Received packets
4) Jitter
5) Average End-to-End delay
6) Packet delivery ratio

For seven different network scenarios, several parametric values have been decided as shown in Table I.

IV. RESULTS AND DISCUSSION

After completion of simulation work, overall results are recorded in Tables II–VIII. Results are recorded in terms of simulation time, packet size, pause time, network size, connections, speed, and number of nodes.

TABLE II. PERFORMANCE PARAMETERS W. R. T. SIMULATION TIME

Simulation Time Vs ↓	AODV	AOMDV	DSDV	DSR	M-DART
Received packets	75135	75093	74982	25285	74748
PDR (%)	99.9471	99.9403	99.9331	99.6995	99.9963
Average E2E delay (ms)	0.86405	0.91192	0.41152	3.2763	0.003916
Total Dropped Packets	4	7	5	1	0
Throughput (kbps)	**44341.882**	**48696.29**	**48619.503**	**16395.914**	**48459.239**
Jitter	**1.1223**	**0.7351**	**0.0007**	**0.1466**	**0.0039**

TABLE III. PERFORMANCE PARAMETERS W. R. T. PACKET SIZE

Packet Size (bytes) Vs ↓	AODV	AOMDV	DSDV	DSR	M-DART
Received packets	4895	4990	5990	4823	3278
PDR (%)	88.46	91.55	86.374	58.28	91.36
Average E2E delay (ms)	1099.035	1076.44	848.015	2178.46	1025.30
Total Dropped Packets	237	188	215	112	84
Throughput (kbps)	507.35	549.44	629.36	465.41	347.26
Jitter	0.2228	0.0758	0.0079	1.1958	0.2107

TABLE IV. PERFORMANCE PARAMETERS W. R. T. PAUSE TIME

Pause time (s) Vs ↓	AODV	AOMDV	DSDV	DSR	M-DART
Received packets	8126	7588	9698	1059	5290
PDR (%)	94.25	95.10	93.17	87.53	94.58
Average E2E delay (ms)	1240.30	1557.98	934.678	441.134	829.14
Total Dropped Packets	147	99	98	6	71
Throughput (kbps)	366.21	353.48	448.23	288.03	245.44
Jitter (ms)	0.1885	0.3352	0.06925	0.1370	0.2032

TABLE V. PERFORMANCE PARAMETERS W. R. T. NETWORK SIZE

Network size Vs ↓	AODV	AOMDV	DSR	DSDV	M-DART
Received packets	9861	9721	19719	10456	5007
PDR (%)	94.4	95.397	66.51	93.76	94.45
Average E2E delay (ms)	685.72	654.88	1208.10	629.88	480.84
Total Dropped Packets	274	227	153	183	179
Throughput (kbps)	445.01	451.75	432.81	462.64	231.077
Jitter (ms)	0.05573	0.02290	0.60892	0.01248	0.15108

TABLE VI. PERFORMANCE PARAMETERS W. R. T. CONNECTIONS

Connections Vs ↓	AODV	AOMDV	DSDV	DSR	M-DART
Received packets	9217	9575	10110	9733	6400
PDR (%)	94.96	96.079	94.367	83437	96.65
Average E2E delay (ms)	624.99	590.92	531.028	894.48	483.288
Total Dropped Packets	8380	6527	1903	2450	3405
Throughput (kbps)	414.28	441.89	480.64	351.43	295.37
Jitter (ms)	0.070769	0.03328	0.009788	0.6086	0.05422

TABLE VII. PERFORMANCE PARAMETERS W. R. T. SPEED

Speed (m/s) Vs ↓	AODV	AOMDV	DSR	DSDV	M-DART
Received packets	9292	9269	9009	8964	5163
PDR (%)	93.06	94.67	75.14	93.64	93.97
Average E2E delay (ms)	680.88	832.60	1388.83	788.10	656.59
Total Dropped Packets	351	254	119	188	143
Throughput (kbps)	420.54	433.15	402.25	475.15	240.52
Jitter (ms)	0.0607	0.0454	0.8243	0.0182	0.2014

TABLE VIII: PERFORMANCE PARAMETERS W.R.T. NODES

Nodes Vs ↓	AODV	AOMDV	DSR	DSDV	M-DART
Received packets	8604	8334	8411	8121	5972
PDR (%)	97.478	97.794	83.472	96.326	98.147
Average E2E delay (ms)	301.184	291.847	413.201	216.953	317.707
Total Dropped Packets	97	114	43	90	74
Throughput (kbps)	383.665	384.324	373.076	404.43	278.118
Jitter (ms)	0.0346	0.0261	0.2603	1.6213	0.0662

By varying the network connections, performance of routing protocols has been evaluated in terms of different metrics as shown in Fig. 1. Detailed results are discussed as below:

- **Varying the Connections—Received packets:**

Received packets have been evaluated for all five protocols by varying the number of connections as 5 to 30. In case of AODV and AOMDV, mostly received packets are decreasing as the numbers of connections are increased; while it is fluctuating for DSDV, DSR, and M-DART. DSDV has highest performance while M-DART shows very poor performance. As compared to AODV, AOMDV has more number of received packets, i.e., 9515.

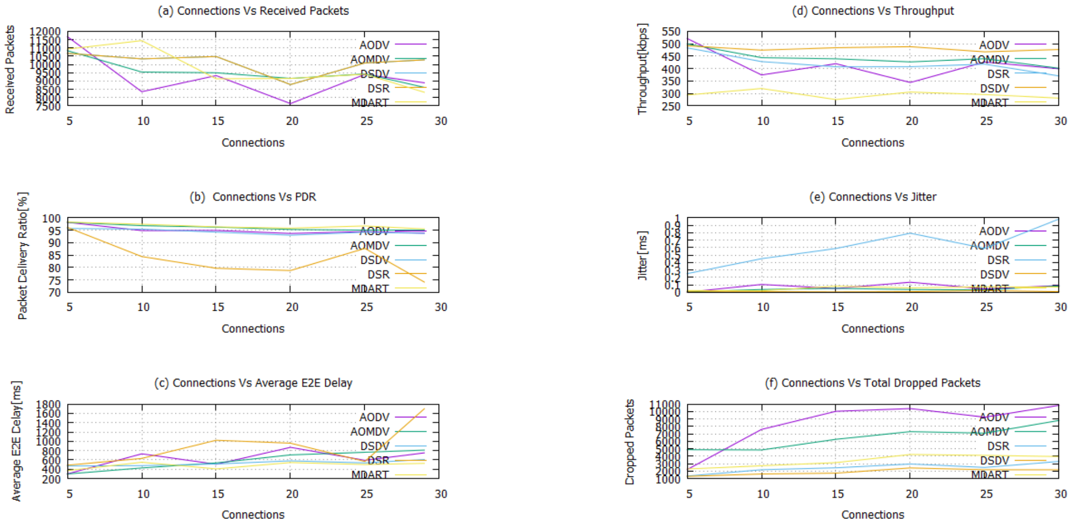

Fig. 1. Performance analysis by varying the connections.

- **Varying the Connections—PDR:**

Packet delivery ratio is highest for M-DART while it is lowest for DSR routing protocol. AOMDV works well as compared to AODV. There are small changes in PDR for all routing protocols as numbers of connections are increased. For all protocols, packet delivery ratio is highest at 5 network connections.

- **Varying the Connections—Average E2E Delay:**

There are fluctuations in average end to end delay as the numbers of connections are increased. As numbers of connections are more, M-DART presents the best results while DSR shows poor performance. AOMDV routing protocol works well as compared to AODV and DSR.

- **Varying the Connections—Average Throughput:**

By varying the number of connections, throughput for all protocols has been analyzed. Results show that DSDV is best suitable protocol while M-DART presents a very poor performance. Throughput for AOMDV (441.89 kbps) is highest than AODV (414.28 kbps). It means that AOMDV is most appropriate protocol as compared to AODV in respect of number of network connections.

- **Varying the Connections—Total Dropped Packets:**

While varying the number of connections, it has been observed that AODV has highest number of dropped packets while it is lowest for DSDV. DSR works well as compared to M-DART, AODV, AOMDV routing protocols. Performance of AOMDV is better than AODV.

- **Varying the Connections—Jitter:**

When numbers of connections are increased from 5 to 30, DSDV presents excellent results while DSR routing protocol comes under worst case. AOMDV works well as compared to AODV and M-DART. There is little bit fluctuations of jitter while number of connections are increased.

By changing the speed of moving nodes, routing protocols has been analyzed and results are graphically represented as illustrated in Fig. 2. This work is presented in details as below:

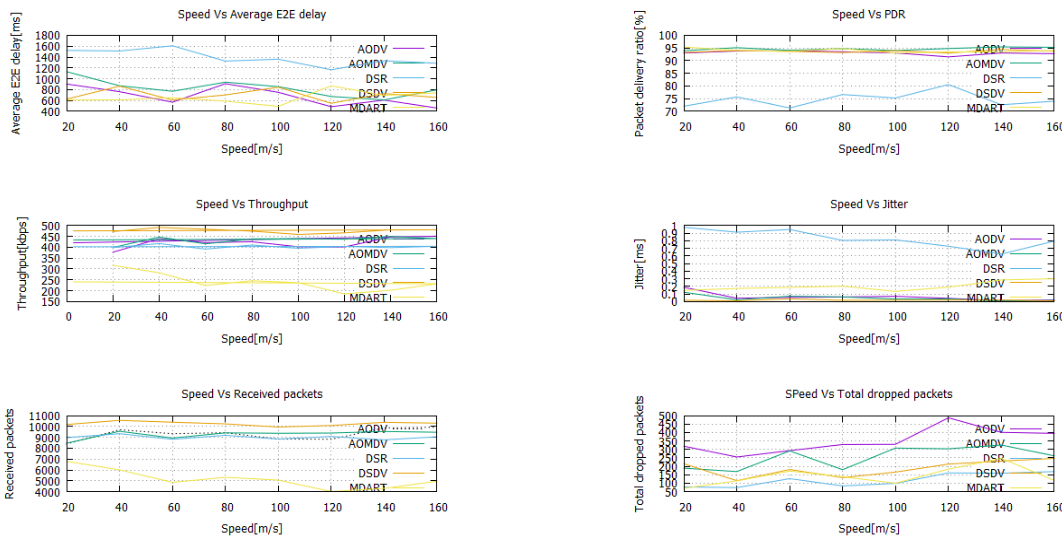

Fig. 2. Performance analysis by varying the speed.

- **Varying the Speed—Average E2E Delay:**

Average end to end delay has been analyzed by varying the speed (20–180 m/s) for all protocols. M-DART has lowest average end to end delay while it is highest in case of DSR routing protocol. AODV has better performance as compared to AOMDV, DSR, and DSDV. In most of the cases, as speed is increased average end to end delay is slightly decreased.

- **Varying the Speed—Average Throughput:**

At various speed values (20, 40, 60, 80, 100, 120, 140, 160 m/s), throughput for all protocols has been observed. Throughput is fluctuating as speed values are changed. DSDV shows best performance while M-DART has lowest throughput value. AOMDV works well as compared to AODV, DSR, and M-DART routing protocols.

- **Varying the Speed—Jitter:**

Jitter for all protocols have been observed by varying speed. DSDV shows better results as compared to other routing protocols. AOMDV works well as compared to AODV. DSR has very poor performance in respect of jitter.

- **Varying the Speed—Total Dropped Packets:**

When we observed the performance of routing protocols in respect of speed Vs total dropped packets, it has been identified that DSR has lowest dropped packets while it is highest in case of AODV routing protocol. Results show that M-DART works well as compared to AODV, AOMDV, and DSDV.

- **Varying the Speed—Received Packets:**

As speed is increased, received packets are also increased for AODV, AOMDV, DSR, and DSDV. But in case of M-DART, received packets are decreased as the speed values are increased. AODV has highest received packets while it is lowest in case of M-DART. AOMDV presents better performance as compared to M-DART, DSR, and DSDV routing protocols.

- **Varying the Speed—PDR:**

Packet delivery ratio has been observed by varying the speed values for all five protocols. PDR fluctuates as speed is increased. AOMDV has excellent performance while DSR comes under worst case. M-DART shows better results as compared to AODV, DSR, DSDV routing protocols.

Effect of pause time on efficiency of several routing protocols is recorded and results are discussed in terms of performance metrics such as throughput, dropped packets, and packet delivery ratio etc. Simulation results are graphically presented in Fig. 3.

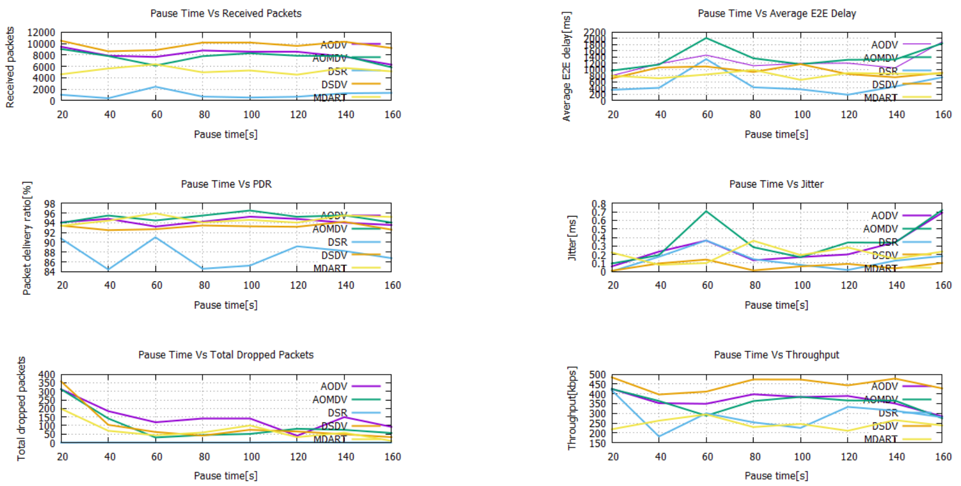

Fig. 3. Performance analysis by varying the pause time.

- **Varying the Pause Time—Received Packets:**

Total received packets are fluctuating when pause time is varying from 20–160 s. DSDV has maximum received packets while DSR presents very poor performance. AODV protocol shows better results as compared to AOMDV, DSR, and M-DART.

- **Varying the Pause Time—PDR:**

PDR has been observed by varying the pause time (20, 40, 60, 80, 100, 120, 140, 160 s). Packet delivery ratio for AOMDV is excellent while DSR has very low. results shows that AODV has better performance as compared to DSR, DSDV, and M-DART.

- **Varying the Pause Time—Total Dropped Packets:**

Total dropped packets have been observed for all protocols by varying the pause time. AODV has 147 dropped packets while DSR has 6 dropped packets. M-DART works well as compared to DSDV, AODV, and AOMDV.

- **Varying the Pause Time—Average E2E Delay:**

Average E2E delay for AOMDV is 1557.98 ms which is highest amongst all the routing DSR has lowest average end to end delay. Performance of of AODV is better than AOMDV routing protocol. Results show that M-DART is most appropriate protocol as compared to AODV, AOMDV, and DSDV in respect of pause time variations.

- **Varying the Pause Time—Jitter:**

Jitter for various routing protocols has been analysed at different values of pause time. DSDV presents better performance while AOMDV has higher jitter. AODV works well as compared to AOMDV, and M-DART routing protocols.

- **Varying the Pause Time—Throughput:**

Throughput for AODV is 366.21 kbps while it is 245.44 kbps for M-DART. These results show that AODV presents better results.

In terms of performance metrics, evaluation of routing protocols is carried out by varying the simulation time(as shown in Fig. 4).

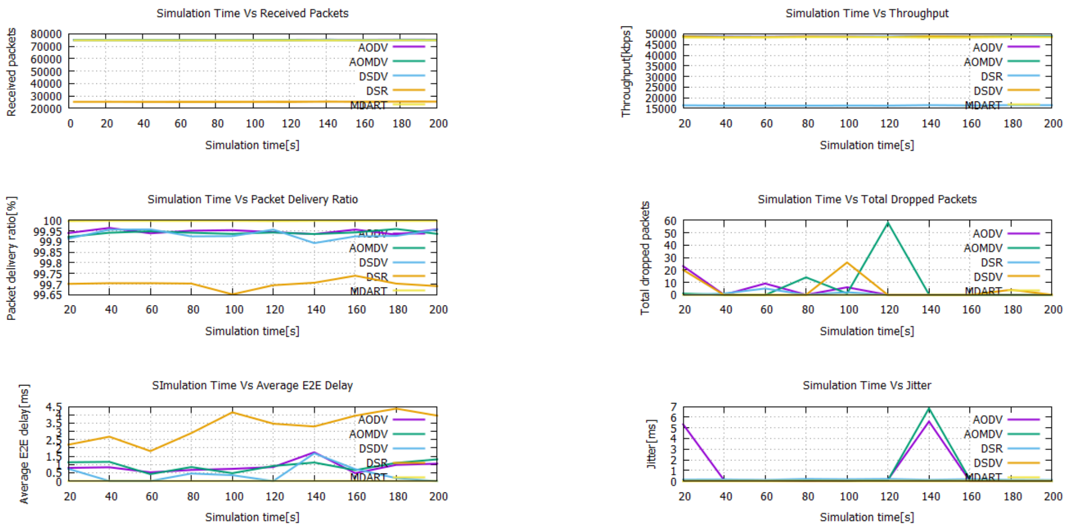

Fig. 4. Performance analysis by varying the simulation time.

- **Varying the simulation time—Packet received:**

Number of received packets have been analysed by varying the simulation time (20, 40, 60, 80, 100, 120, 140, 160, 180, 200 s) for routing protocols. For AODV, received packets are lowest at 120s simulation time while it is highest at 200 s simulation time. In case of AOMDV, received packets are lowest at simulation time 60s, while it is highest at simulation time 140 s. For DSDV, received packets are decreasing from simulation time 20 s to 100 s, but, suddenly it is increasing upto 140 s and again decreasing up to 200 s simulation time. In case of DSR, it is fluctuating at various values of simulation time. Received packets are increasing from simulation time 20 s to 200 s in case of M-DART routing protocol. Overall, AODV have highest received packets and DSR having lowest number of received packets. AOMDV performs better than M-DART routing protocol in respect of received packets.

- **Varying the simulation time—PDR:**

PDR is fluctuating by varying the simulation time for all routing protocols. Generally, PDR is increasing from 20 s to 200 s simulation times for AODV, AOMDV, and DSDV routing protocol. But, it is almost constant for DSR and M-DART routing protocols. Overall, PDR is highest for M-DART, while DSDV having lowest PDR. AODV and AOMDV have almost same PDR. M-DART performs better as compared to AODV, AOMDV, DSDV, and DSR routing protocols.

- **Varying the Simulation Time—Average End to End Delay:**

As simulation time is varying, average end to end delay remains constant, i.e., approximately zero in case of M-DART and DSDV, while it is fluctuating from 0 to 1 and vice-versa for AODV and AOMDV routing protocols. DSR having the worst performance for all simulation times (20–200 s). Overall M-DART performs better while DSR comes under worst case. As compared to AOMDV, AODV have lowest average end to end delay.

- **Varying the Simulation Time—Throughput:**

As simulation time is changing, the throughput is also fluctuating for AODV, AOMDV, DSR, DSDV, and M-DART routing protocols. From simulation time 20 s to 60 s, AODV performs better as compared to other protocols. But, overall AOMDV have highest throughput while it is lowest for DSR routing protocol. M-DART performs better as compared to AODV, DSR, and DSDV routing protocols.

- **Varying the Simulation Time—Total Dropped Packets:**

Total dropped packets are decreasing for AODV as well as simulation time is increased for all simulation times, M-DART have no packet dropped. Overall M-DART performs better while AOMDV comes under worst case. DSR have less packet dropped as compared to AODV, DSDV, and AOMDV routing protocols.

- **Varying the Simulation Time—Jitter:**

DSR, DSDV, and M-DART have very low jitter as compared to AODV and AOMDV routing protocols. Overall DSDV and M-DART routing protocols have 0.007 ms and 0.0039 ms jitter respectively. AOMDV performs better than AODV in case of jitter. Overall DSDV works well while AODV comes under worst case.

On different packet size, simulation work is performed and results are illustrated in Fig. 5. Detailed discussion is presented as given below:

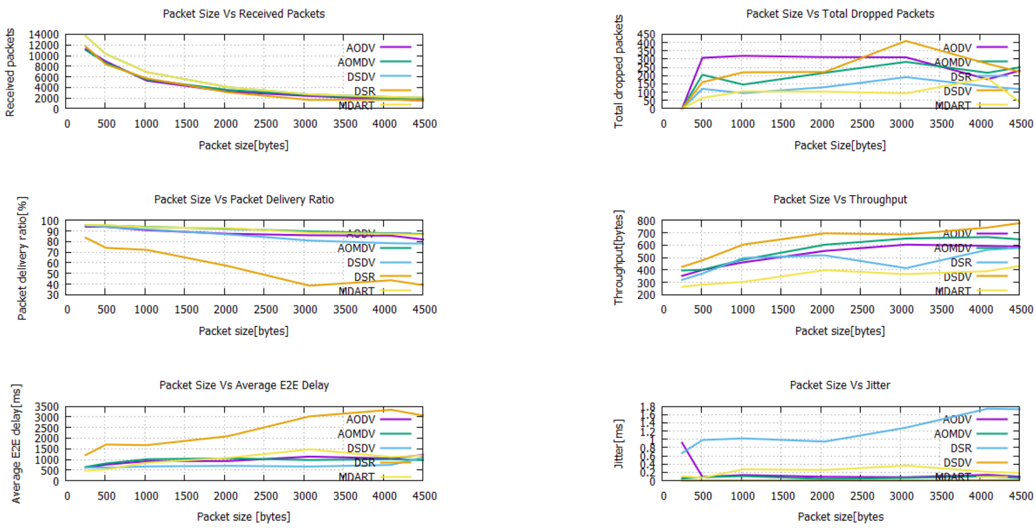

Fig. 5. Performance analysis by varying the packet size.

- **Varying the Packet Size—Total Received Packets:**

By varying the packet size from 256 bytes to 4500 bytes, total received packets were investigated for AODV, AOMDV, DSDV, DSR, and M-DART routing protocols. For all routing protocols, as packet size is increasing, total received packets are decreased. It is highest at 256 bytes packet size while it is lowest at 4500 bytes packet size for all protocols. Overall, total received packets are 5970 for DSDV while it is 3278 bytes for M-DART. It means DSDV performs well as compared to other protocols while M-DART have very poor performance. AOMDV works well as compared to AODV and DSR routing protocols in respect of received packets while varying the packet size.

- **Varying the Packet Size—PDR:**

As packet size is increased, PDR is decreasing for AODV, AOMDV, DSDV, DSR, and M-DART routing protocols. Overall packet delivery ratio for AOMDV is highest while it is lowest for DSR routing protocols. It means AOMDV performance is best while it is worst for DSR.

- **Varying the Packet Size—Average End to End Delay:**

Average end to end delay is increasing as the packet size is increased for AODV protocol while it is fluctuating for AOMDV, DSDV, DSR, and M-DART routing protocols. Overall average end to end delay is highest for DSR while it is lowest for DSDV routing protocol. It means DSR have very poor performance and DSDV works well when packet size is varying. AOMDV performance is better than AODV routing protocol.

- **Varying the Packet Size—Total Dropped Packets:**

Dropped packets analysis work has been carried out by varying the packet size. No packet dropped is recorded for 256 bytes packet size. But from 512 bytes to 4500 bytes packet size, total dropped packets are fluctuating. Maximum number of dropped packets (237) has been recorded for AODV while it is lowest (84) for M-DART routing protocol. Performance of M-DART is excellence while AODV has very poor performance while varying the packet size. AOMDV works well as compared to AODV routing protocol.

- **Varying the Packet Size—Throughput:**

By varying the packet size (256–4500 bytes) throughput for AODV, AOMDV, DSR, DSDV, and M-DART has been identified. DSDV has 629.36 kbps throughput which is highest and M-DART has lowest throughput i.e., 347.26 kbps as compared to other routing protocols. DSDV outperforms as compared to other routing protocols. As compared to AODV, AOMDV has better throughput (549.44 kbps). Throughput is increasing for DSDV as the packet size is increased. For AODV and M-DART, throughput is fluctuating with increasing the packet size.

- **Varying the Packet Size—Jitter:**

Jitter is fluctuating for all protocols by varying the packet size. AOMDV has 0.07580 ms jitter while AODV has 0.2228 ms. DSR performs very poor while DSDV has excellent record in respect of jitter. AOMDV works well as compared to AODV and M-DART routing protocols.

Throughput, packet delivery ratio, jitter, average end to end delay, received packets, and total dropped packets is analysed by varying the network size. Simulation results for Network size versus different performance parameters is shown in Fig. 6.

- **Varying the Network Size—Received packets:**

Varying the network size, received packets are investigated for various routing protocols. From network size 100 m × 100 m to 700 × 700 m, received packets are decreased for AOMDV, DSR. In case of AODV, DSDV, and M-DART, as network size is increased received packets are fluctuating. Overall, DSDV shows best results while M-DART has very poor performance. AODV is better than AOMDV, DSR, and M-DART routing protocols.

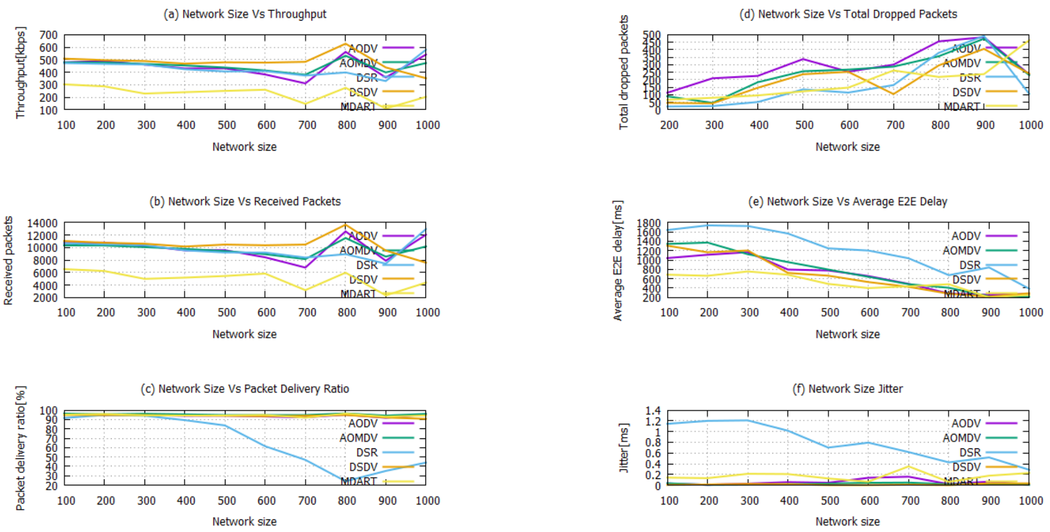

Fig. 6. Performance analysis by varying the network size.

- **Varying the Network Size—PDR:**

Packet delivery ratio is frequently changed by varying the network size for all routing protocols. PDR for AOMDV has highest packet delivery ratio (95.397%) while it is very low in case of DSR routing protocol. Simulation results indicate that AOMDV performs better results while DSR comes under worst case. M-DART is better than DSDV and DSR routing protocols.

- **Varying the Network Size—Total Dropped Packets:**

When we observed the effect of network size, it has been identified that total dropped packets for DSR are very less while AODV shows very poor performance. M-DART works well as compared to DSDV, AODV, and AOMDV routing protocols.

- **Varying the Network Size—Average E2E Delay:**

Mostly in all cases, as network size is enlarged, average end to end delay for all routing protocols is decreased. DSR has highest delay (1208.10 ms) while it is very low in case of M-DART routing protocol. AOMDV performs better than AODV and DSR routing protocols.

- **Varying the Network Size—Jitter**

DSDV has better results when we are enlarging the network size. AODV present better performance than AODV, DSR, and M-DART routing protocols.

- **Varying the network size—Throughput**

Throughput for all routing protocols has been analysed by varying the network size. In most of the cases, throughput is decreased as network size is increased. DSDV has highest throughput (438.85 kbps) while it is very low for M-DART, i.e., 109.96 kbps.

As shown in Fig. 7, evaluation of AODV, AOMDV, DSR, DSDV, and M-DART routing protocols are simulated in terms of several metrics. Detiled discussion for the above resuls is presented as below:

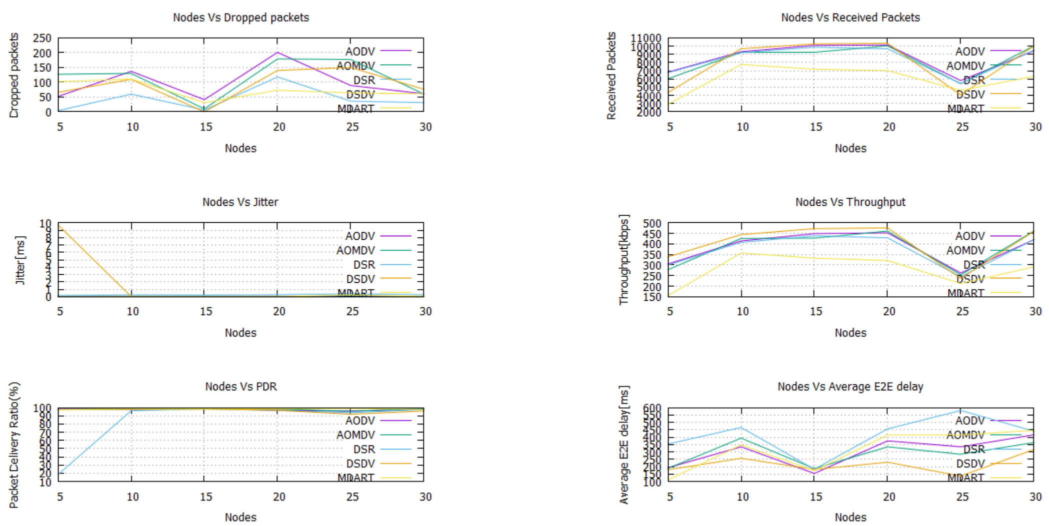

Fig. 7. Performance analysis by varying the nodes.

- **Varying the Nodes—Received Packets:**

In case of AODV, AOMDV, and DSDV as nodes are increased from 5 to 20, received packets are also increased. When we analyzed the performance of DSR and M-DART, it has been observed that total received packets are fluctuating by varying the nodes. Out of all five routing protcols, AODV presents best results while M-DART has very poor performance.

- **Varying the Nodes—PDR:**

By varying the number of nodes from 5 to 30, we have evaluated the packet delivery ratio for AODV, AOMDV, DSR, DSDV, and M-DART routing protocols. Results show that M-DART presents best results as compared to AODV, AOMDV, DSR, and DSDV routing protcols. Fluctuation of packet delivery ratio is negligible for AOMDV and M-DART as nodes are varying.

- **Varying the Nodes—Total Dropped packets:**

AOMDV shows very poor results by varying the nodes. Best performance is presented by DSR routing protcol. AODV works well as compared to AOMDV protocol.

- **Varying the Nodes—Average E2E Delay:**

As nodes are increased from 5 to 30, average E2E delay is fluctuating for all five protocols. It is highest in case of AODV, M-DART, and DSDV for 30 nodes. Overall, DSDV works well as compared to other routing protcols.

- **Varying the Nodes—Throughput:**

Throughput for DSDV is highest (404.43 kbps) while M-DART has very low throughput (278.118 kbps). throughput is varying as well as nodes are increased. AOMDV has better resullts as compared to AODV and M-DART routing protocols.

- **Varying the Nodes—Jitter:**

We analyzed the jitter for all protcols by varying the node values (5, 10, 15, 20, 25, 30). Performance of AOMDV is excellent while DSDV comes under worst case. M-DART works well as compared to DSDV and DSR routing protcols.

We observed and analyzed all the results and graphs received from the implementation work. It is clearly indicate that multi-path based routing protocols produce better results. Multi-path based routing protocols like M-DART and AOMDV have low delays for data communication.

V. Conclusion

Wireless ad hoc networks are generally installed into small areas and no centralised infrastructural administration is required. Based on evaluation work carried out by considering the performance parameters; it has been observed that AODV, DSR, and DSDV shows best performance results while receiving the number of packets. Packet delivery ratio (%age) for AOMDV and M-DART is excellent. If we consider average end to end delay then we can select M-DART and DSDV as best suitable routing protocol. In other case to avoid the dropped packets in data communication process, choose the M-DART and DSR protocols. Results indicate that throughput is better for M-DART and DSR. By considering the jitter, DSDV is best suitable routing protocol. To receive maximum throughput and minimum jitter, DSDV works well in all aspects. For Maximum PDR and minimum average end to end delay, AOMDV and M-DART are most recommended routing protocols. In most of the simulation scenarios, performance of AOMDV is better than AODV protocol. It has been concluded that AOMDV and M-DART routing protocols produce better results. Based on network scenarios and performance parameters, a best appropriate protocol may be selected. In future work, some more parameters and protocols (like Temporally Ordered Routing Algorithm) will be considered for evaluation study. We will simulate all the experimental work in Network Simulator-3 (NS-3).

Conflict of Interest

The author declares that there is no conflict of interest.

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