CHAPTER-5

Performance Analysis on Standard and Revised Routing Models of AODV, DSDV and OLSR

5.1 Introduction

Development of new MANET routing protocols necessitates testing against well-known protocols in different simulation environments. Routing protocols are acute features performing in wireless mobile networks. The infrastructure less and dynamic nature of MANETs poses a major trial to accurate and effectual data routing. Routing algorithms initiate selection of routes between source and the destination nodes. Mobile ad-hoc networks are ad-hoc natured which has the features of self-forming and self-healing. A mobile ad hoc network usually symbolized as a MANET has a set of nodes that communicate to each other straightly without having access points or base stations. The dynamic and infrastructure less nature of mobile ad hoc networks postures a key challenge to efficient & accurate data packet routing. This leads to incredible expanse of research in routing protocols adjustable to the dynamic ad hoc network states such as; size of the network, density of traffic scenarios and network splitting. MANET nodes act as host and the routers; routing algorithms perform route selection processes between network nodes. Mobile ad-hoc networks are expected to work in absence of any network infrastructure such as; access points or base stations.

New researches and developments in mobile ad-hoc networks expose some important determinations that enable mobile ad-hoc networks in the existence of centralized infrastructure also. Multi-hop cellular networks and self-organizing packet radio ad-hoc networks with overlay are some examples of such determinations. The standard behind mobile ad-hoc networking is multi-hop relaying. Network topologies of mobile ad-hoc networks keep changing randomly due to dynamic mobility of nodes. Mobile ad-hoc networks encounter frequent path breaks due to node mobility. Mobile ad hoc networks utilize routing protocols to find error-free paths between network nodes; routing protocols are responsible in ensuring error-free and efficient routes.

This chapter evaluates performances of the standard and revised models of AODV, DSDV and OLSR routing protocols. MANET nodes are mobile in nature, their movements and speed can be random which makes them to own dynamic network topologies [Bai *et al.* (2003)]. Routing in ad hoc networks becoming challenging due to increased usage of portable wireless devices. Such devices are designed to support any network, technically advanced and bandwidth consuming with high defined video graphic applications etc. Many researchers have motivated on the algorithmic complexity of ad-hoc routers [Das *et al.* (1997), Guha *et al.* (1996), Parekh *et al.* (1994)]. Some researchers proposed new routing solutions [Perkins *et al.* (1994), Johnson *et al.* (1996)]. MANET routing protocols are optimized to reduce number of hops from a source to the destination. Based on route discovery procedure and maintenance of existing routes, routing protocols can be classified as reactive or on demand, proactive or table driven and hybrid. [Arunima Patel *et al.* (2012)].

Hybrid protocols are developed by combining features of reactive and proactive protocols. On-demand routing protocols has lesser overheads as compare to table driven routing protocols [Ali Khosrozadeh *et al.* (2011)]. Fig.5.1 demonstrates a simple mobile ad-hoc network with mobile nodes (MN).

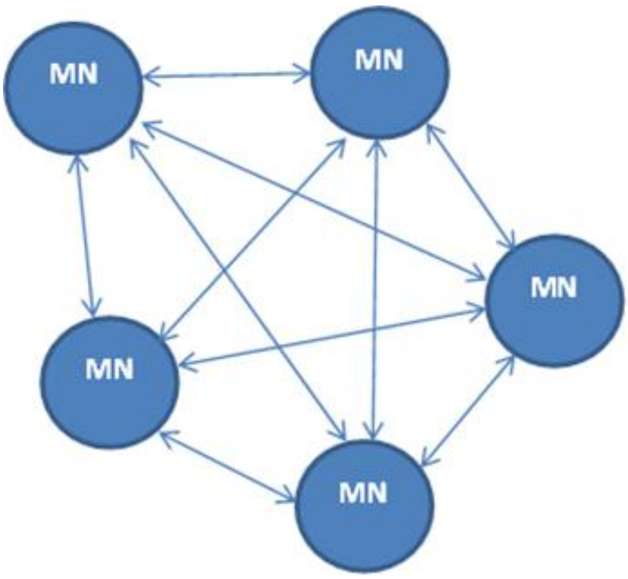


Fig.5.1. MANET with mobile nodes MN

Functioning of mobile ad-hoc networks does not require a centralized control setup and network infrastructure has been the topic of important research. In mobile ad-hoc networks, nodes also act as intermediate and end systems, they self-form and self-heal their communication links [Conti *et al.* (2007)]. The key challenges in MANETs are "dy-connectivity in the face of wireless channels and nodes moving out of range from one another" [Hemanth Narra *et al.* (2014)].

Many researchers were proposed new versions of MANET routing protocols but, still four well-known popular protocols are noticeable in the research community; AODV, DSDV, OLSR and DSR. Characteristics and performances of these four routing protocols facilitate a base with which new protocols can be compared through analysis [Hemanth Narra *et al.* (2011)]. MANETs may form by small or large set of nodes which establish communication links with each other directly without the aid of any network infrastructure. Routing algorithms create precise and proficient routes between source-destination pairs. Mobile ad-hoc networks are expected to provide link connection proficiencies in the regions where communication infrastructure is not available. Fig.5.2 determines another type of mobile ad-hoc network with different portable hand held devices.

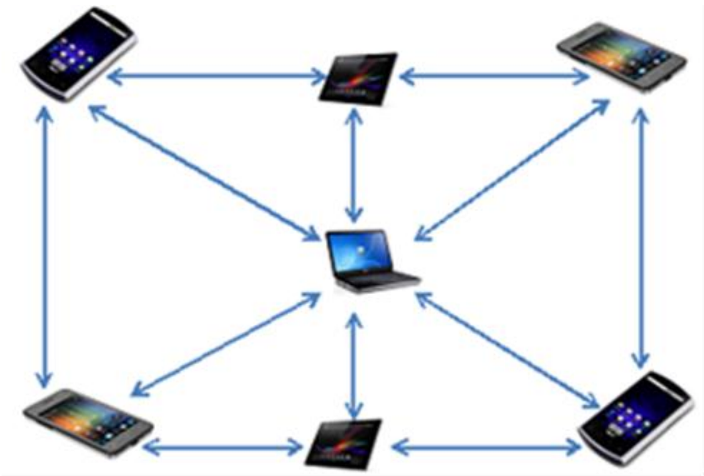


Fig.5.2. MANET with different portable devices

Many researchers investigated performances of the AODV, DSDV and OLSR under various simulation environments considering certain parameters over the others. Outcome of these researches are just the study of their behaviour on varied general network scenario specifications. Routing with powerful performance is a major challenge in installing mobile ad-hoc networks [Qutaiba Razouqi *et al.* (2013)]. Some researches in wireless network architectures reveal that; mobile ad-hoc network nodes can function in the presence of fixed infrastructure also. Some examples pertaining to these research solutions are: MCN (Multi-hop Cellular Network) [Lin *et al.* (2000)] and SOPRANO (Self-Organizing Packet Radio Ad-hoc Network with Overlay) [Zadeh *et al.* (2002)]. These are termed as hybrid architectures because; these networks are developed by combining the features of ad-hoc wireless networks and conventional cellular networks, which improve the capacity of the networks [Siva Ram Murthy *et al.* (2007)].

Though mobile ad-hoc networks propose many possibilities, fruitful deployments needs genuine solutions to various problems. These problems can be QoS (Quality of Service) provisioning, applications based on real-time, supportive functioning, effective energy relaying, provision for multicast traffic and load balancing. Fig.5.3 presents a mobile ad-hoc network constituted by various nodes 'N'.

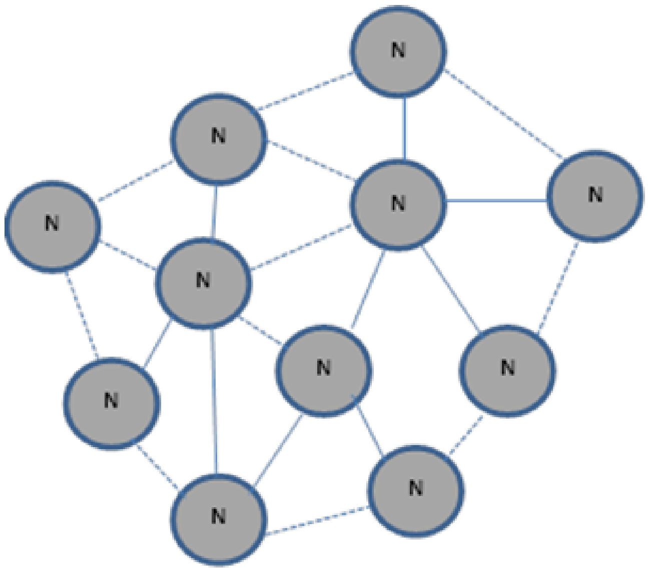


Fig.5.3. MANET constituted with member nodes 'N'

As discussed earlier, mobile ad-hoc networks do not possesses any fixed established network infrastructure; they function with bandwidth-constrained wireless links and resource-constrained nodes. The key challenges that a MANET routing protocol faces are: mobility of nodes, hidden and visible terminal problems, error-prone channel state and resource or energy constraints. MANET routing protocols can be classified into various types based on various criteria, these can be broadly classified into four categories based on: usage of specific resources, topology of routing, usage of time-based information for routing and routing information update mechanism [Siva Ram Murthy *et al.* (2007)]. However, the classification of these routing protocols is not reciprocally exclusive because of their presence in multiple classes.

In chapter 3 and chapter 4, analysis on the standard models of AODV, DSDV and OLSR routing protocols were studied to test the node density, node pause time, node velocity and transmit power effects. Conclusions of these studies reveals degraded performances in AODV and DSDV protocols as compare to the OLSR routing protocol. Hence, current study was focused on possible improvements in performances of AODV and DSDV protocols considering node density as main network parameter. Performance analysis of OLSR routing protocol was also studied in this chapter. New designs of the standard AODV, DSDV and OLSR protocols were obtained by revising their attribute values. Performances of the newly designed models were compared with the standard models. Performance comparison of newly designed models was also studied in this chapter.

5.2 Route Discovery

The process of route discovery between a source and the destination takes place by means of Routing. Routing algorithms chooses shortest and optimal routes between source nodes and the destination nodes. Each MANET node acts as a host and the router. Routing protocols ensures creation of precise and proficient routes or paths. Routing protocols are responsible towards correct and timely delivery of data packets [Rutvij *et al.* (2012)]. A routing protocol describes the method by which active links between mobile nodes (communicating source-destination node pairs) gets established. Routing algorithm determines the way by which link paths are established between a source node and the destination node. In mobile ad-hoc networks, network topologies are determined by the nodes as they are mobile in nature. A new node of MANET broadcasts its presence to all other nodes of the network and it listens to broadcasts made by all other neighboring nodes.

5.3 Types of Routing Protocols

Routing protocols in mobile ad-hoc networks can be categorized into three types based on their characteristics and update mechanisms; proactive or table driven routing protocols, reactive or on-demand routing protocols and hybrid protocols (combination of reactive and proactive protocols) [Perkins *et al.* (1999), Siva Ram Murthy *et al.* (2007)]. Link overheads in mobile ad-hoc network protocols can be reduced by having smaller routing tables. In mobile ad-hoc networks, discovery of root takes place by means of routing process; these processes are controlled by routing protocols or routing algorithms. The main aim of these routing protocols is to ensure establishment of paths in a specified time and to confirm error free paths between network nodes. These protocols are responsible for accuracy in discharging of data packets within the set time frame.

5.3.1 Proactive OR Table-Driven Routing Protocols

Proactive routing protocols maintain routing information of all the member nodes of the network and update already existing routes and add new routes. Updating of existing routes and adding new routes are takes place by broadcasting latest routing information among all the nodes of the network. This promotes availability of ready routes to the desired destinations as and when required. Proactive protocols are totally depends on information available in their routing tables and by these tables only they able to achieve proper and accurate routes. In case of larger dynamic networks, “convergence may not be possible” [Hemanth Narra *et al.* (2011)]. Routing tables of these protocols rise along with the density and dimension of the network. Proactive or table-driven routing protocols have an overhead of flooding route announcements to sustain convergence.

Examples: DSDV, OLSR, WRP and CGSR.

5.3.2 Reactive OR On-Demand Routing Protocols

Reactive or on-demand routing protocols create routes only when routes are required. Hence, nodes do not require updating their routing tables frequently and they do not sustain routes for the member nodes of the network. When any node desires to have a route to a particular new destination, then it has to initiate a route request and wait until the discovery of the required route. Reactive or on-demand routing protocols do not maintain routing tables, which causes delay in discovery of routes to the new destinations; this is one of the disadvantages of the reactive or on-demand routing protocols.

Examples: AODV, DSR, SSA and ABR.

5.3.3 Hybrid Protocols

Hybrid routing protocols were developed by combining the features of reactive and proactive routing protocols [Perkins *et al.* (1999)]. Hybrid routing protocols cartels the advantages of proactive as well as reactive routing protocols and at the same time, they overcomes the disadvantages of proactive and reactive routing protocols [Prof. Dr.Dhote *et al.* (2010)].

Examples: CEDAR, ZRP and ZHLS.

5.4 Performance Affecting Parameters

Various factors affect performance of the MANET routing protocols, some of them include;

1. **Transmit Power**: In data propagation, transmit power is considered as major factor. Characteristics of the ad –hoc network can be changed by changing the transmitted power. “As power increases, the influence of mobility decreases and the effective density increases” [IR 10].

2. **Node Velocity:** Mobility is the key factor in mobile ad-hoc networks. Every node of the MANET moves from one point to another. Performance degrades for higher values of node velocity due to multiple link failures [Kumar *et al.* (2015)].

3. **Node Density:** It is the population of nodes in an ad-hoc network. Lesser values of node density promote lower reachability and higher values do not gain improvements so, optimum values are considered [Kumar *et al.* (2015)].

4. **Mobility Model:** Mobility models drive the nodes in an ad-hoc network. Mobility model defines exact location of a mobile node. Performance variation occurs from one mobility model to another. Random way point is one of the mobility models which is extensively used to evaluate mobile ad-hoc network routing protocols.

5. **Transmission region:** It is the region in which nodes move from one point to another.

6. **No. of Source/Sink Pairs:** These are the fixed connections which send data packets to the applications.

7. **Type of Traffic:** These are the different types of applications traffics. These traffics have their own parameters, these parameters also affect the performance of the MANET routing protocols. CBR, Exponential and Pareto are some types of traffic generators in the mobile ad-hoc networks.

8. **Protocol Parameters:** Protocol parameters also considered in evaluating performance of the mobile ad-hoc network routing protocols.

5.5 Quality of Service (QoS) in MANETs

Quality of service refers to the performance level of the service that a network offers. QoS (Quality of Service) deals with determined network services offered to its users, improvements in quality and better usage of resources. The purpose of QoS facility is to deliver fine usage of network resources. Offered Network services to the users can be measurable requirements like; rate of maximum packet loss, jitter, higher values of delay and minimum bandwidth [Siva Ram Murthy *et al.* (2007)]. Delay comprises of various delays such as packet queuing delay, propagation delay and transmission delay. Maximum variation in delay is termed as jitter. User's requests have to be fulfilled by the service providing network through some kind of service guarantee.

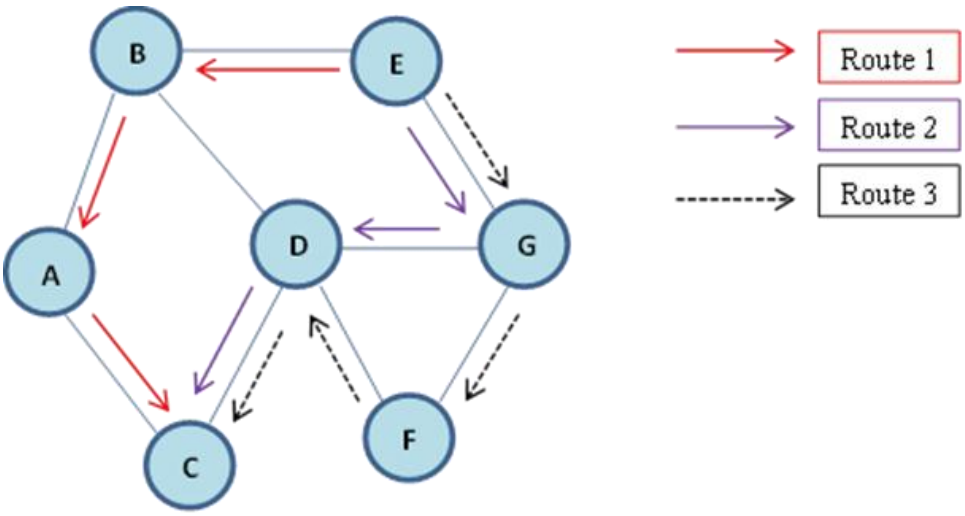


Fig.5.4. QoS routing in MANETs

Quality of service provisions must process the user's requests by providing loop-free routes along with required resources. The process of providing suitable loop-free routes which fulfills QoS supplies as desired by the services is called QoS routing. After the route finding process, the resource reservation protocol is engaged to ensure required resources along the route. QoS assurances can only be provided through some resource reservation procedures. Fig.5.4 illustrates functioning of QoS routing in a mobile ad-hoc network. Here, there are seven network nodes namely A, B, C, D, E and F. For instance, a packet stream is required to establish between the node E and node C with a BW (Band Width) assurance of 5 Mbps, then the QoS routing protocol seeks a best route that caters the required bandwidth. There are three routes in between the node E and node C; they are E-B-A-C, E-G-D-C and E-G-F-D-C.

Table - 5.1: Link Attributes

Route No.	Route	Hop Count	BW (Mbps)	EED (ms)
Route1	E-B-A-C	3	5	13
Route2	E-G-D-C	3	8	17
Route3	E-G-F-D-C	4	7	21

Here, QoS routing protocol picks route1 that is E-B-A-C because, out of all the three routes, route1 only can provide the required bandwidth of 5Mbps. Route1 may or may not be optimal in terms of other link attributes such as hop count and EED (End to End delay). Other available routes may be optimal in terms of hop count and EED. Table - 5.1 illustrates the link attributes of the above network. Different packet flow has their own QoS requirements, QoS routing protocols has to seek for the best optimal routes with enough resources to fulfill these QoS requirements. Management modules of the QoS routing protocols manages resource availability along the specific routes. In order to select a possible route, the QoS routing protocols take necessary assistance from these modules. In general QoS, routing protocols consume minimum resources.

The QoS metrics are categorized into three types; multiplicative, concave and additive metrics. In mobile ad hoc networks, the topological information maintained by the nodes assists the QoS routing protocols. QoS routing protocols often face performance degradation due to trade-off affects [Siva Ram Murthy *et al.* (2007)]. When path break occurs, these routing protocols either re-compute the broken paths or bypass those paths without degrading QoS requirement level. Some examples of QoS routing protocols are: triggered-based distributed, ticket-based and predictive location-based QoS routing protocol.

5.5.1 Triggered-based distributed QoS routing protocol

The TDR (Trigger-based Distributed Routing) QoS routing protocol was projected by S.De, S.K. Das, H. Wu and C. Qiao during the year 2002, in order to upkeep real-time applications in mobile ad hoc wireless networks. This protocol is also called as on-demand distributed QoS routing protocol, it functions in distributed manner [De *et al.* (2002)]. In TDR, each and every nodes of the network maintains only the native neighborhood information which in turn promotes reduction in storage and computing overheads. In TDR, only active routes are maintained because, this helps in reducing control overheads.

5.5.2 Ticket-based QoS routing protocol

The ticket-based QoS routing protocol is also a distributed type QoS routing protocol developed for mobile ad-hoc networks. When QoS routing computation is under process, the ticket-based QoS routing protocol can bear the information which is under indefinite state and this protocol performs well during high degree of imprecision. Ticket-based protocol can review multiple paths in parallel mode to seek feasible paths of QoS [Chen *et al.* (1999)]. In ticket-based routing, the source node issues tickets for probing packet which in turn, limits the search of multiple paths. Intermediate nodes in the network maintain state information and this information are utilized for accurate probing of the routes. This protocol employs hop-by-hop selection mechanism for finding best feasible paths.

5.5.3 Predictive location-based QoS routing protocol

This protocol predicts the node locations in mobile ad hoc networks. Sometimes, prediction mechanism of this protocol experiences problems due to existence of stale in the routing information. In location-based prediction, reservation of resources along the path between the source node and the destination node is not possible except QoS-aware admission control. This protocol receipts required help from the location, update protocol and schemes that predicts delay [Shah *et al.* (2002)]. Each node in the network, takes help from the update protocol to transmit its geographic location and information pertaining to the available resources to all their neighbors. The updated messages so received from the neighbor nodes are helpful in assuming the network topology.

In PLBQR (Predictive Location-Based QoS Routing), the update protocol broadcasts two types of update messages; update type1 and update type2. The type1 update messages are periodically generated by each and every node in the network, whereas type2 update messages gets generated during significant changes in the velocity of the node [Siva Ram Murthy *et al.* (2007)]. Link state information like error rate, cost, loss rate, jitter, bandwidth and delay supports QoS and hence these constraints must be obtainable and controllable in the network. Researchers Ying Ge, Thomas Kunz and Louise Lamont have worked on OLSR integration with QoS routing and proposed some theorems [Ying Ge *et al.* (2002)].

5.6 Route Discovery in AODV

Ad-hoc on demand distance vector routing (AODV) was developed by utilizing some main properties of DSR (Dynamic Source Routing) and DSDV

(Destination Sequenced Distance Vector) routing protocols [Johnson *et al.* (1996)]. It was cooperatively developed by C.Perkins, E.Belding-Royer and S.Das on July'2003. AODV is a typical on demand type routing protocol, utilizes an on-demand methodology for finding routes in mobile ad hoc networks. It provides routes only on demand basis. In AODV, fresh routes are ensured with the help of sequence numbers associated with the routing information, route between the source and the destination pair is expected to be symmetric [IR 16] and previous hop life time of the active route is updated along the reverse path back to the source.

AODV does not work with multiple addresses over each interface. Selection of source address in AODV is complicated, when AODV does not have a route, the loop back route is returned, this results the packet to be looped backed and handled with cache [IR 15]. Procedures of route finding and updated routing tables are used to maintain new routing information [Ashish Bagwari *et al.* (2012)]. Each and every node maintains a routing table which holds details of next hop address in order to reach specific destination. The source node 'S' initiate route discovery with its desired destination node 'D' only when it does not have valid routes to the destination in its route cache. The source node generates a RREQ (Route Request) message and broadcasts it throughout the network till it reaches the destination node "D". The destination node "D" generates a RREP (Route Reply) message for the source node to confirm the path. If path break found for any reason, then the destination node 'D' generates RERR (Route Error) message and broadcasts it. Fig.5.5 illustrates route discovery in AODV.

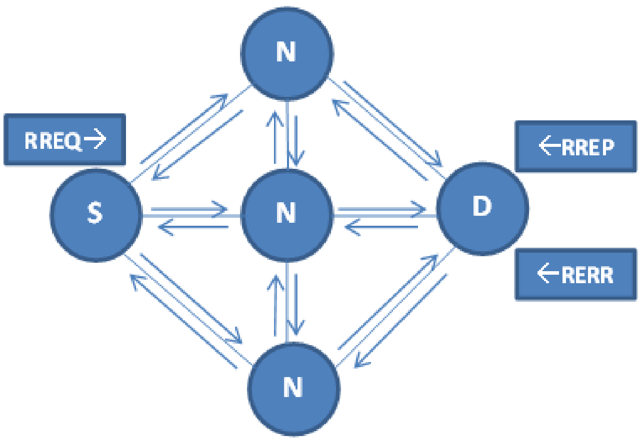


Fig.5.5. Route discovery in AODV

In AODV, selection of source address is tricky, when AODV does not have a route, the loop back route is returned. This causes the packet to go for loop back and cached when route is found. TCP (Transmission control protocol, a connection oriented protocol) needs to build endpoint four tuples and build a pseudo-header for the purpose of check-summing. Therefore, AODV required guessing the eventual source address. This problem does not occur for single interface and nodes with single addresses. During processing of multiple outgoing interfaces, AODV follows to pick the first available interface of the AODV. Network nodes verify to determine whether or not it has received a RREQ with the same source address and RREQ ID (Route Request Identity). When such RREQ received, then the nodes discard the new RREQ received. During the creation or updating of the reverse route, the following actions are taken over the route [IR 16]:

- From the RREQ, originating source sequence number is compared with the corresponding sequence number of the destination in the routing table and copied it if it has a greater value.
- The valid sequence number is therefore set as true.
- In the routing table, next hop entry becomes RREQ received from the node.
- Hop count entry of the routing table will be copied to the RREQ message.
- Life time is set to the maximum of existing life time and minimal life time.

In AODV, if the RREQ has the incremented value, then the destination node should increase its own sequence number by one. Else, sequence number of the destination node does not change prior to the generation of RREP message. During creation or updating routing table of the destination, following actions takes place:

- The created route is marked as active route.
- The sequence number of the destination is marked as valid one.
- In the routing table, next hop entry is the address of the node from which RREP is received.
- Value of the hop counter is set to be hop count of RREP+1.
- The Expiry time is set to the real time plus the life time value of RREP.

When a member node of the network receives hello message from any of its neighbors then that node ensures the active route to that neighbor. If no active routes are present then it will create a route for that neighbor. When a route discovery tried at RREQ retries with the maximum TTL without receiving RREP, then all the data packets of that destination are dropped and destination unreachable message is delivered to the source [IR 16].

5.7 Route Discovery in DSDV

Destination sequenced distance vector (DSDV) routing was developed based on the Bellman-Ford routing algorithm [Rakesh Kumar Jha *et al.* (2015)]. DSDV is a proactive or table-driven routing protocol. Route selection processes of DSDV are carried out by distance vector shortest path algorithm. DSDV routing protocol in MANETs was invented by revising the Conventional Distributed Bellman-Ford (DBF) technique. Earlier, DBF technique was in effective use in major dynamic packet switched data networks. It was used to compute shortest path between the source and the destination nodes. During routing, the DBF technique generally create routing loops, in order to reduce these routing loops, DSDV routing protocol was introduced with a new parameter known as Destination Sequence Number (DSN) [Sreekanth Vakati *et al.* (2013)]. DSDV protocol is same as the conventional RIP (Routing Information Protocol) except an additional feature in routing table known as sequence number [Teressa Longjam *et al.* (2013)].

DSDV oriented mobile ad hoc network nodes transmit a periodically increasing sequence number throughout the network; they broadcast updated routing information and incremented sequence number to all their neighbors. This makes updating of route information and routing table in all the network nodes. Nodes so updated are then become ready to initiate any particular path between a source and the destination nodes. In DSDV, every node holds routing information in its routing table. Routing table of DSDV has the attributes like; available destinations, sequence number allotted by the destination node and the hop count. Hop count is needed to reach the destination node. Routing tables of network nodes helps in establishing communication links between the nodes. Nodes broadcast their routing information frequently throughout the network. Routing information so broadcasted has the fields such as; nodes, new sequence number, destination IP address and number of hops that are required in reaching requisite destination.

DSDV uses “full dump “and “incremental dump” packets in overcoming transmission link overheads. The unit of broadcasting routing information is NPDU (Network Protocol Date Unit) [Teressa Longjam *et al.* (2013)]. In DSDV, routing table of a node is updated when the node receives routing information from the neighbour node. This updating is possible only when set norms are fulfilled. The “full dump” possesses the data related to the routing whereas “incremental dump” retains the changed data since the last “full dump”. These updated dump packets are also referred as the ways of broadcasting in DSDV. Whenever a node receives latest routing information, it increases the metric and retransmits the routing information by broadcasting it throughout the network. Prior to the transmission, metric increasing process is carried out because incoming packets need to travel further one hop more in order to reach their destinations.

Mobility of the nodes from one place to other results in link breaks. Routing tables of the nodes are assigned infinity value for broken links [Teressa Longjam *et al.* (2013)]. These infinity values of the routing tables define no next hop for the conforming destinations. In the routing tables, even number value of the sequence number field remarks that the communication link is initiated by the nodes and odd values remarks to link break, which has infinity metric. DSDV uses bidirectional links and it has a drawback of providing single route for a source and the destination pair [IR 17].

5.7.1 Routing Tables

In DSDV, routing table arrangement is very simple. Entries of the routing table have a sequence number which gets incremented whenever a node transmits an updated message [IR 17]. Routing tables of the nodes gets updated periodically whenever network topology changes. This updated information of the routing tables is broadcasted throughout the network. DSDV upholds two routing tables, one for forwarding packets and the other is for incremental routing packets. Route discovery processes of DSDV promote network nodes to transmit routing information periodically. Routing information carries the destination node address, new sequence number, hop count information and sequence number of that particular destination node. Whenever change in network topology occurs, network nodes transmit the information of such changes throughout the network.

5.7.2 Updating of Routing Tables

In DSDV, when a node receives updated route information from the other nodes of the network, it updates its routing table as follows [IR 17]:

a) Nodes maintain sequence numbers in their routing tables, if any new address possesses a higher sequence number then the node selects routes of higher sequence numbers and at the same time they abandon low value sequence numbers.

b) When sequence number of the incoming packet is same as already available route then, the routes of low cost are selected for data communication.

c) New route information has its own metrics and all of these metrics are incremented.

d) This procedure sustains till every nodes of the network gets updated. For Identical data packets lower cost metric values are considered and rest packets are rejected. For broken links, a cost metric value of infinity and the new incremented sequence number are assigned. Sequence number of this metric is greater than or equal to the sequence number of that particular node. Fig.5.6 demonstrates a routing process in DSDV, there are eight mobile nodes in the network: ‘A’, ‘B’, ‘C’, ‘D’, ‘E’, ‘F’, ‘G’ and ‘H’. Neighbors of mobile node ‘B’ are: ‘A’, ‘C’, ‘D’ and ‘H’. Table - 5.2 illustrates routing table of node ‘B’. The dashed lines show no communication links between the corresponding nodes. Consequently, Node ‘B’ does not have any information about the node ‘H’.

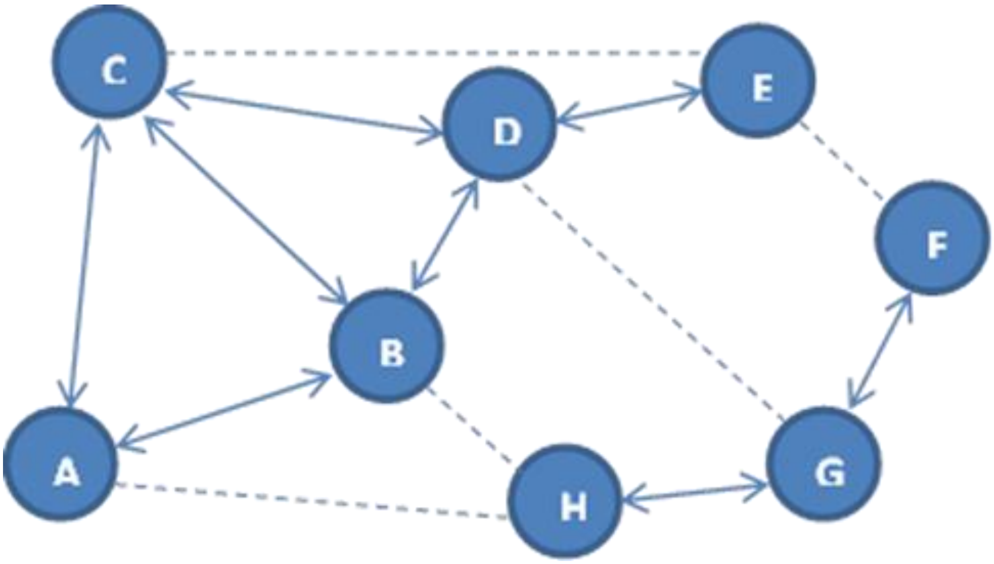


Fig.5.6. Process of routing in DSDV

Table - 5.2: Routing Table of Mobile Node 'B'

Destination Node	Next Hop	Metric	Sequence Number of the Destination Node
A	A	1	221
B	0	0	734
C	C	1	412
D	D	1	268
E	D	2	520
H	A	Infinity	616

5.8 Multi Point Relaying in OLSR

The optimized link state routing (OLSR) is one of the well-known proactive routing protocols in MANETs that works on an efficient link state mechanism called MPR (Multi Point Relaying) [Clausen *et al.* (2001)]. MPR is an effective mechanism in OLSR through which link state packet forwarding takes place. OLSR optimizes the original link state routing protocol, optimizations in OLSR are done in two methods;

one is by reducing control packet sizes and the other is by reducing that number of links which are used for forwarding the packets of link state [Siva Ram Murthy *et al.* (2007)]. The link state size reduction is done by announcing only a subset of links which are available in the updates of link state. These subsets are the neighbors of every node in the network, which are chosen for carrying link state updates.

Subsets of neighbor nodes have the responsibility of packet forwarding are known as MPRs (Multi Point Relays). Periodic link state updates are possible due to usage of these multi point relays in the process of optimization. During creation of new links or when an existing link breaks, the link state update mechanism do not produce any extra control packets. In dense deployment of mobile ad-hoc networks, the optimization of link state updating realizes higher efficiency.

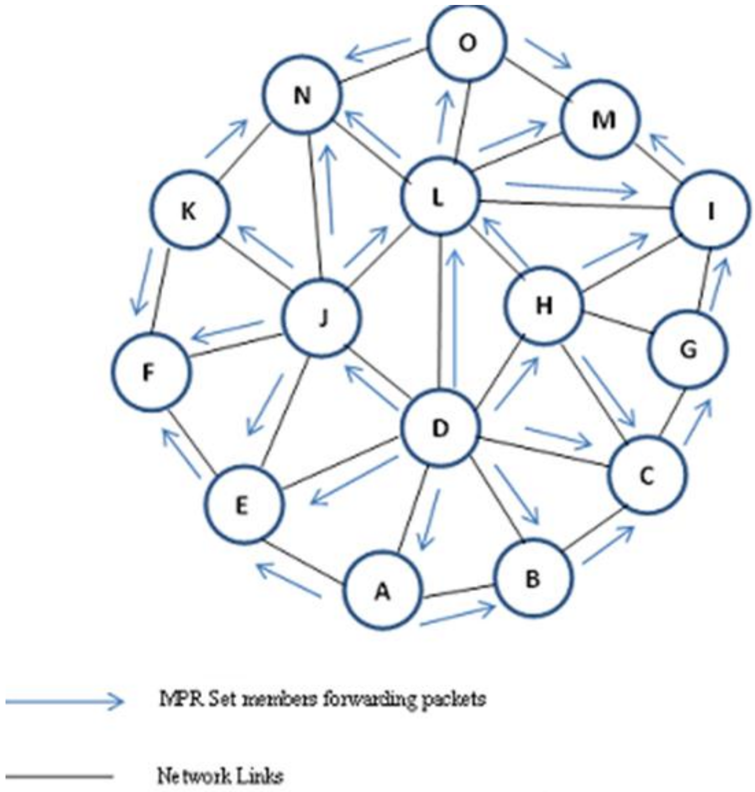


Fig.5.7. Flooding in OLSR

In Fig.5.7, the network is going through a flooding process, where number of transmissions is almost equal to the number of nodes. In OLSR, subset nodes which act as multipoint relays are also called as MPR set. Each and every node in the network chooses its MPR set and these MPR sets executes the processing and forwarding of link state packets which are originally produced by the leading node of these MPR sets. Other nodes of the network which are not the member of these MPR sets, can only process the link state packets so generated by the leading node, but they do not forward the packets. Each and every node in the network retains MPR selectors, which are the neighbor nodes of them. The associates of MPR selectors and MPR set keep varying time to time.

The associates of MPR set are chosen in such a fashion that each node in that node's two-hop neighborhood possesses bidirectional links. Each node in the network evaluates paths to the destination through the associate nodes in the MPR set, therefore, these MPR sets expressively responsible in achieving the OLSR performance. Nodes in the network concludes their MPR set by transmitting HELLO messages, these messages holds the neighbor list of the node with whom the node already has bidirectional links. HELLO message also holds information pertaining to the MPRs (Multi Point Relays). The nodes that collect these HELLO messages then update their two-hop topology tables. Each node in the network holds neighbor table, these tables are utilized for storing information such as; list of neighbors, position of the neighbor nodes and the two-hop neighbors.

Neighbor nodes in the network are found in three possible link states namely, multi-point relay, unidirectional and bidirectional. Every entry in the neighbor tables has a related value of timeout, stale entries in the neighbor tables are removed by the help of timeout values when they reach expiry. In OLSR, Every MPR set has a sequence number, which gets increased with the new sets of multi point relays. When network initialization takes place, the MPR sets remain same like in neighbor set, during network initialization, these MPR sets does not require to be optimal. When a MPR set holds less number of nodes, efficiency of the routing protocol increases equated to link state routing. Each and every node of the network generates TC (Topology Control) messages periodically. These TC messages hold information related to the network topology, by the help of these messages, updating of routing tables carried out.

OLSR routing protocol has four such type of topology control messages namely, HELLO, TC, HNA (Host and Network Association) and MID (Multiple

Interface Declaration) [IR 18]. HELLO messages provide information related to the link status and host neighbor details. TC messages helps in broadcasting neighbors of the nodes in the network. HNA messages are broadcasted to share external routing information; it holds information related to the network. MID messages are transmitted all over the network to inform the nodes in the network that the host has the capability of establishing multiple interfaces of the routing protocol [Siva Ram Murthy *et al.* (2007)].

5.9 Performance Evaluation

Performance evaluation of standard and the revised models of AODV, DSDV and OLSR routing protocols have been carried out by the help of metrics of performance evaluating parameters namely, the throughput, packet delivery ratio, end to end delay, packet loss and normalized routing load. Received packet data obtained from the experiments was used to calculate performances of the routing protocols. Performances of either routing protocol models were well compared and discussed in the result section.

5.10 Network and Protocol Modelling

Network and protocol modelling involves creation of general network scenarios and attribute revised models of AODV, DSDV and OLSR. Different network and protocol models were created for this analysis by the help of network simulator. Same have been discussed in detail at result section of this chapter. Simulation based tests on standard and revised models of the routing protocols were performed using network simulator 3 (NS3). An Acer Core i7, 64 bit machine with 6GB RAM was used for installing 3.13 version of the network simulator3 on Cent-OS Linux platform. Initially, the network simulator was configured and tested as per NS3 software guidelines [IR 15] and conducted some experiments to verify the results. Network Simulator-3 is a discrete-event based network simulator. It is assembled as set of library, which can be linked to C++ main program statically or dynamically. The C++ main program in NS-3 defines simulation topology and it starts the simulator.

Almost all the APIs (Application program Interfaces) of NS-3 have been exported to Python, in order to allow Python programs to import NS-3 modules. As compare to NS-2 (Network Simulator-2), NS-3 has enhanced simulation capabilities. It was developed from the scratch in order to replace NS-2 APIs. It was developed mainly for research and educational use. NS-3 is an open-source network simulator attempts to continue open environment for researchers for sharing and contribution of software developed by them [IR 6]. Attributes of the standard algorithmic models of AODV, DSDV and OLSR routing protocols were revised in order to achieve possible improvements in their performances and to study their behavior for different network scenarios. 'MANET routing compare' script available in NS3 was used to test the performances of the routing protocols.

5.11 Results and Discussions

This section presents the results obtained from different experiments conducted over routing protocols. Results of all the three routing protocols have been presented in three different sections. Section 'A' presents results of the AODV routing protocol, section 'B' presents results of DSDV and section 'C' presents the results of OLSR routing protocol. Section 'D' presents comparative performance analysis of attribute revised models of AODV, DSDV and OLSR for different node densities and node velocities.

SECTION: A (AODV)

This section presents experimental results of AODV along with general network parameters used, modified core parameters of the AODV routing algorithm and its routing metrics. Investigations on AODV have been carried out by keeping 10 numbers of source/sink connections fixed and by varying node densities. The simulation scenarios and obtained results are presented in the following tables and graphs with discussions. General network parameters used have been tabled in Table - 5.3 and revised parameters of AODV routing protocol are cited in Table - 5.4 [IR 16].

Table - 5.3: General simulation parameters (Section: A)

Parameter	Assigned Value
Number of Nodes	30,40,50,60,70,80,90,100
Simulation Time	150 seconds
Pause Time	No pause time
Wi-Fi mode	Ad-hoc
Wi-Fi Rate	2Mbps (802.11b)
Transmit Power	7.5 dBm
Mobility model	Random Waypoint mobility model
No. of Source/Sink	10
Sent Data Rate	2048 bits per second (2.048Kbps)
Packet Size	64 Bytes
Node Speed	20 m/s
Protocols used	AODV
Region	300x1500 m

Table - 5.4: Revised values of AODV parameters

Parameter	**Assigned Value**
RREQ Retries	3
RREQ Rate Limit	20 RREQ per second
Active Route Timeout	5 seconds
Net Diameter	45
Node Traversal Time	50 ms
Net Traversal Time	4.5 seconds
Path Discovery Time	9 seconds
My Route Timeout	18 seconds
Hello Interval	2 seconds
Allowed Hello Loss	3
Delete Period	25 seconds
Next Hop Wait	60 mille seconds
Timeout Buffer	3
Blacklist Timeout	13.5 seconds
Max Queue Time	30 seconds (Default used)
Max Queue Length	64 (Default used)

AODV Parameter Metrics:

$$(1)\ \text{Net Traversal Time} = (2\ \times \text{Net Diameter}) \times (\text{Node Traversal Time}) \quad (5.6)$$

$$(2)\ \text{Path Discovery Time} = (2\ \times \text{Net Traversal Time}) \quad (5.7)$$

$$(3)\ \text{My Route Timeout}\ = (2\ \times \max\ (\text{Path Discovery Time},\ \text{Active Route Timeout}) \quad (5.8)$$

$$(4)\ \text{Delete Period}\ = (5\ \times \max\ (\text{Active Route Timeout},\ \text{Hello Interval}) \quad (5.9)$$

$$(5)\ \text{Next Hop Wait} = (\text{Node Traversal Time}\ + 10\ \text{Millie seconds}) \quad (5.10)$$

$$(6)\ \text{Blacklist Timeout} = (\text{RREQ Retries}\ \times \text{Net Traversal Time}) \quad (5.11)$$

(i) Throughput

Here, throughput of the default (standard) AODV was compared with the revised AODV. Throughput data shown in Table - 5.5 was prepared by the help of experimental data and metric calculations. According to the results, it is observed that; for 30, 60, 70, 80, 90 and 100 number of nodes, revised AODV has shown better performance as compared to the default AODV.

Table - 5.5: Throughput (in Kbps) (Section: A)

No. of Nodes	AODV (Default)	AODV (Modified)
30	16.04	17.02
40	17.93	16.18
50	14.47	13.69
60	1.87	13.58
70	9.73	13.82
80	11.62	16.40
90	0.68	3.50
100	1.42	12.81

Default AODV has shown better performance for 40 and 50 numbers of nodes. Fig.5.8 shows performance graphs of default and modified AODV routing protocols.

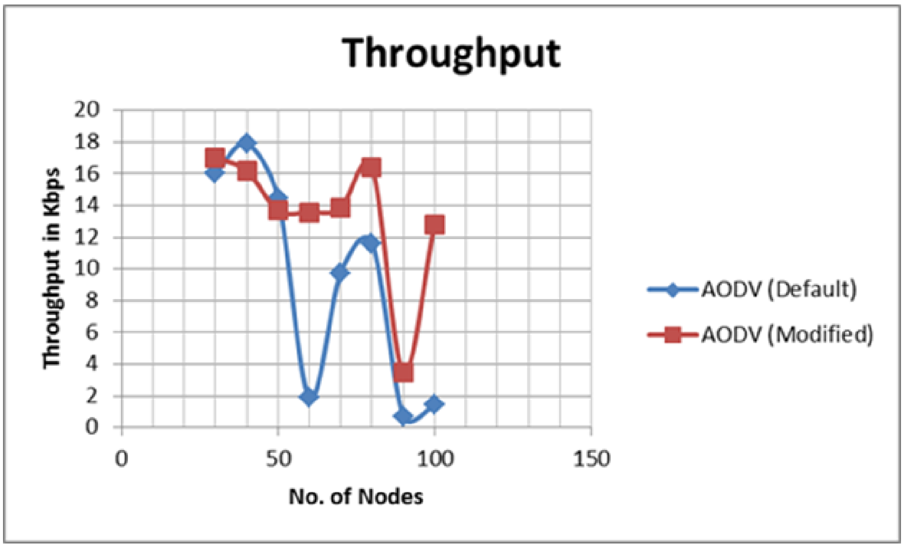


Fig.5.8. Throughput over No. of nodes (Section: A)

(ii) Packet Delivery Ratio (PDR)

Table - 5.6 shows PDR data sheet of default as well as modified AODV routing protocol. Here, revised AODV has shown better performance in terms of packet delivery percentage. Modified AODV has maximum packet delivery of 85.10 % for 30 number of nodes, whereas, default AODV has 80.22 % of packet delivery.

Table - 5.6: Packet Delivery Ratio (in %) (Section: A)

No. of Nodes	AODV (Default)	AODV (Modified)
30	80.22	85.10
40	89.63	80.88
50	72.33	68.45
60	9.35	67.88
70	48.63	69.10
80	58.08	82.10
90	3.42	17.48
100	7.08	64.05

When we compare PDR values obtained in either routing models, the modified AODV has shown better performance by achieving improved packet delivery. Fig.5.9 demonstrates performance graphs.

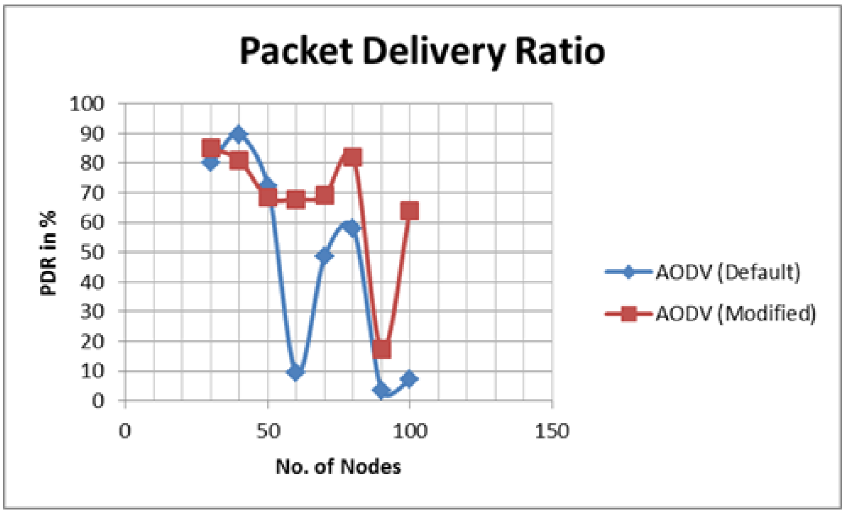


Fig.5.9. PDR over No. of nodes (Section: A)

(iii) End to End Delay (EED)

Delay scenarios in default and modified AODV routing protocols have been shown in Table - 5.7. As compare to default AODV routing model, modified AODV model has achieved least delays in delivering data packets. In order to achieve better performance of a routing protocol, end-to-end delay must have lesser values.

Table - 5.7: End to End Delay (in Millie Seconds) (Section: A)

No. of nodes	AODV (Default)	AODV (Modified)
30	6.17	4.38
40	2.89	5.91
50	9.56	11.52
60	242.38	11.83
70	26.41	11.18
80	18.04	5.48
90	706.71	117.99
100	327.94	14.03

As compare to default AODV, the modified AODV model has minimum delay of 4.38 Millie seconds for 30 numbers of nodes. However, default AODV has a delay of 6.17 Millie seconds for same numbers of nodes. Fig.5.10 determines the results.

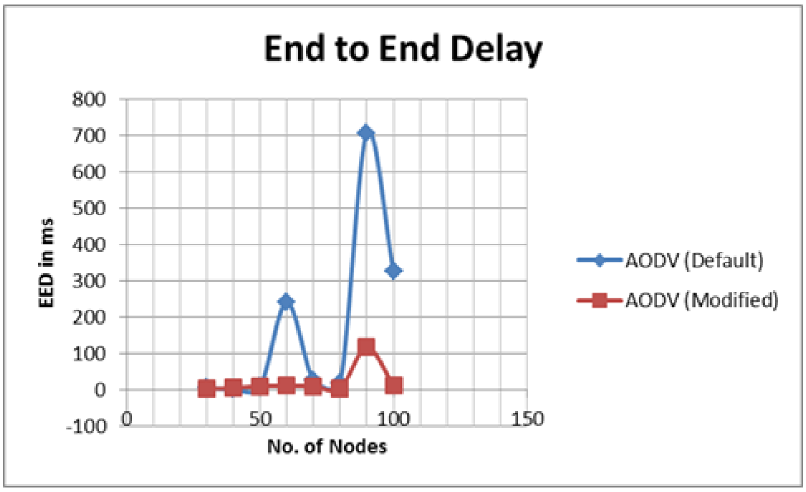


Fig.5.10. EED over No. of nodes (Section: A)

(iv) Packet Loss (PL)

Packet loss data sheet shown in Table - 5.8 reveals that the modified AODV routing protocol has better performances by achieving minimum data packet losses as compare to default model. For various numbers of varying node sets, the modified AODV has achieved minimum packet losses. However, default AODV routing has shown better performance for 40 and 50 numbers of nodes.

Table - 5.8: Packet Loss (in No. of packets) (Section: A)

No. of Nodes	AODV (Default)	AODV (Modified)
30	1187	894
40	622	1147
50	1660	1893
60	5439	1927
70	3082	1854
80	2515	1079
90	5795	4951
100	5575	2157

Fig.5.11 demonstrates the graphical representation of packet losses in default and modified AODV routing protocols, where modified AODV has shown better

performance.

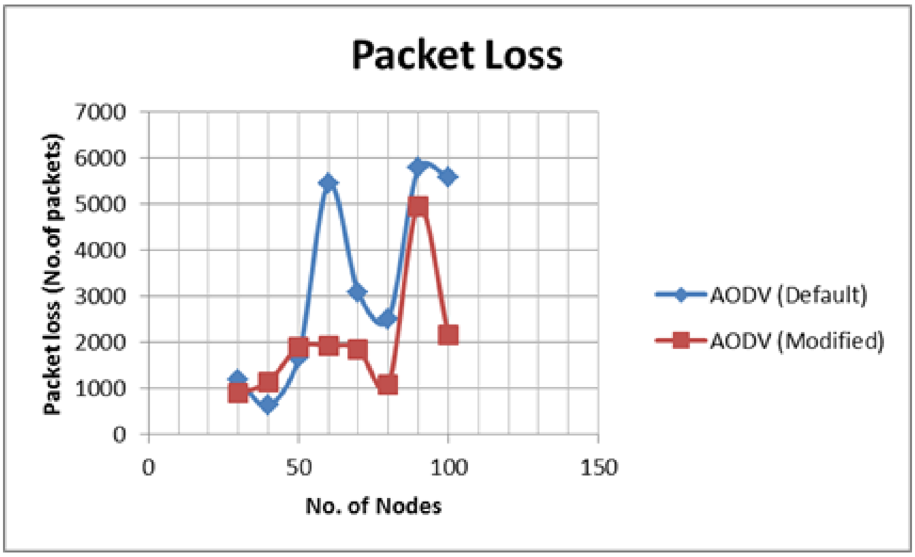


Fig.5.11. Packet loss over No. of nodes (Section: A)

(v) Normalized Routing Load (NRL)

Regularized routing load data have been tabled in Table - 5.9, table indicates; modified AODV has achieved better values of NRL as compare to default AODV model. For some nodes, default AODV has shown better results.

Table - 5.9: Normalized Routing Load (Section: A)

No. of Nodes	AODV (Default)	AODV (Modified)
30	0.802	0.851
40	0.896	0.809
50	0.723	0.685
60	0.094	0.679
70	0.486	0.691
80	0.581	0.82
90	0.034	0.175
100	0.071	0.641

Performance enhancement in modified AODV routing model can be seen in Fig.5.12. Initially, it is degrading but after some interval of time, it is gradually increasing.

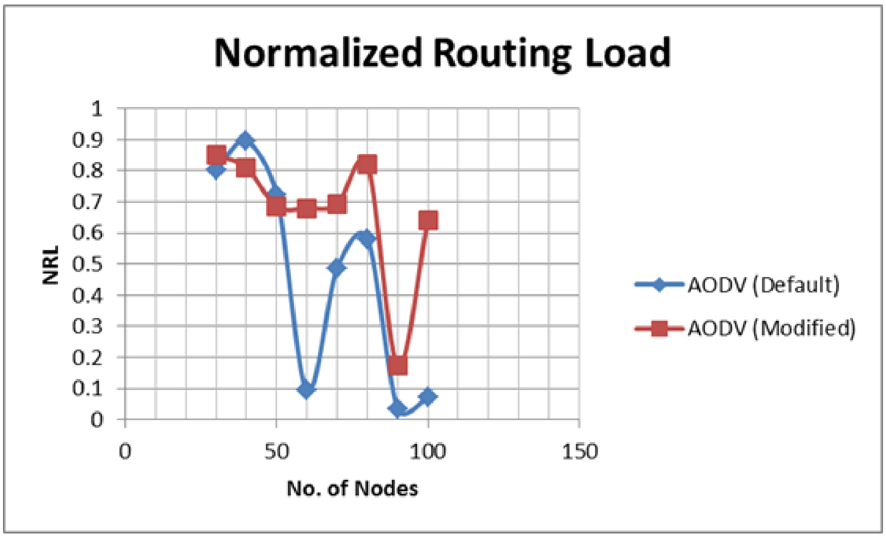


Fig.5.12. NRL over No. of nodes (Section: A)

SECTION: B (DSDV)

This section presents experimental results of DSDV along with the common network parameters used and revised essential parameters of the DSDV routing algorithm. Examinations on DSDV have been carried out by keeping 10 numbers of source/sink connections fixed and varied node densities. The simulation scenarios and obtained results are presented in the following tables and graphs with discussions. Common network simulation parameters have been tabled in Table - 5.10 and revised parameters of DSDV [IR 19] routing protocol are cited in Table - 5.11.

Table - 5.10: General Network Simulation Parameters (Section: B)

1	Number of Nodes	30,40,50,60,70,80,90,100
2	Simulation Time set for	150 seconds
3	Halt Time	0 second
4	Wi-Fi	In Ad-hoc mode
5	Wi-Fi Rate	2Mbps (802.11b)
6	Transmit Power	7.5 dBm
7	Mobility model	Random Waypoint
8	Number of Source/Sink	10

9	Sent Data Rate	2048 bits per second (2.048Kbps)
10	Size of the Data Packet	64 Bytes
11	Node Velocity	20 m/s
12	Protocols used	DSDV
13	Simulation Region	300x1500 m
14	Loss Model	Friis loss model

Here, a typical MANET of 50 numbers of nodes was considered with no pause or halt time. Wi-Fi was in ad-hoc mode with a rate of 2 Mbps. Ten numbers of source/sink pairs were taken with a transmission power of 7.5 dBm. Sent data rate was 2.048 Kbps with a packet size of 64 Bytes. Node mobility was set to 20 m/s with random waypoint mobility and friss loss models. A rectangular simulation region was set at 300x1500 meters.

Table - 5.11: Revised Values of DSDV Parameters

Parameter	Assigned Value
Periodic Update Interval	10 Seconds
Settling Time	3 Seconds
Maximum Queue Length	300 Packets
Maximum Queued Packets per Destination	6 Packets
Maximum Queue Time	10 Seconds
Enable Buffering	True
Enable Weighted Settling Time	False
Hold Time	2
Weighted Factor	0.875
Enable Route Aggregation	False
Route Aggregation Time	2 Seconds

(i) Throughput

Throughput results of section B (DSDV) have been shown in Table - 5.12. As compare to throughputs gained by default DSDV routing, the modified DSDV model has achieved better throughput results. For 30, 40, 50, 60, 70, 80, 90 set of nodes, the modified DSDV model has shown improved results. However, for 100 numbers of nodes, the default (standard) DSDV model has gained slightly better throughput.

Table - 5.12: Throughput in Kbps (Section: B)

No. of Nodes	DSDV (Default)	DSDV (Modified)
30	14.95	16.86
40	14.30	15.56
50	12.64	13.30
60	14.87	16.01
70	14.58	16.33
80	15.60	16.36
90	13.47	14.14
100	13.58	12.85

Fig.5.13 shows throughputs gained by both the routing models in graphical form, where modified DSDV routing model has shown improved throughputs as compared to the default DSDV routing model.

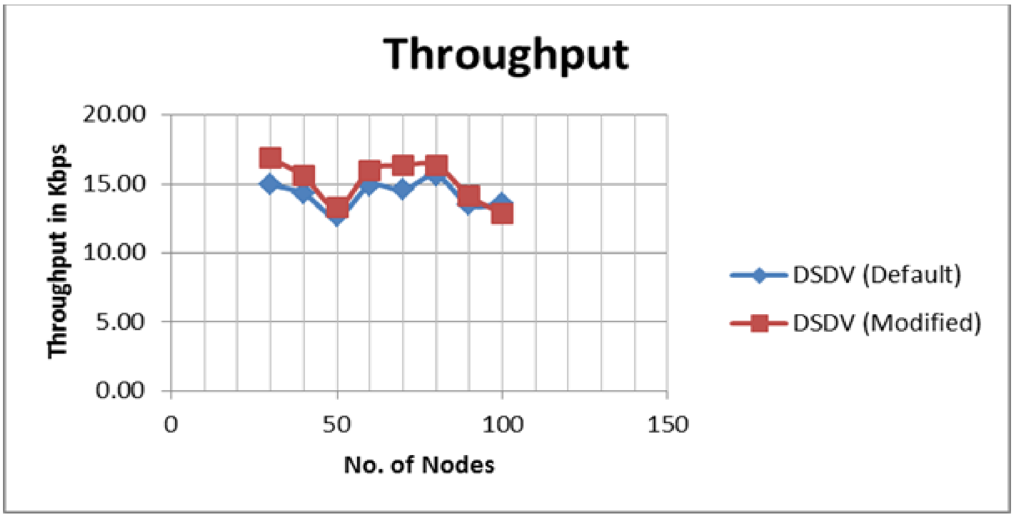


Fig.5.13. Throughput over No. of Nodes (Section: B)

(ii) Packet Delivery Ratio (PDR)

Like in throughput, here in packet delivery ratio also, modified DSDV has shown better packet delivery for different node sets. The default DSDV model has attained better packet delivery for 100 numbers of nodes. Table - 5.13 displays the calculated data of PDR values.

Table - 5.13: Packet delivery ratio in % (Section: B)

No. of Nodes	DSDV (Default)	DSDV (Modified)
30	74.73	84.32
40	71.52	77.82
50	63.22	66.50
60	74.35	80.03
70	72.88	81.67
80	77.98	81.82
90	67.33	70.70
100	67.88	64.25

Fig.5.14 explores performances of the default and modified DSDV protocol models, where, modified DSDV has shown improvements in packet delivery.

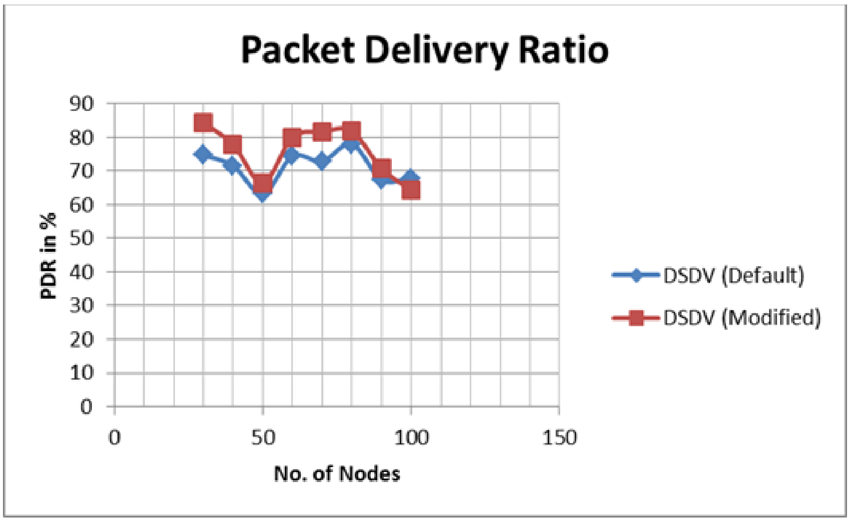


Fig.5.14. PDR over No. of Nodes (Section: B)

(iii) End to End Delay (EED)

As compare to standard DSDV routing model, the attribute revised DSDV model has attained minimum delays in delivering data packets for different node densities. However, average end to end delay was slightly better for 100 numbers nodes in default DSDV model. Table - 5.14 explores EED values achieved by either routing models.

Table - 5.14: End to end delay in mille seconds (Section: B)

No. of Nodes	DSDV (Default)	DSDV (Modified)
30	8.45	4.65
40	9.96	7.13
50	14.55	12.59
60	8.62	6.24
70	9.30	5.61
80	7.06	5.56
90	12.13	10.36
100	11.83	13.91

Fig.5.15 shows EED graphs of the standard and revised DSDV routing models.

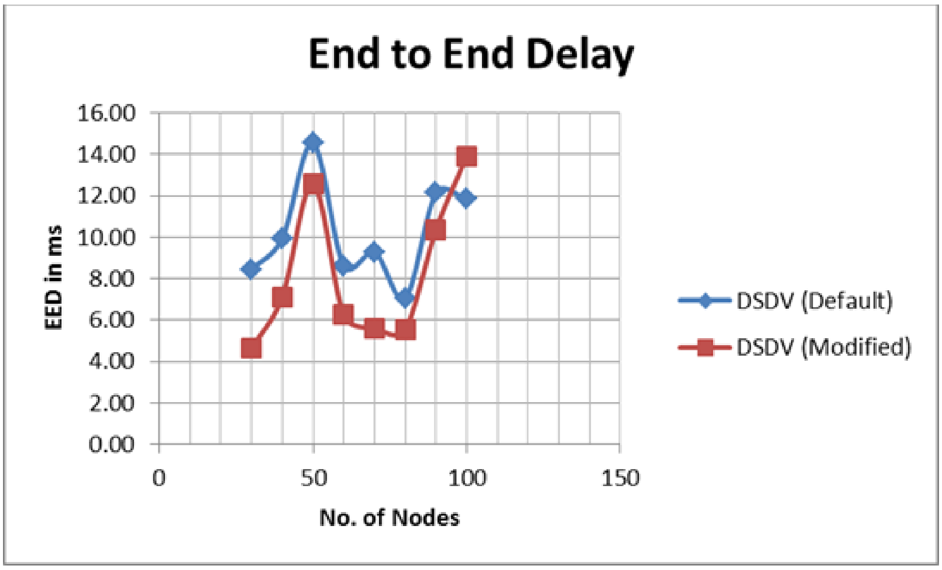


Fig.5.15. End to end delay over No. of Nodes (Section: B)

(iv) Packet Loss (PL)

The modified DSDV routing model has encountered minimum packet losses as compare to the default DSDV model. Modified DSDV has minimum packet loss of 941 packets for 30 numbers of nodes. Default DSDV has less numbers of packet losses for 100 numbers of nodes. Table - 5.15 displays the calculated data of packet losses obtained in both the routing models.

Table - 5.15: Packet loss (No. of Packets) (Section: B)

No. of Nodes	DSDV (Default)	DSDV (Modified)
30	1516	941
40	1709	1331
50	2207	2010
60	1539	1198
70	1627	1100
80	1321	1091
90	1960	1758
100	1927	2145

Fig.5.16 shows graphical representation of packet losses encountered in default and attributes revised DSDV routing models.

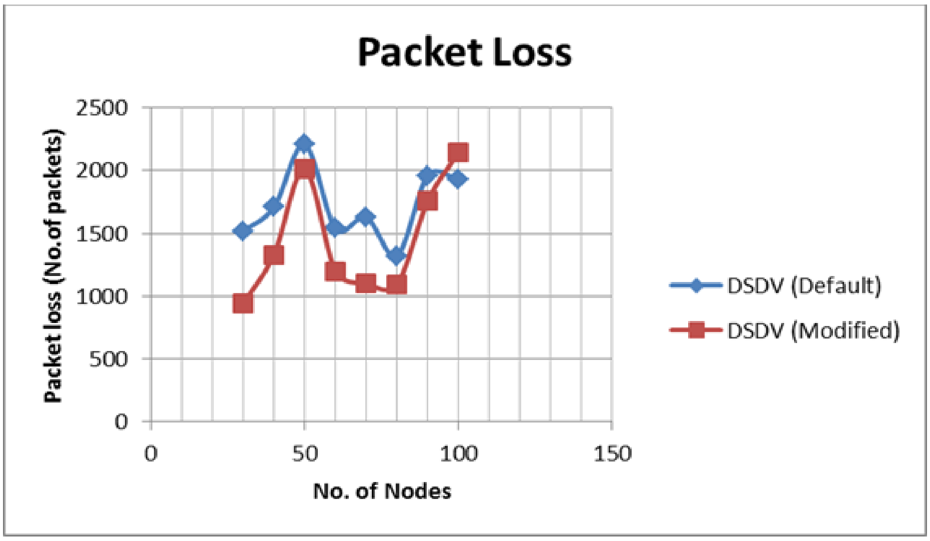


Fig.5.16. Packet loss over No. of Nodes (Section: B)

(v) Normalized Routing Load (NRL)

Regularized routing loads attained by either routing models have been tabled in Table - 5.16. For different node densities, the modified DSDV routing model has achieved better NRL values as compare to default routing model. Table - 5.16 explores the NRL results.

Table - 5.16: Normalized Routing Load (Section: B)

No. of Nodes	DSDV (Default)	DSDV (Modified)
30	0.747	0.843
40	0.715	0.778
50	0.632	0.665
60	0.744	0.800
70	0.729	0.817
80	0.780	0.818
90	0.673	0.707
100	0.679	0.643

NRL graphs of the modified and default routing models have been shown in Fig.5.17. Here, revised DSDV model has shown better NRL values. However, for 100 numbers of nodes, the standard model has shown slightly higher values.

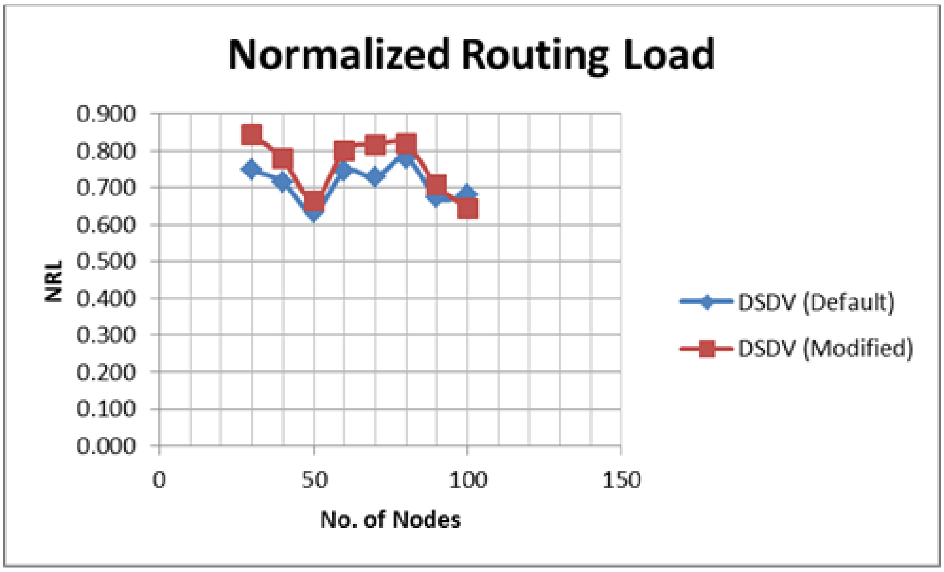


Fig.5.17. NRL over No. of Nodes (Section: B)

SECTION: C (OLSR)

Section 'C' presents; performance analysis of the OLSR routing protocol, general network parameters used, revised attributes of the OLSR routing algorithm and its routing metrics. Inspections on optimized link state routing were conducted by keeping same 10 numbers of source/sink pair stable connections and by varying number of network nodes. The network scenarios and experimental results are presented in the subsequent tables and graphs with discussions. General network parameters have been tabled in Table - 5.17 and modified parameters of OLSR [IR 20] routing protocol has been cited in Table - 5.18.

Table - 5.17: General simulation parameters (Section: C)

Network Parameter	Assigned Value
Network Nodes	First Scenario : 30,40,50,60,70,80,90,100 Second & Third Scenario: 50
Set Simulation Time	150 seconds
Set Pause Time	No pause time
Wi-Fi mode	Ad-hoc
Wi-Fi Rate	2Mbps (802.11b)
Transmit Power	First and Second Scenario: 7.5dBm Third Scenario: 3.5,4.5,5.5,6.5,7.5,8.5,9.5,10.5dBm
Node Mobility model	Random Waypoint mobility model (RWMM)
Source/Sink pairs	10 No.s
Sent Data Rate	2.048Kbps (2048 bits per second)
Data Packet Size	64 Bytes
Node Mobility Speed	First and Third Scenario: 20 m/s Second Scenario: 10,20,30,40,50,60,70,80 m/s
MANET Protocols used	Standard and Revised OLSR
Network Region	300x1500 m (Rectangular)
Traffic	CBR (Constant Bit Rate)

OLSR Parameters:

Table - 5.18: Revised attributes of OLSR parameters

Protocol Parameter	Assigned Value
Refresh Interval	2 Seconds
Unspecified link	Set to 0
Asymmetric link	Set to 1
Symmetric link	Set to 2
Lost link	Set to 3
Not neighbor	Set to 0
Symmetric neighbor	Set to 1
Asymmetric neighbor	Set to 2
Maximum number of messages per packet	64
Maximum number of HELLOS per message	12
Maximum number of addresses on a message	64
Maximum allowed jitter	4 Seconds
HELLO Interval	4 Seconds
TC messages emission interval	3 Seconds
MID messages emission interval	2 Seconds
HNA messages emission interval	3 Seconds
Willingness of a node to carry and forward traffic for other nodes	Set to: “OLSR_WILL_ALWAYS”
Dup holding time	30 Seconds

OLSR Holding Time Metrics [IR 8]:

(1) Neighbor Holding Time $= (3 \times \text{OLSR Refresh Interval})$ (5.12)

(2) Top Holding Time $= (3 \times \text{TC messages emission interval})$ (5.13)

(3) MID Holding Time $= (3 \times \text{MID messages emission interval})$ (5.14)

(4) HNA Holding Time $= (3 \times \text{HNA messages emission interval})$ (5.15)

Simulation based experiments on standard and attribute revised models of OLSR routing protocol were carried out in three simulation scenarios. Fig.5.18 explores execution of the OLSR program script. Network parameters in all the scenarios were set as per Table - 5.17. In the first scenario, the typical MANET was tested for different set of network nodes i.e. 30,40,50,60,70,80,90 and 100 set of nodes. Where, node velocities was set to 20 m/s with a transmit power of 7.5dBm. Obtained data for various performances evaluating metrics have been tabulated in Table - 5.19.

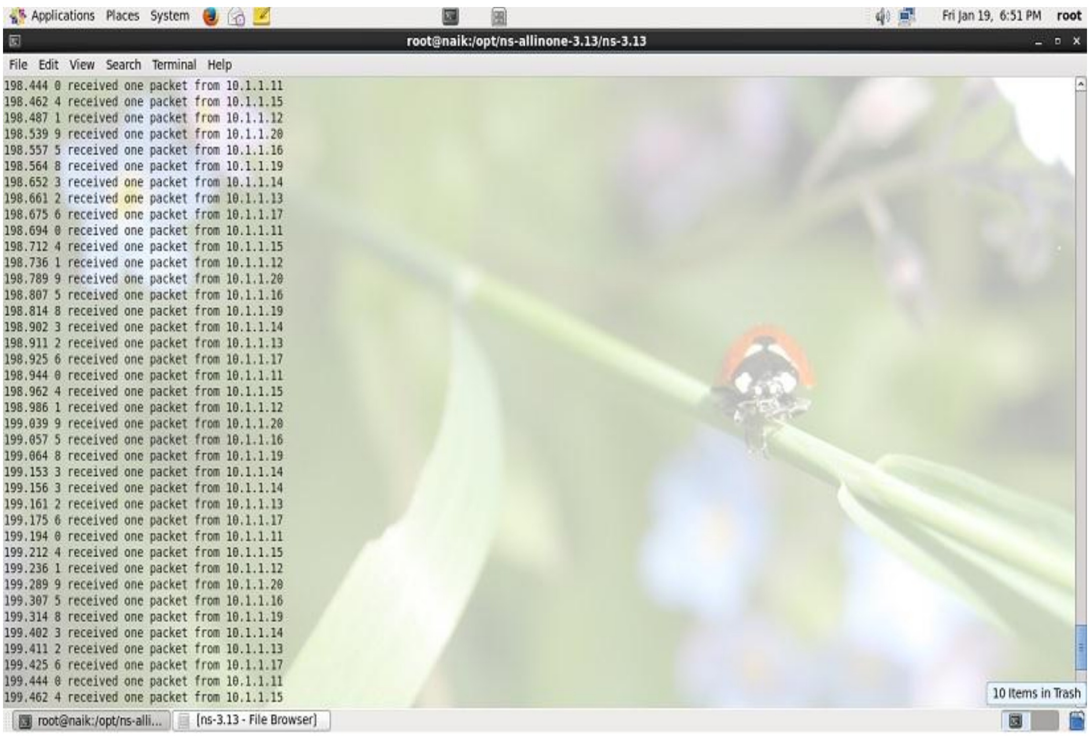


Fig.5.18. OLSR Script under execution (Section: C)

Table - 5.19: Data sheet of different node densities

No. of Nodes	Throughput in Kbps		Packet Delivery Ratio in %		End to End delay in mille seconds		Packet Loss		Normalized Routing Load	
	S.OLSR	R.OLSR	S.OLSR	R.OLSR	S.OLSR	R.OLSR	S.OLSR	R.OLSR	S.OLSR	R.OLSR
30	18.27	18.96	91.33	94.78	2.37	1.38	520	313	0.913	0.948
40	16.93	18.66	84.67	93.28	4.53	1.80	920	403	0.847	0.933
50	17.99	18.95	89.93	94.75	2.80	1.39	604	315	0.899	0.948
60	18.91	19.08	94.55	95.38	1.44	1.21	327	277	0.946	0.954
70	18.99	19.11	94.97	95.57	1.33	1.16	302	266	0.950	0.956
80	18.60	18.78	93	93.92	1.88	1.62	420	365	0.930	0.939
90	17.47	18.29	87.37	91.47	3.62	2.33	758	512	0.874	0.915
100	18.45	18.19	92.25	90.97	2.10	2.48	465	542	0.923	0.910

In the second scenario, different node velocities were considered for a set of 50 nodes with a transmit power of 7.5dBm. Diverse node speeds considered for the experiments were; 10, 20, 30, 40, 50, 60, 70 and 80 m/s. Evaluated data for different performance calculating metrics are shown in Table - 5.20.

Table - 5.20: Data sheet of different node velocities

Node Velocity in m/s	Throughput in Kbps		Packet Delivery Ratio in %		End to End delay in mille seconds		Packet Loss		Normalized Routing Load	
	S.OLSR	R.OLSR	S.OLSR	R.OLSR	S.OLSR	R.OLSR	S.OLSR	R.OLSR	S.OLSR	R.OLSR
10	18.60	18.54	92.98	92.72	1.89	1.96	421	437	0.930	0.927
20	17.99	18.95	89.93	94.75	2.80	1.39	604	315	0.899	0.948
30	17.86	17.96	89.32	89.78	2.99	2.84	641	613	0.893	0.898
40	16.00	17.24	79.98	86.20	6.26	4.00	1201	828	0.800	0.862
50	16.16	16.38	80.78	81.88	5.95	5.53	1153	1087	0.808	0.819
60	15.69	16.03	78.47	80.17	6.86	6.19	1292	1190	0.785	0.802
70	15.16	15.20	75.82	76.02	7.97	7.89	1451	1439	0.758	0.760
80	13.93	14.63	69.63	73.15	10.90	9.18	1822	1611	0.696	0.732

In the third scenario, we have considered different transmit powers as; 3.5, 4.5, 6.5, 7.5, 8.5, 9.5 and 10.5 dBm keeping 50 number of mobile nodes with a node velocity of 20 m/s. Calculated values for different metrics are shown in Table - 5.21.

Table - 5.21: Data sheet of different node transmit power

Trans mit Power in dBm	Throughput in Kbps		Packet Delivery Ratio in %		End to End delay in mille seconds		Packet Loss		Normalized Routing Load	
	S.OLSR	R.OLSR	S.OLSR	R.OLSR	S.OLSR	R.OLSR	S.OLSR	R.OLSR	S.OLSR	R.OLSR
3.5	13.31	15.36	66.53	76.82	12.58	7.55	2008	1391	0.665	0.768
4.5	15.18	17.34	75.90	86.68	7.94	3.84	1446	799	0.759	0.867
5.5	16.08	17.90	80.38	89.48	6.10	2.94	1177	631	0.804	0.895
6.5	17.23	18.53	86.13	92.67	4.02	1.98	832	440	0.861	0.927
7.5	17.99	18.95	89.93	94.75	2.80	1.39	604	315	0.899	0.948
8.5	18.16	18.93	90.82	94.63	2.53	1.42	551	322	0.908	0.946
9.5	19.18	19.43	95.90	97.15	1.07	0.73	246	171	0.959	0.972
10.5	19.42	19.56	97.10	97.80	0.75	0.56	174	132	0.971	0.978

(i) Throughput

Fig.5.19 presents performances curves of the standard and revised OLSR routing models for different node sets. The revised OLSR routing model has shown improved performance as compared to its standard version. In 30, 50, 60 and 70 numbers of node sets, better network throughput have been achieved. However, in 40 numbers of nodes set, a growth of 1.73 Kbps can be observed.

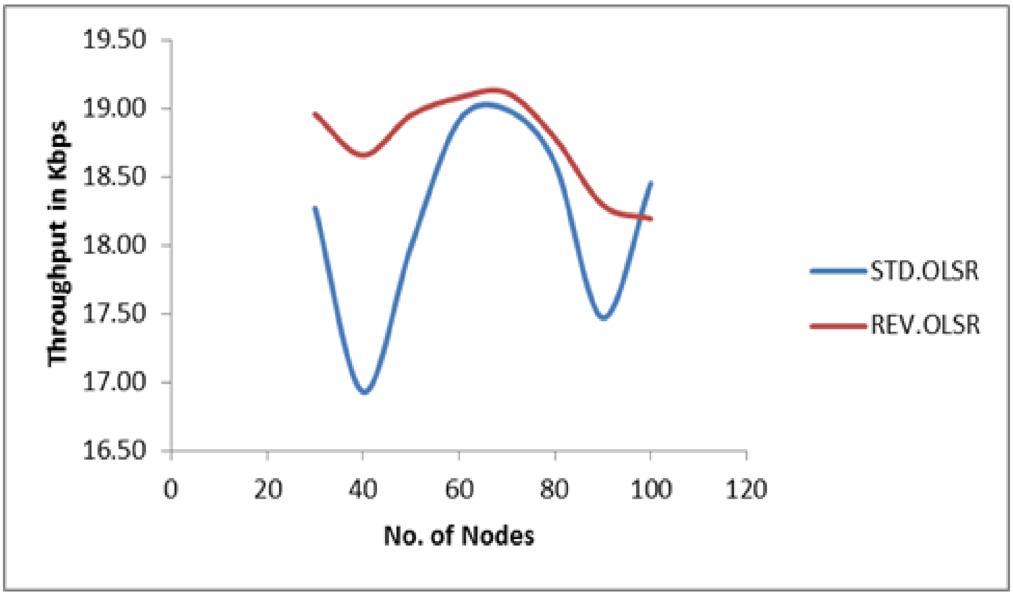


Fig.5.19. Throughput vs. No. of Nodes (Section: C)

Fig.5.20 shows throughput graphs of both the routing models for different node velocities. Here, revised model has shown enhanced throughput. For lesser values of node speed, the revised model has gained better throughput. However, for the node speed 70 m/s, a slight increment in throughput was witnessed.

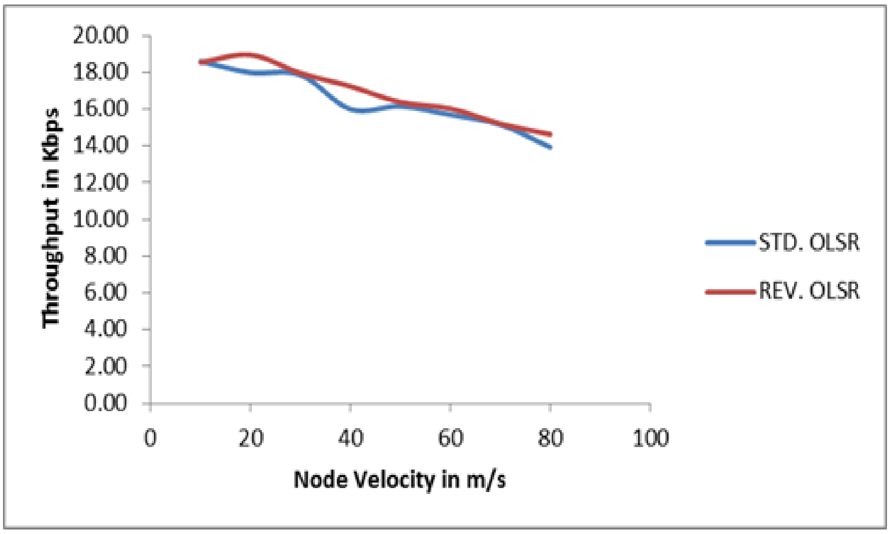


Fig.5.20. Throughput Vs Node Velocity (Section: C)

In Fig.5.21, enhanced network throughput can be seen for diverse values of node transmit power. Here, lesser values of transmission power gained maximum throughput as compared to higher values. Though, higher values of transmission power also showed slight increments in network throughput.

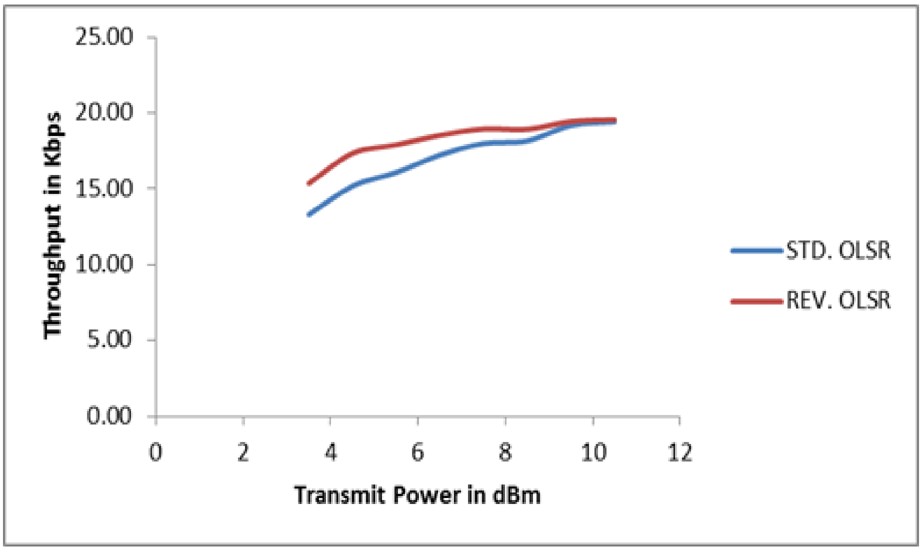


Fig.5.21. Throughput vs. Transmit Power (Section: C)

(ii) Packet Delivery Ratio

The revised OLSR model has shown enhanced results in delivering data packets to the destination nodes as compare to standard routing model for different sets of node densities. Revised OLSR has witnessed peak delivery of 95.57% packets, whereas standard OLSR has shown better delivery of 92.25% packets for 100 numbers of nodes. Fig.5.22 displays the performances of both the routing models, where, revised OLSR has shown improvement in performance for all the set of nodes except for 100 numbers of nodes.

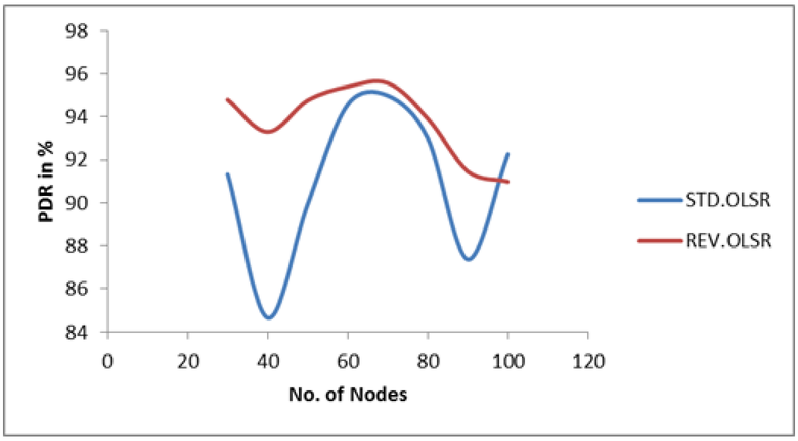


Fig.5.22. PDR vs. No. of Nodes (Section: C)

For different values of node velocities, the revised OLSR routing protocol has gained better packet delivery. Fig.5.23 shows the performances of both the routing protocols. For 20, 40 and 80 m/s, the revised model has shown remarkable data packet delivery.

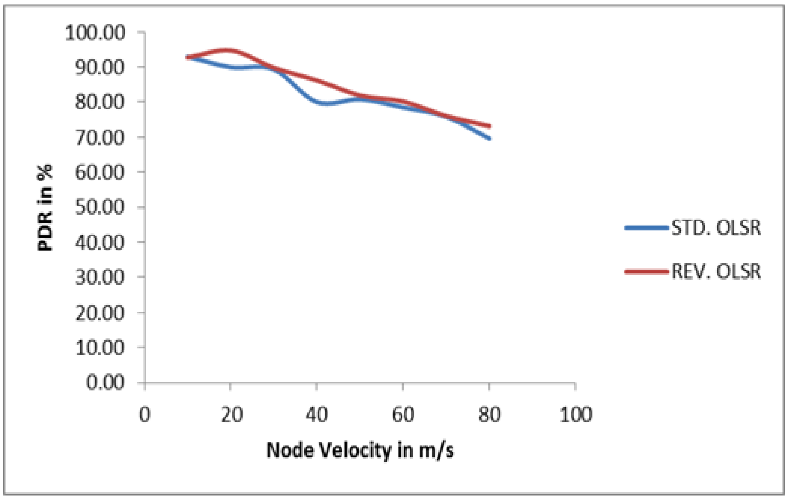


Fig.5.23. PDR vs. Node Velocity (Section: C)

Fig.5.24 reveals performances of the standard and revised OLSR routing models for different node transmission power. Here, the revised OLSR model has shown better and improved performances in delivering data packets from source to the destination nodes.

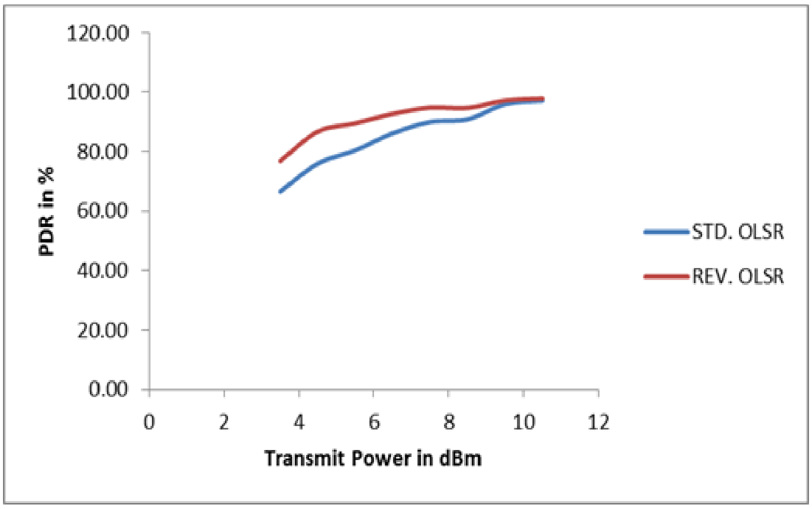


Fig.5.24. PDR vs. Transmit Power (Section: C)

(iii) End to End Delay

End to end delay encountered in delivering data packets by the revised and standard OLSR protocols have been revealed in Fig.5.25. As compared to the standard OLSR routing, the amended OLSR protocol has met with minimum delays for different node densities. Better performance of routing protocols can also be attained by gaining lesser delay values.

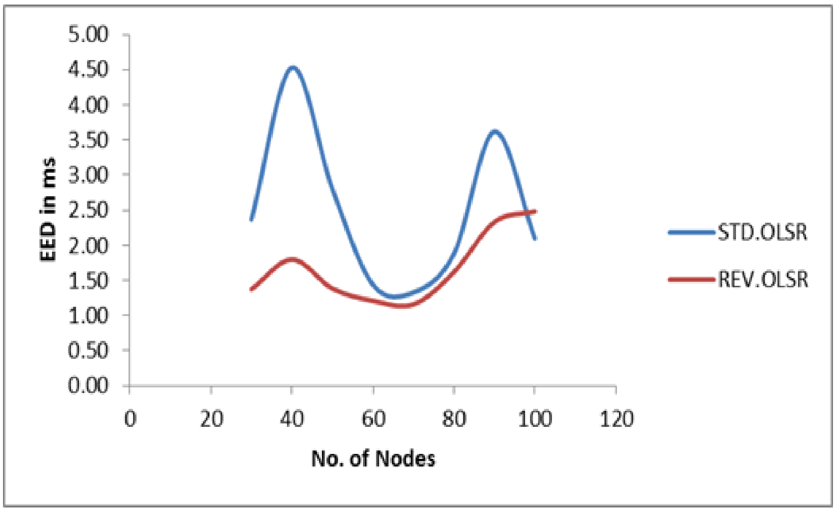


Fig.5.25. EED vs. No. of Nodes (Section: C)

Fig.5.26 illustrates the end to end delay faced by both the routing protocols while transporting data packets from source to the destination nodes. For different node velocities, the revised OLSR routing protocol has come across minimum delay as compared to the standard OLSR model. For the node speed 40 m/s, the revised OLSR met with a minimum delay of 1.8 mille seconds whereas the standard OLSR has 4.53 mille seconds.

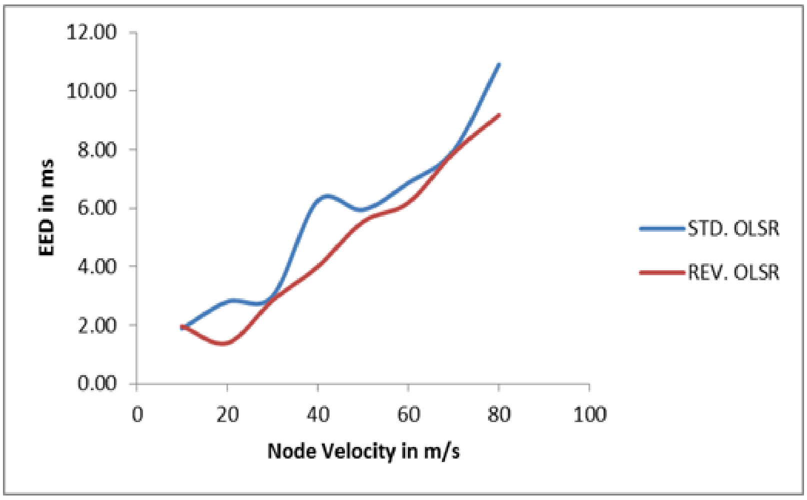


Fig.5.26. EED vs. Node Velocity (Section: C)

For different transmit power, the revised OLSR has shown better data packet delivery by gaining minimum packet losses. Fig.5.27 shows the performances of both the routing protocols. At 3.5 and 4.5dBm, the revised OLSR has shown the best performance as compared to other values of transmit power.

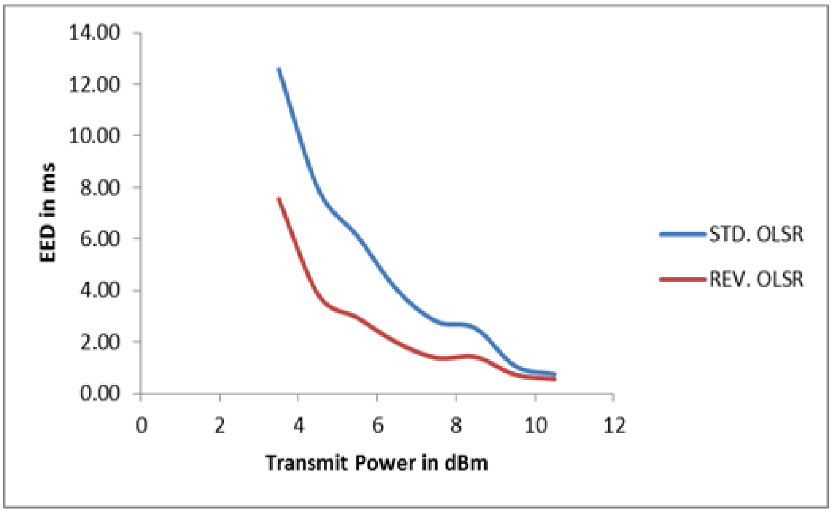


Fig.5.27. EED vs. Transmit Power (Section: C)

(iv) Packet Loss

Fig.5.28 displays packet loss graphs of the standard and revised OLSR routing protocols for various node densities. The revised protocol has a minimum packet loss of 266 packets for 70 numbers of nodes, whereas, the standard OLSR has minimum losses 465 packets for 100 numbers of nodes. The amended OLSR model has encountered minimum packet losses during data packet transmission sessions as compare to the standard OLSR protocol model.

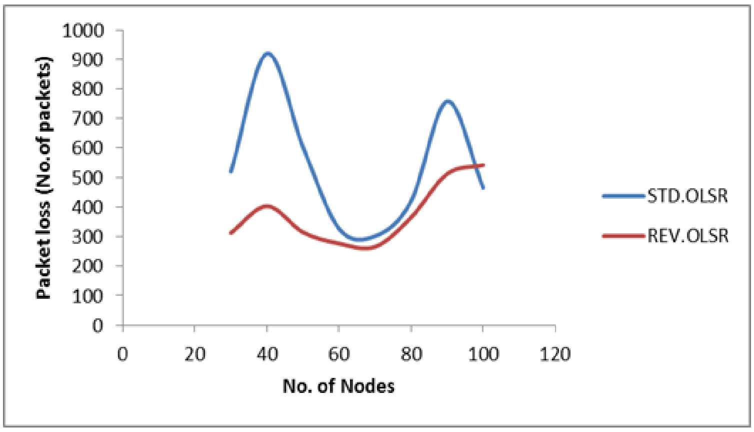


Fig.5.28. Packet Loss vs. No. of Nodes (Section: C)

Fig.5.29 represents packet loss scenarios in either OLSR routing models. As compared to standard OLSR routing model, the revised model has shown better performances having minimum losses and high gain at different node velocities. At node speed of 20 m/s, the standard model has a loss of 604 numbers of data packets, whereas the revised model lost 315 numbers of packets.

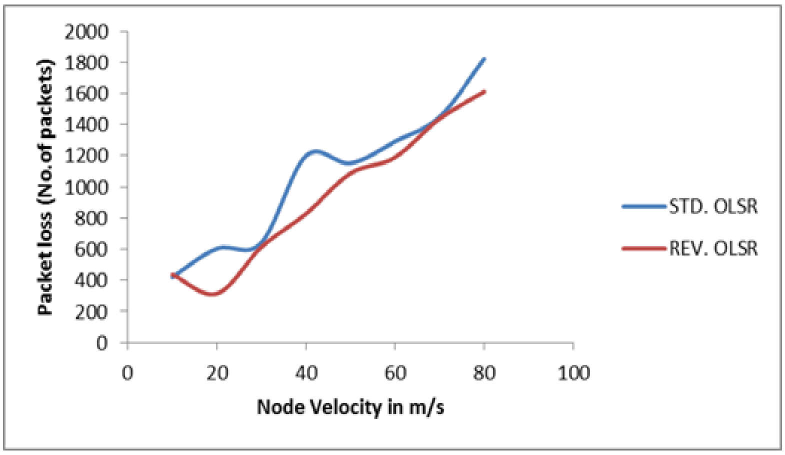


Fig.5.29. Packet Loss vs. Node Velocity (Section: C)

As opposed to the standard OLSR routing protocol, the revised protocol has performed better by having minimum packet losses for different node transmission power. Fig.5.30 displays performance curves of both the routing protocols. To 3.5dBm, the standard OLSR has faced a loss of 2008 numbers of packets, whereas the revised OLSR has a loss of 1391 numbers of data packets.

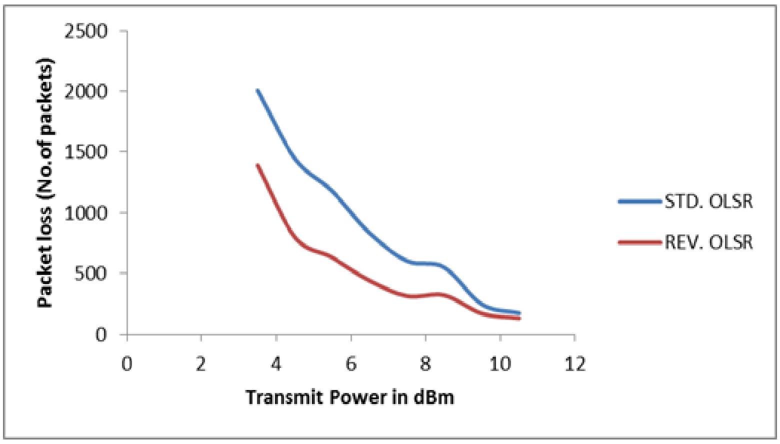


Fig.5.30. Packet Loss vs. Transmit Power (Section: C)

(v) Normalized Routing Load

Performance curves of Fig.5.31 reveals routing loads handled by the standard and revised OLSR routing protocols for different node population scenarios. Like in other metrics discussed above, as compared to the standard OLSR model, the revised OLSR model has performed better in handling routing overheads for various node densities. Better results of normalized routing load show improved performances of the routing protocol; however, it may consume more bandwidth.

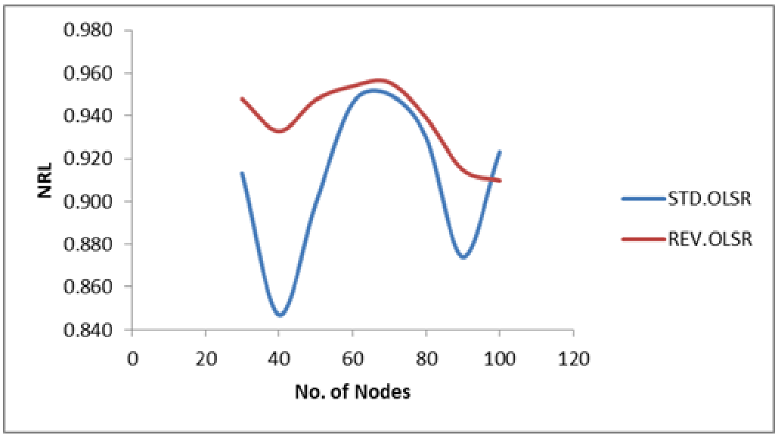


Fig.5.31. NRL vs. No. of Nodes (Section: C)

Fig.5.32 shows graphical representation of normalized routing load handled by both the OLSR models for different node velocities. Comparing to the standard OLSR model, the revised OLSR has shown better performance in normalizing the routing load.

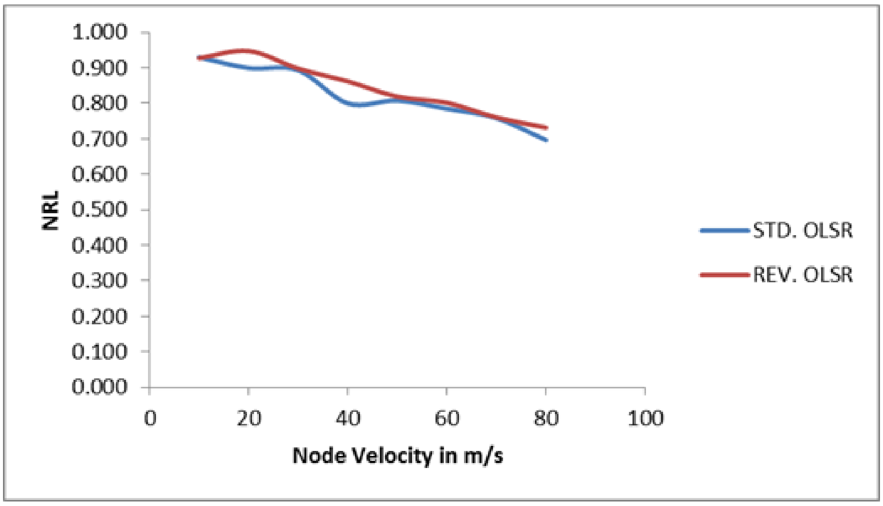


Fig.5.32. NRL vs. Node Velocity (Section: C)

The normalized routing load versus transmit power graphs shown in Fig.5.33 represents performances of the standard and the revised OLSR routing protocols for different transmit power values. As compared to the standard OLSR routing, the revised routing model has shown better results in normalizing the routing load and minimizing the routing overheads.

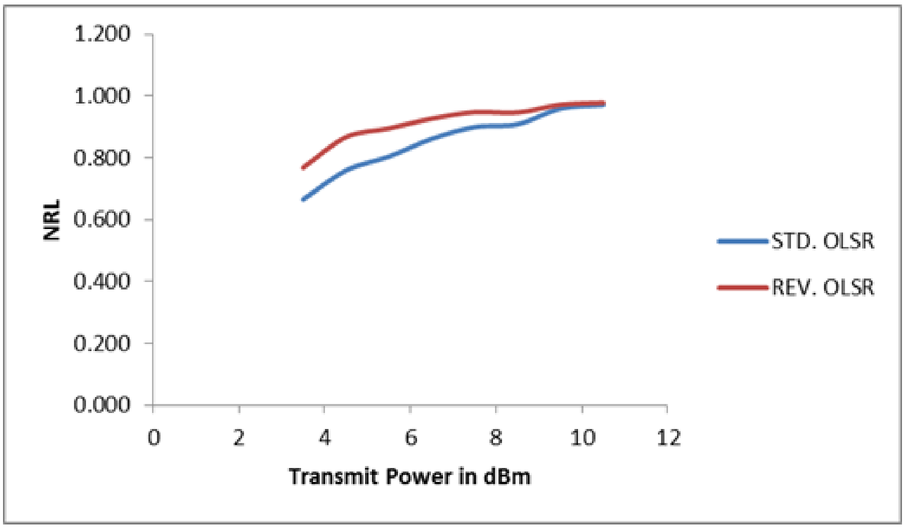


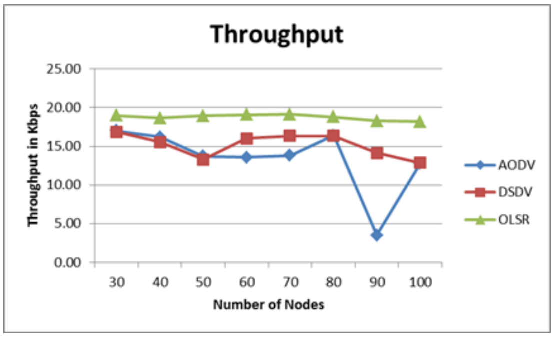
Fig.5.33. NRL vs. Transmit Power (Section: C)

SECTION: D

This section deals with the study and comparative performance analysis of attribute revised AODV, DSDV and OLSR routing models. These routing protocol models were tested on different node densities and node velocities. Different node densities considered for these experiments were; 30,40,50,60,70,80,90 and 100 numbers of nodes. Diverse node velocities considered were; 5,10,15,20,25,30,35 and 40 m/s. General simulation parameters were set as per Table - 5.10 excepting other values of node velocities with ten numbers of source/sink nodes. Attributes of the protocol parameters were set as per Table - 5.4, Table - 5.11 and Table - 5.18. Performance metric wise results along with discussions are presented in the following sub sections.

(i) Throughput

Fig.5.34 shows the throughput gained by AODV, DSDV and OLSR routing protocols for different node densities. As compare to AODV and DSDV, OLSR has shown better performances for lesser and dense node densities. When we compare throughputs of AODV and DSDV, both has almost equal performances for lesser node densities and for larger node densities, DSDV has shown better results in terms of network throughput. For 90 numbers of nodes, the throughput of the AODV was decreased and for 100 numbers of nodes, it has resumed its performance level. Fig.5.35 signifies the throughput graphs of OLSR, DSDV and AODV for different node velocities. From the experimental results, it is determined that the OLSR routing protocol has gained better throughput as compare to other two routing protocols. The OLSR has achieved the maximum average throughput of 18.59 Kbps for different node velocities. As compare to DSDV, the AODV routing protocol has achieved marginally better throughput.



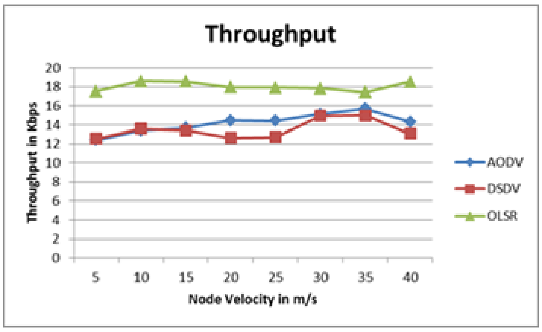
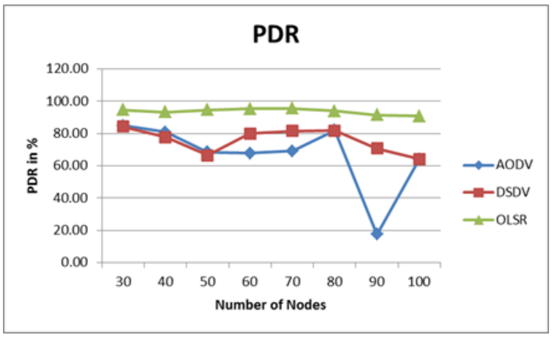


Fig.5.34. Throughput vs. No. of Nodes **Fig.5.35. Throughput vs. Node Velocity**

(ii) Packet Delivery Ratio

Fig.5.36 shows packet delivery scenarios in all the three routing models for different node densities. Here, as compare to AODV and DSDV, the OLSR routing protocol has achieved better packet delivery for every node set. For lesser number of nodes, AODV and DSDV models were shown equal packet delivery. However, DSDV has shown better packet delivery as compare to the AODV routing protocol. Fig.5.37 displays packet delivery graphs of OLSR, AODV and DSDV routing models for different node velocities. Experimental results show that; performance of the OLSR routing protocol was better than AODV and DSDV routing protocols. The OLSR has achieved a maximum of 90% packet delivery and the AODV gained 75% of packet delivery. The DSDV routing protocol gained slightly reduced performances as compare to the OLSR and DSDV routing protocols.



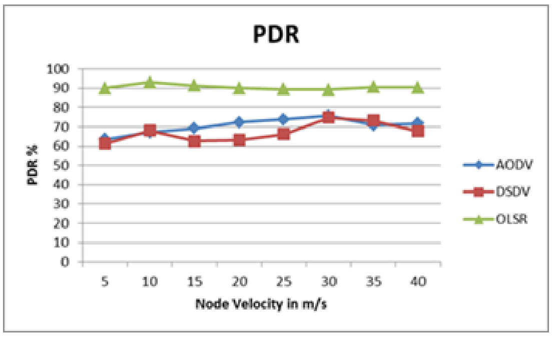


Fig.5.36. PDR vs. No. of Nodes **Fig.5.37. Throughput vs. Node Velocity**

(iii) End to End Delay

End to end delay encountered in revised AODV, DSDV and OLSR routing models for different node densities is shown in Fig.5.38. Here, delay scenarios reveal better performance of the OLSR routing model as it met with less delay during packet transmission. As compare to AODV, the DSDV protocol has lesser delay for high node densities. Fig.5.39 explores delay scenarios faced by all the three routing models for diverse values of node velocities. Here also, the revised OLSR routing model has shown better performances by gaining minimum delays during packets transmission from the source nodes to the destination nodes.

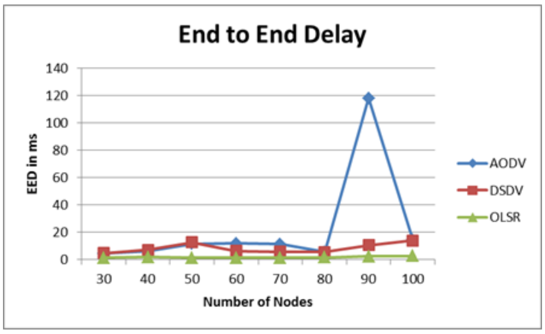


Fig.5.38. EED vs. No. of Nodes

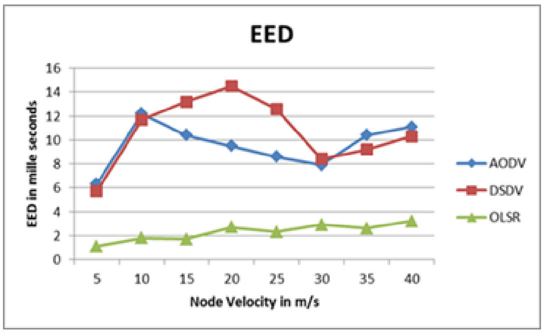


Fig.5.39. EED vs. Node Velocity

(iii) Packet Loss

Fig.5.40 reveals packet losses encountered in AODV, DSDV and OLSR routing models for diverse node density scenarios. As compare to AODV and DSDV, the OLSR routing protocol has met with less number of packet losses. DSDV has less packet losses for higher number of nodes whereas; AODV has large number packet losses. Packet loss scenarios of all the three routing protocols for different node velocities are shown in Fig.5.41. Here, the OLSR has performed well by gaining minimum packet losses of 340 numbers of packets. Performances of DSDV and AODV protocols reveal that the AODV has met with minimum packet losses and the DSDV routing protocol has achieved better results for node speeds 25, 10 and 5 m/s. If we compare the results of DSDV and AODV, the AODV routing protocol has better performance results.

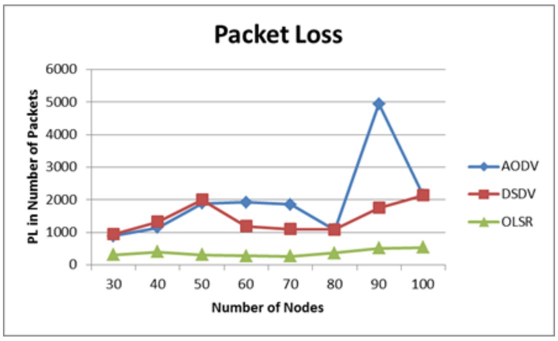


Fig.5.40. PL vs. No. of Nodes

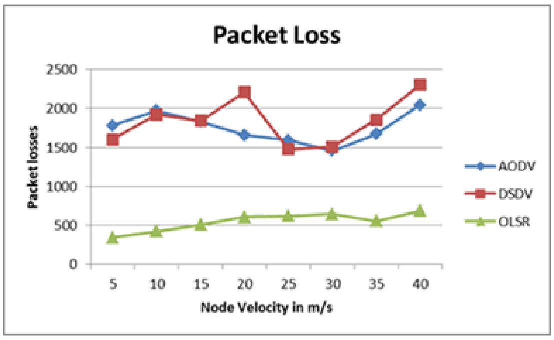


Fig.5.41. PL vs. Node Velocity

(iv) Normalized Routing Load

Like in results of other metrics, results of the normalized routing load results too conclude better performance of the revised OLSR routing model. As compare to AODV, DSDV has shown better performance for higher node densities. The AODV routing protocol has shown least performances in terms of NRL for lesser node densities. Fig.5.42 reveals performances of all the three routing protocols in terms normalized routing load. Fig.5.43 signifies the performances of the routing protocols for various values of node velocity. Here too, performance of the OLSR routing model was better in terms of normalization of routing load as compared to other two routing protocols. As compare to DSDV, performance of the AODV routing protocol is marginally better for offered routing load.

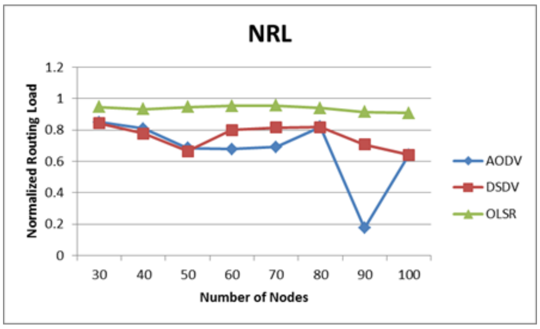


Fig.5.42. NRL vs. No. of Nodes

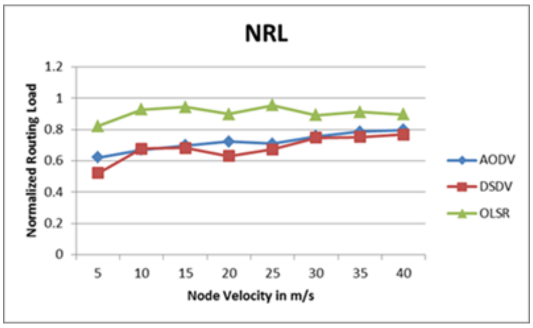


Fig.5.43. NRL vs. Node Velocity

5.12 Conclusions

In this chapter, performance comparison of the standard and attribute revised models of AODV, DSDV and OLSR routing protocols were studied and analysed. These analyses were carried out in three different sections; section 'A' deals with analysis of the AODV routing protocol, section 'B' deals with the DSDV and section 'C' deals with the OLSR routing protocol. In each section, performance of the revised routing model was compared with performance of the standard routing model in order to check performance improvements. Routing attributes of the protocols were altered to test possible improvement in performances of the routing protocols. As per experimental results and metric calculations; the throughput, packet delivery ratio, end to end delay, packet loss and normalized routing load of the revised AODV, DSDV and OLSR routing models were shown better and enhanced performances as compare to the default or standard AODV, DSDV and OLSR routing models. These performance enhancements were possible by the help of simulation platforms used, selection of suitable general network parameters and protocol attributes.

In this chapter, comparative performances of the revised routing models were also discussed in section ‘D’. Where, the revised OLSR model has shown better performances in terms of the throughput, packet delivery ratio, end to end delay, packet loss and normalized routing load metrics. Attribute revised routing models are helpful in gaining maximum efficiency of the MANETs in various deployment scenarios. Revised versions of the AODV, DSDV and OLSR routing protocols can be utilized as MANET routing protocols in real networks comprising of small or large set of nodes. Further scope of research in this direction is still open and challenging, same have been discussed in detail in chapter 7 of this thesis.