Chapter 3

Routing Protocols

Chapter describes an overview of routing protocols used in ad hoc networks. An overview is given of the routing problem, classification of ad hoc routing protocols are discussed. Using this classification, the various classes of routing protocols are discussed with samples of each class.

Ad-Hoc networking is a concept in computer communications, which means that users wanting to communicate with each other form a temporary network, without any form of centralized administration. Each node participating in the network acts both as host and a router and therefore is willing to forward packets for other nodes, which makes use of a routing protocol. Each node has to maintain some form of information regarding the network around it, and some algorithm governing the sending and receiving of data packets. This algorithm, together with the supporting information regarding network conditions, is called a ***"ROUTING PROTOCOL"*** [1, 2].

Characteristics of Ad hoc networks impose a set of new demands on the routing protocol. The most important characteristic is the dynamic topology, which is a due to the node mobility, nodes can change position quite frequently, which means that there is a need a routing protocol that quickly adapts to topology changes. Due to power limitation, the routing protocol should try to minimize control traffic, such as periodic update messages, conserving memory, power and bandwidth resources. The main function of the routing protocol is to detect and maintain the optimal route to send data packets between a source and destination via intermediate node(s).

The 1990s have seen a rapid growth of research interests in mobile ad hoc networking. The infrastructure less and the dynamic nature of these networks demands new set of networking strategies to be implemented in order to provide efficient end-to-end communication. MANETs employ the traditional TCP/IP structure to provide end-to-end communication between nodes. However, due to their mobility and the limited resource in wireless networks, each layer in the TCP/IP model requires redefinition or modifications to function efficiently in MANETs.

Routing in the MANETs has received a tremendous amount of attention from researchers. This has led to development of many different routing protocols for MANETs, and each provides an improvement over a number of different strategies considered in the literature for a given network scenario. Therefore, it is quite difficult to determine which protocols may perform best under a number of different network scenarios, such as increasing node density and traffic. [3, 4], provides an overview of a wide range of routing protocols proposed in the literature. They also provide a performance comparison of all routing protocols and suggest which protocols may perform best in large networks. [5], discusses numerous routing protocols and algorithms. Their performance under various network environments and traffic conditions has been studied and compared. Several surveys and comparative analyses of MANET routing protocols have been published. [6,7,8] has discussed the results of a detailed packet-level simulation comparing four multi-hop wireless ad hoc network routing protocols that cover a range of design choices: DSDV, TORA, DSR, and AODV [8]. They have presented the results of simulations of networks of 50 mobile nodes.

A number of routing protocols have been implemented and compare the performance of on-demand reactive routing protocols for mobile ad hoc networks. A simulation model with MAC and physical layer models is used to study interlayer interactions and their performance implications. A variety of workload and scenarios, as characterized by mobility, load and size of the ad hoc network were simulated. The performance differentials are analyzed using varying network load, mobility, and network size. These simulations are carried in Qualnet network simulator to run ad hoc simulations.

3.1 Properties of Routing Protocols

Some of the desirable properties of routing protocols are shown in **Table 3.1**.

Sr. No.	Property	Comments
1	Loop free	To improve the overall performance, we want the routing protocol to guarantee that the routes supplied are loop-free. This avoids any waste of bandwidth or CPU consumption.
2	Demand based operation	To minimize the control overhead [6, 7] in the network and thus not wasting network resources more than necessary, the protocol should be reactive. This means that the protocol should only react when needed and that the protocol should not periodically broadcast control information.
3	Power conservation	The nodes in an ad-hoc network can be laptops and thin clients, such as PDAs that are very limited in battery power [8] and therefore uses some sort of stand-by mode to save power. It is therefore important that the routing protocol has support for these sleep-modes.
4	Distributed operation	The protocols should not be dependent on a centralized controlling node. This is the case even for stationary networks. The difference is that nodes in an ad-hoc network can enter/leave the network very easily and because of mobility the

		network can be partitioned.
5	Quality of service support	Some sort of Quality of service [9] support is probably necessary to incorporate into the routing protocol. This has a lot to do with what these networks will be used for. It could for instance be real-time traffic support.
6	Unidirectional link support	The radio environment can cause the formation of unidirectional links. Utilization of these links and not only the bi-directional links improves the routing protocol performance.
7	Multiple routes	To reduce the number of reactions to topological changes and congestion multiple routed could be used. If one route has become invalid, it is possible that another stored route could still be valid and thus saving the routing protocol from initiating another route discovery procedure.

Table 3.1 : Routing Protocols- Properties

None of the proposed protocols from MANET have all these properties, but it is necessary to remember that the protocols are still under development and are probably extended with more functionally. The primary function is still to find a route to the destination, not to find the best/optimal/shortest-path route.

3.2 Routing Protocols -Classification

Routing can be defined as detecting and maintaining the optimal route to send data packets between a source and destination via intermediate node(S) in a network [8, 9]. Criteria for designing and classifying routing protocols for wireless ad hoc networks are based on, what routing information is exchanged; when and how the routing information is exchanged, when and how routes are computed and so on[10].classification of routing protocol is shown in **Figure 3.1**.

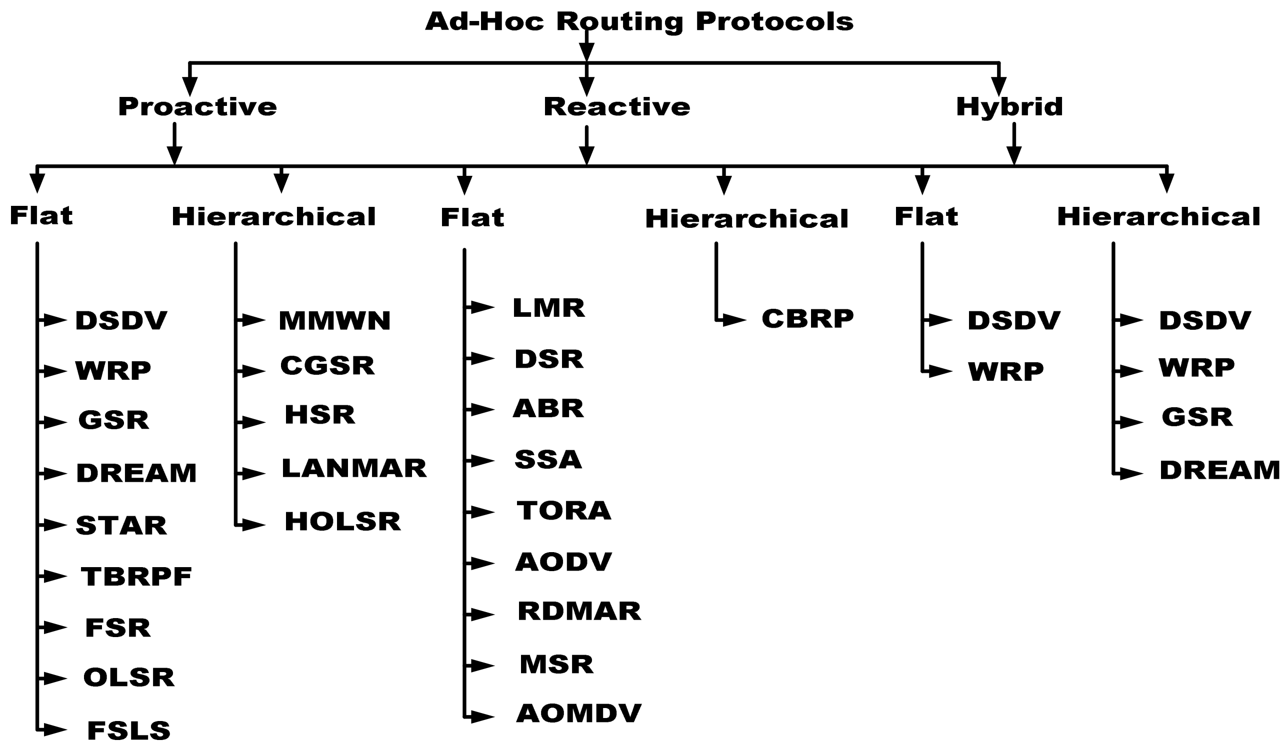

Figure 3.1: Ad hoc Routing Protocols – Classification

- Proactive routing protocol-routes to a destination are determined when a node joins the network or changes its location, and are maintained by periodic route updates[11]
- Reactive routing protocols- routes are discovered when needed and expire after a certain period. [12]
- Hybrid routing protocols - combines the features of both pro-active and reactive routing protocols, to scale well with network size and node density [13].
- Flat routing protocols- nodes are addressed by a flat addressing scheme and each node plays an equal role in routing [14], while in hierarchical routing protocols different nodes have different routing responsibilities and uses a hierarchical addressing system [15] to address the nodes.

[16] Examines routing protocols designed for ad hoc networks by first describing the operation of each of the protocols and then comparison of various characteristics. Paper has described current table-driven protocols, on-demand, qualitative comparisons of table-driven protocols and demand-driven protocols, its Applications and challenges facing ad hoc mobile wireless networks are discussed. A comprehensive review can be found in [17]. Here we briefly present several protocols proposed recently. In hierarchical routing, the overhead and complexity comes from the selection and maintenance of the cluster head. There are several algorithms to select a cluster head, for example, low-ID algorithm [18],

weighted algorithm [19] and highest-connectivity algorithm [20]. When one cluster change will cause additional leader changes in the network, this is called rippling effect. The Adaptive Routing using Clusters (ARC) protocol [21] solves this problem by limiting the leadership changes only to occur when one cluster becomes a subset of another cluster. The dynamic features of ad-hoc networks demand a new set of routing protocols that are different from the routing schemes used in traditional wired networks [22]. A wide range of routing protocols has been proposed to overcome the limitations of wired routing protocols. Paper outlines the working mechanisms of state-of the-art ad-hoc routing protocols, their evaluation, comparison of functionalities and characteristics along with related research challenges.

3.3 Performance metrics

To evaluate the performance of routing protocols, both qualitative and quantitative metrics are needed. Routing protocols use several metrics to calculate the best path for routing the packets to its destination [23]. These metrics are a standard measurement that could be number of hops, which is used by the routing algorithm to determine the optimal path for the packet to its destination. Most of the routing protocols ensure the qualitative metrics [24]. The quantitative metrics depicted in **Table 3.2** are used to compare the performance.

Sr. No.	**Performance Metrics-Parameter**	**Explanation/Definitions/Relations**
1	Packet Delivery Ratio (PDR)	Packet Delivery Ratio (PDR) is the ratio of the successfully delivered packets to those generated by CBR sources as shown in the formula of the following part. The higher the PDR, the lower the packet loss rate, the more efficient the routing protocol from the data delivery point of view. In real time communications, the routing protocol with higher PDR may not be considered better than the one with lower PDR, since packets which arrive late could be useless although they reach the destination successfully. Real time traffic is delay sensitive. This number presents the effectiveness of a protocol. Higher value implies better performance [23]. The ratio of the number of data packets received by the receivers verses the number of data packets supposed to be received. $$Packet\ delivery\ ratio = \frac{received\_packets}{Sent\_packets} X100$$
2	Average End-to-end delay:	End-to-end delay [24] indicates how long time it took for a packet to travel from the source to the receiver. The end-to-end delay calculates the

		delay of the packet which is successfully transmitted from the source to the destination. This end-to-end delay includes all possible delays caused by buffering during route discovery latency, queuing in the interface queue, retransmission delays at the MAC, propagation and transfer times [25]. It is the duration of the time a packet travels from the application layer of the source to the destination. End-to-end delay is one of the most important metrics when analyzing the performance in QoS aware routing protocols. The average end-to-end delay is averaged out of all the end to end delay of successfully transmitted packets. $$Average\ end\ to\ end\ packet\ delivery\ time = \frac{\sum(Tr - Ts)}{Number\ of\ Packets}$$ Where Tr = The receive time Ts = The send time
3	Throughput	The throughput [26] is defined as the total amount of data a receiver actually receives from the sender divided by the time between receiving the fast packet and last packet. $$Throughput = \frac{Successful\ ly\ \mathrm{Re}\ ceivedPack\ ets}{Simulation\ TimeElapse\ d}$$
4	Jitter	Jitter metric [27], which is used in this paper, is a quantifier of the changeability over time of the packet latency across a network and can be a measurement for the quality of a communication. A zero jitter shows a very high quality communication without any latency. In a specific stream of packets, at Si the sender sent packet *i* and the receiver received it at Ri. So the jitter of packet i is: $Ji = \vert (Ri+1 - Ri) - (Si+1 - Si) \vert = \vert (Ri+1 - Si+1) - (Ri - Si) \vert$ If there are M streams of packets between sender and receiver nodes during the entire simulation time and by each stream N packets will be transferred.
5	Pause Time Variation	Pause time [27] is defined as time for which nodes waits on a destination before moving to other destination. This can be used as a parameter as it is measure of mobility of nodes. Low pause time means node will wait for less time thus giving rise to high mobility scenario.

Table 3.2 Performance metrics for evaluation

[28], identifies and defines meaningful metrics for assessing the performance of MANET protocols. They also design and building of a unified simulation environment and evaluate the performance of the different protocols proposed in the IETF in different scenarios. Moreover, they identify critical features required for military MANETs and evaluate the protocols in this context. [29] Has discussed critical networking features and performance metrics for accessing the behavior of an ad-hoc network. Moreover, a strategy for computing the desired quantities is outlined.

3.4 State of Art - Proactive Routing Protocols

Proactive protocols [30] maintain the routing information even before it is needed. Each and every node in the network maintains routing information to every other node in the network. Routes information is generally maintain in the routing tables and is periodically updated as the network topology changes. The routing protocols in this group differ in how topology changes are detected, how routing information is updated, and what sort of routing information is maintained at each node. These routing protocols are based on the working principles of two popular routing algorithms used in wired networks. They are as follows.

- Link-State Routing

In the link-state routing [31], each node maintains at least a partial view of the whole network topology. Each node periodically broadcasts link-state information like link activity and delay of its outgoing links to all the other neighbour nodes using network-wide flooding. When a node receives this information, it updates its view of the network topology and applies a shortest-path algorithm to choose the next hop for each destination. The routing protocols in this group are: Open Shortest Path First (OSPF); Global State Routing (GSR); Fisheye State Routing (FSR); Adaptive Link-State Protocol (ALP); Source Tree Adaptive Routing (STAR); Optimized Link State Routing (OLSR) [32, 33]; Landmark Ad Hoc Routing (LANMAR).

- Distance Vector Routing

In distance vector routing [34] each node periodically monitors the cost of its outgoing links and sends its routing table information to all neighbours. The cost can be measured in terms of the number of hops or time delay or using other evaluation metrics. Each entry in the routing table contains at least the destination ID, the next hop neighbour ID through which the destination can be reached at minimum cost, and the cost to reach the destination. Thus, through periodic monitoring of outgoing links, and dissemination of the routing table information, each node maintains an estimate of the shortest distance to every node in the network topology [35]. The routing protocols in this group are: Distributed Bellman

Ford (DBF); Routing Internet Protocol (RIP); Destination Sequenced Distance Vector (DSDV) [36, 37]; Wireless Routing Protocol (WRP) and Least Resistance Routing (LRR).

3.4.1 Fisheye State Routing Protocol (FSR)

FSR [38] is a proactive type of protocol. It is an implicit hierarchical routing protocol. It uses the "fisheye" technique proposed by Kleinrock and Stevens. The technique was used to reduce the size of information required to represent graphical data. The eye of a fish captures with high detail the pixels near the focal point. The information decreases as the distance from the focal point increases. In routing, the fisheye approach translates to maintaining accurate distance and path quality information about the immediate neighborhood of a node, with progressively less detail as the distance increases. In FSR, link state packets are not flooded, but, nodes maintain a link state table based on the up-to-date information received from neighboring nodes, and periodically exchange it with their local neighbors only, not floods the information (no flooding). Through this exchange process, the table entries with larger sequence numbers replace the ones with smaller sequence numbers. The distances are updated according to the time stamp or sequence number assigned by the node originating the update.

[08] Presents a novel routing protocol for wireless ad hoc networks – Fisheye State Routing (FSR) is presented.FSR introduce the notion of multi-level fisheye scope to reduce routing update overhead in large networks. Nodes exchange link state entries with their neighbors with a frequency which depends on distance to destination. From link state entries, nodes construct the topology map of the entire network and compute optimal routes. Simulation experiments show that FSR is simple, efficient and scalable routing solution in a mobile, ad hoc environment.

[39] Investigates the scalability of the Fish-eye State Routing (FSR) protocol under different network scenarios in mobile ad hoc networks (MANETs). This performance based study simulates FSR under practical network scenarios typical of MANETs, and measures selected metrics that give an introspective look into the performance of FSR. The FSR protocol is compared against the minimum hop-count based reactive Dynamic Source Routing (DSR) protocol [40]. The implementations of both protocols are simulated for varying conditions of network density, node mobility and traffic load. The following performance metrics are evaluated: packet delivery ratio, average hop count per path, control message overhead and energy consumed per node. Simulation results indicate FSR scales relatively better compared to DSR and consumes less energy when operated with moderate to longer link-state broadcast update time intervals in high density networks with moderate to high node mobility and offered traffic load. FSR successfully delivers packets for a majority of the time with relatively lower energy cost in comparison to DSR. Fisheye state routing protocol improves traditional link-state routing in the MANET. By adopting the idea of GRID in FSR, paper [41] proposed an efficient GRID-based fisheye state routing protocol (GFSR). GFSR provides the advantage of less control message exchange and more bandwidth to

transmit data. A hierarchical architecture is used in GFSR [42]. A gateway is elected in each grid and is the only node in the grid to exchange control messages and data packets with other grids. Substantial bandwidth can be saved in this way.

3.4.2 Optimized Link State Routing (OLSR)

The Optimized Link State Routing Protocol (OLSR) [43] is an IP routing protocol optimized for mobile ad-hoc networks, which can also be used on other wireless ad-hoc networks. OLSR is a proactive link-state routing protocol, which uses Hello and Topology Control (TC) messages to discover and then disseminate link state information throughout the mobile ad-hoc network. Individual nodes use this topology information to compute next hop destinations for all nodes in the network using shortest hop forwarding paths. In order to create and maintain routing tables, OLSR generates two kinds of control traffic: HELLO packets and TC packets [44]. Hello packets are periodically sent by each node and are never forwarded by any node. The main purpose of this packet is to gather and transmit up to 2-hops neighborhood information. Basically, a HELLO packet contains the list of a node's 1-hop neighbor. When received by a neighboring node, that node is able to acquire a view of its 2-hops neighborhood at no extra cost.

(OLSR) protocol is a route management protocol for such mobile ad hoc networks. This study presents the work of implementing the OLSR routing protocol. The implementation is done in paper [45] in a modular fashion, allowing for the use of external plugins. Also, this study analyzes certain extensions to the protocol done in relation to the implementation, including Internet connectivity, security and auto-configuration. More technical implementation designs are also covered in [46]. [47] Conducts a simple analysis of measuring network bandwidth consumed by the routing overhead in various environments. Although Optimized Link State Routing (OLSR) and Ad-hoc on demand Distance Vector (AODV) routing protocols are studied in this paper. [48] describes the implementation of the ad-hoc routing protocol "Optimized Link State Routing" (OLSR) within the Click Modular Router framework and the design of a wireless test bed based upon this implementation. The test bed consists of outdoor nodes installed on the roof of campus buildings as well as ordinary PC equipped with wireless interfaces. Embedded devices within a weatherproof enclosure to be installed on the roof of campus buildings were successfully configured to automatically run the developed OLSR Click code.

3.5 Reactive (On Demand) Routing Protocols

Reactive routing protocol does not require maintenance of a route to each destination of the network on a continual basis. Instead, routes are established on demand by the source. When a route is needed by the source, it floods a route request packet to construct a route. Upon receiving route requests, the destination selects the best route based on route selection metrics. In reactive routing protocols, control communication overhead is greatly reduced compared with proactive routing protocols and no effect is made to maintain the total network topology. A list includes: Lightweight Mobile Routing (LMR) ; Dynamic Source Routing (DSR) [49] ;Ad-Hoc On Demand Distance Vector (AODV) routing[50] ; Associativity-Based Routing (ABR); Signal Stability-Based Adaptive (SSA) routing; Routing On-demand Acyclic Multipath (ROAM) algorithm; Multipath Dynamic Source Routing (MDSR); Relative Distance Micro-discovery Ad Hoc Routing (RD-MAR) protocol and Efficient Secure Dynamic Source Routing (ESDSR). Focuses on the popular routing algorithms Ad-Hoc on Demand Distance Vector (AODV), Dynamic Source Routing (DSR) both being reactive routing protocols and Optimized Link State Routing (OLSR) [51], a proactive routing protocol. They evaluate and compare their performance through simulation using QUALNET simulator.

3.5.1 Ad-Hoc On Demand Distance Vector (AODV) Routing Protocol

AODV is the reactive type of routing protocol. In this, network remains silent until a connection is needed. When node from the network needs a connection, then it will broadcast a request for connection. Other nodes forward this message, and record the node that they heard it from, creating an explosion of temporary routes back to the requesting node. When a node receives such a message and already has a route to the desired node, it sends a message backwards through a temporary route to the requesting node. The requesting node then begins using the route that has the least number of hops through other nodes. Unused entries in the routing tables are recycled after a time. When a link fails, a routing error is passed back to a transmitting node, and the process repeats. The major difference between AODV and other on-demand routing protocols is that it uses a destination sequence number (DestSeqNum) to determine an up-to-date path to the destination. A node updates its path information only if the DestSeqNum of the current packet received is greater than the last DestSeqNum stored at the node.

Features of AODV include the maintenance of time-based states in each node: a routing entry not recently used is expired. In case of a route is broken the neighbours can be notified. Route discovery is based on query and reply cycles, and route information is stored in all intermediate nodes along the route in the form of route table entries. The following control packets are used: routing request message (RREQ) is broadcasted by a node requiring a route to another node, routing reply message (RREP) is unicasted back to the source of RREQ, and route error message (RERR) is sent to notify other nodes of the loss of the link. HELLO messages are used for detecting and monitoring links to neighbours.

[52] Proposes a new protocol that modifies AODV to improve its Performance using *Ant Colony algorithm*. The mobility behavior of nodes in the application is modeled by the random waypoint model through which random locations to which a node move are generated, and the associated speed and pause

time are specified to control the frequency at which the network topology is changed. The *Optimized-AODV* protocol incorporates path accumulation during the route discovery process in AODV to attain extra routing information. It is evident from the results that *Optimized- AODV* improves the performance of AODV under conditions of high load and moderate to high mobility.

[53] Considers the event triggers required for proper operation, the design possibilities and the decisions for our Ad hoc On-demand Distance Vector (AODV) routing protocol implementation, AODV-UCSB. Paper [54] summarizes the design of other publicly available AODV implementations, comparison of different design approaches.

3.5.2 Dynamic Source Routing (DSR)

DSR is a reactive routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes. Network nodes cooperate to forward packets for each other to allow communication over multiple "hops" between nodes not directly within wireless transmission range of one another. As nodes in the network move about or join or leave the network, and as wireless transmission conditions such as sources of interference change, all routing is automatically determined and maintained by the DSR routing protocol. Since the number or sequence of intermediate hops needed to reach any destination may change at any time, the resulting network topology may be quite rich and rapidly changing. The DSR protocol is composed of two main mechanisms that work together to allow the discovery and maintenance of source routes in the ad hoc network [55].

[56] Presents routing protocol for ad hoc networks that uses dynamic source routing. The protocol adapts quickly to routing changes when host movement is frequent, yet requires little or no overhead during periods in which hosts move less frequently. Based on results from a packet-level simulation of mobile hosts operating in an ad hoc network, the protocol performs well over a variety of environmental conditions such as host density and movement rates. For all but the highest rates of host movement simulated, the overhead of the protocol is quite low, falling to just 1% of total data packets transmitted for moderate movement rates in a network of 24 mobile hosts. In all cases, the difference in length between the routes used and the optimal route lengths is negligible, and in most cases, route lengths are on average within a factor of 1.01 of optimal.

[57] Describes the principle mechanisms of Route Discovery and Route Maintenance used by DSR, and have shown how they enable wireless mobile nodes to automatically form a completely self-organizing and self-configuring network among themselves. Author also includes further improvements to the performance of DSR, for example to allow scaling to very large networks, and the addition of new features to the protocol, such as multicast routing and adaptive Quality of Service (QoS) reservations and resource management.

3.6 Hybrid Routing Protocols

Hybrid protocols inherit the advantage of high-speed routing form proactive and less overhead control messages from reactive protocols. The characteristics of proactive and reactive routing protocols can be integrated to achieve hybrid routing technique. Hybrid routing protocols may exhibit proactive or reactive behavior depending on the circumstance, so allow flexibility based on the wireless network. This protocol discovers the route to each node only when it is needed. However, route discovery does not occur through simple flooding but through a mechanism similar to multipoint relays. Partial list of hybrid MANET routing protocols include: Zone Routing Protocol (ZRP); Intrazone Routing Protocol (IARP) and Temporally Ordered Routing Algorithm (TORA) and Landmark Routing Protocol (LAN-MAR)

The Zone Routing Protocol (ZRP) [58] localizes the nodes into sub-networks (zones). Within each zone, proactive routing is adapted to speed up communication among neighbors. The inter-zone communication uses on-demand routing to reduce unnecessary communication. An important issue of zone routing is to determine the size of the zone. An enhanced zone routing protocol, Independent Zone Routing (IZR), which allows adaptive and distributed reconfiguration of the optimized size of zone, is introduced in [59]. Furthermore, the adaptive nature of the IZR enhances the scalability of the ad hoc network.

[60] Describes and analyzes the Zone Routing Protocol (ZRP), a hybrid mobile ad-hoc protocol which divides the network into overlapping routing zones, allowing for the use of independent protocols within and between the zones. [61] presents and examines analytical simulation results for the routing protocol ZRP and the impact of some of its most important attributes to network performance, using the well known network simulator OPNET 10.0.PL2.[62] presents the Zone Routing Protocol and discusses the problem of routing in ad-hoc networks, the motivation of ZRP. Also describe the architecture of ZRP, which consists of three sub-protocols. Paper [63] describes the query control mechanisms, which are used to reduce the traffic amount in the route discovery procedure. ZRP does not define the actual implementation of the protocol components. Paper [64] discusses the problem of routing in networks with unidirectional links, and the proposal for a solution to it. The overhead of the routing protocol is important in the power and bandwidth limited ad-hoc networks, the factors influencing on the traffic amount based on measurements performed in a number of papers. Paper [65] describes the significant issue of choosing an optimal zone radius, and two algorithms for automatic selection of the radius.

Adaptation of the ZRP to changing network conditions requires both an understanding of how the ZRP reacts to changes in network behavior and a mechanism to allow individual nodes to identify these changes, given only limited knowledge of the network behavior. In [66] demonstrate the effects of relative node velocity, node density, network span, and user data activity on the performance of the ZRP. We then introduce two different schemes (“min-searching” and “traffic adaptive”) that allow individual nodes to identify and appropriately react to changes in network configuration, based *only* on information derived from the amount of received ZRP traffic.

3.7 Qualnet simulator

The QualNet Developer IDE is a GUI based program for developing network scenarios that comes with QualNet 5.0. It can be used to visually design network scenarios and then run simulations of these networks. Although networks can be designed and simulated in a command-line fashion as well, on the Developer IDE package.

QualNet is a comprehensive suite of tools for modeling large wired and wireless networks. It uses simulation and emulation to predict the behavior and performance of networks to improve their design, operation and management [67]. QualNet enables users to: Design new protocol models, Optimize new and existing models, Design large wired and wireless networks using pre-configured or user-designed models, Analyze the performance of networks and perform what-if analysis to optimize them.

The kernel of QualNet is a, SNT-proprietary, parallel discrete-event scheduler. It provides the scalability and portability to run hundreds and thousands of nodes with high-fidelity models on a variety of platforms, from laptops and desktops to high performance computing systems. Users do not directly interact with the kernel, but use the QualNet API to develop their protocol models. QualNet includes support for a number of model libraries that enable you to design networks using SNT-developed protocol models. Purchase of QualNet includes the Developer Model Library; additional libraries for modeling WiFi networks, mobile ad-hoc networks (MANET), military radios, WiMAX and cellular models are also available. Refer to the QualNet Model Libraries data sheet for more information or check the products page on our website.

3.8 Performance Evaluation of Routing protocols

[68] Presents a comprehensive study on the performance of common MANET (mobile ad hoc network) routing protocols under realistic network scenarios. The routing protocols used in this study include AODV, DSR, OLSR, OSPFv2 and ZRP, which comprise a good mix of reactive, proactive and hybrid protocols. The paper [69] evaluates these protocols under simulation scenarios based on an actual exercise carried out under the DARPA FCS Communications Program. Mobility of the nodes was simulated using GPS logs from the field exercise. Traffic is simulated using a model of the traffic generation tool that drove traffic in the live exercise, and reads the same script files. To evaluate the performance of the routing protocol on the wireless Ad-Hoc network with the 10 to 50 nodes in the network is considered. The simulation results were carried out in Qualnet 5 simulator to evaluate the performance of the AODV routing protocol on the MANET with the 10 to 50 nodes in the Qualnet simulator with the parameters shown in **Table 3.3**.

The QualNet Developer is a GUI based program for developing network scenarios that comes with QualNet 5.0. It can be used to visually design network scenarios and then run simulations of these networks. Networks can be designed and simulated in a command-line fashion as well. The **Figure 3.2** shows the scenario of the developed Wireless Mobile Ad-Hoc Network in the Qualnet 5.**Figure 3.3** shows the coverage of the transmission of each node whenever it communicates with other.

Network Configurations	
Network Area Size	1500m X 1500m
Simulation Time	300s
Pause Time Interval	30s
Number of Nodes	50
Node Placement	Random
Minimum Speed of Node	5mps
Maximum Speed of Node	20mps
network protocol	IPv4
MAC protocol	802.11
packet reception model	PHY 802.11b
propagation channel frequency	2.4 GHz
propagation model	two ray ground propagation model
Antenna	Omnidirectional
traffic generated between random nodes	CBR
Number of nodes	10 to 50
Routing protocol	FSR,OLSR

Table 3.3: WANET Configuration Parameters

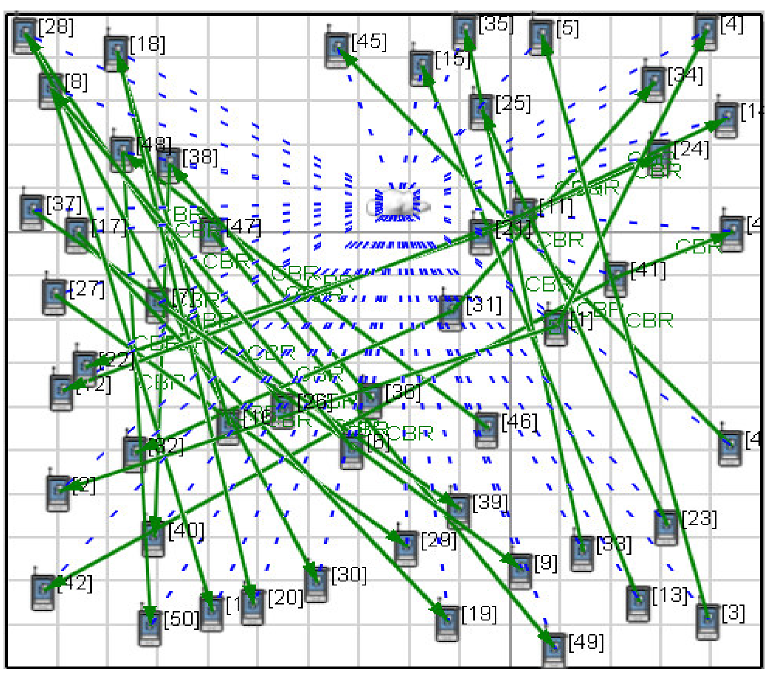

Figure 3.2: Scenario Created For Wireless Ad-Hoc Network in Qualnet

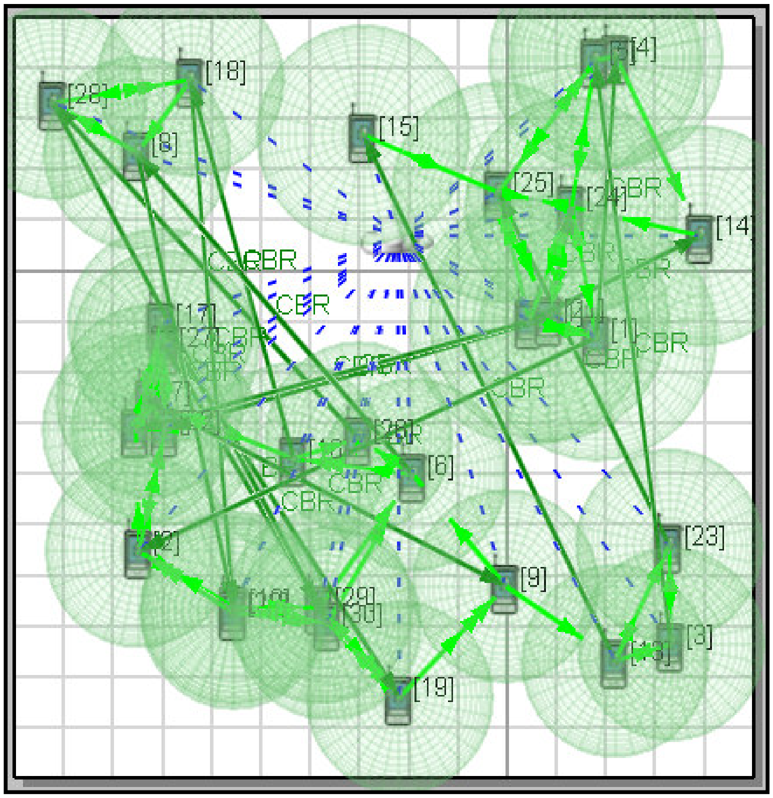

Figure 3.3: Information packet exchange between the nodes of the network in Qualnet

3.8.1 Simulation of proactive routing protocols: FSR & OLSR

Simulation of proactive type of routing protocol viz. FSR and OLSR is performed in Qualnet Simulator Developer version-5. The network nodes have the random connection between them. The performance evaluation was done by varying the speed of the nodes and also for different number of nodes in the range of 10 nodes to 50 nodes **(Table 3.4).**

Packet Delivery Ratio V/S Mobility						Packet Delivery Ratio V/S Node Density				
Mobility(seconds)						Node Density				
	200	**400**	**600**	**800**	**1000**	**10**	**20**	**30**	**40**	**50**
FSR	0.29545	0.01515	0.02652	0.02273	0.01894	0.12879	0.38168	0.27438	0.79681	0.33333
OLSR	0.27227	0.06061	0.03409	0.01894	0.01515	0.13614	0.16031	0.19246	0.40139	0.42711

Table 3.4: Packet Delivery Ratio V/S Mobility, Node Density

Average Throughput V/S Mobility						Average Throughput V/S Node Density				
Mobility(Seconds)						Node Density				
	200	**400**	**600**	**800**	**1000**	**10**	**20**	**30**	**40**	**50**
FSR	356.2	12.6	12.2	10.6	9.4	69.4	984.1	668.933	1902.45	741.76
OLSR	346.1	50.4	16.1	9.3	7.6	81	1056.75	719.933	530.85	719.88

Table 3.5: Average Throughput V/S Mobility, Node Density

Average End To End Delay V/S Mobility						Average End To End Delay V/S Node Density				
Mobility(Seconds)						Node Density				
	200	**400**	**600**	**800**	**1000**	**10**	**20**	**30**	**40**	**50**
FSR	0.00166	0.00352	0.00168	0.0032985	0.0003717	0.00276	0.00653	0.00951	0.02795	0.01567
OLSR	0.00194	0.00113	0.001082	0.0030371	0.0004129	0.00332	0.01035	0.00929	0.00775	0.0242
Table 3.6: Average End To End Delay V/S Mobility, Node Density										

Average Jitter V/S Mobility						Average Jitter V/S Node Density				
Mobility(Seconds)						Node Density				
	200	**400**	**600**	**800**	**1000**	**10**	**20**	**30**	**40**	**50**
FSR	0.00029	3.2E-07	3.3E-05	0.00032	4.4E-05	0.00022	0.00109	0.00169	0.00677	0.00362
OLSR	0.00058	0.00034	0.00029	0.00017	7.2E-05	0.00034	0.00204	0.00203	0.00157	0.00426
Table 3.7: Average End To End Delay V/S Mobility, Node Density										

Table 3.4 to 3.7 shows the observations of the comparison proactive routing protocol. **A figure 3.3 to 3.7 depicts** graphical comparisons of the above results for the FSR and OLSR proactive routing protocol.

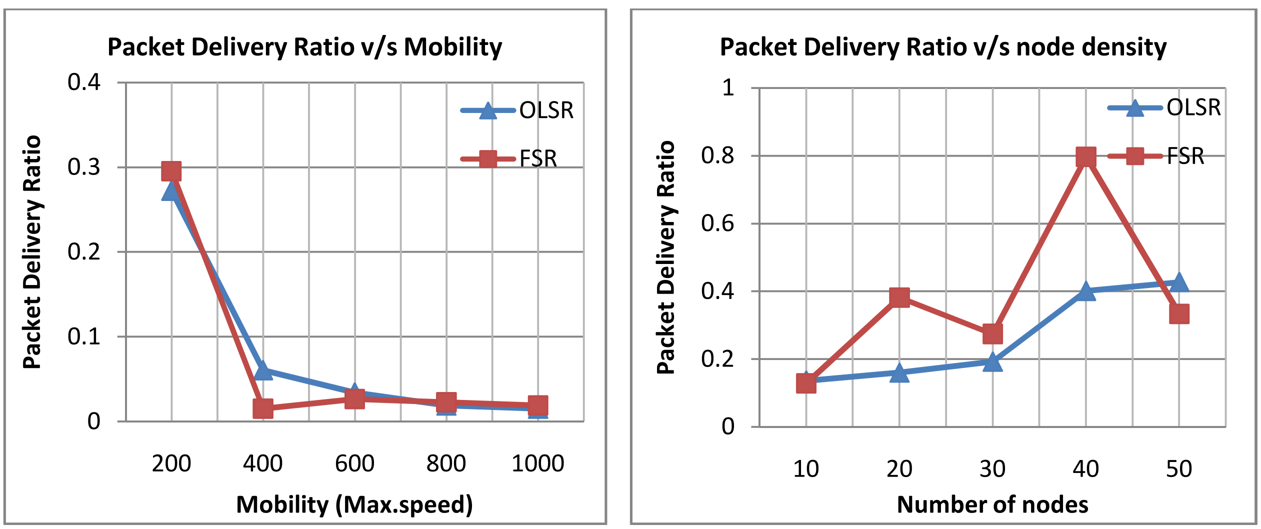

Figure 3.4 : Average Packet Delivery Ratio V/S Maximum Speed and node density

Figure 3.4 we can observe that packet delivery ratio for both the protocol decreased as the mobility of the nodes gets increased, but FSR outperforms OLSR. As no. of nodes increased, among them again FSR performed well, while in case of less number of nodes both the protocols performed poorer in terms of delivery ratio as nodes breakage may be more and no route may be available.

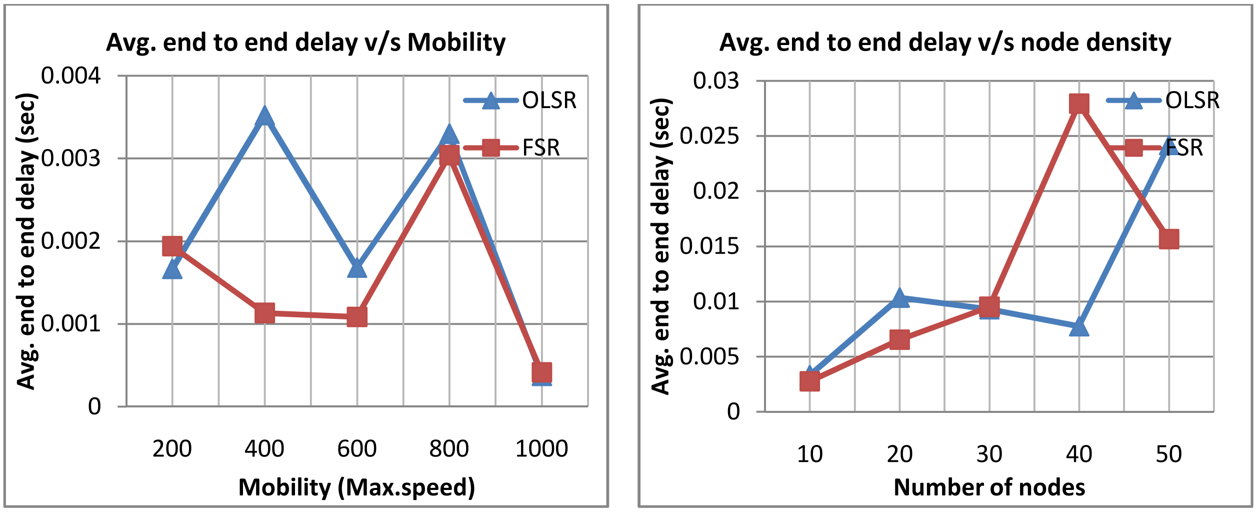

Figure 3.5: Average end to end Delay V/S Maximum Speed and node density

Figure 3.5 shows simulation results on the aspect of average end-to-end delay performance for routing protocols by varying the nodes' maximum movement speed and the node density (number of nodes). The increase of movement speed induces topology change frequently and therefore the probability of broken links also grows. The average end-to-end delay of packet decrease as node's maximum speed increases in both cases but it is less in FSR protocol and FSR performs well compared to OLSR when the node density increase in the network.

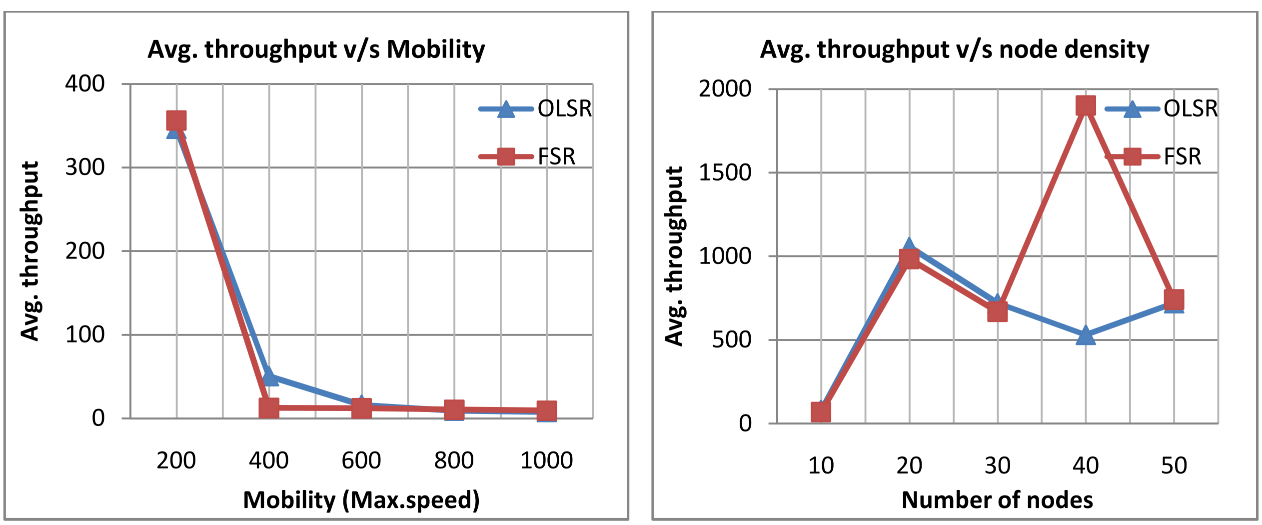

Figure 3.6: Average Throughput V/S Maximum Speed and node density

We observed that the Throughput in **Figure 3.6** for both the protocols are very similar in low density networks and as movement speed increases, its exponential drop suggests that for any further increase in movement speed and node density OLSR and FSR performs not better. The performance of OLSR is better when the scalability of the network is increase.

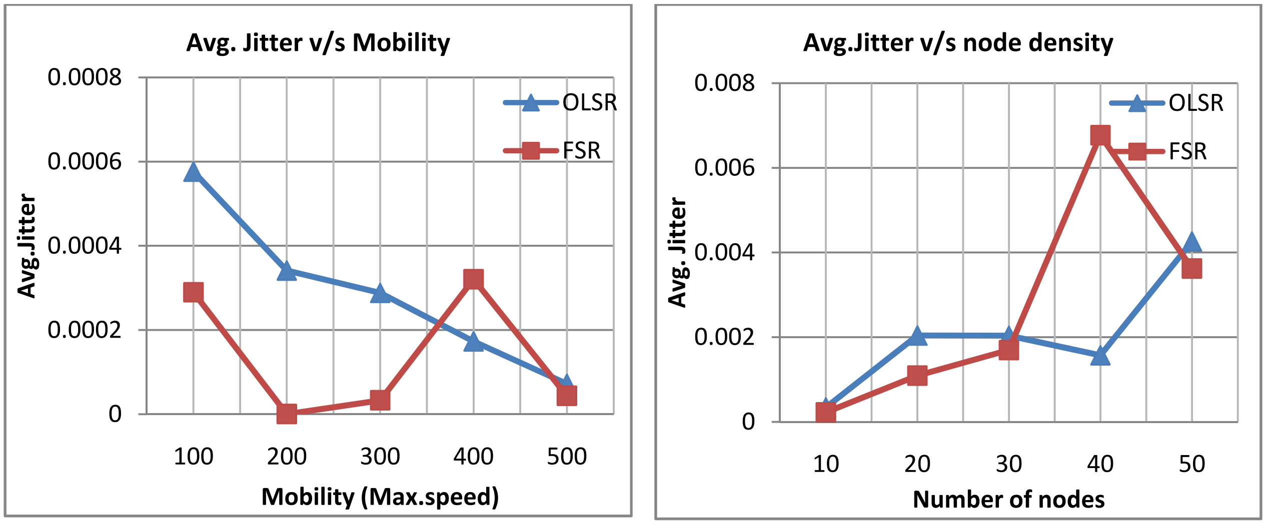

Figure 3.7: Average Jitter V/S Maximum Speed and node density

Figure 3.7 shows the simulation results for the jitter produced whenever we vary the node's maximum movement speed. The increase of the movement speed increases the mobility of the each node and therefore there are chances to occur jitter. From the graph we can observe that the as the movement speed increase, the jitter decrease for OLSR better than the FSR but it is opposite nature when the number of nodes increase in the network.

3.8.2 Simulation of Reactive routing protocols: AODV & DSR[1]

[70] Has compared the performance of two prominent on-demand routing protocols for mobile ad hoc networks: Dynamic Source Routing (DSR), Ad Hoc On-demand distance Vector Routing (AODV). A detailed simulation model with MAC and physical layer models is used to study the interlayer interactions and their performance implications. Here it is discussed that even though DSR and AODV share similar on-demand behavior, the differences in the protocol mechanisms can lead to significant performance differentials. Here the examination of two on demand routing protocols AODV and DSR based on packet delivery ratio, average end to end delay by varying the number of sources, speed and pause time is done. [71] Presents the implementation of Ad Hoc On–Demand Distance Vector (AODV) protocol in NS-2.

There are two major differences between AODV and DSR [72]. AODV uses a traditional RT with one entry per destination, whereas DSR maintains multiple route cache entries for each destination.

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[1] Presented a Paper **"Analysis and Comparison of Proactive and Reactive Routing Protocols for WANET in Qualnet"** at a **State Level Paper Contest** called **"Wireless Technologies in Automation and Communication : WTAC-2010"** held at Institution of Engineering(India),Vasvik Bhavan,Vadodara on 10th January, 2010 organized by IETE Vadodara.

Another difference is that AODV relies on RT entries to propagate route replies back to the source and subsequently to route data packets to their destination. Along with that, AODV uses sequence numbers carried by all routing packets to determine the freshness of routing information and prevent routing loops. Therefore, its connection setup delay is smaller. In this paper, the performance of the three MANET Routing protocols such as DSDV, AODV and DSR was analyzed using NS-2 Simulator. We have done comprehensive simulation results of average End-to-End delay, throughput, and packet delivery ratio over the routing protocols DSDV, DSR and AODV by varying network size, simulation time. Paper [73] concluded that DSR is preferable for moderate traffic with moderate mobility. As AODV routing protocol needs to find route by on demand, End-to-End delay will be higher than other protocols. When the network load is low, AODV performs better in case of packet delivery ratio but it performs badly in terms of average End-to-End delay and throughput. Overall, DSR outperforms AODV because it has less routing overhead when nodes have high mobility considering the above said three metrics.

Simulation of reactive type of routing protocol is performed in Qualnet Simulator Developer version-5. The network has the random connection between the nodes. The performance evaluation was done by varying the speed of the nodes and also for different number of nodes in the range of 10 nodes to 50 nodes.

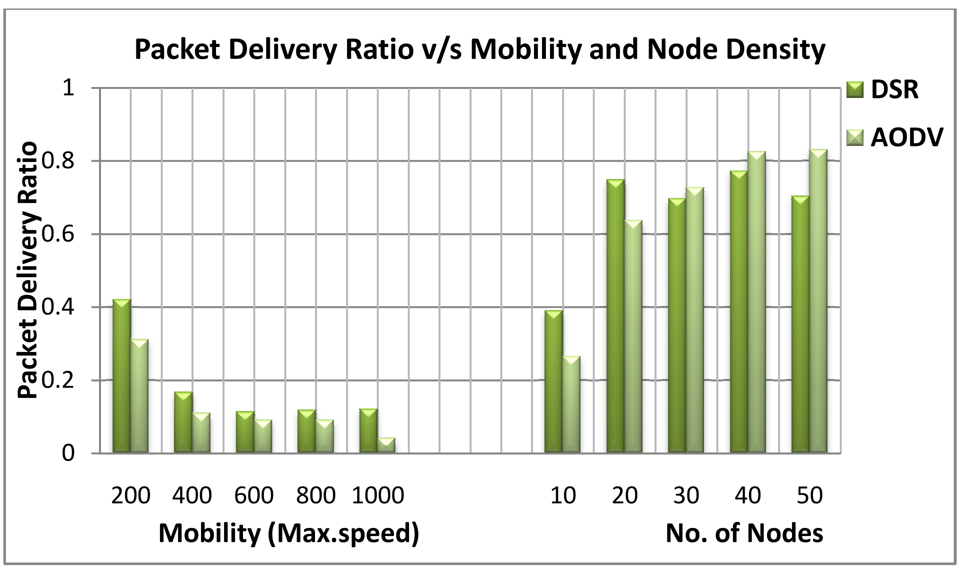

Figure 3.8: Average Packet Delivery Ratio V/S Maximum Speed and node density

Performance results of packet delivery ratio for variation in maximum speed and density is shown in **Figure 3.8**. It is observed that as the nodes maximum speed increase, a packet delivery ratio of protocols decreases. This is due to more frequent link breakage may occur at high speed. The DSR performs better than the AODV as the maximum speed increases. As the network density increases, there is an increase of radio interferences and collisions between nodes due to hidden/exposed terminals. Reactive routing protocol shows better performance as the network density becomes high. There is reduction in network congestion by reducing route control packets. AODV has the better performance when the network node density is higher.

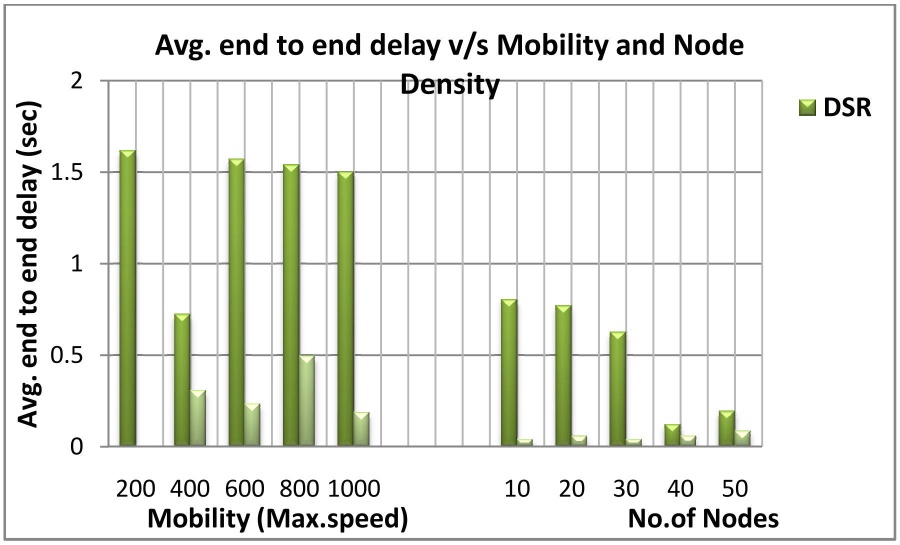

Figure 3.9: Average end to end Delay V/S Maximum Speed and node density

Figure 3.9 depicts simulation results on the aspect of average end-to-end delay performance for reactive routing protocols. The average end-to-end delay of packet decrease as node's maximum speed increases in case of DSR but it is less in AODV protocol. AODV has better performance compared to DSR when the node density and maximum speed increase in the network. This is due to large size of the DSR over head packet when compared to AODV.

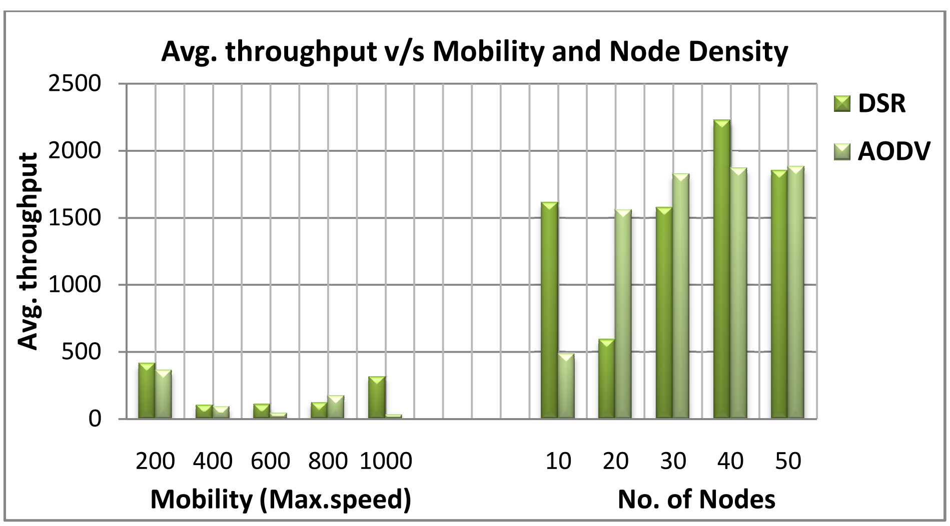

Figure 3.10: Average Throughput V/S Maximum Speed and node density

Figure 3.10 presents results for average throughput. It shows that DSR has higher throughput compared to AODV in high mobility of the nodes. Due to promiscuous listening and aggressive route caching policy DSR has an edge in high density networks.

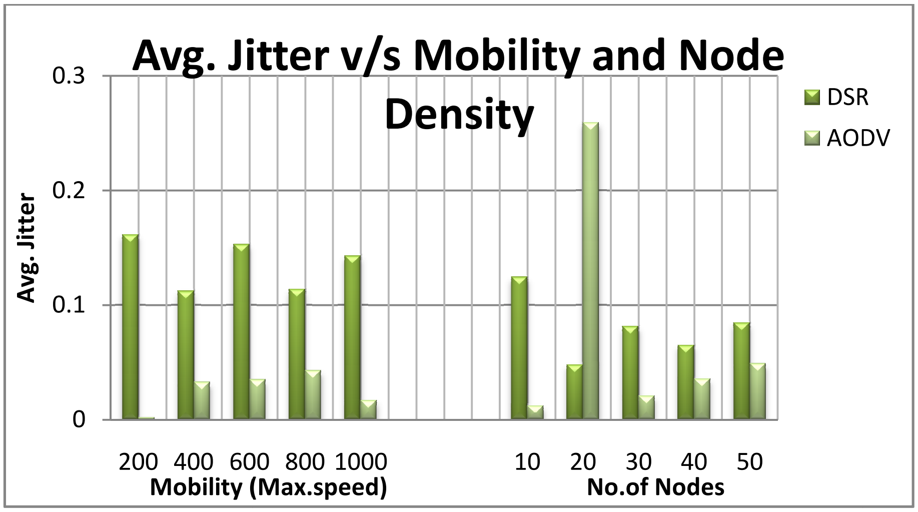

Figure 3.11: Average Jitter V/S Maximum Speed and node density

Figure 3.11describes the simulation results for the jitter produced whenever the node's maximum movement speed and node density varies in the network. The increase in the movement speed and node density AODV has the less jitter compared to the DSR.

3.8.3 Simulation of Hybrid routing protocols: ZRP

The simulation result of hybrid routing protocol in Qualnet Simulator using packet delivery ratio, average end to end delay, average throughput, and average jitter with respect to change in number of nodes and mobility is shown in the following **Table 3.8**.

	NO.OF NODES				
	10	20	30	40	50
packet delivery ratio	0.046296296	0.10798122	0.079449152	0.094813614	0.077278731
average end to end delay	0.000122797	0.000526673	0.000500768	0.001118057	0.001010247
average throughput	58.5	76.5	63.93	188.7	152.74
average jitter	0.00000847	0.000032091	0.000033849	0.00011504	0.000103121

Table 3.8(a): Simulation results: Hybrid Protocols

	Mobility (meter/second)				
	200	400	600	800	1000
packet delivery ratio	0.07945	0.03496	0.03814	0.07203	0.09958
average end to end delay	0.0005	0.00055	0.00214	0.00148	0.00122
average throughput	63.033	20.233	178.8	460.26	488.7
average jitter	3.4E-05	2.2E-05	6.7E-05	4.5E-06	0.00018

Table 3.8(b): Simulation results: Hybrid Protocols

3.8.4 Comparison of proactive, reactive routing protocols[2,3]

The 10 to 50 nodes were generated for each protocol within the terrain of 1500m X 1500m and for the node density variation node can be enabled or disabled according to the network topology and the no. of nodes in the network to study the performance of number of node variation in the network. The random waypoint mobility is provided to realization as a real time simulation with the pause time of 30S, min speed of the 5mps and max speed of 20 mps.

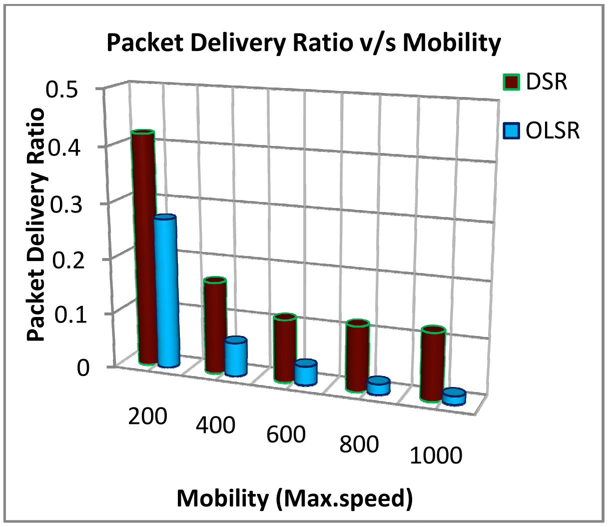

Figure 3.12: Average Packet Delivery Ratio V/S Mobility

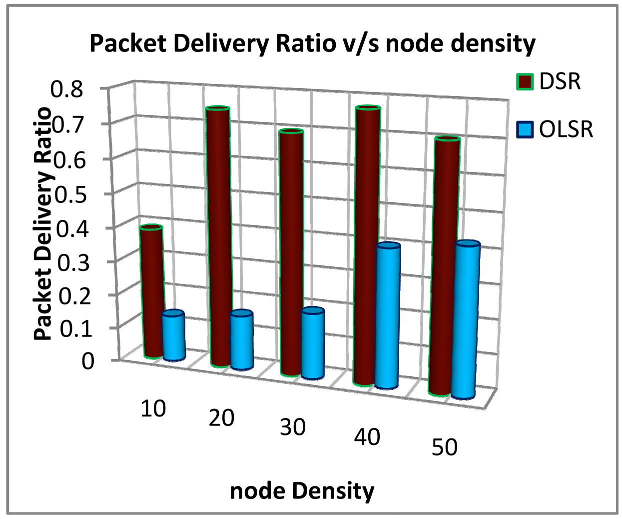

Figure 3.13: Average Packet Delivery Ratio V/S Node Density

Performance results of packet delivery ratio are shown in **Figure 3.12 and Figure 3.13** shows packet delivery ratio of routing protocols according to the increase of node's maximum speed. As the nodes maximum speed increase, a packet delivery rate of proactive and reactive protocols decreases.

Figure 3.14 and 3.15 depicts effect of variation in node density on packet delivery ratio. The packet delivery ratio in both the cases (proactive and reactive protocols) proportionately varies with variation in node density. However reactive routing protocol shows better performance.

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[2] Presented a Paper **"Analysis and Comparison of Proactive and Reactive Routing Protocols for WANET in Qualnet"** at a **National Level Paper Contest** called **"National Technical Paper Contest : NTPC-2010"** held at Institution of Engineering(India),Vasvik Bhavan,Vadodara on 7th March, 2010 organized by IETE Vadodara.

[3] **To be Publish** **(accepted)** Paper entitled **"Analysis and Comparison of Proactive and Reactive Routing Protocols for WANET in Qualnet"** in the **The IUP Journal of Electrical & Electronics Engineering, Banjara Hills, Panjagutta, Hyderabad, AP, India,** in **The Icfai University Journal of Electrical & Electronics Engineering (IUJEEE)** Division.

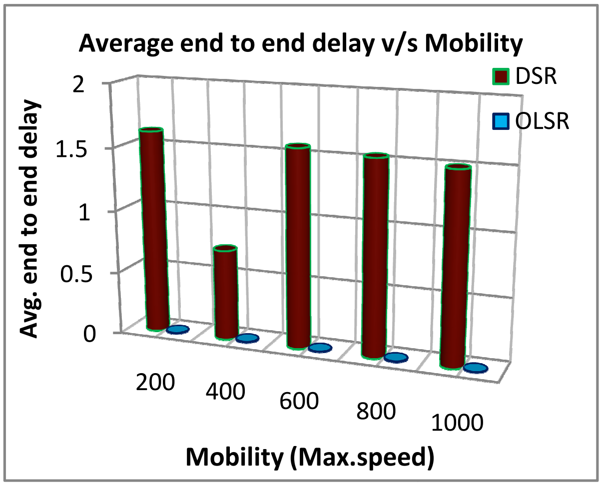

Figure 3.14: Average end to end Delay V/S Mobility

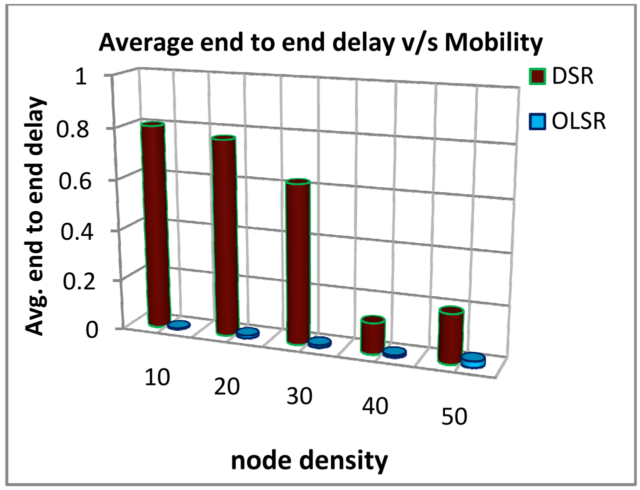

Figure 3.15: Average end to end Delay V/S node density

Figure 3.16 and 3.17 shows simulation results on the aspect of average end-to-end delay performance for reactive and proactive routing protocols by varying the node's maximum movement speed and the node density (number of nodes). The average end-to-end delay of packet decrease as node's maximum speed increases in case of reactive but it is less in proactive routing protocols. This is due to size of the overhead packets are large in reactive routing protocols than the proactive routing protocols.

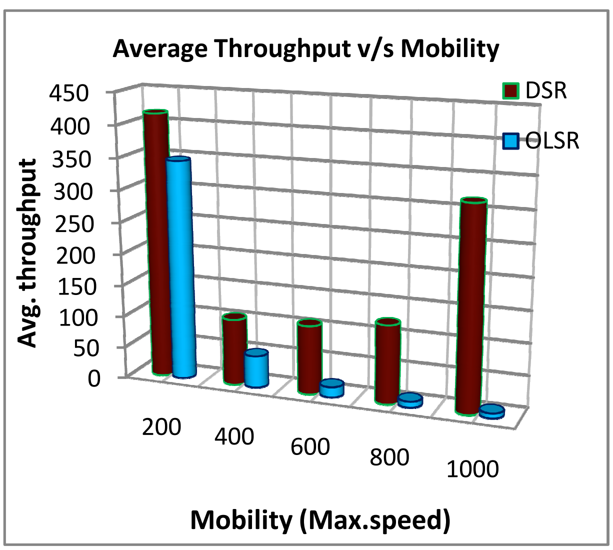

Figure 3.16: Average Throughput V/S Mobility

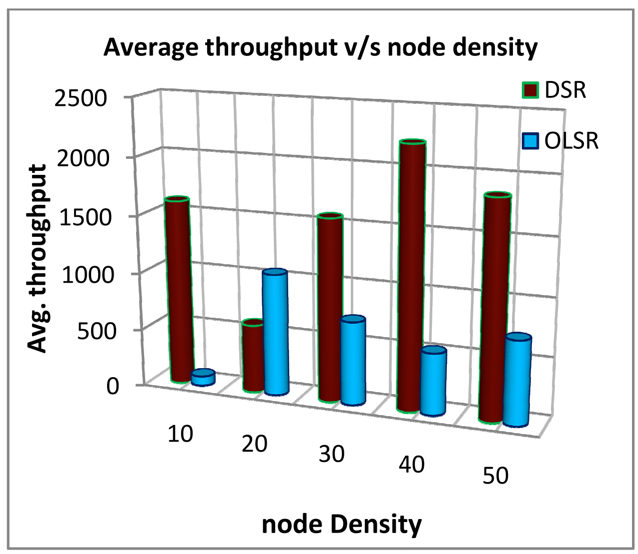

Figure 3.17: Average Throughput V/S node density

It is observed that the Throughput for proactive and reactive routing is very similar in low mobility and reactive protocols has higher throughput compared to proactive in high mobility of the nodes. **Figure 3.18 and 3.19** shows the simulation results for the jitter produced whenever we vary the node's maximum movement speed and node density in the network. The increase in the movement speed and node density proactive protocols has the less jitter compared to the reactive protocols.

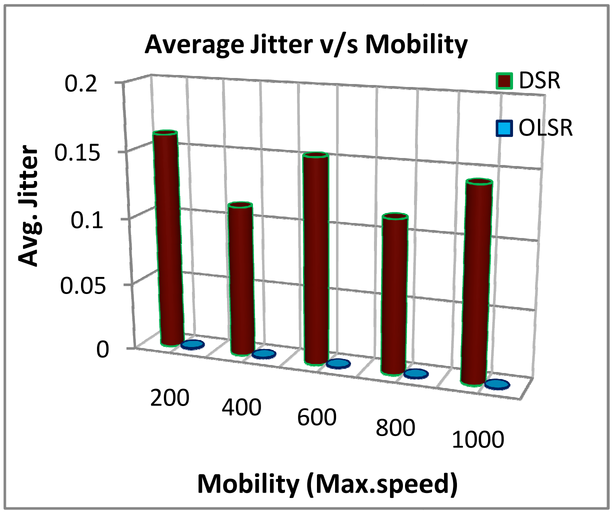

Figure 3.18: Average Jitter V/S Mobility

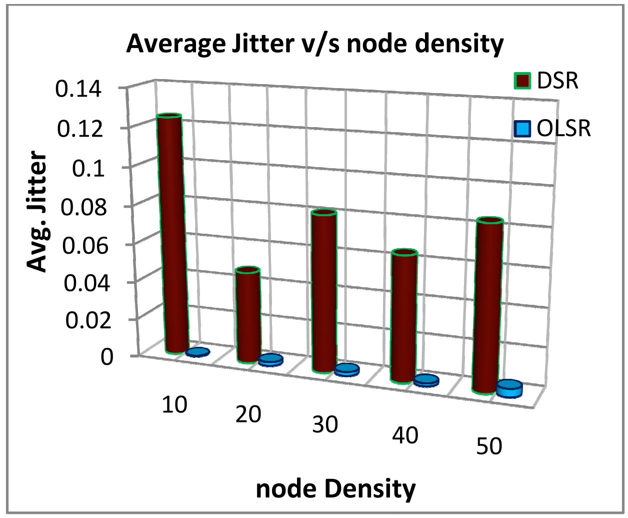

Figure 3.19: Average Jitter V/S node density

3.8.5 Comparison of Proactive, Reactive & Hybrid Routing Protocols[4]

For the comparison of performance of proactive, reactive and hybrid type of protocols, OLSR routing protocol for proactive type, AODV for reactive type and ZRP for hybrid type of protocol are considered in our simulation study.

A variety of routing protocols for ad hoc networks has been proposed in the past. The routing protocols are broadly classified into Proactive, Reactive and Hybrid protocols. In paper [80] evaluates the performance of FSR (Proactive), AODV (Reactive) and ZRP (Hybrid) routing protocols with respect to node density and pause time. The simulation is done using Qualnet simulator. [81] discusses a detailed simulation based performance study and analysis is performed on the Ad-hoc routing protocols like Ad-hoc On- Demand Distance Vector (AODV), Optimized Link State Routing (OLSR), Fisheye State Routing Protocol (FSR) over such kind of networks. The performance differentials are investigated using varying Pause Time and number of nodes. Based on the simulation results, how the performance of each protocol can be improved is also recommended. Simulations of protocols to analyze their performance in different conditions were performed in QualNet 5.0 simulator.

The performance comparison of proactive, reactive and hybrid routing protocol is done in terms of variation in mobility of nodes and the node density in the 1500m X 1500 m area using Qualnet 5.0

[4] Paper entitled **"Comparative Performance Analysis of Routing Protocols for WANET employing Qualnet 5"** in the journal of **Institution of Engineers (India),** Electronics and telecommunication Engineering Division ,Volume 92,July 2011 page 12-17.

developer. The performance metrics are considered here in terms of packet delivery ratio, average end to end delay, average throughput and average jitter.

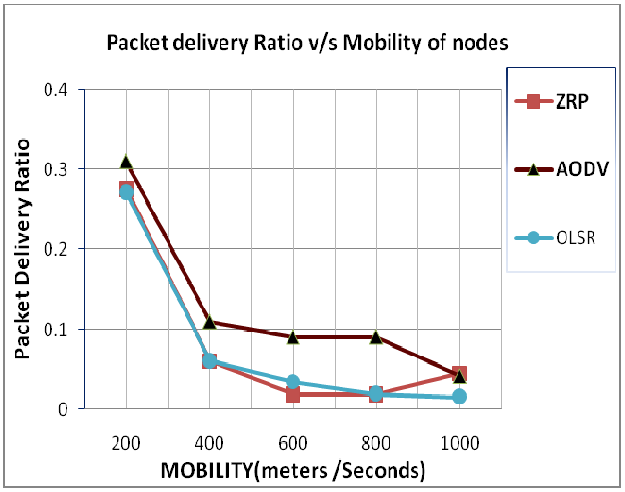

Figure 3.20: Average Packet Delivery Ratio V/S Mobility

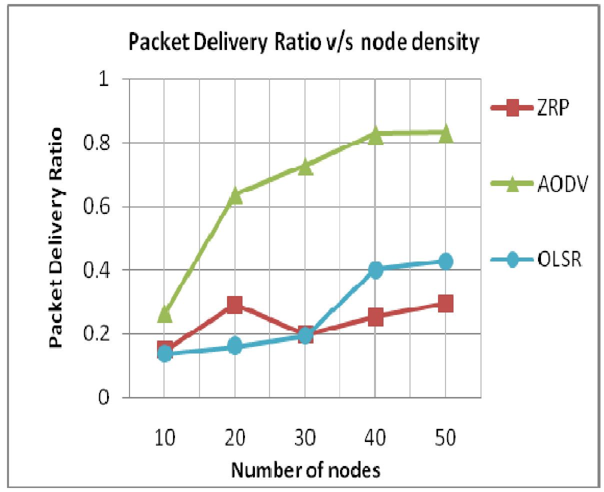

Figure 3.21: Average Packet Delivery Ratio V/S node density

Figure 3.20 describes the effect of varying mobility of the nodes on the packet delivery ratio. As the nodes mobility (maximum speed) increase, a packet delivery rate of all protocols decreases. This is because, in higher speeds, more frequent link breakage may occur and therefore a packet loss rate increases. The hybrid protocol ZRP improves the performance as the mobility increases. From **Figure 3.21** it can be observed that packet deliver ratio of AODV is better than the OLSR and ZRP as node density increases. As the node density increases, there is an increase of radio interferences and collisions between nodes due to hidden/exposed terminals.

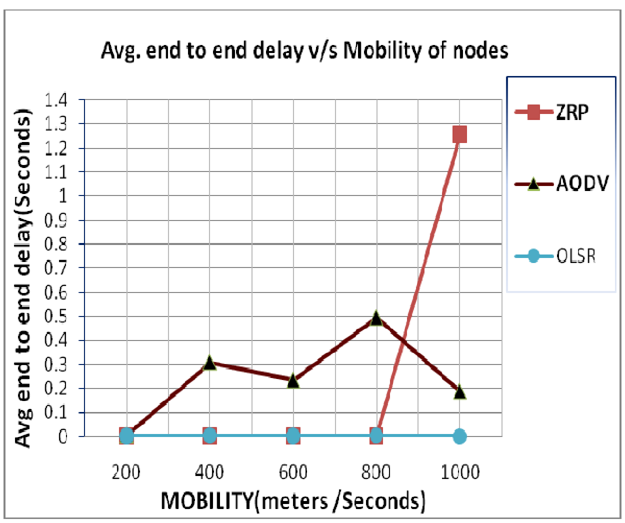

Figure 3.22: Average end to end Delay V/S Mobility

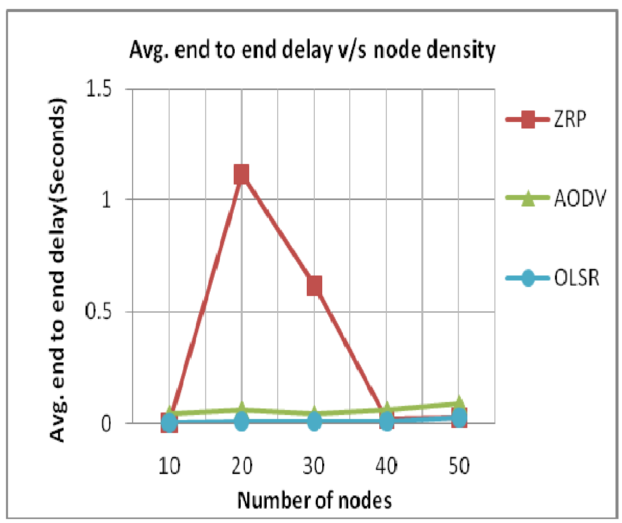

Figure 3.23: Average end to end Delay V/S node density

Figure 3.22 depicts simulation results on the aspect of average end-to-end delay performance for routing protocols by varying the node's mobility (maximum speed). The average end-to-end delay of proactive and hybrid protocol has the almost same performance but better than the reactive as the maximum speed increases. This is due to size of the overhead packets are large in reactive routing protocols than the proactive routing protocols. Effect of change in node density (number of nodes) on average end-to-end delay is shown in **Figure 3.23.** It can be observed that as the node density increases average end-to-end delay for OLSR is less than ZRP and AODV, because in proactive path is predefined so time required to send the packets is less.

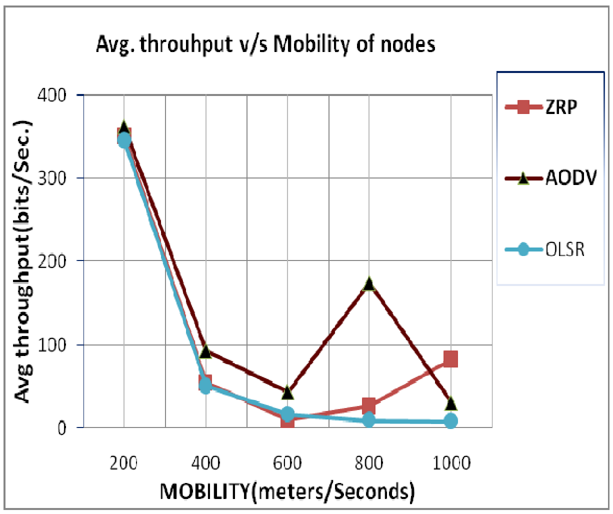

Figure 3.24 :Average Throughput V/S Mobility

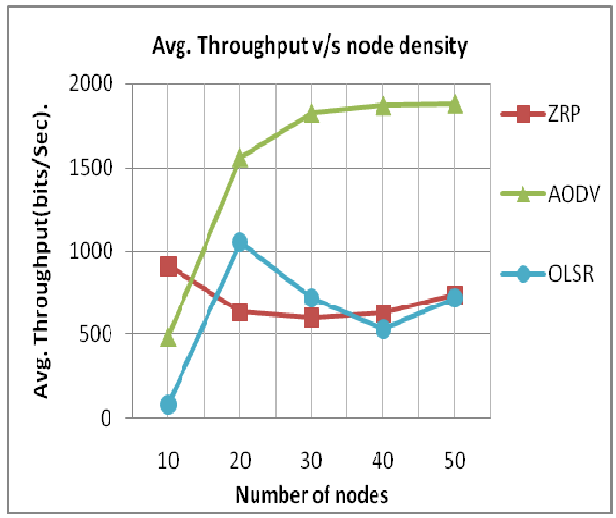

Figure 3.25: Average Throughput V/S node density

Figure 3.24 presents throughput for WANET. The throughput of the ZRP and OLSR is almost same as the mobility of the network is less but as the mobility of the nodes increases the hybrid protocol has the better performance than the proactive and reactive. While in **Figure 3.25** as the node density increases, AODV has the better performance than the OLSR and ZRP.

Figure 3.27 presents the jitter produced with the variation in the node's mobility. It is observed that an increase in the movement speed, proactive and hybrid protocols has the less jitter compared to the reactive protocols and there is decrease in jitter even if node density increases, which can be observed from **Figure 3.28.**

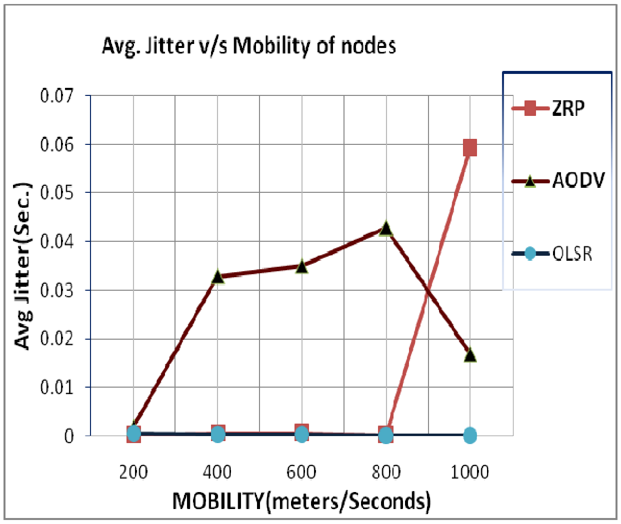

Figure 3.27: Average Jitter V/S Mobility

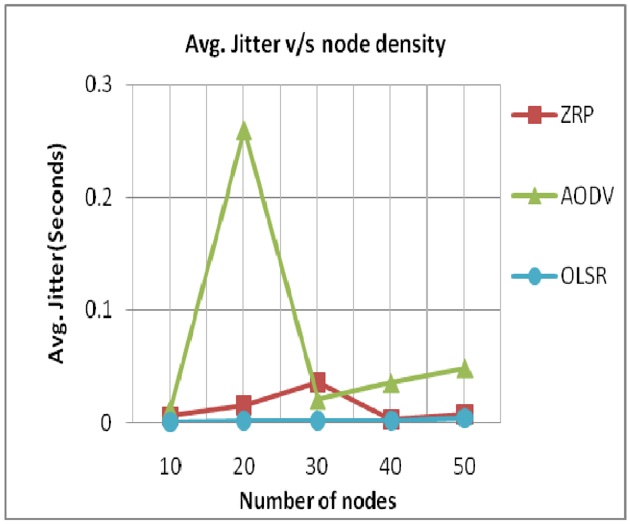

Figure 3.28: Average Jitter V/S node density

The simulation results for the comparison of the proactive, reactive and hybrid protocols considered in this paper is as follows.

Table 3.9 shows the result of the five routing protocol performance in terms of Packet Delivery Ratio with respect to change in mobility of the nodes and the node density in the network. From this we can observe that packet delivery ratio of DSR protocol is more with respect to other protocols.

	Packet Delivery Ratio V/S Mobility					**Packet Delivery Ratio V/S Node Density**				
	Mobility(seconds)					**Node Density**				
	200	**400**	**600**	**800**	**1000**	10	20	30	40	50
DSR	0.42045	0.16667	0.113636	0.1174242	0.1212121	0.39015	0.74809	0.69701	0.77291	0.7037
AODV	0.31061	0.10985	0.090909	0.0909091	0.0416667	0.26515	0.6374	0.72692	0.82567	0.83058
OLSR	0.27227	0.06061	0.034091	0.0189394	0.0151515	0.13614	0.16031	0.19246	0.40139	0.42711
FSR	0.29545	0.01515	0.026515	0.0227273	0.0189394	0.12879	0.38168	0.27438	0.79681	0.33333
ZRP	0.27652	0.06061	0.018939	0.0189394	0.0454545	0.147727	0.290076	0.197659	0.251992	0.293144

Table 3.9 : Packet Delivery Ratio v/s mobility,node density

Average end to end delay of proactive reactive and hybrid protocol with change in mobility and node density in the network is shown in **Table 3.10**, and describes that delay of OLSR protocol is very small with respect to others, because in proactive type of protocol route is already defined whenever one node wants to transmit the packet to the destination, so delay in packet sending and receiving is less.

	Average End To End Delay V/S Mobility					**Average End To End Delay V/S Node Density**				
	Mobility					**Node Density**				
	200	**400**	**600**	**800**	**1000**	**10**	**20**	**30**	**40**	**50**
DSR	1.61868	0.72298	1.571532	1.5405015	1.5025289	0.80354	0.77028	0.62547	0.12231	0.1941
AODV	0.00424	0.30757	0.233623	0.493861	0.1872167	0.04086	0.05749	0.03984	0.05948	0.08599
OLSR	0.00166	0.00352	0.00168	0.0032985	0.0003717	0.00332	0.01035	0.00929	0.00775	0.0242
FSR	0.00194	0.00113	0.001082	0.0030371	0.0004129	0.00276	0.00653	0.00951	0.02795	0.01567
ZRP	0.00217	0.00272	0.000598	0.0016307	1.2594844	0.00342	1.11051	0.61303	0.02042	0.02843

Table 3.10 : Average End To End Delay v/s mobility, node density

Table 3.11 describes the average throughput V/S mobility and node density , from this it can be observe that the DSR and AODV(Reactive) protocols outperforms to all others.

Average Throughput V/S Mobility						Average End To End Delay V/S Node Density				
Mobility						Node Density				
	200	**400**	**600**	**800**	**1000**	**10**	**20**	**30**	**40**	**50**
DSR	416.3	105	108.5	123.8	317	1613.79	593.05	1576.4	2225.73	1851.9
AODV	362.5	92.3	42.9	173.9	29.5	485.2	1560.15	1825.53	1869.1	1880.46
OLSR	346.1	50.4	16.1	9.3	7.6	81	1056.75	719.933	530.85	719.88
FSR	356.2	12.6	12.2	10.6	9.4	69.4	984.1	668.933	1902.45	741.76
ZRP	351.5	54.4	9.7	26.5	83117	914.6	634.7	596.6	625.6	737.06

Table 3.11 : Average Throughput v/s mobility, node density

Table 3.12 shows the performance in terms of average Jitter of the routing protocols with the change in mobility and node density. Jitter of the hybrid (ZRP) routing protocol is very very less in comparison of others.

AVERAGE JITTER V/S MOBILITY						AVERAGE JITTER V/S NODE DENSITY				
MOBILITY						NODE DENSITY				
	200	**400**	**600**	**800**	**1000**	**10**	**20**	**30**	**40**	**50**
DSR	0.16151	0.1123	0.153045	0.1138678	0.1428415	0.12454	0.04801	0.08142	0.06511	0.08457
AODV	0.00177	0.03285	0.035062	0.0428553	0.0168773	0.01215	0.25933	0.0208	0.03577	0.04906
OLSR	0.00058	0.00034	0.000288	0.000173	7.221E-05	0.00034	0.00204	0.00203	0.00157	0.00426
FSR	0.00029	3.2E-07	3.3E-05	0.0003205	4.368E-05	0.00022	0.00109	0.00169	0.00677	0.00362
ZRP	0.00027	0.00061	0.000759	0.0002319	0.0595331	0.0058	0.01575	0.03612	0.00287	0.00779

Table 3.12 : Average Jitter v/s mobility, node density

Summary:

This chapter has described the study and simulation of the routing protocols used for wireless ad hoc network. Here the detail classification of routing protocol is done based on proactive, reactive and hybrid routing protocol. The packet delivery ratio, average end to end delay , average throughput, average jitter are the performance metrics considered to evaluate the performance of the routing protocol for the wireless ad hoc network consist of 10 to 50 nodes. To study detailed of proactive routing protocol FSR and OLSR is considered, AODV and DSR are considered for the reactive type of protocol and ZRP is considered for hybrid type of protocol. The performance comparison of proactive, reactive and hybrid is also done to decide the better protocol in the situation for changing node density and the node mobility in the network.