Performance Comparison of Routing Protocols of MANET in Real World Scenarios

Thesis submitted in partial fulfillment of the requirements for the award of degree of

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CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled, **"Performance Comparison of Routing Protocols of MANET in Real World Scenarios"**, in partial fulfillment of the requirements for the award of degree of Master of Engineering in **Information Security** submitted in Computer Science and Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Dr. Sushma Jain** and refers other researcher's work which are duly listed in the reference section.

The matter presented in the thesis has not been submitted for award of any other degree of this or any other University.

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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Abstract

The increasing spread of mobile nodes along with popularity of high speed IEEE 802.11 standard series makes this kind of ad-hoc network, an important type of access network. Ad-hoc wireless networks are those networks that utilize multi-hop radio relaying and are capable of operating without the support of any fixed infrastructure. Due to limited transmission range, each node behaves as a host as well as a router and thus forwards the packets that are not intended for them, to other nodes and this lead to increase in coverage area. So routing is a core issue in MANET's.

MANET has certain characteristics like dynamic topology, limited bandwidth, limited CPU capacity, limited storage capacity, limited battery power, link failure and energy constraints, which imposes new demands on routing protocol. A variety of routing protocols have been developed to improve the performance of MANET's with respect to correct and efficient route establishment and route maintenance between a pair of stations for message delivery. Examples of commonly used MANET routing protocols are destination sequenced distance vector routing protocol (DSDV), ad-hoc on-demand distance vector (AODV) and optimized link state routing protocol (OLSR),

This present thesis aims to study the performance evaluation and comparison of these three prominent routing protocols based on three real life simulation scenarios. In the first scenario, students investigate the historical site where number of packets being sends and number of nodes in the network are varied. In second scenario rescue operation is studied where the speed with which the nodes move and number of mobile nodes are varied. And in last scenario students explore the national park where direct sequence spread spectrum (DSSS) rate and interval of two packets are varied. Different parameters are varied in different scenarios according to their importance in their respective scenario. Then finally routing efficiencies of these protocols are compared in each scenario, considering various performance metrics like throughput, average delay, total energy consumption and packet delivery ratio. Extensive simulations are made on scenarios using NS-3. In most simulations it is found that among the three protocols, the proactive routing protocols (DSDV, OLSR) performed significantly better than reactive routing protocol (AODV).

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1.1 Mobile Ad-hoc Network

Unprecedented growth of wireless and mobile communication like evolution of 3G, enables worldwide connectivity i.e. users can use their cellular phones to browse the Internet anywhere. However, these networks require a fixed network infrastructure with centralized administration, which consumes lot of time and money for network set-up and maintenance. But easy availability of mobile nodes that includes laptops, PDAs, Cellular phones, palmtops etc. having short range wireless interface and computation capability brings the concept of MANET. Mobile Ad Hoc Networks (MANETs) are a collection of several wireless devices or mobile users that can communicate among themselves over wireless links in a peer to peer basis and thereby creating a dynamic, arbitrary graph. These networks are infrastructureless and there is no centralized administrative in the network. Every node in a network acts as a host and as well as a router which can forward the packets not intended for them to other nodes because of limited transmission range of wireless devices. These networks can self-configure and maintain the network topology dynamically without the infrastructural support [1].

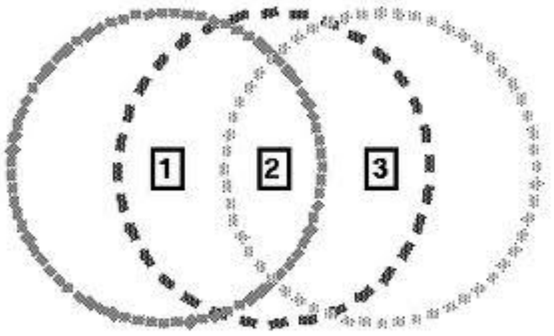

Fig. 1.1 Simple ad-hoc network with three participating nodes

Fig. 1.1 shows an ad hoc network with three wireless mobile hosts. Node 1 is not within the range of node 3’s wireless transmitter and vice versa. If node 1 and node 3 want to exchange packets, they must enlist the services of node 2 to forward the packets for them, since node 2 is within the range overlap between node 1 and node 3. However, MANETs need efficient distributed algorithms to determine network organization, link scheduling and routing. However, determining viable routing paths and delivering messages in a decentralized environment where network topology fluctuates is not a well-defined problem. While the shortest path from the source to destination in a static network is usually the optimal route, this idea is not easily extended to MANETs. Factors such as variable wireless link quality, propagation path loss, fading, multiuser interference, power expended, and topology changes, become relevant issues. The network should be able to alleviate any of these effects. Moreover, in a military environment, preservation of security, latency, reliability, intentional jamming and recovery from failure are significant concerns. Military networks are designed to maintain a low probability of intercept and/or a low probability of detection. Hence, nodes prefer to radiate as little power as necessary and transmit as infrequently as possible, thus decreasing the probability of detection or interception. A lapse in any of these requirements may degrade the performance and dependability of the network. Every scenario requires different parameters to be considered. In Table 1.1 cellular and adhoc wireless networks are compared.

Table 1.1: Difference between cellular networks and ad hoc wireless networks

Cellular Networks	Ad Hoc Wireless Networks
Fixed infrastructure-based	Infrastructure-less
Single-hop wireless links	Multi-hop wireless links
Guaranteed bandwidth (designed for voice traffic)	Shared radio channel (more suitable for best effort data traffic)
Centralized routing	Distributed routing
Circuit-switched (evolving toward packet switching)	Packet-switched (evolving toward emulation of circuit switching)
Seamless connectivity (low call drops during handoffs)	Frequent path breaks due to mobility
High cost and time of deployment	Quick and cost-effective deployment
Reuse of frequency spectrum through geographical channel reuse	Dynamic frequency reuse based on based on carrier sense mechanism
Easier to achieve time synchronization	Time synchronization is difficult and consumes bandwidth
Easier to employ bandwidth reservation	Bandwidth reservation requires complex medium access control protocols
Application domains include mainly	Application domains include battlefields,

civilian and commercial sectors	emergency search, and rescue operations, and collaborative computing
High cost of network maintenance	Self-organization and maintenance properties are built into the network
Mobile hosts are of relatively low complexity	Mobile hosts require more intelligence (should have a transceiver as well as routing/ switching capability)
Widely deployed and currently in the third generation of evolution	Several issues are to be addressed for successful commercial deployment even though widespread use exists in defense.

1.1.1 Advantages and Drawbacks of MANET

Ad hoc networks are really an alternative to fixed networks and attract ISP's, companies due to following advantages [3].

i. **Flexibility and self organization:** This network can be set up quickly among a group of wireless terminal devices for communication. Without any extra settings mobile devices equipped with an 802.11 standard chip can easily join an existing multi hop network. Each node is self configuring and self-maintaining. Thus there is no need to create transmission set up, check errors and information updating manually.

ii. **Low cost:** The price of wireless chip based on IEEE 802.11 standard has been reduced significantly. Another device that adds more cost in infrastructure network is base station that is not required in MANET. System maintenance and configuration training cost is also training cost is not included in this network. Cabling cost is also not a part of this network.

iii. **Extensible coverage:** MANET does not require base station so it can be extended to cover a desired area where an access point or base station is very hard to be established like in desert area.

iv. **Fault tolerance:** MANET supports connection failures, because routing and control packets are designed to manage these situations.

v. **Connectivity:** The use of gateways or centralized points is not necessary for the communication within MANET due to the cooperation between nodes in the task of delivering packets.

1.1.2 Challenges of MANET

As the name suggests, MANET is a group of portable nodes that communicate with each other without any infrastructure. However, there come many challenges to MANET. Some of the challenges of MANET are summarized as follows:

- **i.** **Energy constraints:** Due to limited battery powers in all devices, nodes can't operate for longer time. Therefore, energy management should be done and this process includes shaping the discharge pattern of a node's battery to enhance the battery life; finding routes that result in minimum total energy consumption in the network; using distributed scheduling schemes to improve battery life and handling the processor and interface devices to minimize power consumption [2].
- **ii.** **Bandwidth constraints:** The capacity of wired links is always more than the wireless links. Indeed, several Gbps are available for wired LAN, but commercial applications for wireless LANs work typically around 2 Mbps [3].
- **iii.** **High latency:** If energy conserving design is implemented, it means that nodes are sleeping or idle when they do not have to transmit or forward any data. Therefore when the data exchanges between two nodes through nodes that are sleeping, the delay may be higher if the routing protocol decides that these nodes have to wake up [3].
- **iv.** **Transmission errors:** Fading, multiuser interference and attenuation are other effects of the wireless links that increase the error rate [3].
- **v.** **Location:** Nodes Addressing is another problem for the network layer in MANETs, as in fixed networks the IP addressing is done based on the location of nodes but in MANET it has to do nothing with location [1].
- **vi.** **Roaming:** Roaming algorithms of the fixed network which are based on the existence of guaranteed paths to some destinations are not suitable for MANET due to its continuous change in the network connectivity graph [1].
- **vii.** **Security:** Due to some problems in MANET, various vulnerabilities and attacks can be seen. Attacks are divided into two categories active or passive. Passive attacks are those attacks when the attacker grabs the valuable information by listening to the traffic only and active attacks are done by injecting arbitrary packets to the routing traffic [4].

1.1.3 Applications of MANET

Use of MANET in real life is diverse, from small, static networks to large-scale, mobile, highly dynamic networks. Table 1.2 provides an overview of MANET applications.

Table 1.2: Applications of MANET

Area	**Possible scenarios**
Military Scenarios	MANET supports tactical n/w for automated battlefields and military communications.
Rescue Operations	It provides network in case of environmental disaster, policing and fire fighting, search and rescue operations, supporting doctors and nurses in hospitals,
Education	Universities and campus settings, during meeting or lectures
Commercial and civilian environments	Electronic payments anywhere and anytime, road or accident guidance, taxi cab network, inter-vehicle networks, road and weather conditions, trade fairs, shopping malls, networks of visitors at airports.
Entertainment	Robotic pets, multi-user games, theme parks, wireless P2P networking.
Home and enterprise networking	Conferences, meeting rooms, networks at construction sites, PAN.
Data Networks	It provides support for the exchange of data between mobile devices.
Device Networks	MANET supports wireless connections between various mobile nodes so that they can communicate.
Free internet connection sharing	MANET allows us to share internet freely

	with other mobile devices i.e. extending cellular network access.
Sensor Network	This network consists of devices that have sensing and computational capabilities. It is used in Data tracking of environmental conditions, animal movements, chemical / biological detection, BAN.

1.2 IEEE 802.11

In 1997, the IEEE adopted the first wireless LAN standard, named IEEE 802.11 [5], with data rates up to 2 Mbps. Since then, several task groups have been created to extend the existing IEEE 802.11 standard. Task groups_ 802.11b and 802.11a have completed their work by providing two relevant extensions to the original standard 802.11, which are often referred to with the friendly name of wireless Fidelity (Wi-Fi). In July 1999, IEEE creates 802.11b specification which supports bandwidth up to 11 Mbps, comparable to traditional Ethernet. 802.11b uses the same unregulated radio signaling frequency i.e. 2.4 GHz as the original 802.11 standard and with backward compatibility. This standard becomes an "overnight success", with its several products available on the market. Pros of 802.11b are lowest cost; signal range is good and not easily obstructed. Its cons are slowest maximum speed; home appliances may interfere on the unregulated frequency band using the same 2.4 GHz [5].

While 802.11b was in development process, IEEE created a second extension to the original 802.11 standard called 802.11a in a regulated frequency spectrum around 5 GHz band, with data rates up to 54 Mbps. This higher frequency compared to 802.11b shortens the range of 802.11a as it means signals have more difficulty in penetrating walls and other obstructions. Due to higher cost of 802.11a as comparable to 802.11b, 802.11a is usually found on business networks whereas later better serves the home market. These two standards utilize two different frequencies, so they are incompatible with each other.

In 2002 and 2003, WLAN products support a new std. called 802.11 with bandwidth up to 54 Mbps and uses 2.4 GHz frequency for greater range. IEEE standard 802.11g is backward compatible with 802.11b, means that 802.11g access points will work with 802.11b wireless adapters. Among the other task groups, it is worth mentioning that 802.11e standard attempts to enhance the MAC with QoS features to support video and voice over 802.11 networks.

Like all IEEE 802 standards, the IEEE 802.11 standards also focus on lowest two levels of the ISO model, the physical layer and data link layer. The 802.11b specification affects only the physical layer, providing higher data rates and more robust connectivity. The IEEE 802.11 standard defines two modes of operation for WLANs. These are infrastructure-based (this configuration called BSS) and infrastructure-less or ad hoc (this configuration called IBSS). Interface cards can be set to work in any mode but not simultaneously. Infrastructure mode resembles cellular infrastructure based networks. It is the mode commonly used to construct Wi-Fi hotspots, i.e. to provide wireless access capability to the internet. Whereas in adhoc mode, any device that is within the transmission range of any other device, after a synchronization phase, can start communicating [2].

- **Direct Sequence Spread Spectrum (DSSS) technology**

Spread spectrum is a means of transmission in which the signal occupies a bandwidth in excess of the minimum necessary to send the information. The band spread is accomplished by means of a code which is independent of the data, and synchronized reception with the code at the receiver is used for de-spreading and subsequent data recovery. In DSSS each node is assigned a unique n-bit code called a chip sequence. N is known as the chipping rate of the system. These codes assigned to the nodes are orthogonal to each other, which mean normalized inner product of the vector representations of any two codes is zero. At the transmitter side, the input to the DSSS is a modulated signal. That signal is then mixed with PN code (a sequence random for certain length and after that it repeats; code is regarded as a shared secret between sender and receiver) and sent. At the receiver side, that signal is demodulated with that same PN-code and second demodulation is also done using same technique as used by input signal for modulation. For transmitting a 1 bit, a node sends its chip sequence. To transmit a 0 bit, it sends the one’s complement of its chip sequence. No other patterns are permitted e.g. for m=8, if node is assigned the chip sequence 00011011, it sends a 1 bit by sending 00011011 and 0 bit by sending 11100100. Hence, transmission of a signal using CDMA occupies n times the bandwidth that would be required for narrow-band transmission of the same signal [2].

To support noisy environments as well as extended range, IEEE 802.11b WLANs use dynamic rate shifting, allowing data rates to be automatically adjusted to compensate for the varying nature of the radio channel. Mainly users connect at 11 Mbps rate but when nodes move beyond the optimal range for 11 Mbps operation, or if interference is present, 802.11b nodes will transmit at lower speeds, lowering down to 5.5, 2 and 1 Mbps. Rate shifting is a physical layer mechanism transparent to the upper layers of the protocol layer and to the user. IEEE 802.11 Parameters for DSSS are shown in a tabular form in Table 1.3. The main benefits from the DSSS Rate technology are mentioned as follows:

- Anti-jamming
- Anti-interference
- Low property of interference
- Used in CDMA
- Message privacy
- High resolution ranging and timing
- Sharing of a single channel among multiple users

Table 1.3: IEEE 802.11 Parameters for DSSS [2]

Parameter	DSSS
t_{slot}	20 µsec
SIFS	10 µsec
PIFS	SIFS + t_{slot}
DIFS	SIFS + (2 * t_{slot})
Operating Frequency	2.4 Ghz
Maximum Data Rate	2 Mbps
CW_{min}	31
CW_{max}	1,023

1.3 Mobility Models

In order to thoroughly simulate a new protocol for an adhoc network, the protocol should be tested under realistic conditions including, but not limited to, buffer space for storage of messages, a sensible transmission range, representative data traffic models and realistic movement of mobile users. Mobility patterns are the key criteria that influence the performance characteristics of the MANETs. Currently there are two types of mobility models used in the simulation of networks. These are traces and synthetic models [6]. Traces are those patterns that are observed in real life systems. These provide accurate information, especially when large number of nodes is involved and an appropriately long observation period whereas synthetic models attempts to represent the behaviors of nodes realistically without the use of traces. Some synthetic entity mobility models [7] for MANETs are described as follows:

i. **Random Walk Mobility Model:** A mobility model based on random directions and speeds.
ii. **Random Waypoint Mobility Model:** A model that includes pause time between speed and change in destination.
iii. **Random Direction Mobility Model:** A model that forces MNs to move to the edge of the simulation field area before changing direction and speed.
iv. **A Boundless Simulation Area Mobility Model:** A model that converts a two dimensional rectangular simulation area into a torus shaped area.
v. **Gauss-Markov Mobility Model:** A model that uses one tuning parameter (α) to vary the degree of randomness in the mobility pattern.
vi. **A Probabilistic Version of the Random Walk Mobility Model:** A model that utilizes a set of probabilities to determine the next position (x, y) of a mobile node.
vii. **City selection Mobility Model:** A model in which a simulation area represents streets within a city.

Categorization of mobility models that allow researchers to simulate situations where mobile nodes decisions on movement depend upon the other mobile nodes in the group are discussed as follows [7]:

i. **Exponential Correlated Random Mobility Model:** A group mobility model that uses a motion function to generate movements that MNs will follow.
ii. **Column Mobility Model:** A group mobility model where the set of MNs form a single line and uniformly moves forward in a particular direction.
iii. **Nomadic Community Mobility Model:** A group mobility model where a set of MNs move together from one location to another location.
iv. **Pursue Mobility Model:** A group mobility model where a set of MNs follow a given target and according to that their movements are decided.

v. **Reference Point Group Mobility Model:** A group mobility model where group movements are based upon the path traveled by a logical center as a reference.

vi. A mobility model should mimic the movements of real mobile nodes. Changes in speed and direction must occur in reasonable time slots that means it will be of no use if MNs travel in straight lines at constant speeds throughout the course of entire simulation because in MANET, nodes does not travel in such a restrict manner. Based on specific mobility characteristics, mobility models can also be classified into several classes based on their mobility characteristics. When the movement of nodes is affected by its movement history, we refer to this type of mobility models as models with temporal dependency. In some scenarios, when mobile nodes travel in a correlated manner, we refer to this type of mobility as spatial dependency. When the movement of nodes is bounded by obstacles or streets, then these mobility models are called models with geographic restriction.

1.3.1 Random based mobility models

In random-based mobility models, the mobile nodes move freely and randomly without restrictions. Random characteristics of mobile nodes in a MANET consist of a stochastic process, and each node’s movement consist of a sequence of random length intervals called mobility epoch and during which a node moves with certain speed in a certain direction. The speed and direction of a mobile node may vary in accordance to mobility criteria depending on the kinds of mobility models from epoch to epoch. One of the random based mobility models is random direction mobility model which is described as follows [8].

- **Random Direction mobility model**

In order to remove the flaw in random waypoint mobility model, this model was created. In random waypoint model, each mobile node randomly selects one destination in the simulation field. It then travels towards this destination with constant velocity chosen randomly from [0, V] where V is the maximum allowable velocity for every mobile node and upon reaching the destination, the node stops for a duration called pause time T_{pause} .Then again it select new destination and this process goes on. But the problem is that probability of choosing a new destination is high in the centre of the simulation area. It appears that node converge, disperse, converge again goes on. So to alleviate this type of behavior and to promote a semi-constant no. of neighbors, random direction mobility model was developed. In this model, MNs instead of choosing random destination choose random direction. After choosing a random direction, MN moves to the border of the simulation area in that selected direction. After reaching to the boundary, MN stops for a certain period of time and chooses another direction and this process continues [8].

1.3.2 Limitations of random based mobility models.

Random mobility models are simple to implement and analyzed but they may not adequately capture certain mobility characteristics of some real scenarios, including:

i. **Temporal Dependency of Velocity:** As we have seen the velocity of MNs is memory less process that means velocity at current epoch is independent of the previous epoch. Thus, sudden stop, sudden acceleration and sharp turn may frequently occur. But in many real life scenarios speed of vehicles accelerate incrementally and direction change is also smooth.

ii. **Spatial dependency of velocity:** In random mobility models, MNs moves independently of other nodes. But in some real life scenarios including museum touring and battlefield communication, the mobile nodes moves behind some leader node. Hence, mobility of various MNs is indeed correlated.

iii. **Geographic restrictions of movement:** In random mobility models, nodes move randomly and freely with in a simulation area without any restrictions. However, in many realistic cases, like in urban areas, the movement of MNs is mainly bounded by obstacles, buildings or streets.

1.3.3 Mobility models with temporal dependency

The movement patterns of the mobility models with temporal dependency are likely to be influenced by their movement histories that the current velocity of a mobile node may depend on its previous velocity. So there is a correlation between velocities of single node at different time slots. Gauss-Markov Mobility model is one of the examples of this mobility model which is defined as follows [8].

- **Gauss Markov mobility model**

In this model, the velocity of node is assumed to be correlated over time that means the value of speed and direction at the nth instance is calculated based upon the value at (n-1)st instance. To ensure that an MN does not remain near an edge of the simulation grid for a longer period of time, so when the MN is going to move beyond the boundaries, then the direction of movement is forced to flip 180 degree.

The degree of dependency is determined by the memory level parameter α. α is a tuning parameter whose value lies at or between 0 and 1, to reflect the randomness of this process. Totally random motion is obtained by setting $\alpha = 0$ and at $\alpha = 1$linear motion is obtained. For any intermediate levels of randomness, vary the value of α between 0 and 1. In [9] it is observed that as α increase, the node paths become less random and become more predictable and it is shown that sudden stops and sharp turns are eliminated in this model.

1.4 Routing in MANETs

MANET consists of a set of portable mobile nodes that are connected by wireless links. The network topology that means the physical connectivity of the communication network, in such a network may keep changing randomly. To move the information from source to destination, a routing algorithm is required. The routing concept basically involves two activities. Firstly, finding optimal routing paths and secondly, transferring the packets throughout the network. Path determination could be complex but packet switching is straight forward. Different metrics are taken by different protocols to find the best path e.g. number of hops as a metric.

Routing protocols that are used in traditional networks cannot be directly applied in adhoc networks due to their highly dynamic topology, bandwidth constrained wireless links, absence of established infrastructure for centralized administration, and energy constrained nodes and these are described as follows [2]:

i. **Mobility:** Due to random movement of intermediate or end nodes, on-going session suffers from frequent path breaks. Such situations do not arise in wired networks because of their reliable links where all the nodes are stationary. Even though during path breaks, wired networks find alternate routes, but their convergence is very low. Therefore, protocols made for wired network cannot be used in MANET where the mobility of nodes results in frequently changing network topologies. Routing protocols for MANET must be able to perform effective and efficient mobility management.

ii. **Bandwidth constraint**: Due to the advanced technologies used in wired networks like advent of fiber optics and exploitation of wavelength division multiplexing (WDM). But in wireless networks, due to limited radio band data rates it can offer are much less than that of infrastructure wired network. This limited bandwidth availability also imposes some constraints on routing protocols in maintaining topological information as it involves more control overhead and this lead to more bandwidth wastage.

iii. **Error prone shared broadcast radio channel:** Wireless links have time-varying characteristics in terms of link error probability and link capacity. This requires that to find alternate routes with better quality links, MANET routing protocol should interacts with the MAC layer. Also, transmissions in MANET result in collisions of data and control packets and this is attributed to the hidden terminal problem. Hidden terminal problems refer to the collision of data or control packets at the sink node due to the simultaneous transmission of those nodes that are not within the direct range of source, but are within the direct range of sink.

iv. **Resource constraints:** Battery life and processing power are the two resources that are essential and also limited and that form major constraints for the nodes in MANET. Devices used in MANET in most cases require portability, so there are size and weight constraints. Along with them there are restrictions on the power source. But increasing the battery power and processing ability, makes the nodes bulky and less portable.

1.4.1 Characteristics of ideal routing protocol for MANET

Due to the above issues in MANET, wired network protocols cannot be applied to adhoc wireless networks. So specialized routing protocols are required that address the above challenges. Some of the characteristics of good routing protocol are mentioned as follows [2]:

- Routing protocol must be fully distributed as centralized routing involves high control overhead and a risk of single point of failure and hence not scalable.
- It must be adaptive to frequent topology changes caused by the random mobility of nodes.
- It must follow localized state, as global state maintenance involves a huge state propagation control overhead.

- It must be free from stale routes and also loop free.
- There should be limited number of broadcasts made by each node to keep the packet collisions at minimum and transmission should be reliable enough to get maximum packet delivery ratio.
- Convergence must be quick that means it must converge to optimal routes once the network topology becomes stable.
- It must use constrained resources like bandwidth, memory, computing power, and battery power optimally.
- It should support certain level of quality of service (QoS) as required by applications, and also support for time-sensitive traffic.
- Every node in the network should store information regarding the stable local topology only, that means a node should get updates from local topology to which node belongs rather than from topology of parts of the network with which the node does not have any traffic correspondence and this topology also called remote topology.

1.4.2 Classifications of routing protocols

Routing protocols can be broadly classified into four categories based on following criteria [2].

1. Routing information update mechanism
2. use of temporal information for routing
3. routing topology
4. utilization of specific resources

1.4.2.1 Based on routing information update mechanism: Routing protocols based on this mechanism can be classified into following three major categories [2].

i. **Proactive or table-driven routing protocols:** In proactive routing protocols, every node maintains the routing tables to store the network topology information at all times. This can be done in different ways, and thus divides the protocol into two subclasses: Event driven and regular updated protocols. Event driven protocols send update packets only when there is change in topology, whereas regular updated protocols always send their topology information to other nodes at regular intervals. Whenever a node requires a path to a destination, it runs path finding algorithm on the topology information it maintains. Event driven routing protocols are CBRP, DSDV, GSR, LMR, TORA and WRP where as regular updated protocols are GPSR, OLSR, and STAR.

ii. **Reactive or on-demand routing protocols:** These protocols will not maintain correct routing information on all nodes at all times but they obtain the necessary path when it is required, by using a connection establishment process. In this process, when a node does not have enough routing information to send the message to destination, a node broadcasts the route request packet to all neighbors to discover the route. Clearly, applications that are used over reactive routing protocol need to be tolerant for such initial setup delay. The advantage lies in the fact that it does not carry routing overhead data for routes which are not even used, but this advantage may diminish in some scenarios where there is lot of traffic to a huge variety of nodes because in this case the route-setup traffic can grow larger to maintain correct routing information on each node. Examples are ABR, AODV, CEDAR, DSR, LAR and WAR.

iii. **Hybrid routing protocols:** This protocol combines the features of the above two protocols that means for routing of nodes that are within a particular geographic region, a table-driven routing approach is used and for nodes that are located beyond this region, an on-demand routing approach is used. Examples are CEDAR, ZRP and ZHLS.

1.4.2.2 Based on the use of temporal information for routing

Since the path breaks are much more frequent in adhoc networks than in wired networks, so the use of temporal information regarding the lifetime of the paths selected and the lifetime of the wireless links assumes significance. Routing protocols that fall under this category can be classified into two types.

i. **Routing protocols using past temporal information:** These routing protocols use information about the status of links at the time of routing or about the past status of the links to make routing decisions. Examples are DSDV, WRP, STAR, DSR, AODV, and FSR.

ii. **Routing protocols that use future temporal information:** These routing protocols use information about the expected future status of the wireless links to make approximate routing decisions. Apart of including lifetime of wireless links, future status information also includes information regarding the lifetime of the node (based on the discharge rate of non-replenish able resources and remaining battery charge) and prediction of link and location availability. Examples are FORP, RABR and LBR.

1.4.2.3 Based on the routing topology

Hierarchical topology routing is being used in the Internet in order to reduce the state information maintained at the core routers. Due to relatively smaller number of nodes in MANET, either a flat or hierarchical topology for routing is used [2].

i. **Flat topology routing protocols:** Flat routing is simple and efficient for small networks. In a flat structure, all nodes in a network are at same level and also have the same routing functionality. But the problem arises when network becomes large because volume of routing information will be large and it will take a long time for routing information to arrive at remote nodes. Protocols that fall under this category use same addressing scheme as used in 80.3 LANs. It assumes globally unique addressing scheme for nodes in MANET. Examples are DSR, AODV, ABR, and SSA.

ii. **Hierarchical topology routing protocols:** It is based on the idea of organizing MNs in groups and then assigning nodes different functionalities inside and outside of a group. Control overhead is less as compare to flat routing protocols as both routing table size and update packet size includes only part of the network instead of the whole network information. There are two ways to build hierarchy structure i.e. explicit and implicit hierarchy. The most popular way of creating hierarchy is to group nodes close to each other geographically into explicit clusters. Each cluster has a cluster head (leading node) to communicate to other nodes on behalf of the cluster. And another way is each node has a local scope. Various routing strategies are incorporated inside and outside the scope. As mobile nodes have only a single omnidirectional antenna for wireless communications, this type of hierarchy will be referred to as “logical hierarchy” to distinguish from the physical hierarchy. Protocols belonging to this category make use of logical addressing scheme. In other words, this hierarchy could be based on hop distance or based on geographical information. Examples are CGSR, FSR and HSR.

1.4.2.4 Based on the utilization of specific resources

i. **Power aware routing:** Routing protocols under this category aims at minimizing the consumption of battery power either locally or globally in the network, which is very important resource in wireless adhoc networks. Example PAR.

ii. **Geographical information assisted routing:** Protocols under this category reduce the control overhead and improve the performance of routing by effectively utilizing the available geographical information. Example LAR.

1.4.3 Ad-hoc On-Demand Distance Vector (AODV) protocol

AODV algorithm enables dynamic, self-starting, multihop routing between participating MNs wanting to establish and maintain an adhoc network. It does not require nodes to maintain any routes information that are not in active communication and it allows nodes to obtain routes quickly when required. It allows mobile nodes to respond to link failure and topology change in a timely manner. When links break, this protocol causes the affected set of nodes to be notified so that they invalidate that particular route. AODV uses destination sequence numbers (created by the destination) for each route entry to ensure loop freedom and to help in choosing the best route from the two by selecting the route with greatest sequence number [10].

1.4.3.1 Overview

AODV borrows most of the advantageous concepts from DSR and DSDV protocols. AODV uses three message types- Route Requests (RREQs), Route Replies (RREPs) and Route errors (RERRs). These messages are not blindly forwarded. They use normal IP header processing i.e. requesting node uses its IP address as the originator address and uses 255.255.255.255 as the broadcast address. RREQ message is disseminated widely throughout the network but controlled by TTL value in IP header.

1) Routing

Sequence numbers are used for removing old information from the network. The destination sequence number (DSN) for each possible destination host is stored in the routing table (RT) and it is updated only when the host receives the message with higher sequence number (SN). The host also keeps its own SN, which must be incremented only in two cases: before it sends RREQ message and when in respond to

RREQ message, host sends a RREP message. AODV protocol supports the SN to be rolled over without any issues.

AODV does not play any role when end points have valid routes to each other. When a route to a new destination is required, the node broadcasts a RREQ message throughout the network to find a fresh route to a destination. RREQ message includes the DSN which is last known SN of the destination host entry found in the Routing table (RT). But if it does not contain any entry for the destination host, then the unknown SN flag must be set. For every new request, RREQ ID sequence number is incremented. When host receives RREQ message, it copies the hop count in its routing table and increases the hop count by one in RREQ message and adds the information about the next hop specifying to which the node the message should be forwarded to. The host must set the DSN in the RREQ message if the seq. number is greater in routing table than in the received RREQ message. Finally, the host broadcast the RREQ packet and decreases its TTL field.

RREP packet can only be generated by destination host or any node having validated route but only if the D field is not set. If the receiver is the intermediate host having validated route, then it copies the destination address and the requested host sequence number to the RREP message but if the receiver is the destination host then its own SN is incremented and copied to the RREP message. If the receiver is intermediate host then it just copies DSN from the routing table and adds the node address from where it has received RREQ message to the destination address field.

When the link breakage happens the node must remove the existing route in the RT and determine which neighbors can be affected with this breakage and finally sends the RERR message to the corresponding neighbors. RERR message can be broadcast or unicast. When a source node learns about the path break, it reestablishes the route if required by the higher layers but if the path break is detected by intermediate node, the node informs the end nodes by sending an route reply with the hop count set as infinity.

Although being a reactive protocol, it uses hello messages periodically to inform that the link to the host is alive. These messages are broadcasted with TTL equals to 1. When any node receives this message, it updates the lifetime of the host in the routing table but if node does not receive any information for specified amount of time, then the routing info in the RT is marked as lost. The routes that are generated by Hello messages and are not used for any routing purpose should not generate any RERR message during link breakage.

AODV is a routing protocol and it deals with route table management. Table information must be kept even for short-lived routes, such as storing reverse paths towards nodes originating RREQs. With each route table entry these fields are used- Destination IP address, destination sequence number, valid destination sequence number flag, state and routing flags, network interface, hop count, next hop, list of precursors (containing the IP address for each its neighbors that use it as a next hop towards each destination) and lifetime.

2) Interesting concepts of AODV

- **Reduced space complexity:** This protocol ensures that the nodes that are not in the active path do not maintain any information about this route. If a node does not receive any RREP from its neighbors for route request, it deletes all reverse information that is stored by nodes on receiving RREQ message.
- **Maximum utilization of the bandwidth:** This was the major achievement of this protocol. Demand on the available bandwidth is less as this protocol does not require any global advertisements. And a monotonically increased SN counter is maintained in order to remove any stale cached routes. All the nodes in an active path updating their routing tables also make sure of max utilization of bandwidth. It is required that all the intermediate nodes should maintain fresh routes as these routing tables will be used repeatedly in case of receiving RREQ from another source for same destination. All the nodes on receiving RREP messages, compare with the RREP that was propagated last using the DSNs and are discarded if they are not better enough than the already propagated RREPs.
- **Simple:** This algorithm gives flexibility to each node behaving as a router, by maintaining a simple routing table and its initiating path discovery request, makes the network self-starting.
- **Most effective routing info:** If a node receives another RREP with smaller hop count as compared to received earlier, it updates its routing information with this better path and propagates it.

- **Most current routing info:** If a node receives another RREP with greater DSN as compared to received earlier, it updates its routing information with this better path and propagates it.
- **Loop-free routes:** Source-id and broadcast–id pair is used to get the loop free routes.
- **Withstanding dynamic topology and broken links:** Random and freely moments of MNs makes this network a highly dynamic. And due to frequent topology change, possibility of links breakage increases. So, when the intermediate nodes discover the link breakage, they propagates RERR packet and in response to it source node re –initializes the path discovery if it still desires the route. This ensures quick maintenance to broken links.

14.3.2 Advantages and Limitations of AODV

I. Advantages of AODV

- Due to its flat hierarchy structure, it does not need any central administrative system to manage the routing process. AODV also tend to reduce the control traffic messages overhead but at the cost of increased latency in finding efficient routes.
- Removes counting to infinity problem and gives loop free routes by the usage of SNs.
- AODV keeps the overhead of the messages small. In case when the source node is having information about the path to the destination in its routing table, the overhead it creates is minimal. AODV is better than simple protocols which need to keep the entire route in their messages from source to destination. RREQ and RREP generate less overhead as compare to control messages. It updates only those hosts that may be affected due to topology change or link breakage using RERR message.

II. Limitations of AODV

- **Requirement on broadcast medium-** AODV requires that the MNs in the broadcast medium can detect each other’s broadcasts.
- **Overhead on the bandwidth-** When an RREQ packet travels from node to node in discovering process of the route, on demand, it sets up the reverse path

with the address of all the MNs through which it is passing and also it takes away all this information all its way.

- **Vulnerable to misuse-** RREQ, RREP and RRER messages can be misused for insider attacks including route invasion, route disruption, node isolation and resources consumption. This algorithm lacks support for high throughput routing metric and it is designed to support the shortest hop count metric.
- **High route discovery latency-** AODV is a on demand routing protocol and this means that route will not be discovered until a flow is initiated. This latency results high average delay in large-scale mesh networks.

14.4 Destination Sequencing Distance Vector (DSDV) Protocol

This protocol is adapted from the conventional RIP by adding a new attribute, seq. number, to each route table entry. The main aim of adding this attribute is to prevent the formation of routing loops and to distinguish stale route information from the new [11].

1) Packet Routing and routing table management

In DSDV, each mobile node of a adhoc network maintains a routing table, which contains the information about all destinations, the metric, the next hop to each destination and a seq. number generated by the destination node. Using such routing table information, packets are send between the nodes of an adhoc network. Due to the dynamically changing topology in MANET, each node updates the routing table by sending the advertisements periodically or when new information is available, to maintain the consistency of the table.

As soon as topology changes are detected, each node advertises routing information using multicasting or broadcasting a routing table update packet. This packet starts out with a metric one to direct connected nodes and this indicates that each receiving neighbor is 1 hop away from the node. After receiving the update packet, the receiving nodes updates their routing table with incrementing the metric by 1 and further broadcasts it to their neighbors. This process is repeated until all the nodes have received a copy of the update packet. The update data is kept for a while before updating its routing table and retransmitting, to wait for the arrival of best route for each destination node in each node. If a node receives multiple update packets for the same destination during the waiting time period, then the routes with more recent seq.

numbers are always preferred for the packet forwarding decisions. But if only the sequence numbers have been changed then the routing information is not necessarily advertised immediately. If the update packets are having the same seq. number with the same node then the update packet with the smallest metric will be stored and the existing route will be discarded. In this case, the advertisement of routes that are nearly about to change may be delayed until, the best routes have been found and this delay leads to damp the fluctuations of the routing table. The elements of routing table of each node changes dynamically to keep the consistency with dynamically changing topology and to reach this consistency, routing information advertisement must be quick enough to ensure that each node can locate all other mobile nodes in the dynamic network.

Sequence number is monotonically increasing number to distinguish stale updates from the new one by uniquely identifying each update from a given node. In addition to the sequence number and the metric for each entry of the update packet, it also contains the address of the final destination and the address of the next hop.

There are two types of update packets, one is called full dump and other is called incremental. Full dump updates carries all the available routing information and incremental updates carries only the routing information changed since the last full dump. Each node send the full dump using multiple network protocol data units (NPDUs) and these updates can be transmitted relatively infrequently when very small movement of mobile nodes is occurring. But incremental update packets are sent between the full dumps for partial changes such as receiving new sequence numbers and during fewer significant route changes. Incremental updates should be fitted in one NPDU and when the size of an incremental update approaches to the maximum size of a NPDU then a full dump is scheduled to make the next incremental update smaller.

2) Responding to topology changes

Due to the dynamic behavior of this network, links can be broken when the nodes move from one place to another or have been shut down. And whether the links have been broken or not can be inferred if no broadcasts have been received for a while and may be detected by the communication hardware. Infinity is assigned to the broken link. When the link to next hop has broken then any route through this neighbor is immediately assigned an infinity metric and also the detecting node will immediately broadcast an update packet and find out the modified routes.

To describe the broken links, any node other than the destination node generates a seq. number, greater than the last received sequence number from the destination. Metric of infinity and this newly generated seq. number is placed in update message and broadcasts over the network. To avoid any conflict in generating a same sequence number between nodes themselves and their neighbors, nodes only generate even numbers for themselves and neighbors only generate odd numbers for the mobile nodes responding to the link changes.

The routes to a lost node will be re-established when it comes back into the network and then this lost node broadcasts its next update with an equal or incremented sequence number and a finite metric. This update message will be flushed over the whole network to indicate its presence in the network again.

14.4.2 Advantages and Limitations of DSDV

I. Advantages of DSDV

- Guarantees loop free paths.
- Count to infinity problem is reduced in this protocol.
- Extra traffic can be avoided by using incremental updates instead of full dump updates.
- In DSDV, amount of space used by RT is reduced because it maintains only the best path, instead of maintaining multiple paths to every destination.

II. Limitations of DSDV

- Wastage of bandwidth due to unnecessary advertising of routing info even if there is no change in the network topology.
- Multipath routing is not supported by DSDV.
- Difficult to find the time delay for the advertisement of routes.
- Each and every host in the network maintains a routing table for advertisement, but for large traffic this would lead to overhead, which consumes more bandwidth.
- Wireless media differs from wired media due to its asymmetric connection. In wireless networks, unidirectional links are prevalent but DSDV assumes that all the wireless links in MANETs are bidirectional.

14.5 OLSR

OLSR, a proactive routing protocol adapts a classical link state protocol for routing in MANET. As it is a proactive routing protocol, it uses the update messages periodically to keep the topology information up to date at each node. In classical protocol, the link state packet contains the entire neighbor list and its associated link cost metric and hence this generates the large control packet overhead. Also, these packets are flushed into the entire network and hence do not scale well to the low bandwidth requirements of MANET. So, to overcome these problems OLSR is developed in 2005. OLSR reduces these problems by minimizing the control packet overhead and doing the flooding mechanism efficiently [12].

14.5.1 Overview of OLSR

In OLSR, routes are always available when needed. It is an optimized version of the pure link state protocol. The frequently topological changes in MANET cause the flooding of the topological information to all available nodes in the network. So OLSR uses Multipoint Relays (MPR) to reduce the flooding of broadcasts by minimizing the same broadcast in some regions in the network and another reduce is to provide the shortest path. Reducing the time interval for the control messages transmission bring more reactivity to the topological changes.

OLSR uses two types of control messages. Hello messages and Topology control (TC) messages. Hello messages are used for locating the information about the link status and also the host neighbors. And by using these Hello messages, MPR selector set is made which describes which neighbors has selected this host to act as MPR and with the help of this information the host can calculate its own set of the MPRs where as TC messages are used for broadcasting about own advertised neighbors which includes the MPR selector list. Hello messages are sent only one hop away but TC messages are broadcasted periodically throughout the network and only the MPR can forward the TC messages. The other type of message is Multiple Interface Declaration (MID) message. This type of message is used for informing other host that the announcing host can have multiple interface addresses and these messages are broadcasted only by MPR’s. There is also a Host and Network Association (HNA) message which provides the possibility for routing to the external addresses by giving the information about the network and netmask addresses.

1) Neighbor Sensing

Hello messages are broadcasted periodically one hop away for neighbor sensing. To know whether the link between two hosts is bidirectional or not, following process happens. When the first host receives the Hello message from the second one, it sets the second node status to asymmetric and when the first one sends a Hello message and includes that, the second host set first node status to symmetric in own routing table. Finally, when second node send again Hello message and includes first, then first node sets the second node status as symmetric. Hello messages contain information how often the host sends Hello messages, information about its neighbor and willingness of host to act as MPR.

2) Multipoint Relays

MPR is the key idea behind reducing the problems of classical link state protocol. MPR reduces the number of nodes which broadcasts the information throughout entire the network. Multipoint relays is a host one's hop neighbor which forwards its messages i.e. only the MPR's can forward the data. To make the protocol work efficiently, MPR set of hosts is kept small. When the host gets a new broadcast message, then using the message's sender interface address from the MPR selector set, MPR forward the message in its behalf. Due to the frequent changes in the adhoc network, the MPR selector sets are updated frequently using Hello messages.

3) Topology Information

In order to exchange the topological information, MPR need to send the TC message. TC message includes the sequence number of each message and the own set of advertised links. The node must increment the sequence number when the links are removed from the topological control message or when the links are added to the TC message. When the nodes advertised links set becomes empty, it sends empty TC messages for particular specified amount of time, to invalidate previous TC messages. These messages exist in the network until it has again some information to send. When there is a change in the MPR selector set, it means link failure has happened and hence TC message needs to be sending as soon as possible.

14.5.2 Advantages and Limitations of OLSR

I. Advantages of OLSR

- OLSR is a flat routing protocol and hence it does not need critical administrative system to handle its routing process. All the nodes have all the routing information in the network. However, as a drawback OLSR needs that each node sends the updated topology information periodically throughout the network, this increases the protocols bandwidth usage but it is minimized by the MPRs, which allows forwarding the topology messages only.
- To adjust the topological changes reactively, the time intervals for broadcasting the Hello messages are changed. It also increases the protocols suitability with the rapid changes of the source and destination pairs. Also, the link reliability for control messages is not required, since the messages are sent periodically but not sequentially.
- Due to the OLSR simplicity in using interfaces, it is very easy to integrate this protocol in the existing operating systems, without changing the format of the header of the IP messages. OLSR only interacts with the host’s RT.
- OLSR algorithm is well suited for the application which does not tolerate the long delays in the transmission of data packets. OLSR performs best in dense network where the most communication is concentrated b/w a large number of nodes.
- OLSR has also extensions to allow for multiple OLSR interface addresses and also provide the external routing information by giving the possibility for routing to the external addresses. According to this information there is possibility to have nodes in the MANET which can act as gateways to another possible network.

II. Limitations of OLSR

- Bandwidth is used constantly.
- All the routing delays and bandwidth overhead is at the MPR nodes because they act as localized forwarding routers.
- The RT size grows nonlinearly.
- Due to the traffic created by control messages, actual packets may be blocked frequently.

A comparison of the characteristics of the above three mentioned adhoc routing protocols AODV, DSDV and OLSR is given in table 1.4.

Table 1.4: Comparison of AODV, DSDV and OLSR routing protocols

Protocol Property	**AODV**	**DSDV**	**OLSR**
Multiple Routes	No	No	Yes
Distributed	Yes	Yes	Yes
Unidir. Link support	No	No	Yes
Multicast	Yes	No	Yes
Periodic Broadcast	Yes	Yes	Yes
QoS support	No	No	Yes
Reactive	Yes	No	No
Beacon Packets	No	Yes	Yes

14.6 Network Simulator (NS-3)

NS-3 simulator is an open source discrete-event network simulator targeted primarily for networking research and educational purposes. NS-3 focused on improving upon the core architecture, software integration, models, and educational components of ns-2. Some ns-2 models that are written in C++ have already been ported to new simulator ns-3 e.g. OLSR and Error Model were originally written for ns-2. OTcl-based models will not be ported since this would be equivalent to a complete rewrite. The simulation network architecture just looks like IP architecture stack. In ns-3 nodes may have or may not have mobility. Nodes have network devices, which incorporates Layer 1 and Layer 2 and these devices acts as an interface with Layer 3. The layer 3 (Network Layer) supports the Lay.er 4 (Transport layer), which is finally used by Layer 5 objects [57].

14.6.1 Features of NS-3

1. **Based on Programming languages**
   - NS-3 is implemented using C++ language only.
   - With the advancements of hardware capabilities, compilation time is not an issue for ns-3 as like for ns-2.
   - A simulation script is written as a C++ program, which is not possible at all in ns-2 and there is also a limited support for Python in visualization and scripting.

- Bi-language system (C++/Tcl) in ns-2 makes the debugging process very complex, but for debugging in ns-3 only knowledge of C++ is enough.

2. **Based on memory management**
    - As ns-3 is implemented in C++, all C++ memory management functions such as malloc, free, new and delete are still available.
    - There is automatic de-allocation of objects particularly when dealing with packet objects using reference counting.
3. **Based on packets.**
    - In ns-3 a packet consists of a single buffer of bytes and a collection of small tags containing meta-data but in ns-2, a packet consists of 2 distinct regions- one for headers and second for storing payload data.
    - The buffer corresponds exactly to the bits that would be transmitted over a real network and information (Header and Trailer) is added to the packet using subclasses and there is generally easy way to determine if a specific header is attached.
    - But ns-2 never frees the memory used to store packets until simulation terminates, it just repeatedly reuses the allocated packets, as a result, the header region of a packet includes all headers defined as part of the used protocol, even if that particular packet don't use that particular header.
    - Unlike ns-2, there is generally easy way to determine if a specific header is attached.
4. **Based on performance**
    - The total computation time required to run a simulation scales better in ns-3 rather than ns-2. This is due to the removal of overhead associated with the oTcl interpreter and associated with interfacing oTcl with C++.
    - NS-3 performs better than ns-2 in terms of memory management as the aggregation system prevents not required parameters from being stored and also packets do not contain unused reserved header space.
5. **Based on simulation output**
    - NS3 has an emulation mode which allows for the integration with real n/w.
    - NS-2 employs NAM, a Tcl based animation system that produces the visual representation of the network described.

2. Literature Review

Several researchers have done the quantitative and qualitative analysis of MANET routing protocols by means of various performance metrics. For analysis different simulators has been used. Reliability, bandwidth and battery power are the main challenges of MANET which were always taken into consideration for analysis purpose. Although the use of simulations has increased but the credibility of the simulation results has decreased [13]. The main disadvantage of simulation studies are that, all the simulations are general and are based on random assumptions. Due to which, the conclusions of these simulation studies can't be used directly in MANETs applications and it is difficult to choose a proper routing protocol for a given MANET application [14]. In this chapter, all the research that has been already done is analyzed by considering the simulation parameters that have been used and the respective conclusions that have been made.

2.1 General Studies

Much of the initial research was based on the comparison of different routing protocols of MANET. More specifically, they concentrate on comparing the protocols having different routing methodologies like comparing reactive and proactive routing protocols. Next are presented the existing work related to these types of comparisons.

Broch *et al*. (1998) has compared the DSDV, DSR, AODV and TORA protocols using ns-2 simulator and presents the results of simulation of network size of 50 nodes by varying pause times. It was concluded that DSDV performs well when nodes mobility rate and movement speed is low but failed to converge as node mobility increases. TORA was the worst performer in terms of routing packet overhead but still delivered over 90% packets with 10 or 20 nodes. AODV and DSR both perform well at all mobility rates and movement speeds but at high rates of node mobility DSR outperforms AODV [15]. Castaneda *et al.* (1998) have evaluated the performance of SPF, DSDV, TORA, DSR and AODV with respect to fraction of packets delivered, routing delay and end-to-end delay. Both small (30 nodes) and medium sized (60 nodes) networks are used. It was concluded that proactive protocols provide excellent performance in terms of packet delivery fraction and end-to-end delays, however, at the cost of higher routing load. The reactive protocols shows worst packet delivery fraction but are more efficient in terms of the routing load. In spite of maintaining multiple redundant paths, TORA did not perform well. Also, the routing load differentials between all routing protocols reduce with the large number of nodes in the network. Rate of mobility and network size do not seem to affect the performance, like producing higher routing load, higher delay and higher dropped packets [16]. Perkins *et al*. (2001) analyze AODV and DSR by varying pause times with number of nodes (10- 40) and compare packet delivery ratio, average delay, throughput, normalized routing load and normalized MAC load. It was concluded that for application- oriented metrics such as throughput and delay, DSR outperforms AODV in less stressful situations and however AODV outperforms DSR in more stressful situation and DSR consistently generates less routing load than AODV [17].

Bourkerche *et al.* (2001) has done the performance comparison of AODV, DSR and CBRP routing protocols using ns-2 simulator by varying pause times of mobile nodes. Performance metrics used were throughput, normalized routing overhead and end-to-end delay of data packets. It was observed that AODV has lower throughput than DSR and CBRP. CBRP has high routing overhead than DSR [18]. Hong Jiang *at al.* (2001) compared the performance of three routing protocols STAR, AODV and DSR using the GloMoSim simulation environment and also took into account the variety of environmental factors that influence protocol performance. The performance metrics used are control overhead, amount of data delivered, and average latency in packet delivery. It was concluded that STAR achieves better overall performance than AODV and DSR in less dense networks and in case of densely connected networks, STAR performs much better in terms of control overhead while AODV performs better in terms of data delivery [19]. Jorg *et al.* (2003) presented a performance comparison of four different routing protocols (DSR, AODV, ZRP and LAR1) as a function of different network sizes, varying number of nodes and area sizes. The main aim of their work was to test the ability of different protocols to react on frequent network topology changes like link breaks, node movement and so on. They did not include the protocol's performance under heavy load. Therefore only rather small packet sizes and one source node were selected [41]. Jayakumar *et al.* (2007) has also compared the AODV and DSR routing protocols using ns-2 simulator. Four performance metrics were used for evaluation purposes that are average end-to-end delay, Normalized MAC load, packet delivery fraction and normalized routing load. The simulation results brought important characteristics of differences between the two reactive protocols [20].

Mbarusshimana (2007) evaluated the performance of AODV, DSR and OLSR protocols under CBR traffic with different network conditions. It was concluded that the proactive routing protocols are superior over on-demand routing protocols in sending such traffic at the cost of higher routing load [21]. Venugopal *et al.* (2008) evaluated the performance of AODV, DSR and DSDV routing protocols by varying number of nodes while considering packet delivery ratio, no of packets dropped, end-to-end delay and average routing overhead as their performance metrics. Results indicate that DSR and AODV are superior to the DSDV in all cases especially for large number of nodes. For real time traffic AODV is preferred over DSR and DSDV. DSDV's performance is superior during less number of nodes and less mobility and concluded that architecture of routing protocol should take into consideration the features of the lower layer protocols [22]. Mittal *et al.* (2009) evaluated the performance of AODV, DSR and ZRP in variable pause times using QualNet simulator based on average end-to-end delay, PDR and TTL based hop count [23]. Biradar (2009) compared the performance of AODV and DSR and shows that even though they belong to same category but their differences in the protocol mechanics can lead to significant performance differentials and these differentials were analyzed using varying mobility [24]. Karthikeyan *et al.* (2010) compared proactive and reactive protocols using NS-2 simulator, based on significant performance metrics like latency, throughput and packet loss for higher node densities with 10 and 26 nodes. It was observed that AODV produces very minimal latency with consistent throughput even with increasing number of nodes [25].

Harminder (2010) compared the performance of two reactive routing protocols AODV and DSR by using group mobility model and by varying network load, type of traffic (TCP and CBR) and mobility parameters. The metrics used for performance analysis are PDR, end-to-end delay, normalized routing load and routing overhead. It was concluded that in this model with CBR traffic sources, AODV perform better but in case of TCP traffic, DSR perform better in high load or high mobility situation. In all the traffic types, end-to end delay of AODV is less than DSR and routing load of DSR is less than AODV [27]. Manickam (2011) evaluated the performance of three MANET routing protocols such as AODV, DSDV and DSR using NS-2 simulator by varying network size and simulation time. Performance metrics used were average end-to-end delay, throughput and packet delivery ratio. Results showed that DSDV is suitable for limited number of nodes with low mobility. DSR is preferable for moderate traffic with moderate mobility. DSDV produces lowest end-to-end delay. At low traffic AODV performs better in case of packet delivery ratio but performs badly in case of throughput and average end-to-end delay. Overall DSR outperforms AODV when nodes have high mobility [28]. Supriya *et al.* (2011) compared AODV and DSR protocols by using three performance metrics PDR, end-to-end delay and routing load. Simulations were done by varying, number of sources and for each pause time using ns-2 simulator [31].

Srivastva *et al.* (2012) compared DSDV and AODV using ns-2 simulator by changing the parameters packet size and time interval between packet sending. The performance metrics includes delay and throughput [33]. Khanvilkar (2013) compared the network performance of DSR, AODV and DSDV routing protocols by varying simulation time and using throughput, overhead, pause time, delay as performance metrics. Simulation was carried out using ns-2 simulator, under position based routing mechanism [35]. Jassim *et al.* (2013) analyze several scenarios of AODV routing protocol using the OPNET simulator in order to investigate the behavior of IEEE 802.11b with low load traffic size in FTP protocol and to determine and evaluate the performance of fixed and mobile ad hoc networks. The RW mobility model was used as pattern of mobility. The performance metrics were route discovery time, number of hops per route, total route request sent, upload response time, download response time and delivery ratio were studied for various number of nodes and file sizes. Simulation results shows that the scenario of 9 nodes for both fixed and mobile perform better in most of the performance metrics and also performance automatically degrades with the increment in number of nodes [37].

2.2 Mobility based performance comparison

In previous studies random waypoint model was mainly used due to its simplicity and ease in implementation. This has probably been the main reason for its wide spread. But recent research has started focusing on alternative mobility pattern models and routing protocol independent metrics to characterize them. Research that has been done under this category is shown below.

Igbesoko *et al.* (2000) did detailed simulations of the DSDV, AODV and DSR routing protocols across these models- RWP, MM, GMM, RPGM, HMM. They observed that DSR outperformed other protocols followed by AODV and then DSDV [39]. Yasser *et al. (*2010) compared the performance of AODV, DSDV and DSR routing protocol for routing packets between wireless nodes. The scenario they implemented consists of dynamic network size and different number of movement speed at constant pause time [26]. Abouchabaka *et al.* (2011) conducted a behavior study of OLSR using two traffic types VBR and CBR over various mobility models such as Random Way Point, Random Direction. The results show that OLSR behavior changes according to the model and the used traffics [29]. Mazhar *et al.* (2011) compared a number of reactive and proactive routing protocols including AODV, DSR, DSDV, OLSR and DYMO with respect to various mobility models implemented in ns-2. The results show a fair comparison of the capabilities and limitations of different types of mobility patterns and their suitability for routing protocols [30]. Kaushik *et al.* (2012) studied the performance of AODV, DSR and OLSR, DSDV, TORA protocols using various mobility models like RPGM, CMM and RWP based on PDR, end- o-end delay, throughput and routing overhead using ns-2 simulator in the area of 700* 700 m^2 [26]. Saadi *et al.* (2012) conducted the simulations of three protocols AODV, DSDV and DSR using Manhattan Grid Mobility Model in different environments specified by varying mobility rate, network load and number of nodes. They analyzed the performance differentials using NS-2, NAM and AWK. These protocols were compared in terms of PDR, throughput and average end-to-end delay. Results concluded that in terms of PDR and throughput, AODV and DSR performs better than DSDV. However in terms of average end-to-end delay, DSDV appears to be the best one [40].

Sudhesh *et al.* (2012) investigated the performance of MANET routing protocols AODV and DSDV by using freeway and random waypoint mobility model using TCP traffic. The metrics used were PDR, end-to-end delay, Packet loss, throughput, normalized routing load and routing overhead. It was concluded that DSDV performance is better than AODV but at the cost of higher end-to-end delay in both mobility models and it was also observed that both the routing protocols give optimized result in RW mobility model as compared to freeway mobility model [34]. Timcenko *et al.*(2013) studied the performance of three widely used routing protocols DSDV, AODV and DSR with respect to reference point group mobility (RPGM) and entity mobility models (RW, GM and MG) using ns-2 simulator. Results have indicated that the relative ranking of MANET routing protocols depends on mobility models used. DSDV shows stable performance with all mobility models but best with models that have lower level of independence. AODV performs best with reference point group model but with entity models, AODV shows the highest routing overhead and acceptable average delays with the increase of node speed. With MG and GM models, at higher node speeds, DSR experiences lowest routing overhead, on the count of higher average delays. DSR performs best with the RW model [36].

2.3 Scenario based performance comparison

Yatani *et al.* (2004) support children's collaborative learning in a museum. They create a group of two children and make them communicable by using transceivers and Personal Digital Assistants. They have to answer 13 questions related to the exhibitions [51]. Russell *et al.* (2004) outline the teaching environments that would facilitate students in giving real-time feedback for the teacher and then teacher will see the feedback immediately and react depending on the comments given. They believe that this will increase students' participation and collaboration [52]. A.Vasiliou and A.A. Economides have made simulations based on scenarios mostly or educational purposes. More specifically, they studied the benefits of collaborative learning through education based trips with the use of MANETs [54], they investigate the scalability and communication among multiple rescue teams and also they have studied the environmental monitoring from scientists [54] and the collection of data from sensors and Finally they have made performance evaluations for multicast MANETs [54].

Sadavism *et al.* (2005) analyzed that DSDV would be the most suitable protocol for rescue operations, since at any given time the needed routing tables are updated to take the reference point in an evacuation scenario [55]. Reina *et al.* (2011, 2012) showed the behavior of reactive protocols in emergency and disaster scenarios. They found that AODV provides best performance in terms of routing metrics within this category [56]. Vijayavani *et al.* (2012) developed a realistic mobility model by giving the real time observation of MNs movement in a realistic environment. He compared DSDV and AODV with realistic mobility model by taking throughput, delay, packet delivery ratio and protocol overhead as their performance metrics. Results showed that AODV perform better than DSDV routing protocol [32]. Liliana Enciso *et al.* (2013) took a scenario of a emergency and rescue operations in a real urban area. They calculated the density of nodes and the mobility model required for the validation study of DSDV, AODV and CBRP. The experimental results showed that CBRP performs best among them but CBRP a hierarchal routing protocol, losses little information during the routing process. The mean fluctuation and the delay were also much smaller in CBRP protocol than in DSDV and AODV [53].

2.4 Energy based performance comparison

Energy consumption in ad hoc networks is a very important factor. Mainly, portable nodes (being small) impose stringent constraints on the processing power and battery size, which in turn limits services and applications that can be supported by nodes. Hence, this becomes a bigger issue in MANET as each portable node behaves as both an end system and a router at the same time. So, additional energy is required to forward packets from other nodes. Some research that has been done is described below. Chang *et al.* (2000) proposed an algorithm to select the routes until the drain out of the batteries is maximized. Also, to maximize the lifetime of the network, they proposed that the traffic should be routed such that the energy is balanced among the nodes in proportion to their energy consumption, instead of routing to minimize absolute consumed power [43]. Xu *et al.* (2000) proposed two algorithms, one is Adaptive Fidelity Energy-Conserving Algorithm (AFECA) that makes the use of information about local node density for adjusting the length of time the node is in sleep mode and another one is Basic Energy Conserving Algorithm (BECA) that puts the radio of a node into “sleep mode” in order to reduce the listening time energy consumption of the node [44]. Another proposal by Cho *et al.* (2001), studied a routing scheme in home adhoc networks where packets are routed through the outlet-plugged devices instead of battery-powered devices to prolong the life time of the batteries [42].

Some researchers did not work on proposing any algorithm, but instead, compared the relative performance of established routing protocols in energy constraint network. Cano *et al.* (2000) measured and compared the energy consumption behavior of the AODV, DSR, TORA and DSDV. The basic methodology they followed is, firstly select the most representative parameters for a MANET and then simulating a basic scenario by varying the selected parameters. The five selected parameters were the mobile node number, the moving area dimensions, the node’s mobility pattern, the data traffic pattern and the number of actual traffic sources [45]. Ahvar *et al.* (2007) compared the performance of DSR, AODV and LAR1. The performance differentials were analyzed by varying network load, mobility and network size. They concluded that LAR1 performed much better than expected for high density networks than other ones. DSR resulted least messaging overhead. During high density networks, AODV generated higher volume of control packets even more than the LAR1 but in low density networks, LAR1 generated higher volume of control packets. End-to-end delay was constantly greater in LAR1 than those of the two, in low density networks and was constantly greater in AODV than other two in high density networks, but when the node mobility was increased from 0 to perpetual mobility, LAR1 resulted in the highest increase rate in delay [46]. J. Khan *et al.* (2011) analyzed four routing protocols (DSR, AODV, DSDV, TORA) and showed that the energy consumption of all the protocols was almost same in small size networks. But, in large and medium size networks, DSR and AODV showed better performance and also TORA protocol showed a poor efficiency in terms of power [48]. Bararti *et al.* (2012) compared the performance of AODV and DSR with respect to average energy consumption and routing energy consumption. Then, an evaluation of how the varying metrics (Number of nodes, Topology size, Packet Rate and Maximum no. of nodes) in different scenarios affect the power consumption in these protocols was discussed. Results concluded that DSR was efficient with most mobility scenarios but at the cost of routing overhead and on the other hand AODV, is efficient with some mobility scenarios by eliminating routing overhead of the DSR protocol. It was also shown that DSR resulted better performance with the perspective of energy consumption for low density networks and also for high density networks than AODV. However, AODV was found effective for low loads. They also analyzed that by considering the routing overhead of AODV and reducing the number of control packets, life time of the network can be increased [49].

It is seen that all the simulations are done by varying some parameters which are shown below.

- Number of nodes
- Interval
- Speed of Nodes
- Topology
- No. of Packets
- Type of Traffic
- Mobility Pattern
- Pause Time
- Packet Size
- Simulation

3. Problem Statement

3.1 Problem in Existing Simulation Studies

In this thesis basic simulation studies are introduced that have been made the last years on MANET routing protocols. As mentioned earlier the disadvantage of these studies is that they are not based on real life scenarios. Probably, this is the only reason MANETs have not been used in day to day applications although they have more advantages than traditional networks. Some of these advantages are:

MANETs could increase mobility and flexibility as it can be brought up and torn down in very short time.

These networks have better coverage in rough areas due to multi-hop relaying

These networks could be more economical in some cases as they eliminate fixed infrastructure costs and reduce power consumption at mobile nodes.

They are more robust than conventional wireless networks because of their non-hierarchical management mechanism.

Due to short communication links (node –to-node instead of node to a central base station), Radio emission levels could be kept at low level and this increases spectrum reuse possibility.

Communication beyond Line Of Sight is possible at high frequencies.

Despite the aforementioned advantages and the potential application possibilities, MANETs are yet far from being deployed on commercial bases. Although various routing protocols are tested for adhoc network using various performance metrics, but successfully transmission of data need better optimization. It is analyzed that one single protocol will probably not be able to work efficiently across all operating conditions and entire range of design parameters and that’s the reason why various real life scenarios should be tested. If as much as simulations are done based on real life, then in result each protocol could be assigned to each scenario with certain parameters and it would result fast implementation for those scenarios.

3.2 Aim of research

The overall goal of this thesis is to evaluate the performance of different routing protocols for MANET in realistic environments and to specify the best choice for each scenario and for certain parameters. For the fulfillment of above said, three real life scenarios are taken and their performances are evaluated using NS-3. In the first scenario, students investigate the historical site where number of packets being sends and number of nodes in the network are changed. In second scenario rescue operation is studied where the speed with which the nodes move and number of mobile nodes are varied. And in last scenario students explore the national park where direct sequence spread spectrum (DSSS) rate and interval of two packets are varied. Different parameters are varied in different scenarios according to their importance in their respective scenario.

4. Implementation

4.1 Experimental Environment

Our experimental platform mainly consists of configuring and installing VMware Player, Linux Operating System and Network Simulator.

4.1.1 Hardware and Software Specifications

Some specifications of System parameters that are used in implementation are given in table 4.1.

Table 4.1: Hardware and Software Specifications

System Parameters	**Specifications**
VMware Player	VMware Player- 6.0.3
Virtual Machine	Ubuntu-12.04, 64bit
Network Simulator	NS-3.33
Programming Platform	.txt file (saved as .cpp)
Graphical Representation	Microsoft Office Excel-2010
Host Machine	Windows 7

4.1.2 Architectural Overview

VMware Player is a hypervisor which is installed on host machine. A virtual machine (a computer defined in software. It’s like running a PC on your PC) is installed in VMWare Player and NS-3.33 is installed in virtual machine. This is the architecture of whole experimental environment that is shown in fig. 4.1.

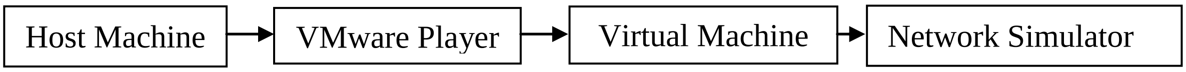

Fig. 4.1 Architectural Flow of Hardware Requirements

4.2 Methodology for comparative analysis of Protocols

To make a comparative analysis of routing protocols, involved in this case study, it is necessary to establish and consummate a logical sequence of steps, illustrated in fig. 4.2.

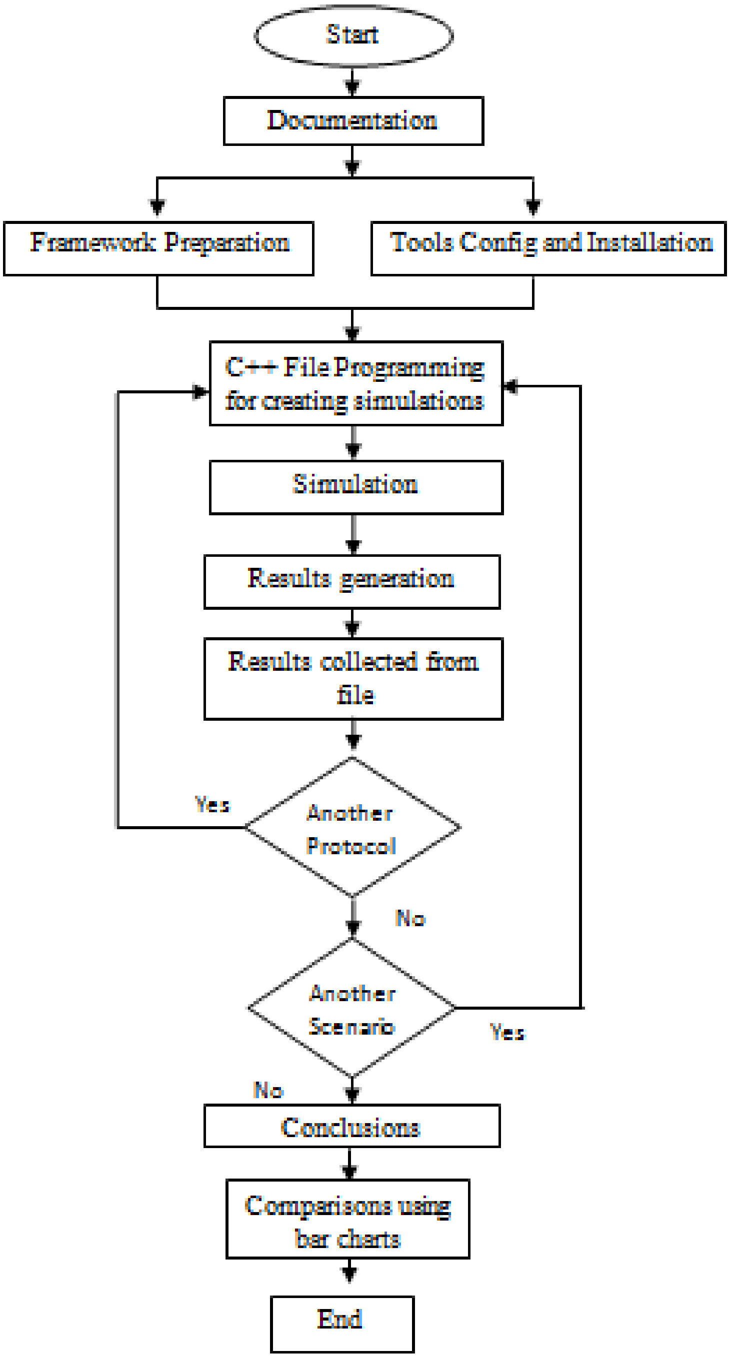

Fig. 4.2 Flow Chart for comparative analysis of Routing Protocols

4.2.1 Implementation of C++ script for creating Simulations

Once the build of NS-3 is done and all tests pass, script can be run by writing following command in terminal of virtual machine.

```
./waf –run progname
```

But to run your simulation under a tool, valgrind or gdb, following command is used to find out the reason of error, if any present.

```
./waf –run progname –command-template=”insight %s”
```

Steps to follow

1) Include required modules in script file. List is shown below.

ns3/core-module.h
ns3/network-module.h
ns3/mobility-module.h
ns3/config-store-module.h
ns3/wifi-module.h
ns3/energy-module.h
ns3/internet-module.h
ns3/aodv-helper.h
ns3/aodv-routing-protocol.h
ns3/delay-jitter-estimation.h
iostream
fstream

Fig. 4.3 List of header files included in C++ script file

2) Initialize all following metrics to 0.

- received_packets
- total_delay
- total_energy_consumption

3) Four different modules are used that are described below:

- void ReceivePacket
    i. Input: socket
    ii. Output: Output is recorded in NS_LOG_UNCOND file. It records received number of packets until now; ip address and port number of sender; received packet size and delay generated.
- static void GenerateTraffic
    i. Input: socket, pkt_size, node, pktCount and pktInterval.
    ii. Output: Generated Traffic
    iii. Above simulation parameters are set using users given input and according to that, traffic is generated.
- void TotalEnergy
    i. Input: oldValue, totalEnergy
    ii. Output: Total energy consumed by radio at every unit interval. This output is also recorded in NS_LOG_UNCOND file.
- int main
    i. Input: argc.,argv.

ii. Initialize simulation parameters like startTime, numPackets, phyMode, packetSize, interval, numNodes and speed. According to the scenario these values are affected. e.g. In scenario 1, no. of packets and no. of nodes are varied and all other are left constant; In scenario 2, speed and no. of nodes are varied and in scenario 3, DSSS Rate and interval is varied.
iii. Set Wifi parameters like set wifi standard, TxGain, RxGain, PropagationDelay, add Propagation Loss, SetChannel, SetRemoteStationManager, SetType.
iv. Set Mobility Model parameters and energy model parameters.
v. Assign IP addresses.
vi. Bind all to each other.
vii. Run the simulator and store the results in NS_LOG_UNCOND file.

4.3 Description of all real world scenarios

In this thesis, three routing protocols are compared and evaluated using simulations by varying number of parameters that affects the reliability of network in a different scenarios using NS-3. Simulations results are analyzed based on different performance metrics. Performance metrics taken into considerations are given below.

- **Average Delay**: It is the time taken by the packet to reach the destination node's MAC protocol from source node's MAC protocol. Delay is one of the main concerns of network quality of service especially in time constrained transmissions.
- **Packet Delivery Ratio**: It is the ratio between the numbers of packets originated by the application layer and the number of packets received by the sinks at the destination. It describes the loss rate which in turn affects the maximum throughput that the network can support. It represents the reliability of the communication.
- **Throughput**: The average rate of successful message delivery over a communication channel.
- **Total Energy Consumption:** The total energy conserved by the portable devices.

4.3.1 Historical site visit

This scenario describes a trip in historical site performed by a school to provide students a holiday and experiences outside their everyday activities. More specifically, the aim of this scenario is to know about Taj Mahal, a white marble mausoleum, widely recognized as “the jewel of Muslim art in India. In this scenario, a group of nodes which includes students and teachers and 1 tour guide is made. Students were told to analyze the mughal art done by mughals and to know about its history, myths and replicas and to make an assignment on it. Further, it is not allowed to interact with each other i.e. no collaboration is succeeded in any point. They can also take the help from internet to complete their assignment but in Taj Mahal, there is no such established network due to its security and also, 1 tour guide could not be able to guide them properly as lots of external noise may be present. So, we propose to use mobile adhoc network in this group in which, tour guide would be providing them hand held devices through which students can watch videos, images and documents as they reach near any art or something else. So, in this way 1 tour guide can guide so many groups.

MANET is made very easily at low cost and at any time between hand-held cellular based devices having wireless interface and computational power. So MANET is being used in our scenario. In a created scenario we have assumed that nodes move in a same direction behind the tour guide with a constant speed of 2 m/s which is the average walking speed.

During this trip, the main factor that can affect the communication reliability is number of nodes and number of packets being sent by tour guide. The DSSS Rate is 11 Mbps. Some of the simulation parameters taken into consideration are shown in Table 4.1

TABLE 4.2 Simulation parameters for historical site visit

Simulation Parameters	**Values**
Number of Nodes	5,10,15,20,25,30
Senders	Tourist guide
Receivers	Students and teachers
Speed of nodes	$2m*sec^{-1}$ (avg. walking speed)
Messages	Text messages, videos, audio, photographs
Movement	Gauss-Markov Mobility Model
Area	1000*1000 m

Protocols	DSDV, AODV,OLSR
DSSS Rate	11Mbps
Data Rate	2200 Kbps
Interval	0-0.015
Packet Size	4096 bytes
No of Packets	50, 100, 150, 200, 250, 300, 350, 400, 450, 500
Simulation Time	180 sec

4.3.2 Rescue operation scenario

MANET can be made during any rescue operation like during a cloud burst in Uttarakhand last year. Rescue and emergency operations are characterized by very dynamic environments, where time is a critical factor. There is a lot of activity and movement on the site as many nodes may arrive and leave the site at different times, e.g. in cases where resources like ambulances, helicopters, fire fighters and police are called out from one to other incidents in the area. Hence in this environment, infrastructure network fails to exist and so the form of a MANET is essential.

In rescue operations, one person is given the responsibility of the whole team and this person has the full overview of all the members of the team at all times. Every member of the team informs him about the evidence they found and any other important information by sending him files, videos or voice messages. During initial times of operation, team has no information about the missing persons but know only about their location the last time they communicate with their base, so the team will search in blind. Hence the mobility model used is Random Direction mobility model.

In this scenario, it is seen that number of nodes and their speed affects the communication. For simulations, DSSS Rate is 11 Mbps, and the speed the team members might have is from 5m/s (corresponds to the speed of average human walking) to 55m/s (speed of the vehicle). Some of the simulation parameters considered is given below.

Table 4.3 Simulation parameters for rescue operation scenario

Simulation Parameters	**Values**
Number of Nodes	10, 20, 30, 40, 50, 60
Senders	Rescue team members
Receivers	Commander
Speed of nodes	5,10, 15, 20, 25, 30, 35, 40, 45, 50m *sec^{-1}

Messages	Text messages, videos, audio, photographs
Movement	Random Direction Mobility Model
Area	500 *500 m
Protocols	DSDV, AODV,OLSR
DSSS Rate	11Mbps
Data Rate	164 Kbps
Interval	0-0.2 sec
Packet Size	1024bytes
No of Packets	150
Simulation Time	180 sec

4.3.3 National Park Exploration

This scenario describes a educational trip to a national park performed by a school to provide students experiences outside their everyday activities. More specifically, the aim of this scenario is to analyze the resource management, preservation structure, variety of species, flora of park and etc. So, in this scenario, a group of 20 students and 1 teacher is made. The students should be able to record their activities and be able to communicate with their teacher for sending the videos, pictures and messages according to their assignment, to their teacher. Further, on the basis of their recorded activities they will be given marks.

A National Park should be left untouched from human structures. So, it is not a good idea to install towers and antennas in such environmentally protected areas. Furthermore, it is not easy and cost-effective to install and maintain the networking infrastructure at such a desert location with rough terrain, with limited resources and access and may create the problems in communicating with their teacher. So a temporary network is required which doesn't require any infrastructure. In this case, use of MANET is imperative.

MANET is made very easily at low cost and at any time between hand-held cellular based devices having wireless interface and computational power. So MANET is being used in our scenario. To know which mobility model is to be used, we take the case that all nodes are moving in same direction with a constant speed of 2 m/s. Due to this Gauss-Markov mobility model is used [14].

During the field trip, the main factor that can affect the communication reliability and delay is the amount of traffic received and sent by the participants. Interval plays an important role in the simulation as according to our definition, traffic is number of packets sent in 1 second. Traffic is also affected by number of packets and packet size. Furthermore, the traffic is Constant Bit Rate (CBR), which means packets are send with same rate continuously. Simulation parameters are described below.

Table 4.4 Simulation parameters for National Park Exploration

Simulation Parameters	**Values**
Number of Nodes	21
Senders	Students
Receivers	Teacher
Speed of nodes	2 m $*\text{sec}^{-1}$
Movement	Gauss- Markov Mobility Model
Area	1000 *500 m
Protocols	DSDV, AODV,OLSR
DSSS Rate	1-2-11Mbps
Data Rate	164 Kbps
Interval	0-0.05-0.1-0.15-0.2-0.25-0.3-0.35-0.4-0.45-0.5 sec
Packet Size	256-512-1024-2048-4096 bytes
No of Packets	250
Simulation Time	180 sec

5. SIMULATION RESULTS

In this section, simulation results are shown for each scenario and in each scenario three protocols are compared based on the performance metrics.

5.1 Historical site visit

In this scenario protocols are compared by varying number of nodes and number of packets sent by each node based on the performance metrics. For variation six different group sizes (5, 10, 15, 20, 25, 30 nodes) and ten different number of packets (from 50-500 with 50 packet step) are used.

- Packet Delivery Ratio

PDR represents how reliable the communication is i.e. higher the PDR, the better the communication reliability is.

In Fig. 5.1 AODV and OLSR outperforms DSDV in every case. OLSR shows best performance when number of packets is 500 resulting 81.65% PDR. At 100, 150, 200 and 400 packets AODV outperforms OLSR, but in all other cases OLSR shows best results.

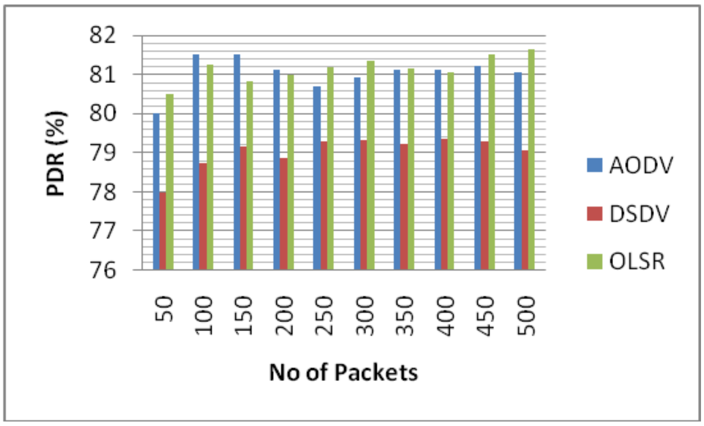

Fig. 5.1 PDR vs. No. of Packets being send when nodes are 5

Fig. 5.2 shows that when no. of nodes is increased to 10 AODV gives worst results. When number of packets is 150, 200, 250, 500, DSDV outperforms OLSR, but at high traffic OLSR performs best from two of them.

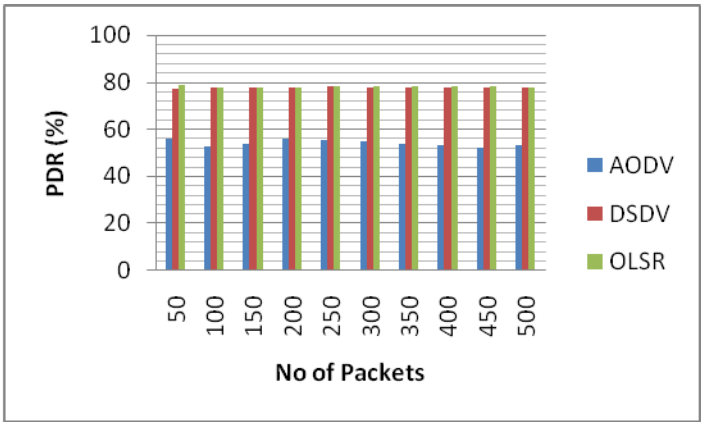

Fig. 5.2 PDR vs. No. of Packets being send when nodes are 10

In Fig. 5.3 AODV shows worst performance. OLSR outperforms DSDV in every case except when number of packets is 50 and 100.

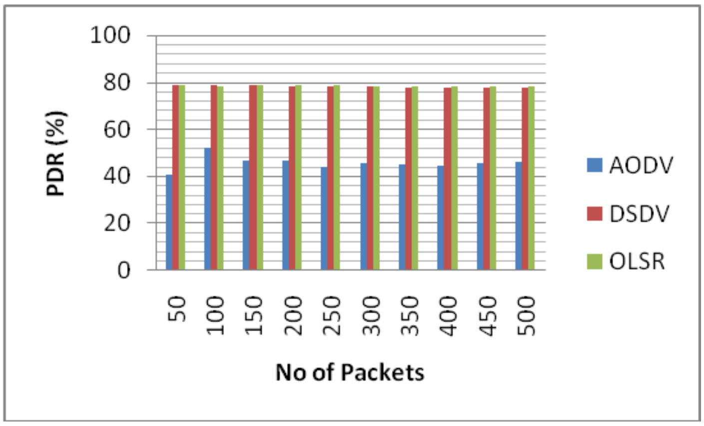

Fig. 5.3 PDR vs. No. of Packets being send when nodes are 15

Fig. 5.4 shows that DSDV and OLSR outperform AODV in every case. OLSR outperforms DSDV only when numbers of packet are 50 and in all other cases DSDV shows best performance by giving maximum packet delivery ratio.

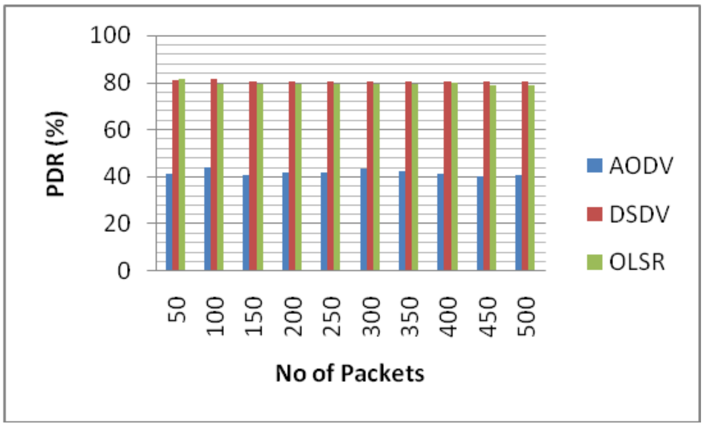

Fig. 5.4 PDR vs. No. of Packets being send when nodes are 20

In Fig. 5.5 it is observed that in every case OLSR outperforms DSDV and AODV.

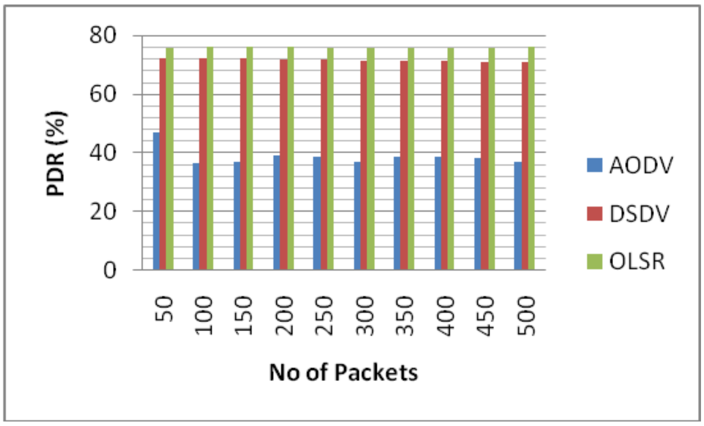

Fig. 5.5 PDR vs. No. of Packets being send when nodes are 25

In Fig. 5.6 OLSR and DSDV outperforms AODV in every case and OLSR performance is better than DSDV.

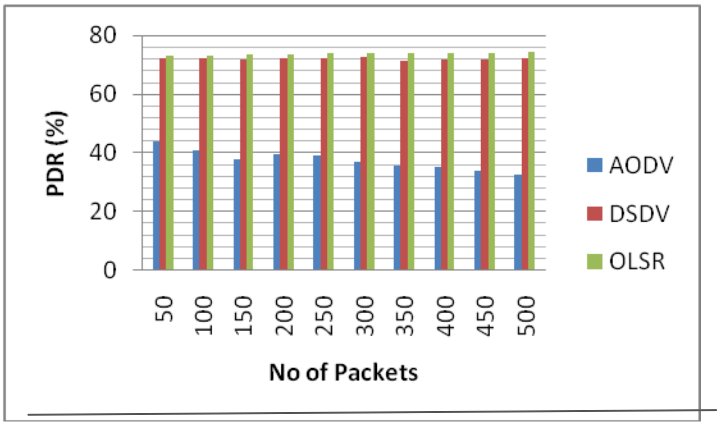

Fig. 5.6 PDR vs. No. of Packets being send when nodes are 30

- Energy consumption

Energy consumption is very important factor. In our scenario nodes may not have the chance to recharge their portable devices. In following figures, energy consumption is compared between these protocols at 11 Mbps DSSS Rates. In Fig. 5.7 it is shown that AODV consumes maximum energy and DSDV consumes minimum.

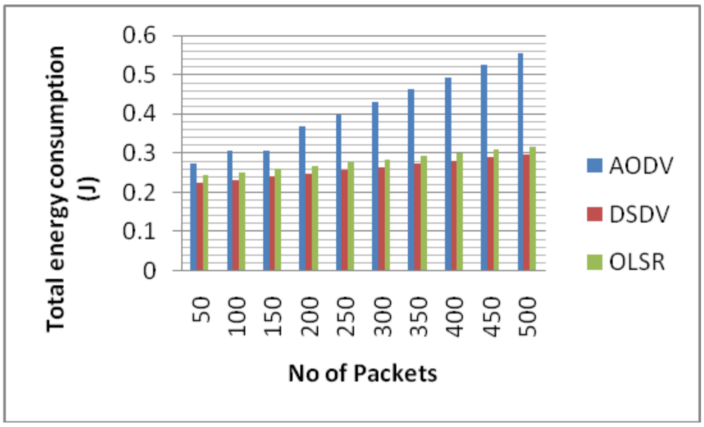

Fig. 5.7 Total energy consumed vs. No. of Packets being send when nodes are 5

Fig. 4.8 shows that AODV consumes maximum energy and DSDV consumes minimum of 0.223626 Joules.

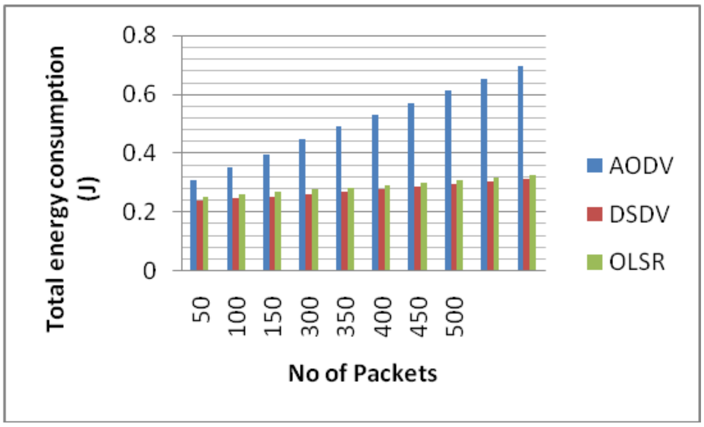

Fig. 5.8 Total energy consumed vs. No. of Packets being send when nodes are 10

In Fig. 5.9 it is shown that AODV consumes maximum and DSDV consumes minimum energy.

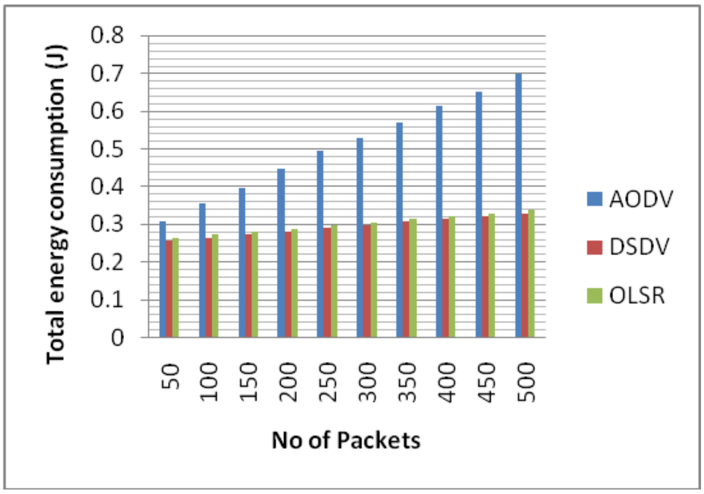

Fig. 5.9 Total energy consumed vs. No. of Packets being send when nodes are 15

In Fig. 5.10 AODV consumes maximum energy and OLSR consumes minimum energy.

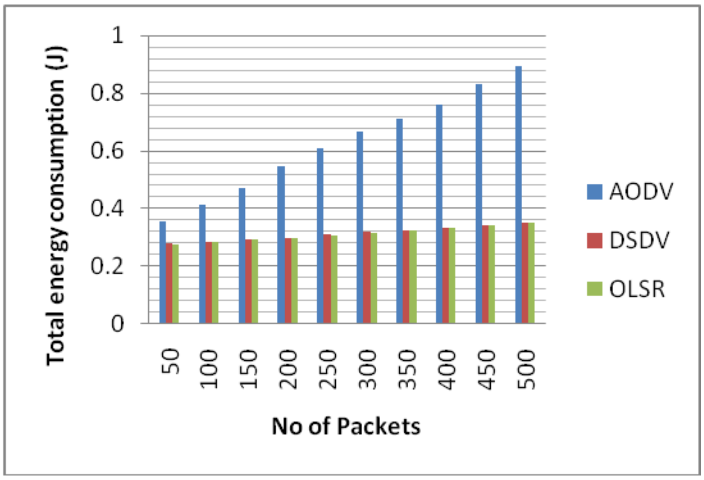

Fig. 5.10 Total energy consumed vs. No. of Packets being send when nodes are 20

Fig. 5.11 shows that AODV consumes maximum energy and OLSR consumes minimum energy.

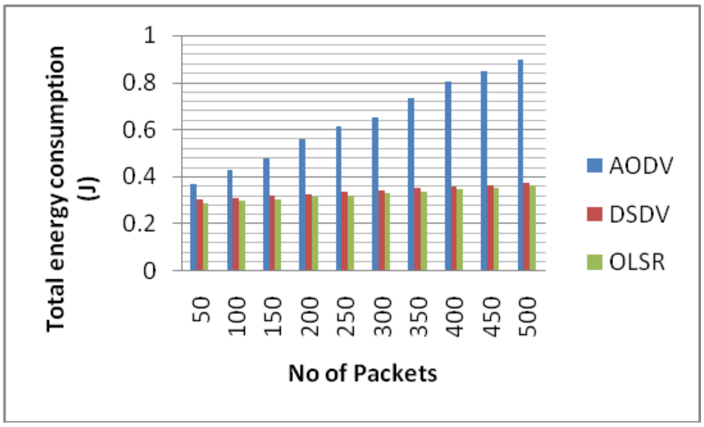

Fig. 5.11 Total energy consumed vs. No. of Packets being send when nodes are 25

Fig. 5.12 shows that AODV consumes maximum energy and OLSR consumes minimum.

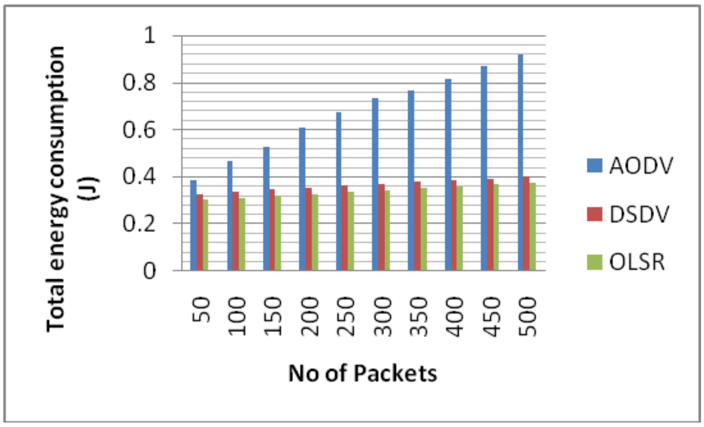

Fig. 5.12 Total energy consumed vs. No. of Packets being send when nodes are 30

- Throughput

It is the average rate of successful message delivery over a communication channel. In following figures, throughput is compared between these protocols at 11 Mbps DSSS Rates.

Fig. 5.13 shows that when number of packets is 150, DSDV results more throughput than AODV and OLSR. Otherwise DSDV shows worst performance in every case. AODV outperforms OLSR at 100, 250, 300, 400, and 450 and in all other cases OLSR outperforms AODV.

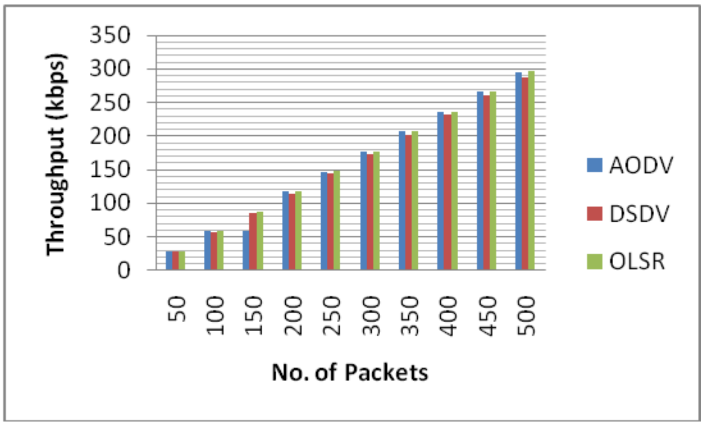

Fig. 5.13 Throughput vs. No. of Packets being send when nodes are 5

Fig. 5.14 shows that when number of packets is 150, 200, 250 and 500 DSDV outperforms OLSR and in all other cases OLSR shows best results.

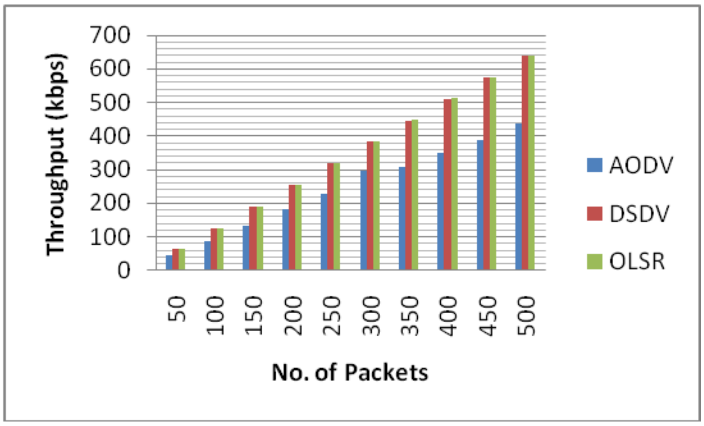

Fig. 5.14 Throughput vs. No. of Packets being send when nodes are 10

Fig. 5.15 shows that when number of packets is 50 and 100 DSDV outperforms OLSR.

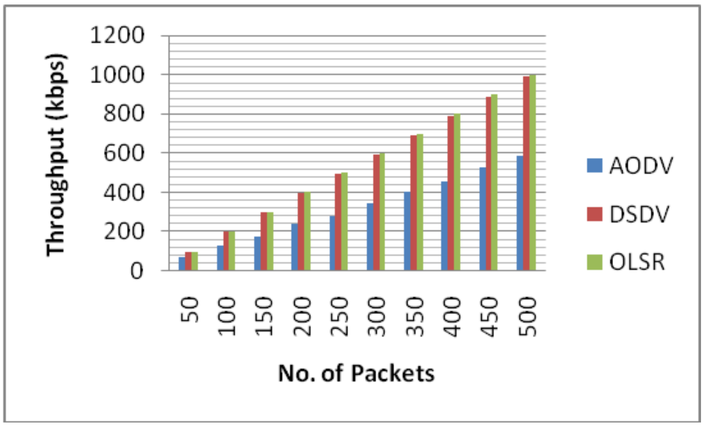

Fig. 5.15 Throughput vs. No. of Packets being send when nodes are 15

In Fig. 5.16 AODV shows worst performance and DSDV outperforms OLSR in every case.

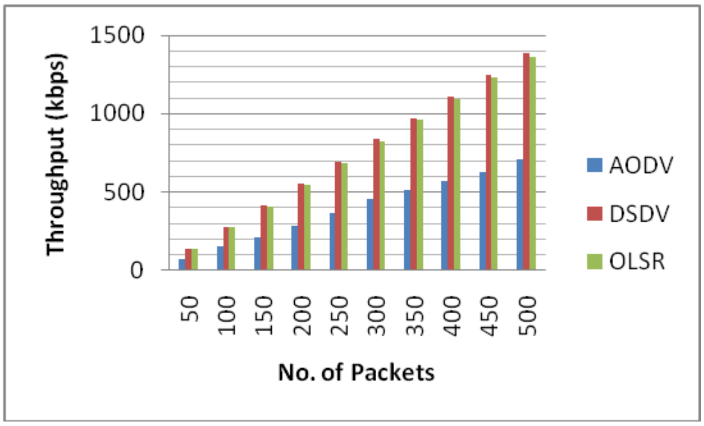

Fig. 5.16 Throughput vs. No. of Packets being send when nodes are 20

In Fig. 5.17 OLSR outperforms DSDV in every case and AODV shows worst performance in all cases.

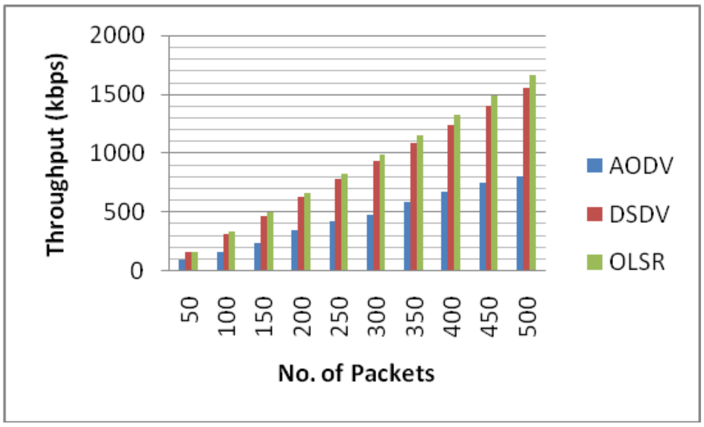

Fig. 5.17 Throughput vs. No. of Packets being send when nodes are 25

Fig. 5.18 shows that OLSR outperforms DSDV in every case and AODV shows worst results in all cases. OLSR shows best results by giving throughput of 1959.34 kbps when no of packets are 500 and number of nodes are 30.

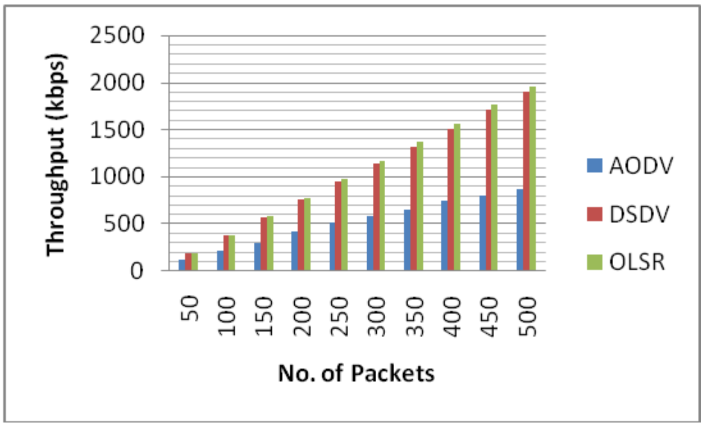

Fig. 5.18 Throughput vs. No. of Packets being send when nodes are 30

- Average delay

To check the communication reliability, average delay is calculated. In following figures, throughput is compared between these protocols at 11 Mbps DSSS Rates.

In Fig. 4.19 it is seen that AODV always shows worst results in each case. Till when number of packets are 250, DSDV and OLSR shows same results and after that the difference between them is increased with DSDV results best.

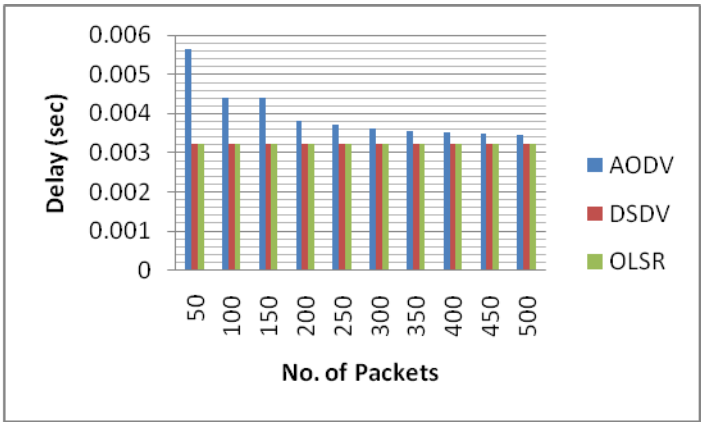

Fig. 5.19 Delay vs. No. of Packets being send when nodes are 5

In Fig. 5.20 DSDV and OLSR outperforms AODV and DSDV always outperforms OLSR.

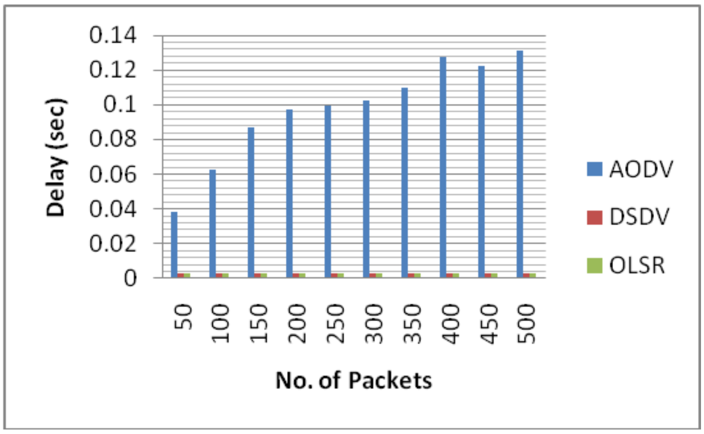

Fig. 5.20 Delay vs. No. of Packets being send when nodes are 10

Figure 5.21 shows that as the traffic increases, AODV start showing worst results and DSDV shows less delay than OLSR till when numbers of packets are 300. After that OLSR outperforms DSDV. In this case DSDV gives minimum delay of 0.0032 seconds when number of nodes are 15 and number of packets are 50.

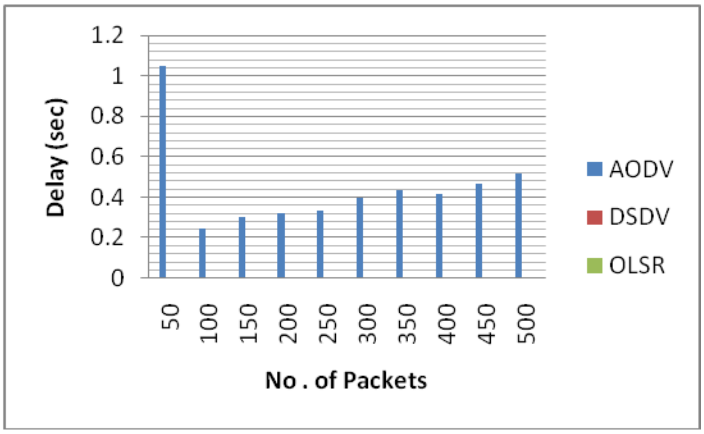

Fig. 5.21 Delay vs. No. of Packets being send when nodes are 15

In fig. 5.22 with increase in traffic AODV is showing maximum delay. DSDV outperforms OLSR during when number of packets are 50, 100, 150, 200, 250 and 300.

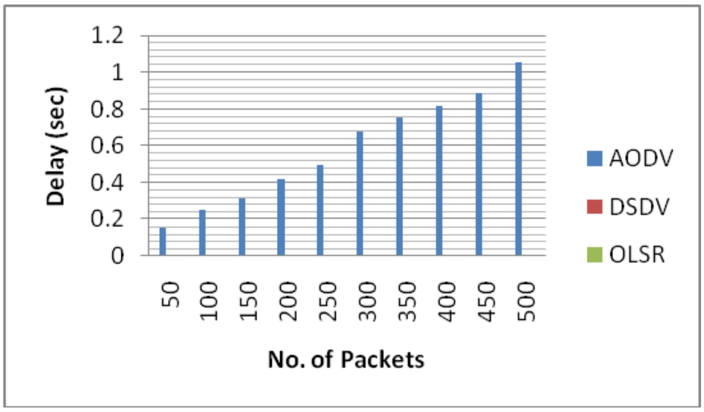

Fig. 5.22 Delay vs. No. of Packets being send when nodes are 20

Figure 5.23 shows that when number of packets is 300,350,400,450 and 500, OLSR outperforms DSDV. Behavior of AODV remains same in each case.

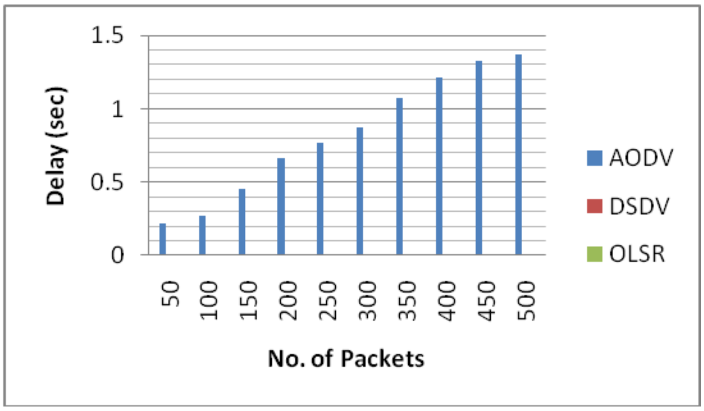

Fig. 5.23 Delay vs. No. of Packets being send when nodes are 25

In Fig. 5.24 AODV behaves same as in earlier cases i.e. it shows worst results. Till number of packets are 300, DSDV gives less delay than OLSR and after that OLSR outperforms DSDV.

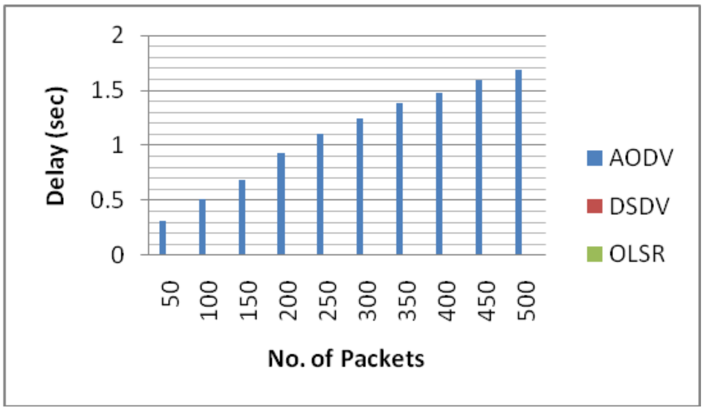

Fig. 5.24 Delay vs. No. of Packets being send when nodes are 30

5.2 Rescue operation scenario

: In this scenario comparisons are based on different values of number of nodes and speed. Eight group sizes (10, 20, 30, 40, 50, 60, 70, 80 nodes) and ten different speed values (5m/s – 50m/s with 5m/s step) are taken while doing simulations.

- Packet delivery ratio

It is analyzed that how number of nodes and their speed affect the packet delivery ratio as PDR represents the reliability the communication.

In Fig. 5.25 OLSR shows 100% PDR . DSDV and OLSR outperform AODV in every case.

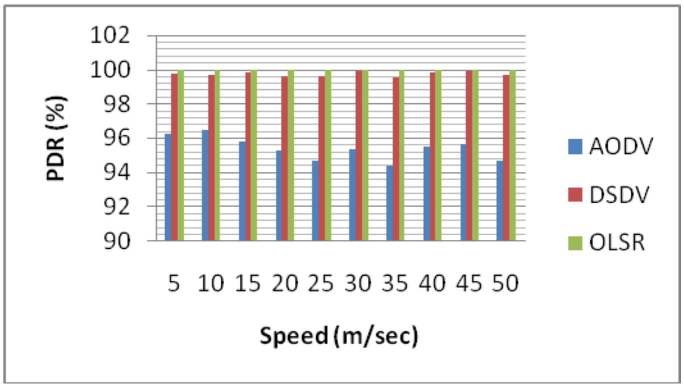

Fig. 5.25 PDR vs. Speed when nodes are 10

Figure 5.26 shows that PDR is maximum in case of OLSR and worst in case of AODV. AODV outputs about 90% PDR.

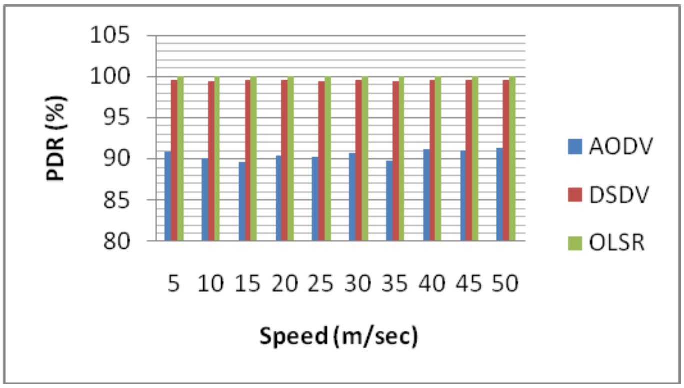

Fig. 5.26 PDR vs. Speed when nodes are 20

In Fig. 5.27 it is observed that AODV performance is degraded to 60% PDR. OLSR outperforms DSDV but with little variations.

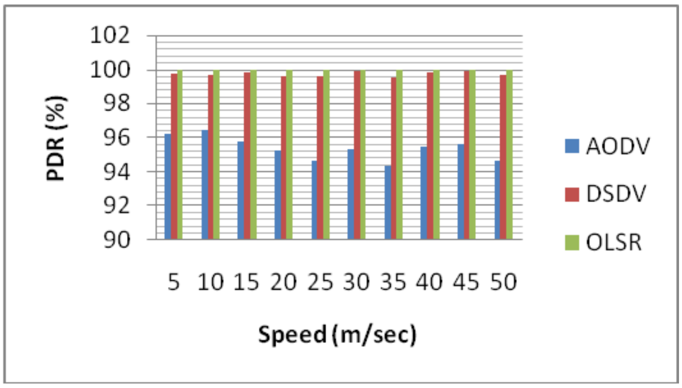

Fig. 5.27 PDR vs. Speed when nodes are 30

In Fig. 5.28 performance of AODV further decreases to near about average of 40%. OLSR outperforms DSDV in every case.

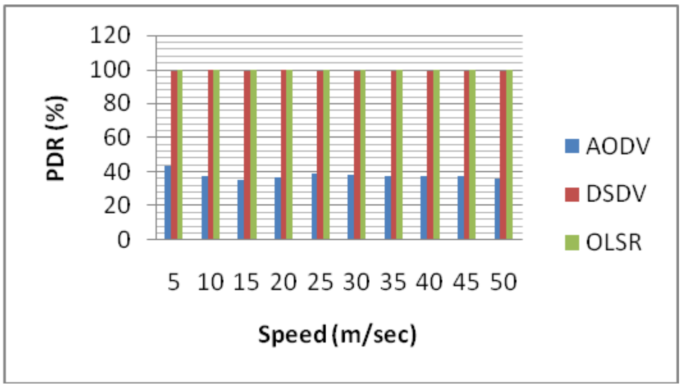

Fig. 5.28 PDR vs. Speed when nodes are 40

In Fig. 5.29 AODV outputs about 30% PDR. OLSR shows best results by giving the best packet delivery ratio.

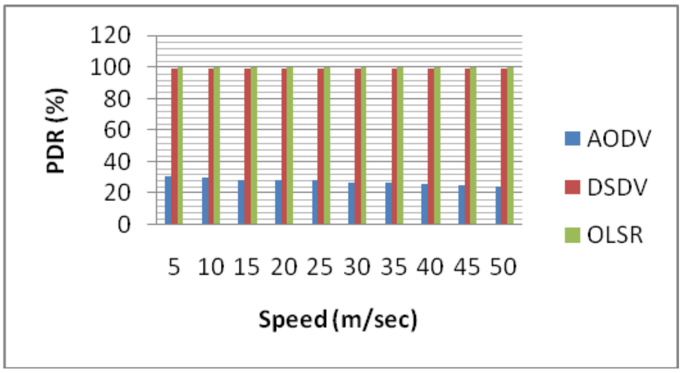

Fig. 5.29 PDR vs. Speed when nodes are 50

In Figure 5.30 AODV outputs about 20% PDR which is worst and OLSR outputs best packet delivery ratio among three of them.

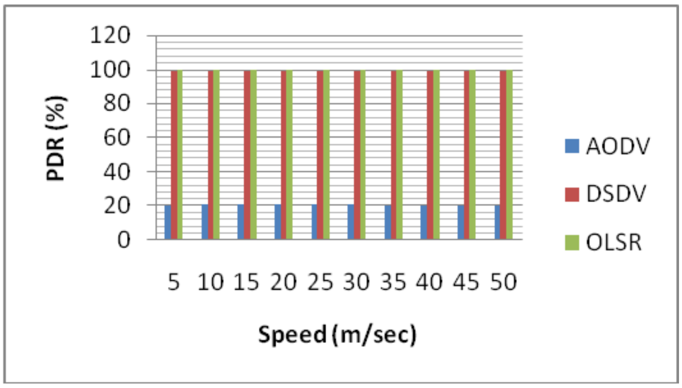

Fig. 5.30 PDR vs. Speed when nodes are 60

Fig. 5.31 shows that AODV results 18% PDR. OLSR and DSDV outperform AODV and also OLSR shows better results than DSDV.

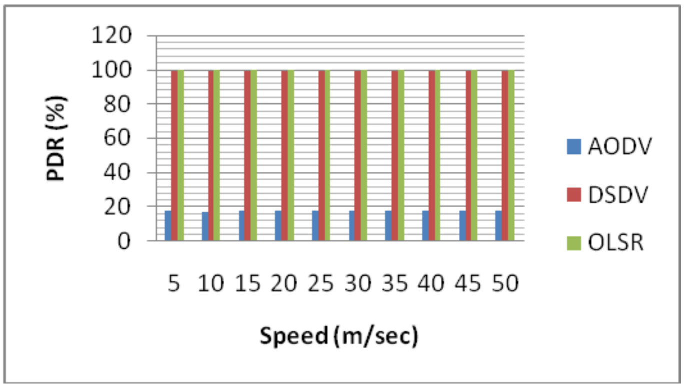

Fig. 5.31 PDR vs. Speed when nodes are 70

In Fig. 5.32 performance of AODV further reduces to 15%. OLSR outperform DSDV in every case.

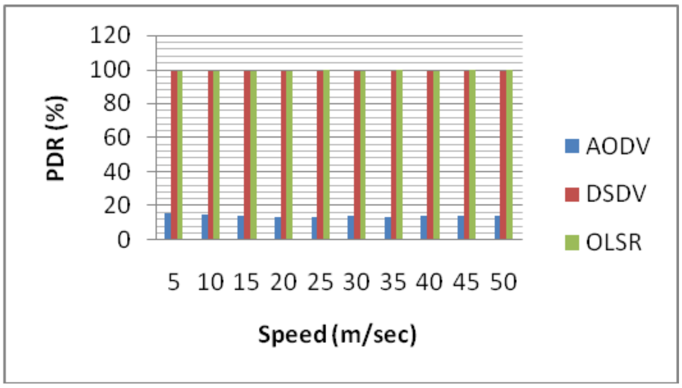

Fig. 5.32 PDR vs. Speed when nodes are 80

- Throughput

Routing protocols are compared based on the throughput they achieve and then results are categorized based on the different speeds the nodes have.

In Fig. 5.33 AODV shows worst throughput among all three protocols and OLSR outperforms DSDV in each case.

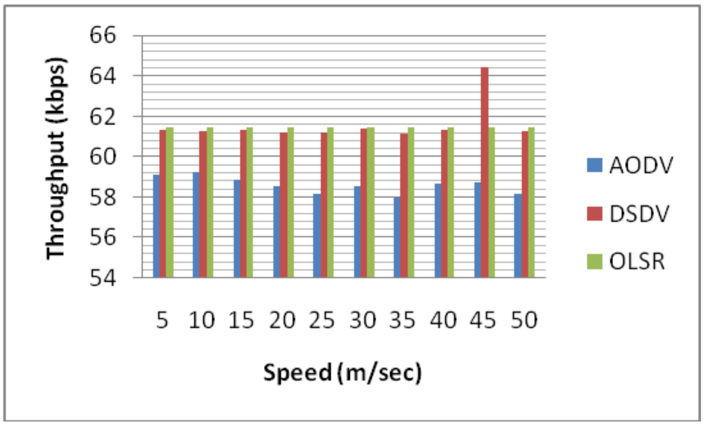

Fig. 5.33 Throughput vs. Speed when nodes are 10

In Fig. 5.34 OLSR and DSDV outperforms AODV in every case. OLSR shows better results than DSDV.

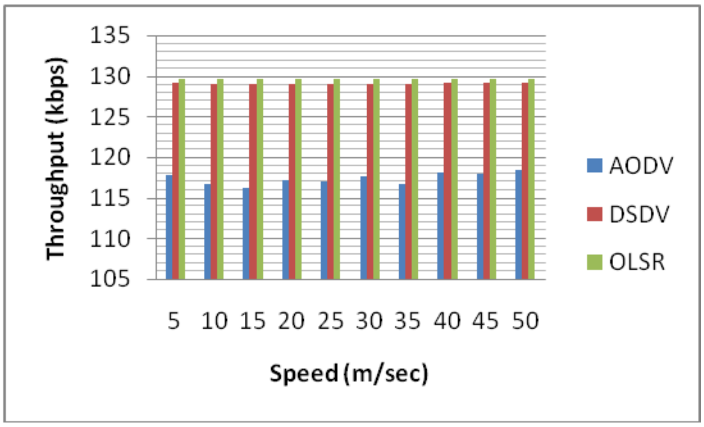

Fig. 5.34 Throughput vs. Speed when nodes are 20

In Fig. 5.35 AODV shows worst performance and OLSR shows best performance among these three protocols in this case.

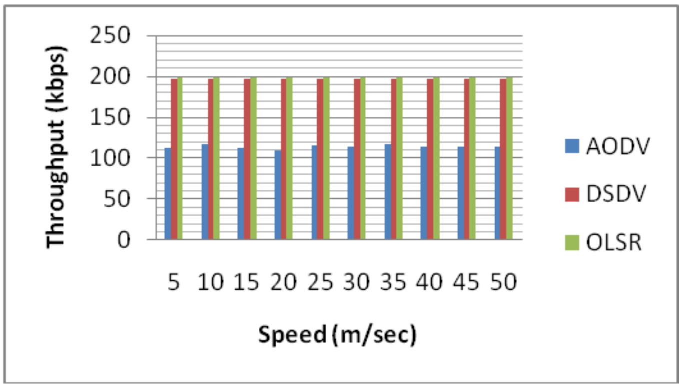

Fig. 5.35 Throughput vs. Speed when nodes are 30

Figure 5.36 signifies that AODV performance starts degrading with increase in speed except at 5 m sec^{-1} where as DSDV and OLSR outperform AODV and show more throughput as compare to previous case and also OLSR outperforms DSDV.

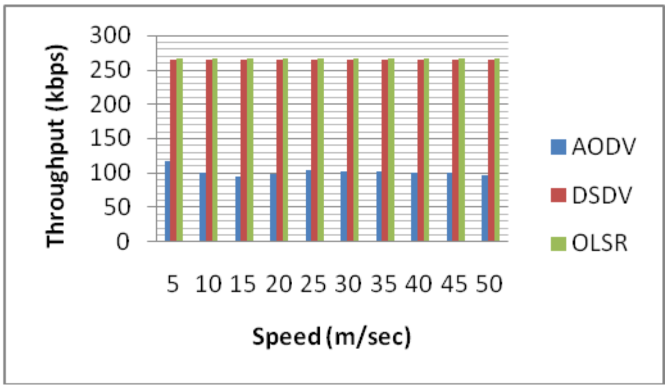

Fig. 5.36 Throughput vs. Speed when nodes are 40

In Fig. 5.37 AODV shows more throughput at 10 and 15 $msec^{-1}$ as compare to previous case but all over it shows worst performance. OLSR outperforms DSDV.

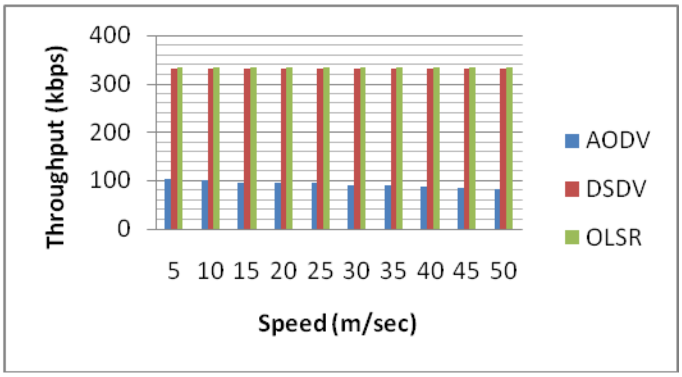

Fig. 5.37 Throughput vs. Speed when nodes are 50

In Fig. 5.38 AODV performance degrades very badly but DSDV and OLSR performs much better than AODV and also OLSR outperforms DSDV.

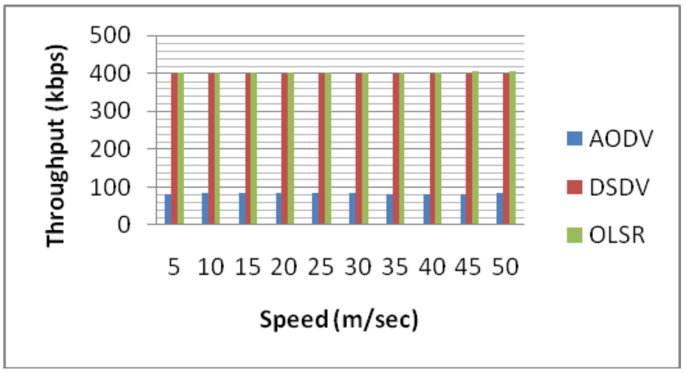

Fig. 5.38 Throughput vs. Speed when nodes are 60

In Fig. 5.39 it is shown that AODV outputs minimum throughput and OLSR gives maximum throughput among these protocols in this case.

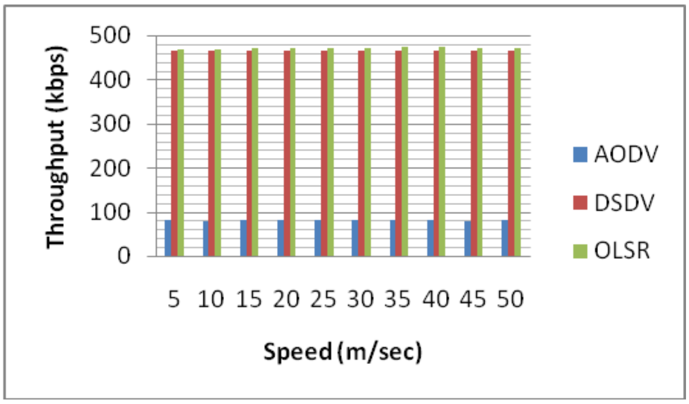

Fig. 5.39 Throughput vs. Speed when nodes are 70

In Fig. 5.40 OLSR gives best throughput of 568.072 at 40 msec^{-1} speed. OLSR and DSDV shows much better results than AODV and also OLSR performs better than DSDV.

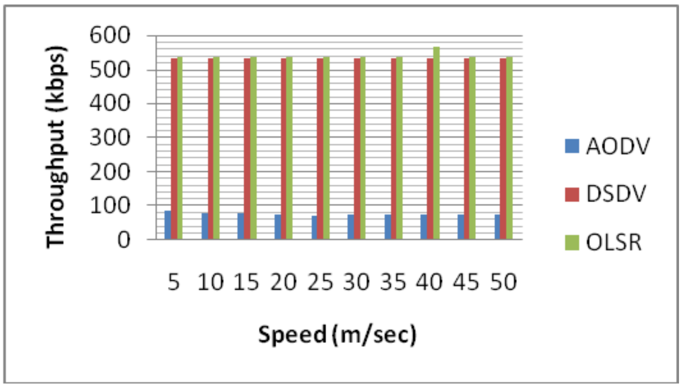

Fig. 5.40 Throughput vs. Speed when nodes are 80

- Delay

Three protocols are compared based on the average delay they achieve and the results are categorized based on the different speeds the nodes have.

In Fig. 5.41 AODV results maximum delay and OLSR shows best results among all the three protocols by showing minimum delay.

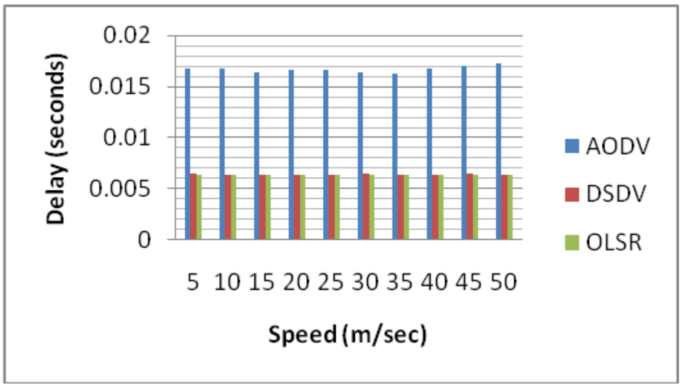

Fig. 5.41 Delay vs. Speed when nodes are 10

In Fig. 5.42 OLSR and DSDV outperforms AODV in each case and OLSR outperforms DSDV.

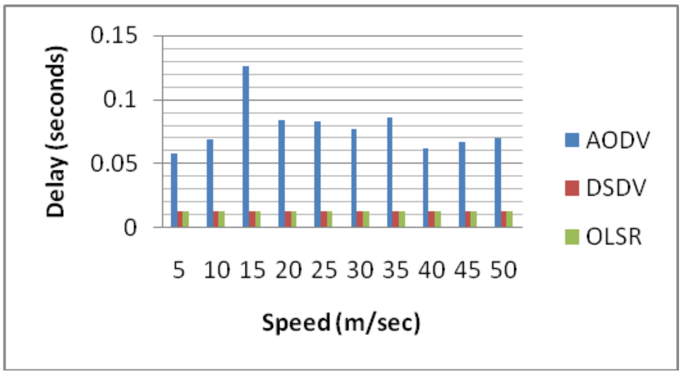

Fig. 5.42 Delay vs. Speed when nodes are 20

In Fig. 5.43 it is observed that AODV produces maximum delay among all three protocols and OLSR outperforms better than DSDV and OLSR.

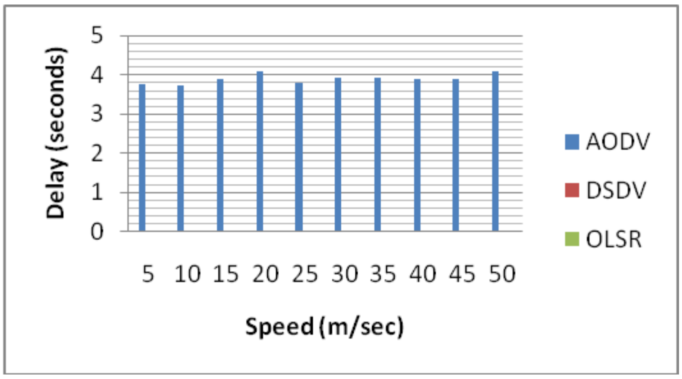

Fig. 4.43 Delay vs. Speed when nodes are 30

In Fig. 5.44 OLSR and DSDV performs much better than AODV and OLSR outperforms DSDV in each case.

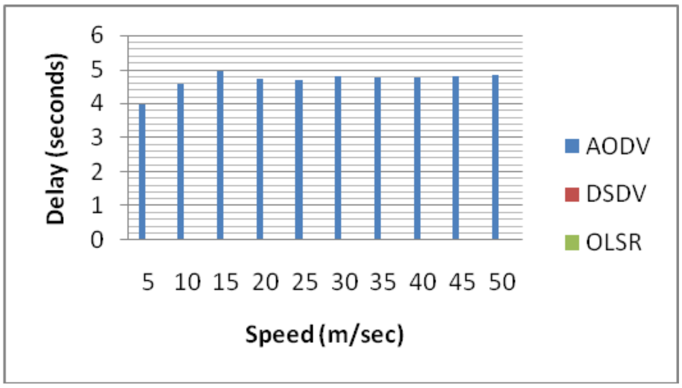

Fig. 5.44 Delay vs. Speed when nodes are 40

In Fig. 5.45 it is seen that AODV performance degrades as compare to earlier cases and OLSR shows best results by resulting minimum delay.

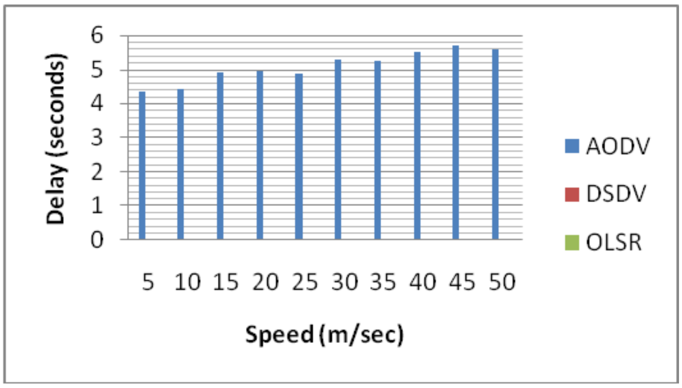

Fig. 5.45 Delay vs. Speed when nodes are 50

In Fig. 5.46 it is observed that AODV performance is worst among all the three protocols and OLSR outperforms DSDV in every case.

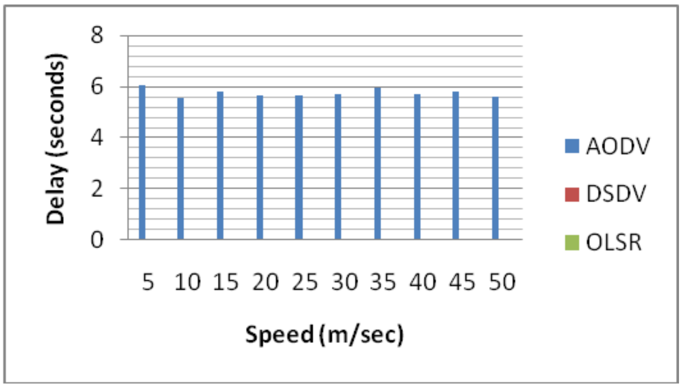

Fig. 5.46 Delay vs. Speed when nodes are 60

In Fig. 5.47 It is analyzed that OLSR performs much better than AODV and shows better results than DSDV.

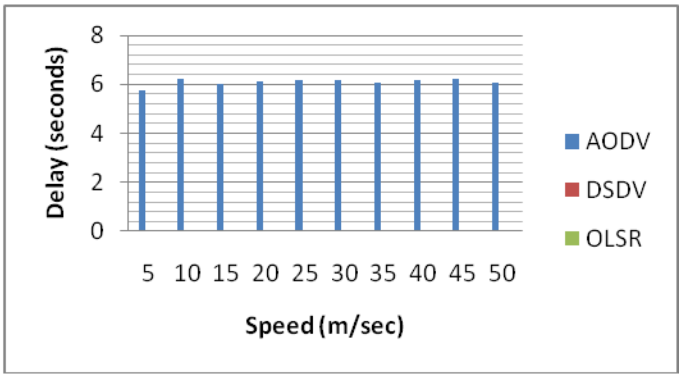

Fig. 5.47 Delay vs. Speed when nodes are 70

Figure 5.48 shows that as the number of nodes and their speeds increases, delay also increases. AODV results maximum delay and OLSR results minimum delay.

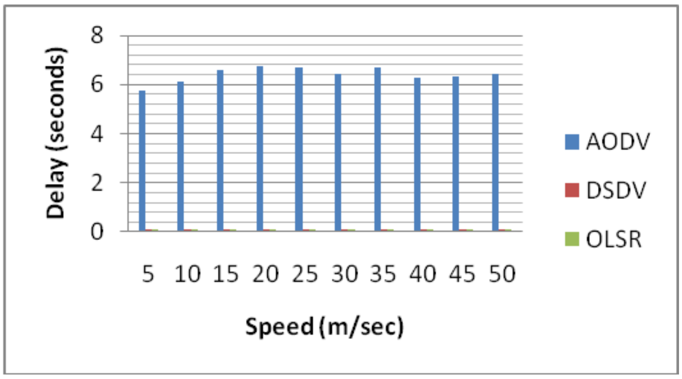

Fig. 5.48 Delay vs. Speed when nodes are 80

- Total energy consumption

Three routing protocols are compared based on the total energy consumption and results are categorized based on the different speeds the nodes have.

In Fig. 5.49 it is seen that AODV consumes maximum and DSDV consumes minimum energy. DSDV outperforms OLSR.

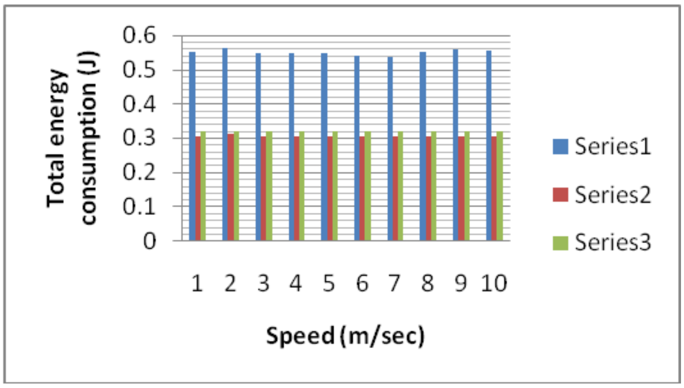

Fig. 5.49 Total energy consumed vs. Speed when nodes are 10

Figure 5.50 shows that DSDV and OLSR outperfrom AODV in every case. At 5, 25, 35 and 40 msec^{-1} DSDV performs better than OLSR.

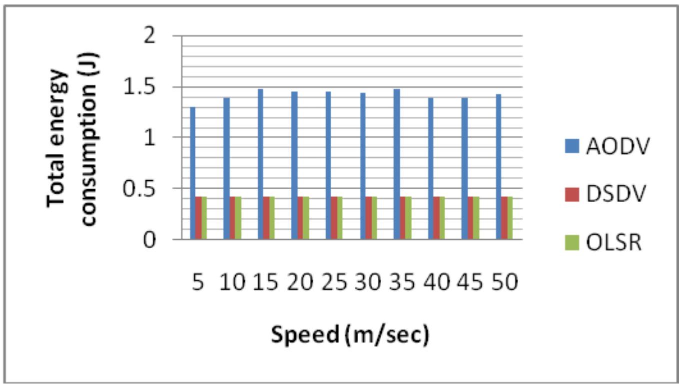

Fig. 5.50 Total energy consumed vs. Speed when nodes are 20

In Fig. 5.51 it is analyzed that OLSR and DSDV outperform AODV and also OLSR shows better results than DSDV.

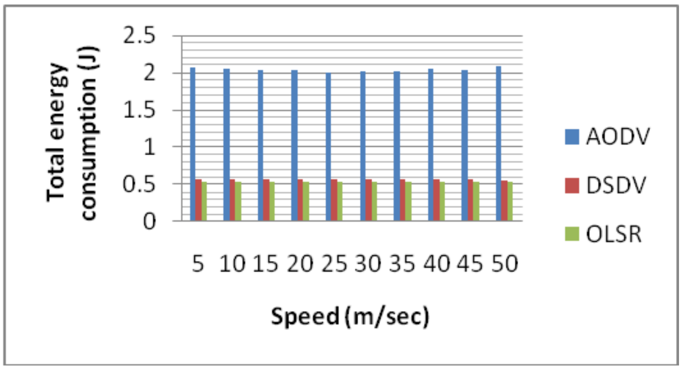

Fig. 5.51 Total energy consumed vs. Speed when nodes are 30

Fig. 5.52 shows that as the speed and number of nodes increases, the total energy consumption of all protocols also increases. OLSR performs best among all the protocols and AODV shows worst results by consuming maximum energy.

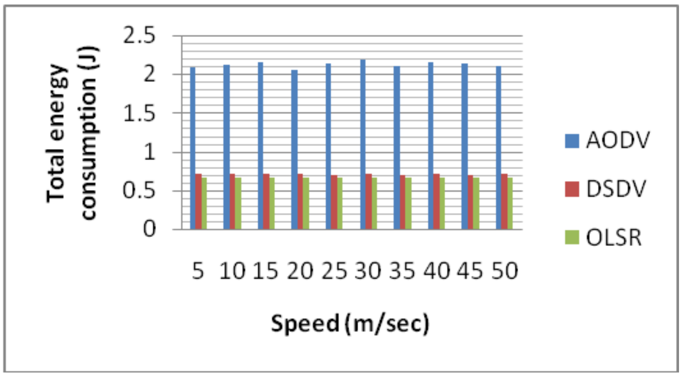

Fig. 5.52 Total energy consumed vs. Speed when nodes are 40

In Fig. 5.53 OLSR shows best performance among all protocols and DSDV performance is much better than AODV.

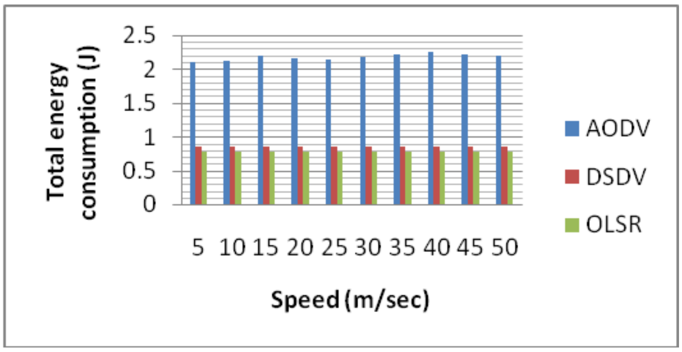

Fig. 5.53 Total energy consumed vs. Speed when nodes are 50

Figure 5.54 signifies that all protocols consume more energy as compare to previous case. OLSR outperforms DSDV.

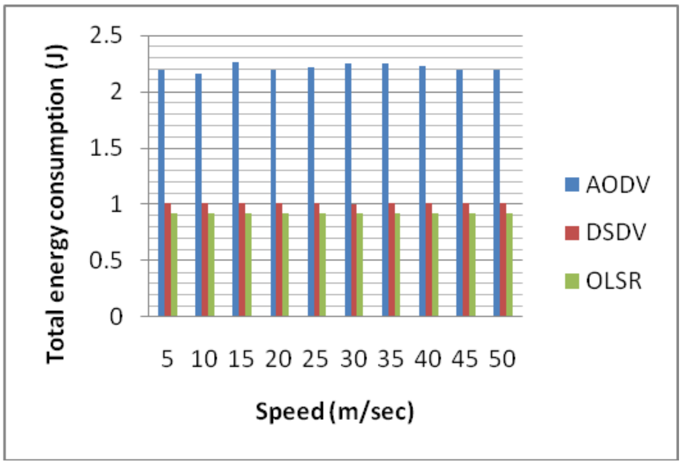

Fig. 5.54 Total energy consumed vs. Speed when nodes are 60

In Fig 5.55, it is observed that in AODV energy consumption of nodes increases as compare to previous cases but very smoothly not at high pace. In OLSR, nodes consume minimum energy and its performance outperforms DSDV.

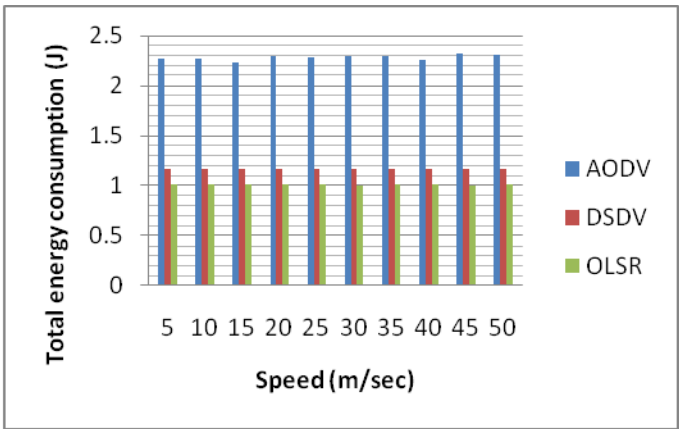

Fig. 5.55 Total energy consumed vs. Speed when nodes are 70

In Fig. 5.56 total energy consumption is minimum in OLSR and maximum in AODV.

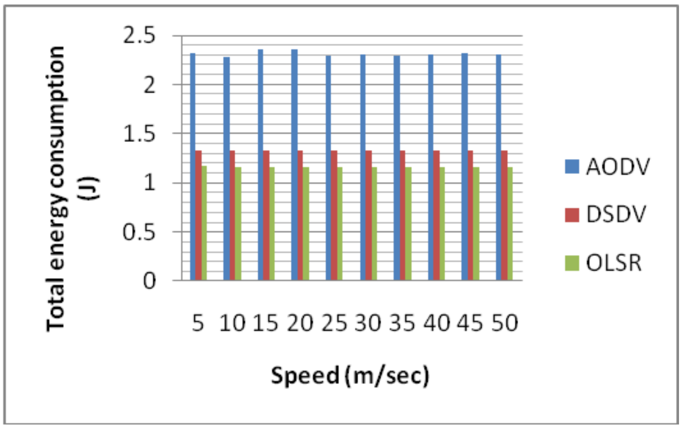

Fig. 5.56 Total energy consumed vs. Speed when nodes are 80

5.3 National Park Exploration

Simulations are done based on the different values of interval, packet size and DSSS Rate. Five different packet sizes (256, 512, 1024, 2048, 4096 bytes) and eleven different interval values (0s - 0.5s with 0.05 steps) are used. The smallest the interval is and biggest the packet size, the heavier the traffic is. Finally, three different values of the DSSS Rate are analyzed (1 Mbps, 2 Mbps and 11Mbps) that how they affect the sharing of a single channel among multiple users. In these simulations it is also analyzed that how different types of traffic affects the communication reliability as different values of packet size and interval determine the data rate.

- Packet Delivery ratio

PDR is the percentage from the send messages that was actually delivered to the destination. Three routing protocols are compared based on the PDR they achieve. Figure 4.57 show that DSDV and OLSR outperform AODV in every case. DSDV performs better than OLSR when the interval is 0 and 0.05 seconds.

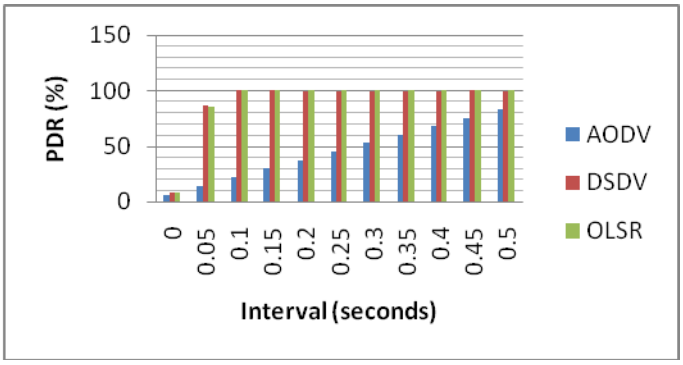

Fig. 5.57 PDR vs. Interval, Packet Size 256, DSSS Rate 1Mbps

In Fig. 5.58 it is clear that AODV’s performance is better as compare to when DSSS Rate was 1 Mbps but it gives worst performance among all the protocols. OLSR performs better than DSDV in every case.

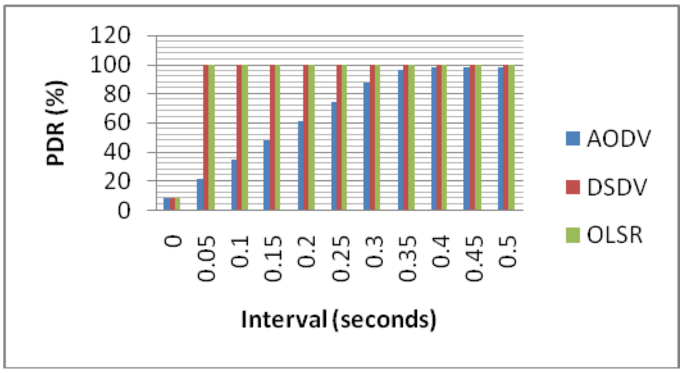

Fig. 5.58 PDR vs. Interval, Packet Size 256, DSSS Rate 2Mbps

Figure 5.59 shows that at only 0 interval, performance of DSDV and OLSR is same, otherwise OLSR outperforms DSDV in every case.

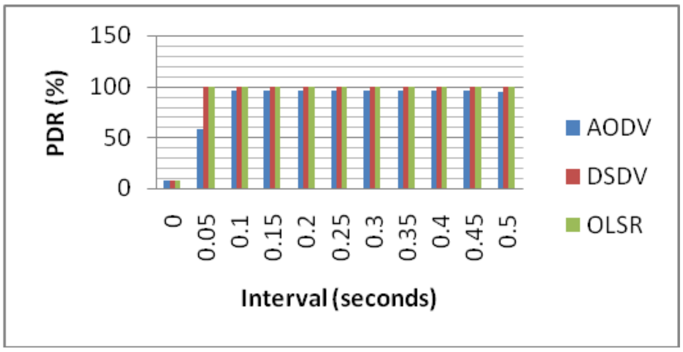

Fig. 5.59 PDR vs. Interval, Packet Size 256, DSSS Rate 11 Mbps

In Fig. 5.60 it is that observed AODV gives worst performance among all protocols and DSDV outperforms OLSR when the interval is 0 and 0.05 seconds.

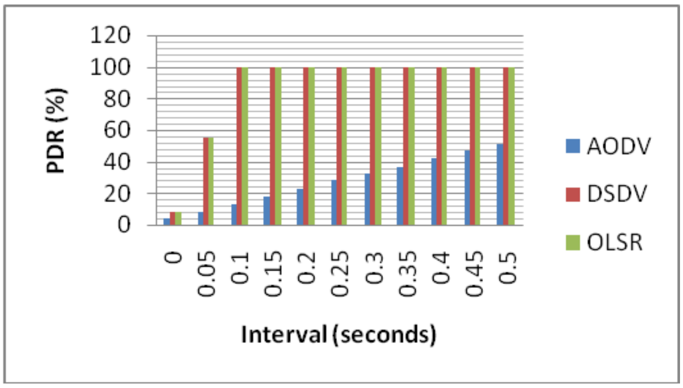

Fig. 5.60 PDR vs. Interval, Packet Size 512, DSSS Rate 1 Mbps

Figure 5.61 shows that OLSR and DSDV performs much better than AODV. AODV perfroms well as DSSS Rate increases and also OLSR results more packet delivery ratio as compare to DSDV.

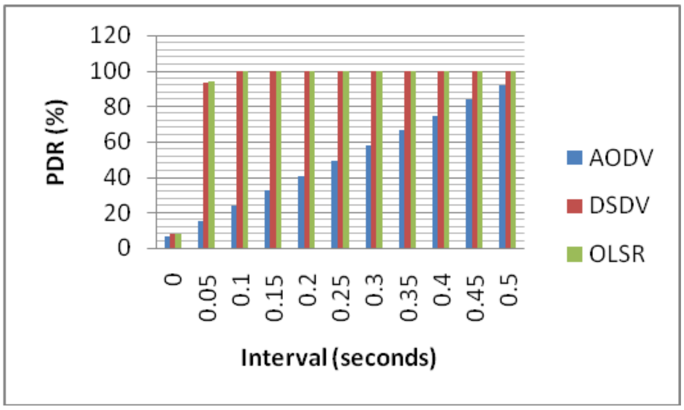

Fig. 5.61 PDR vs. Interval, Packet Size 512, DSSS Rate 2 Mbps

In Fig. 5.62 it is shown that performance of DSDV and OLSR is same when interval is 0 and 0.4 seconds otherwise OLSR performs better than DSDV. Performance of AODV is worst but better than above two cases when DSSS Rate is 1 and 2 Mbps.

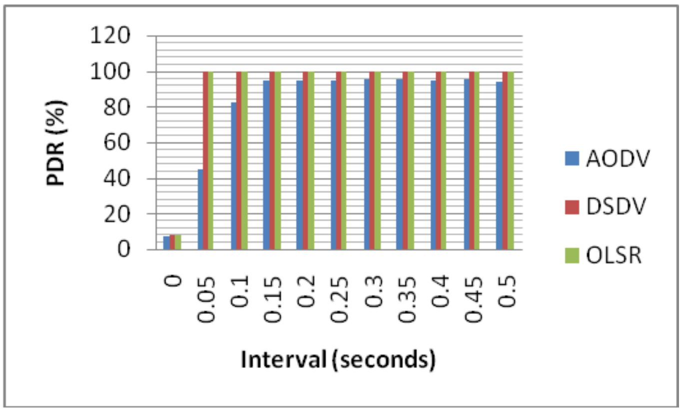

Fig. 5.62 PDR vs. Interval, Packet Size 512, DSSS Rate 11 Mbps

In Fig. 5.63 it is shown that DSDV performs better than OLSR only when the interval is 0 and 0.05 seconds and also OLSR and DSDV outperform AODV in every case.

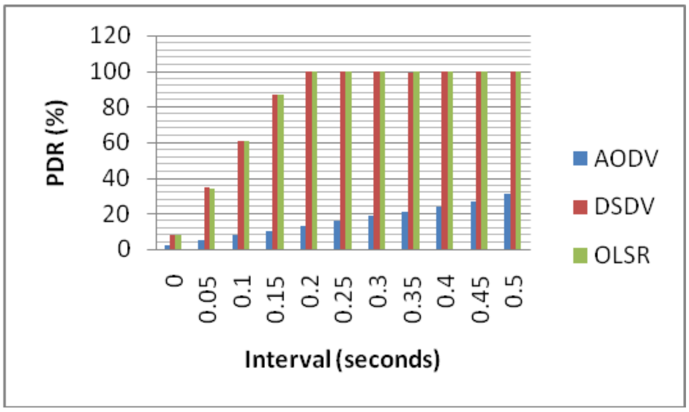

Fig. 5.63 PDR vs. Interval, Packet Size 1024, DSSS Rate 1 Mbps

Figure 5.64 shows that when DSSS Rate increases performance of AODV increases with high pace in all cases as compare to other protocols. Performance of DSDV and

OLSR is same only when the interval is 0.4 and 0.45 seconds otherwise OLSR outperform DSDV. AODV shows worst results among all three protocols.

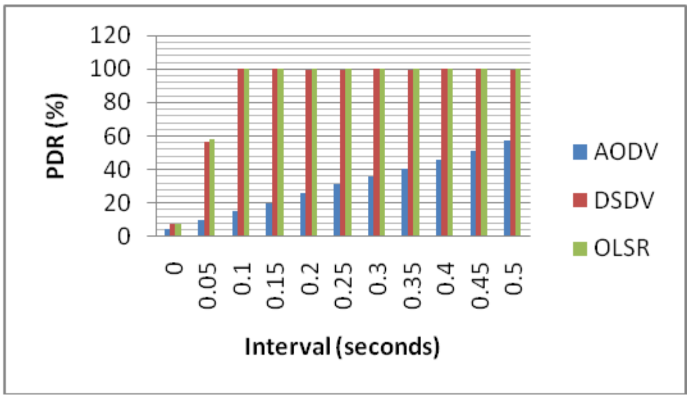

Fig. 5.64 PDR vs. Interval, Packet Size 1024, DSSS Rate 2 Mbps

In Fig. 5.65 OLSR outperforms DSDV in every case except when interval is 0 seconds. AODV performance further increases when DSSS Rate is increased to 11 Mbps.

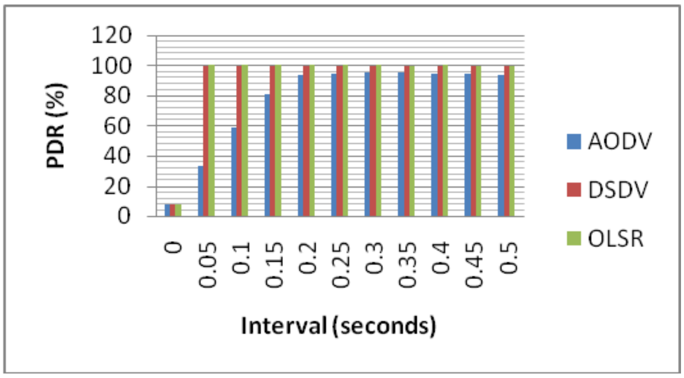

Fig. 5.65 PDR vs. Interval, Packet Size 1024, DSSS Rate 11 Mbps

Figure 5.66 shows that DSDV and OLSR performs much better than AODV in every case.DSDV outperform OLSR only when the interval is 0.05, 0.2, 0.25, 0.3 seconds.

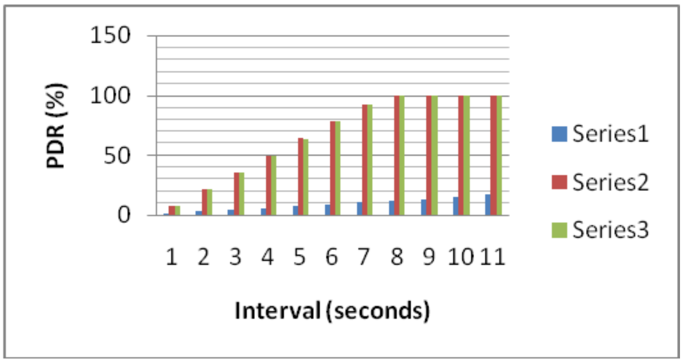

Fig. 5.66 PDR vs. Interval, Packet Size 2048, DSSS Rate 1 Mbps

Figure 5.67 it is shown that at interval of 0 and 0.05 seconds, DSDV and OLSR results same PDR otherwise OLSR performs better than DSDV.AODV performance is worst among them.

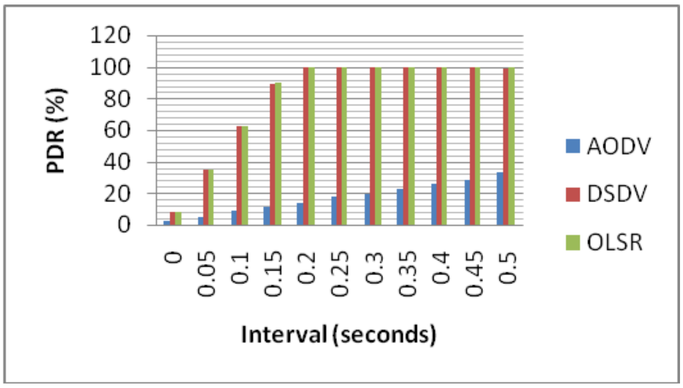

Fig. 5.67 PDR vs. Interval, Packet Size 2048, DSSS Rate 2 Mbps

In Fig. 5.68 it is observed that OLSR outperform DSDV in every case except at interval of 0 seconds. OLSR and DSDV outperform AODV in every case.AODV performance is also much better even at high traffic due to high DSSS Rate.

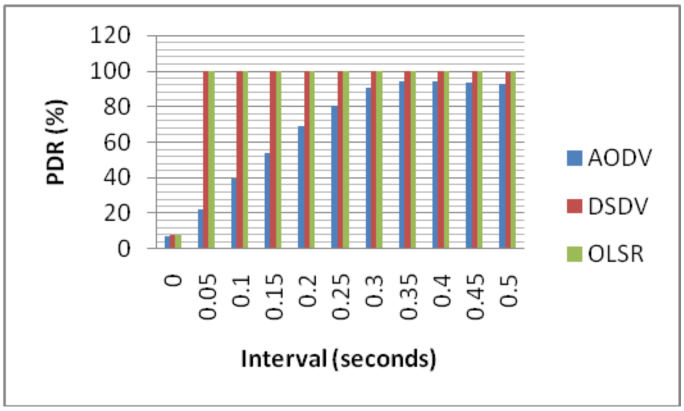

Fig. 5.68 PDR vs. Interval, Packet Size 2048, DSSS Rate 11 Mbps

In Fig. 5.69 it is observed that AODV performance is worst among all the protocols.OLSR outperform DSDV only when the interval is 0, 0.05,0.15 seconds.

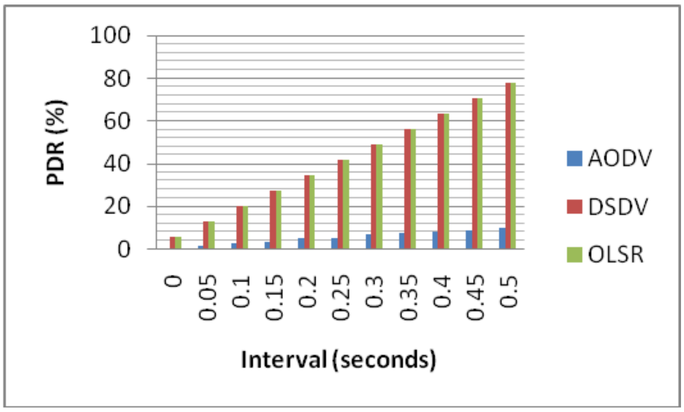

Fig. 5.69 PDR vs. Interval, Packet Size 4096, DSSS Rate 1 Mbps

Figure 5.70 shows that at interval of 0.05 and 0.2 seconds DSDV performs slightly better than OLSR, otherwise OLSR performs better than DSDV. It can also be seen that at interval 0.5 seconds AODV perfroms very well.

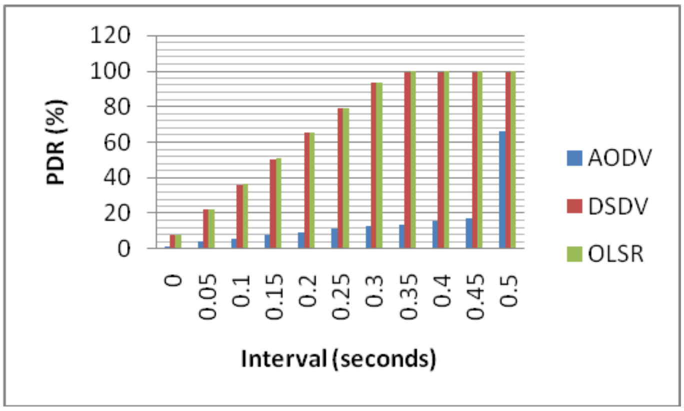

Fig. 5.70 PDR vs. Interval, Packet Size 4096, DSSS Rate 2 Mbps

In Fig. 5.71 it can be seen that at interval of 0.05 and 0.2 seconds DSDV outperforms OLSR and also AODV performs well during the interval of 0.3, 0.35 and 0.4 seconds due to high DSSS Rate.

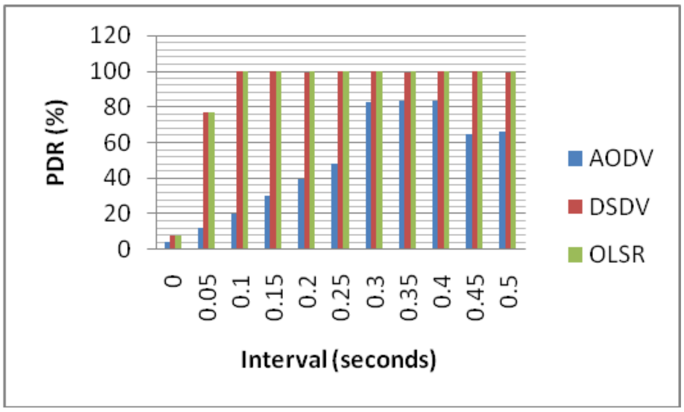

Fig. 5.71 PDR vs. Interval, Packet Size 4096, DSSS Rate 11 Mbps

- Throughput

Three routing protocols are compared based on the throughput they achieve and the results are categorized based on the different packet sizes, intervals and DSSS Rates. In Fig. 5.72 it is observed that DSDV and OLSR outperfroms AODV and also at the intervel of 0 and 0.05 seconds DSDV ouperforms OLSR

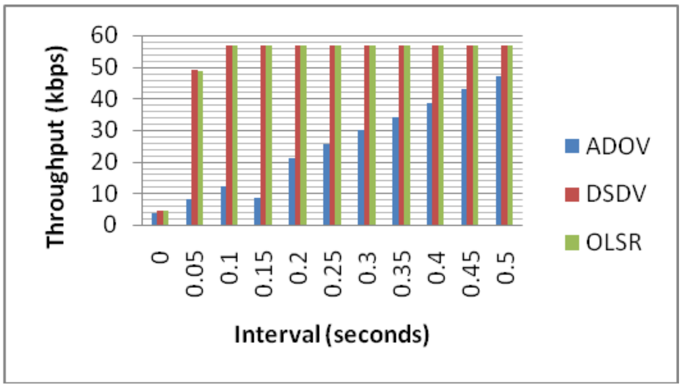

Fig. 5.72 Throughput vs. Interval, Packet Size 256, DSSS Rate 1 Mbps

In Fig. 5.73 OLSR performs better than DSDV by giving more throughput. It can also be seen that AODV performance is worst among all protocols.

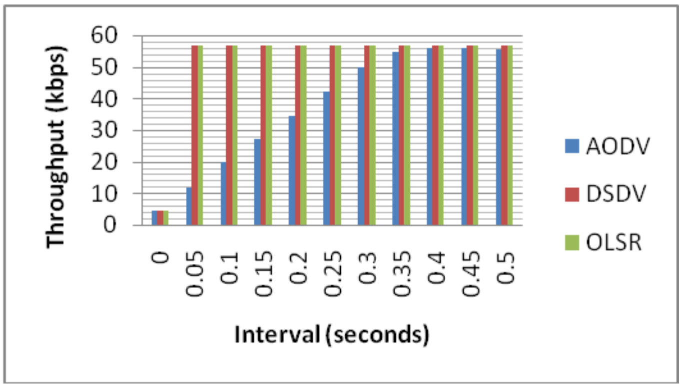

Fig. 5.73 Throughput vs. Interval, Packet Size 256, DSSS Rate 2 Mbps

In Fig. 5.74 it is observed that at the interval of 0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5 seconds OLSR outperforms DSDV and also OLSR and DSDV performs better than AODV.

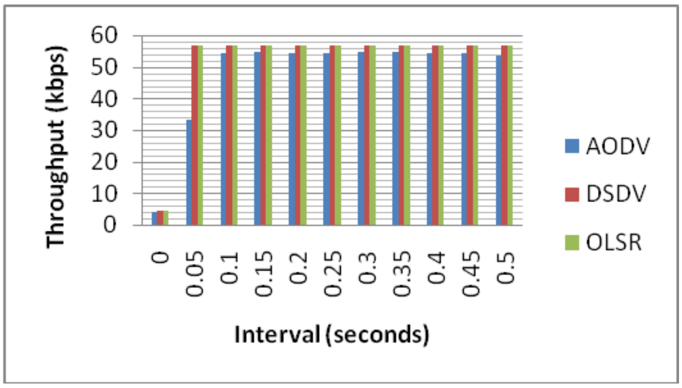

Fig. 5.74 Throughput vs. Interval, Packet Size 256, DSSS Rate 11 Mbps

In Fig. 5.75 it is observed that at the interval of 0 and 0.05 seconds DSDV outperforms OLSR, otherwise OLSR results more throughput as compare to DSDV. If performance of AODV is considered then it is worst among all protocols.

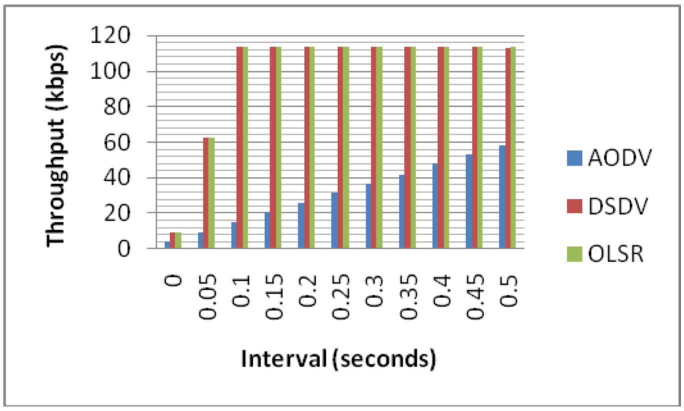

Fig.5.75 Throughput vs. Interval, Packet Size 512, DSSS Rate 1 Mbps

In Fig. 5.76 it is observed that DSDV outperforms OLSR only when the interval is 0 and 0.05 seconds In all other cases OLSR achieves highest throughput than DSDV and also AODV has in every case lowest throughput.

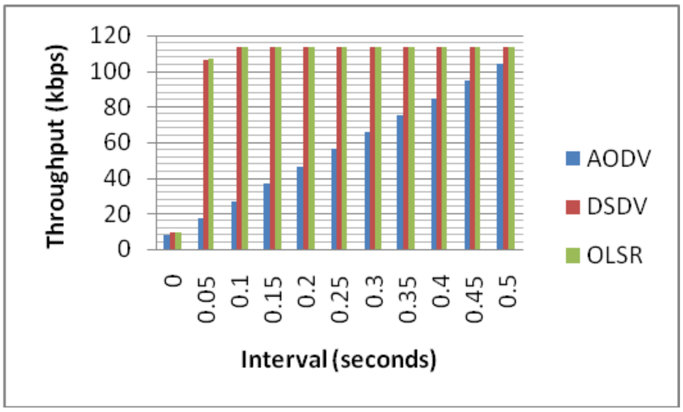

Fig. 5.76 Throughput vs. Interval, Packet Size 512, DSSS Rate 2 Mbps

In Fig. 5.77 it is observed that AODV has in every case lowest throughput.OLSR has highest throughput than DSDV when the interval is 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5 seconds. In all other cases DSDV achieves highest throughput than OLSR.

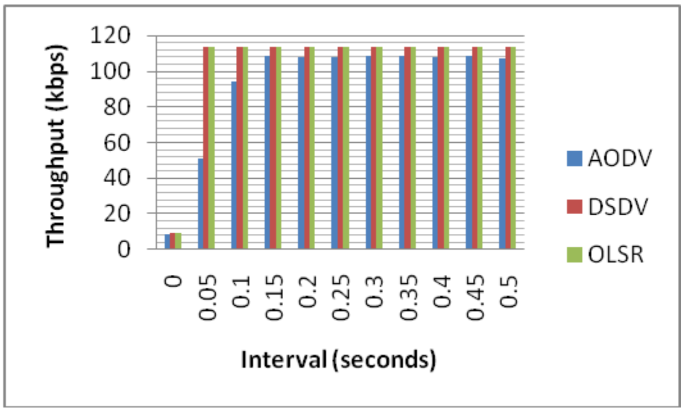

Fig. 5.77 Throughput vs. Interval, Packet Size 512, DSSS Rate 11 Mbps

In Fig. 5.78 it is observed that as the traffic goes on increasing, the performance of AODV starts decreasing and hence it results in every case the lowest throughput. When the interval is 0, 0.05 and 0.1 seconds only then DSDV achieves highest throughput than OLSR. In all other cases OLSR achieves maximum throughput than DSDV.

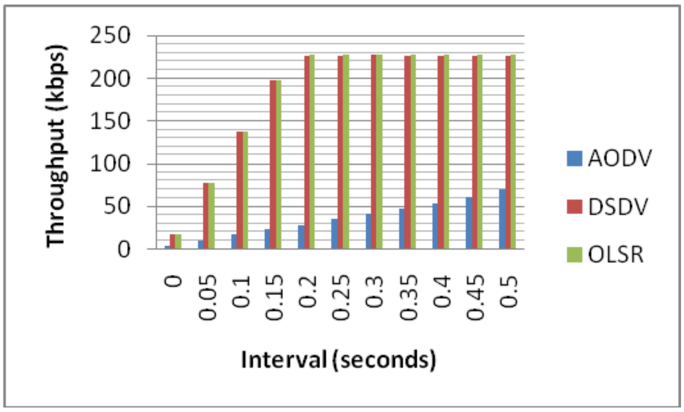

Fig. 5.78 Throughput vs. Interval, Packet Size 1024, DSSS Rate 1 Mbps

In Fig. 5.79 it is observed that performance of DSDV and OLSR is same when the interval is 0 seconds.In all other cases OLSR results maximum throughput than DSDV. When the interval increases AODV also results better throughput than previous interval.

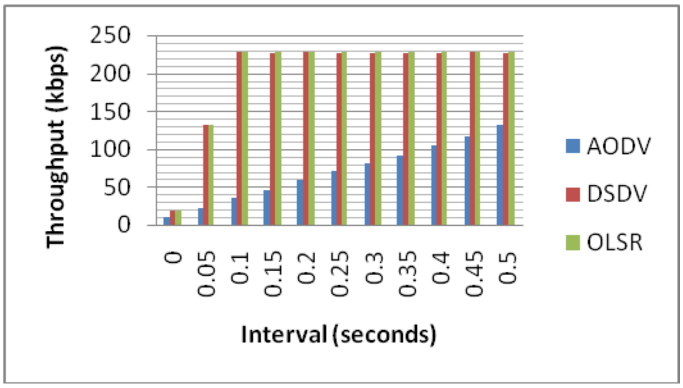

Fig. 5.79 Throughput vs. Interval, Packet Size 1024, DSSS Rate 2 Mbps

In Fig. 5.80 it is observed that as the DSSS Rate increases the performance of AODV also becomes much better. When the interval is 0 seconds the DSDV and OLSR shows same results.In all other cases OLSR results maximum throughput.

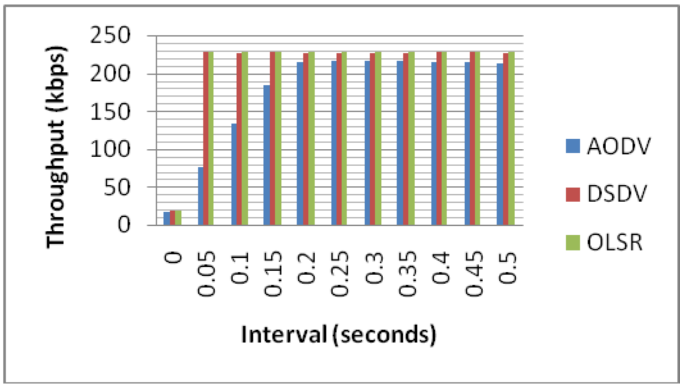

Fig. 5.80 Throughput vs. Interval, Packet Size 1024, DSSS Rate 11 Mbps

In Fig. 5.81 it is observed that when the interval is 0, 0.05, 0.2 and 0.25 seconds DSDV results maximum throughput than OLSR.In all other cases OLSR performance is better than DSDV. AODV shows worst performance among all the protocols.

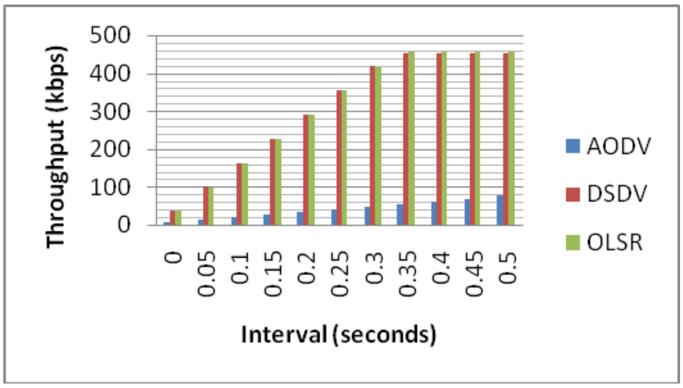

Fig. 5.81 Throughput vs. Interval, Packet Size 2048, DSSS Rate 1 Mbps

In Fig. 5.82 it is observed that AODV results the lowest throughput in every case.When the interval is 0.1, 0.15, 0.2, 0.3, 0.35, 0.4, 0.45 and 0.5 seconds OLSR results maximum throughput than DSDV.In all other cases DSDV achieves maximum throughput than OLSR.

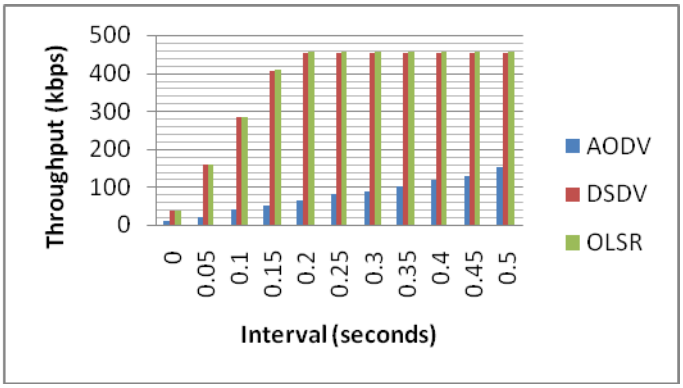

Fig. 5.82 Throughput vs. Interval, Packet Size 2048, DSSS Rate 2 Mbps

In Fig. 5.83 it is observed that at interval of 0 seconds DSDV and OLSR achieves same throughput. In all other cases OLSR results highest throughput than DSDV and also AODV results lowest throughput in every case.

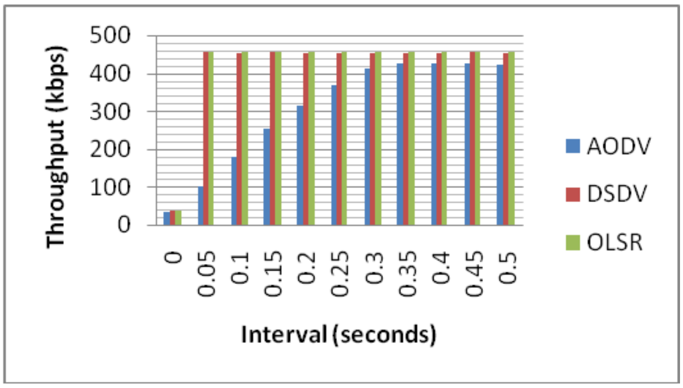

Fig. 5.83 Throughput vs. Interval, Packet Size 2048, DSSS Rate 11 Mbps

In Fig. 5.84 it is observed that when the interval is 0.05, 0.1, 0.2, 0.25, 0.3, 0.35, 04 and 0.5 seconds DSDV achieves highest throughput than OLSR. There is very much difference between the throughput achieves by AODV on one side and DSDV and OLSR on the other side.

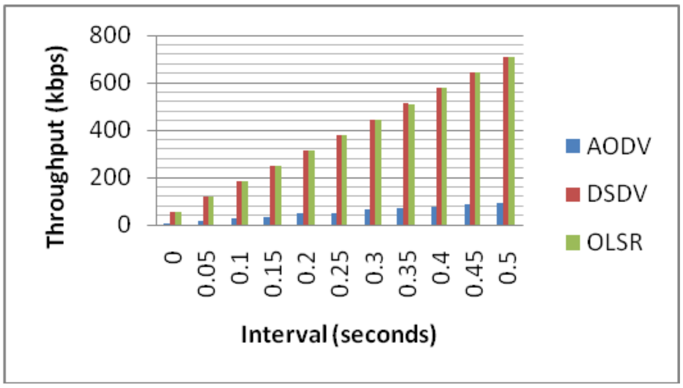

Fig. 5.84 Throughput vs. Interval, Packet Size 4096, DSSS Rate 1 Mbps

In Fig. 5.85 it is observed that at the interval of 0.05 DSDV achieves highest throughput than OLSR and in all other cases OLSR results maximum throughput among all protocols. AODV also achieves much better throughput at interval of 0.5 seconds as compare to other intervals.

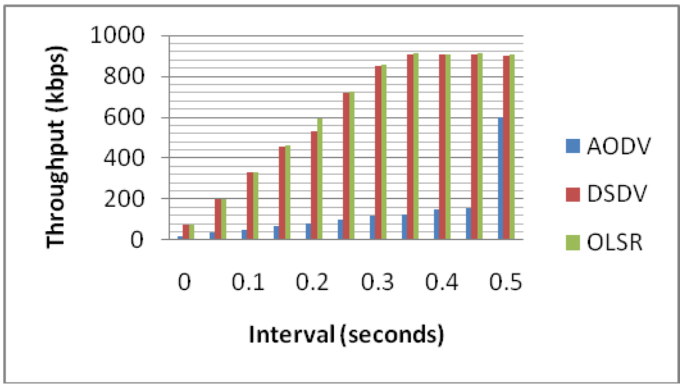

Fig. 5.85 Throughput vs. Interval, Packet Size 4096, DSSS Rate 2 Mbps

In Fig. 5.86 it can be seen that AODV has in every case the lowest throughput and OLSR has highest throughput and outperforms DSDV.

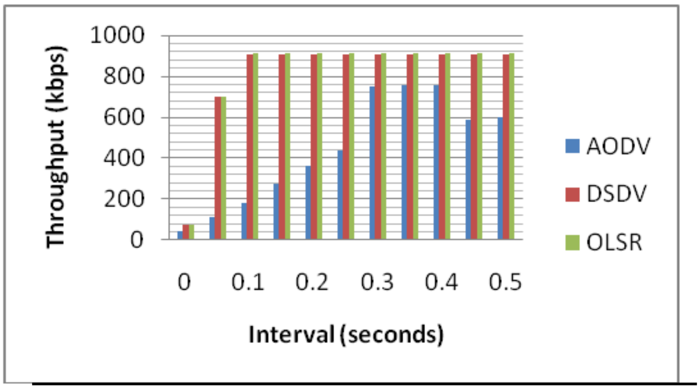

Fig. 5.86 Throughput vs. Interval, Packet Size 4096, DSSS Rate 11 Mbps

- **DELAY**

Three protocols are compared based on the average delay they achieves. The results are categorized based on different packet sizes, interval and DSSS rates.

In Fig. 5.87 it can be observed that AODV has the highest average delay in every case. When the interval is 0, 0.05, 0.15, 0.25 and 0.5 DSDV results minimum delay than OLSR. In all other cases OLSR shows better performance than DSDV.

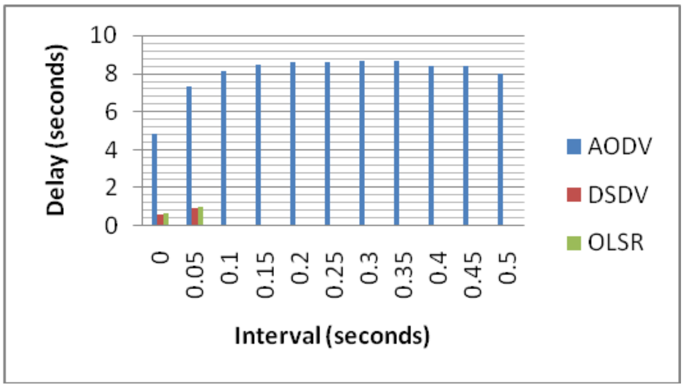

Fig. 5.87 Delay vs. Interval, Packet Size 256 bytes, DSSS Rate 1 Mbps

In Fig. 5.88 it can be observed that at the interval of 0 and 0.35 seconds DSDV results minimum delay. In all other cases OLSR achieves the lowest delay and AODV has the highest average delay in every case.

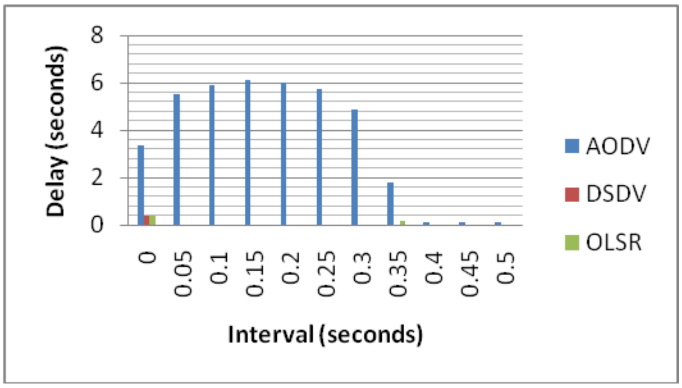

Fig. 5.88 Delay vs. Interval, Packet Size 256, DSSS Rate 2 Mbps

In Fig. 5.89 it can be observed that at the interval of 0 seconds DSDV shows better results than OLSR. In all other cases OLSR achieves the minimum delay and AODV shows better performance as the DSSS Rate increases.

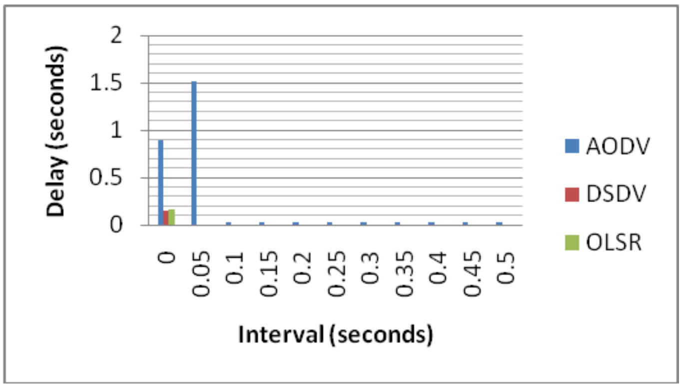

Fig. 5.89 Delay vs. Interval, Packet Size 256, DSSS Rate 11 Mbps

Figure 5.90 shows that AODV achieves maximum delay in every case. When the interval is 0, 0.05 and 0.1 seconds DSDV results minimum delay than OLSR. In all other cases OLSR achieves minimum delay.

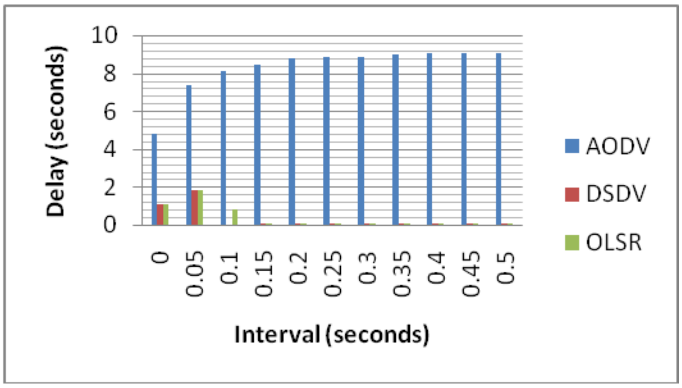

Fig. 5.90 Delay vs. Interval, Packet Size 512, DSSS Rate 1 Mbps

In Fig. 5.91 it is observed that at the interval of 0.1, 0.15, 0.2, 0.25, 0.35, 0.4, 0.45 and 0.5 seconds the performance of OLSR is better than DSDV and in all other cases DSDV achieves minimum delay.

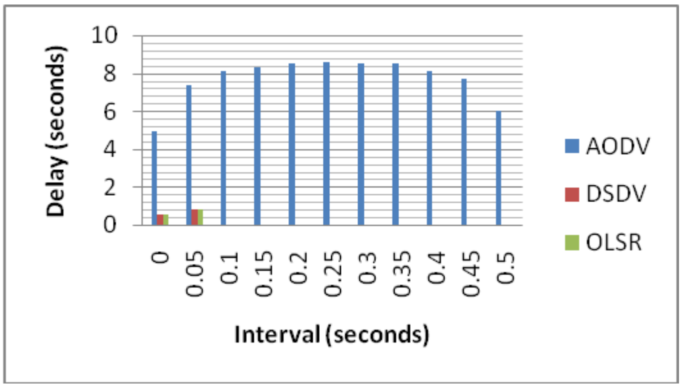

Fig. 5.91 Delay vs. Interval, Packet Size 512, DSSS Rate 2 Mbps

In Fig. 5.92 it is observed that AODV achieves maximum delay in every case. When the interval is 0 and 0.45 seconds DSDV achieves minimum delay than OLSR and in all other cases OLSR shows better performance than DSDV. It is also observed that as the DSSS Rate increases the delay achieved by AODV goes on decreasing.

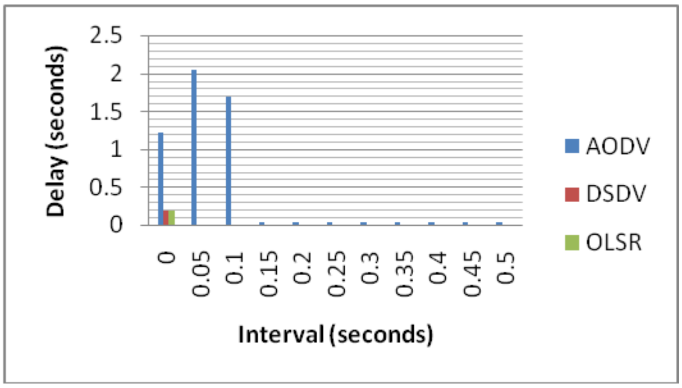

Fig. 5.92 Delay vs. Interval, Packet Size 512, DSSS Rate 11 Mbps

Figure 5.93 shows that at the interval of 0, 0.05, 0.1, 0.15 and 0.4 seconds DSDV achieves minimum delay and in all other cases OLSR performs better than DSDV and also AODV achieves maximim delay among all the three protocols.

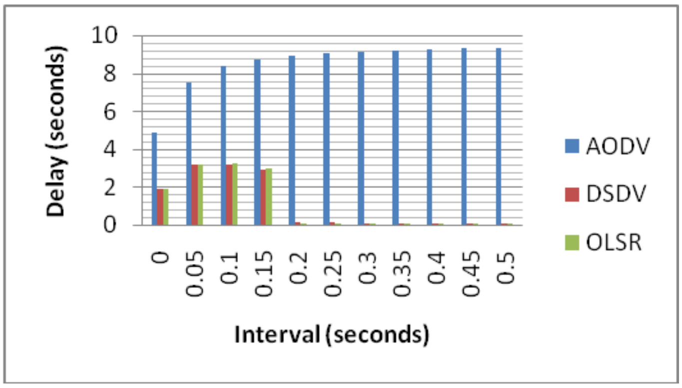

Fig. 5.93 Delay vs. Interval, Packet Size 1024, DSSS Rate 1 Mbps

In Fig. 5.94 it is seen that AODV achieves maximum delay in every case. When the interval is 0, 0.05 and 0.4 seconds DSDV achieves minimum delay than OLSR and in all other remaining cases OLSR achieves minimum delay.

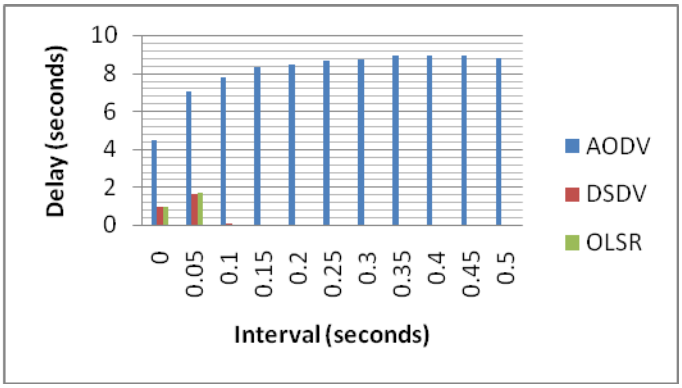

Fig. 5.94 Delay vs. Interval, Packet Size 1024, DSSS Rate 2 Mbps

In Fig. 5.95 it is observed that at the interval of 0 seconds DSDV performs better than OLSR. In all other cases OLSR achieves minimum delay and also AODV shows worst results in every case.

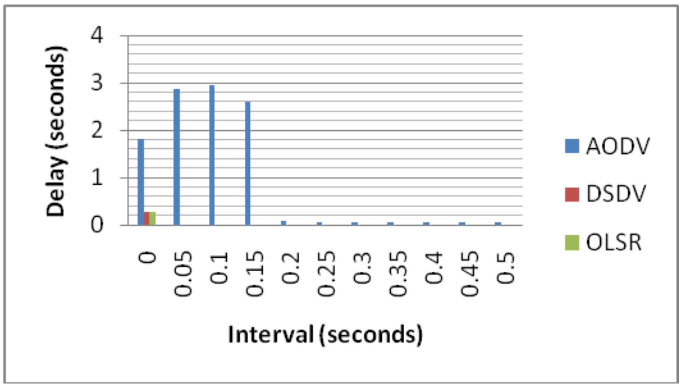

Fig. 5.95 Delay vs. Interval, Packet Size 1024, DSSS Rate 11 Mbps

Figure 5.96 shows that at the interval of 0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3 and 0.35 DSDV achieves minimum delay than OLSR. In all other cases OLSR shows better performance than DSDV.It is also observed that at the low intervals the delay generated by DSDV and OLSR also increases as compare to previous scenarios and AODV shows worst performance in every case.

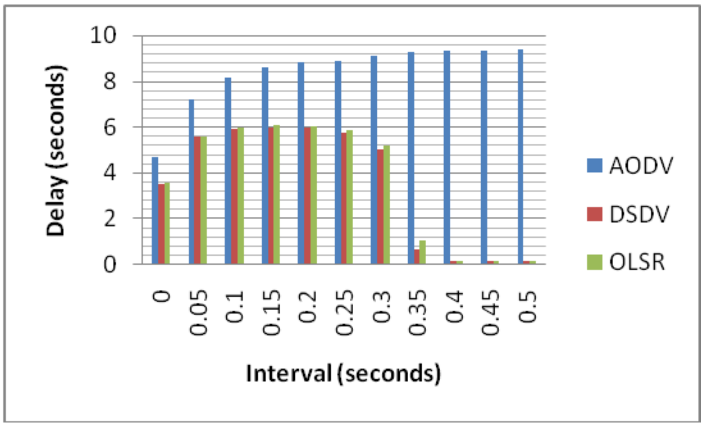

Fig. 5.96 Delay vs. Interval, Packet Size 2048, DSSS Rate 1 Mbps

In Fig. 5.97 it is observed that at the interval of 0.25, 0.3, 0.35 and 0.45 seconds OLSR achieves minimum delay and in all other cases DSDV shows better performance than OLSR and in case of AODV highest delay is achieved.

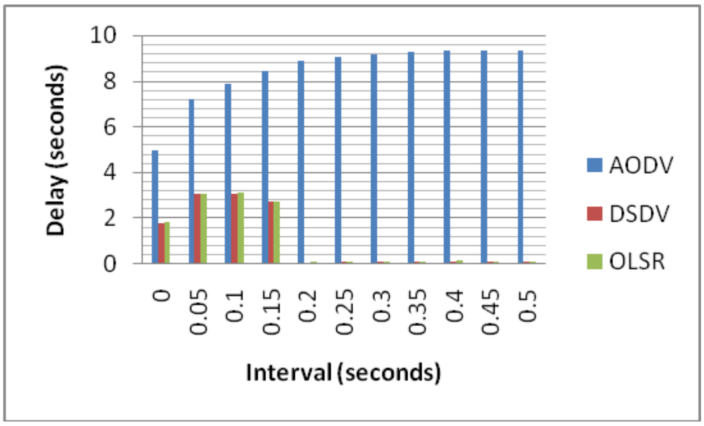

Fig. 5.97 Delay vs. Interval, Packet Size 2048, DSSS Rate 2 Mbps

In Figure 5.98 it is observed that at the interval of 0 seconds DSDV achieves lowest delay and in all other cases OLSR achieves lowest delay. It is also seen that as the DSSS rate increases the performance of AODV also improves but it results maximum delay among all the three protocols.

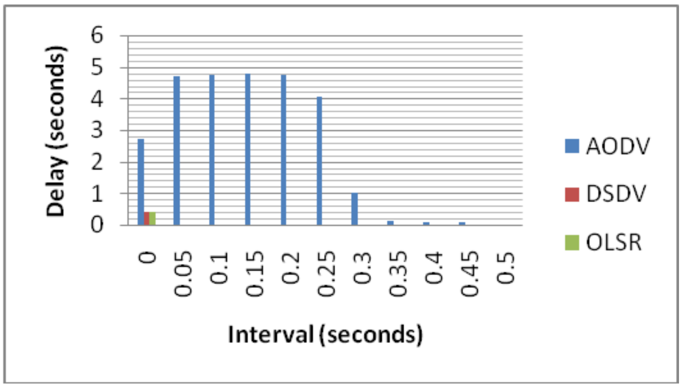

Fig. 5.98 Delay vs. Interval, Packet Size 2048, DSSS Rate 11 Mbps

In Figure 5.99 it is clearly observed that performance of AODV is much better than previous scenarios but it results maximum delay among all the protocols. It is also analyzed that DSDV outperforms OLSR in every case.

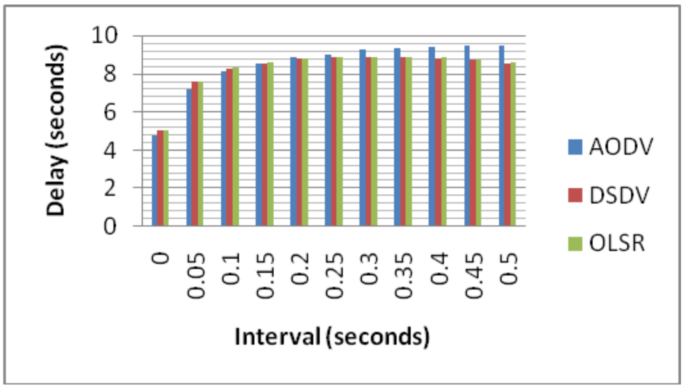

Fig. 5.99 Delay vs. Interval, Packet Size 4096, DSSS Rate 1 Mbps

In Fig. 5.100 it is observed that at the interval of 0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3 and 0.5 seconds the delay achieved by DSDV is minimum. In all other cases OLSR achieves minimum delay and AODV shows worst performance in every case.

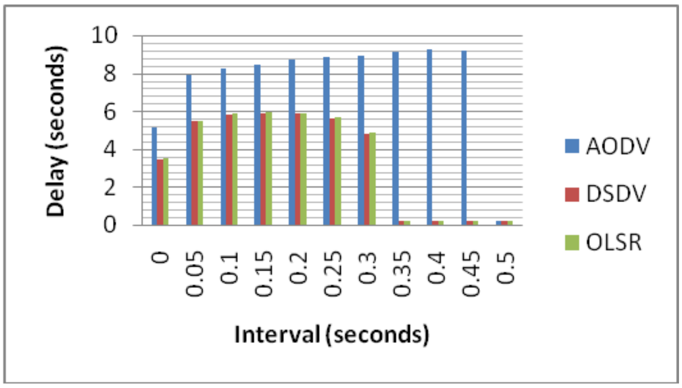

Fig. 5.100 Delay vs. Interval, Packet Size 4096, DSSS Rate 2 Mbps

In Fig. 5.101 it is seen that at the interval of 0, 0.05, 0.15, 0.4 and 0.5 seconds DSDV achieves minimum delay and in all remaining cases OLSR shows best performance. Also the performance of AODV is worst among all other protocols.

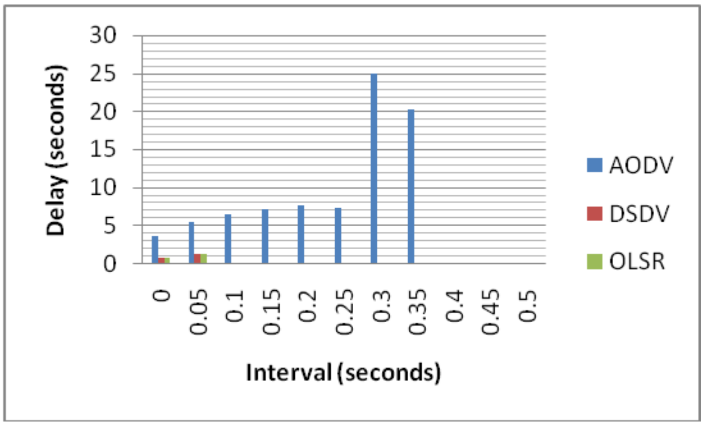

Fig. 4.101 Delay vs. Interval, Packet Size 4096, DSSS Rate 11 Mbps

- Energy consumption

In this section three routing protocols are compared based on total energy consumption they achieve.The simulation results are categorizedbased on the differrent DSSS Rates.

In Fig. 5.102 it is observed that AODV has the highest total energy consumption in every case. Also, DSDV achieves lowest energy consumption than OLSR in all cases.

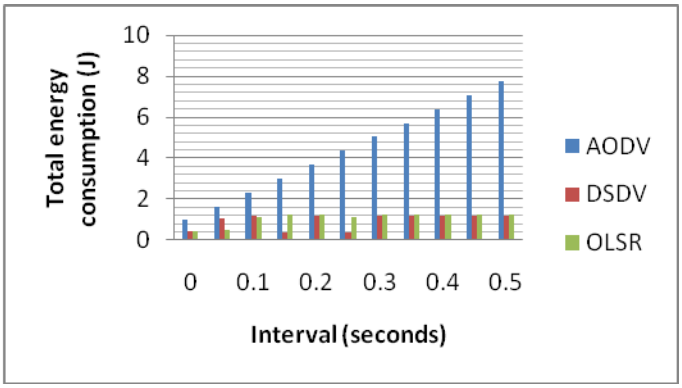

Fig. 5.102 Total Energy Consumed vs. Interval, Packet Size 256, DSSS Rate 1 Mbps

In Fig. 5.103 it is observed that in all cases DSDV achieves lowest energy consumption than OLSR. Also, AODV achieves the highest total energy consumption.

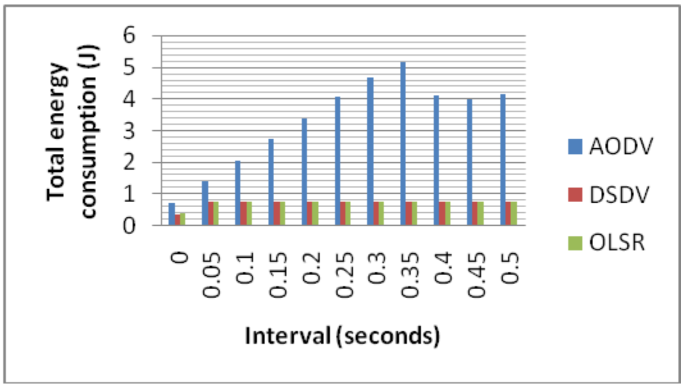

Fig. 5.103 Total Energy Consumed vs. Interval, Packet Size 256, DSSS Rate 2 Mbps

Figure 5.104 shows that AODV consumes highest energy and also, in all cases OLSR achieves lowest energy consumption than DSDV.

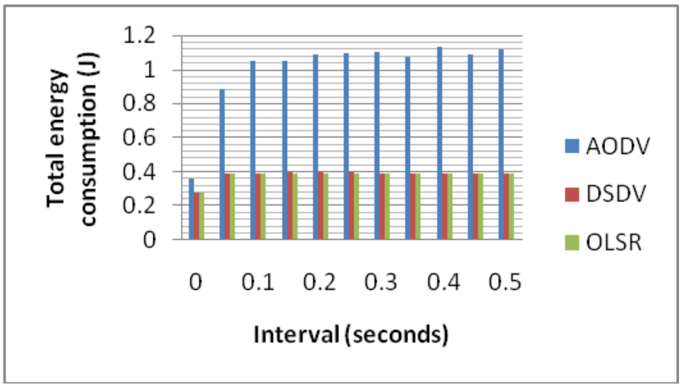

Fig. 5.104 Total Energy Consumed vs. Interval, Packet Size 256, DSSS Rate 11 Mbps

Figure 5.105 shows that DSDV achieves minimum energy consumption than OLSR and also AODV shows worst performance among the three protocols in all cases.

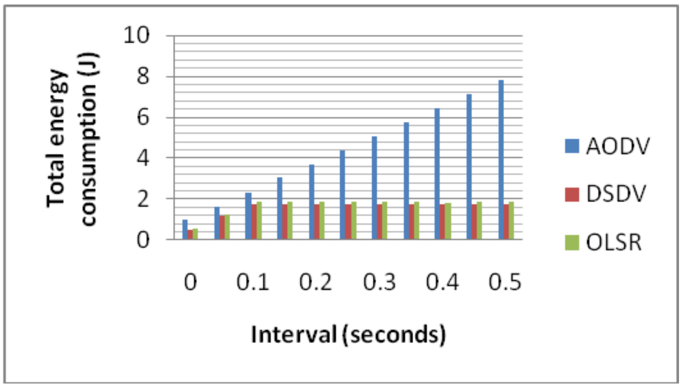

Fig. 5.105 Total Energy Consumed vs. Interval, Packet Size 512, DSSS Rate 1 Mbps

In Fig. 5.106 it is seen that as the interval goes on increasing the energy consumption in AODV protocol also goes on increasing and it shows worst performnace. In all cases DSDV outperforms OLSR.

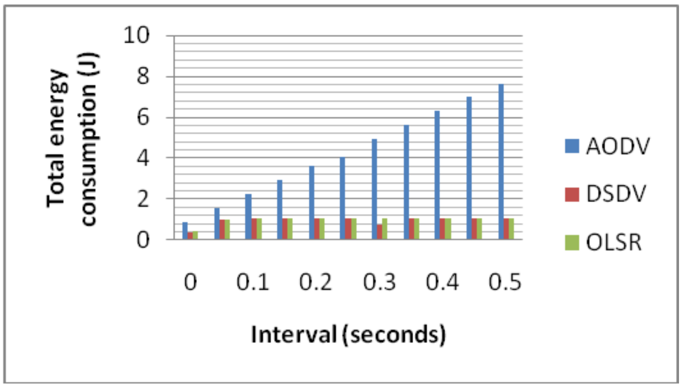

Fig. 5.106 Total Energy Consumed vs. Interval, Packet Size 512, DSSS Rate 2 Mbps

In Fig. 5.107 it is observed that AODV achieves the highest total energy consumption. Also, OLSR shows best reults among all protocols by achieving lowest energy consumption.

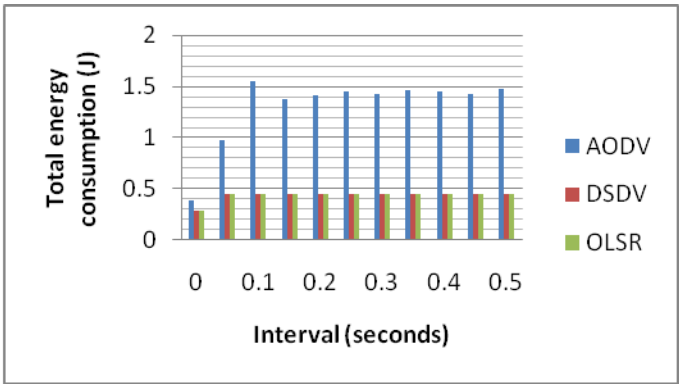

Fig. 5.107 Total Energy Consumed vs. Interval, Packet Size 512, DSSS Rate 11 Mbps

In Fig. 5.108 DSDV protocol achieves minimum energy consumption and also AODV shows worst performance by achieving highest energy consumption.

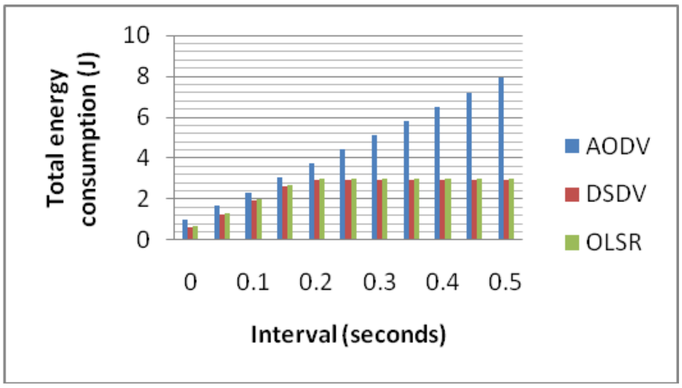

Fig. 5.108 Total Energy Consumed vs. Interval, Packet Size 1024, DSSS Rate 1 Mbps

Figure 5.109 shows that OLSR and DSDV outperforms AODV and also, DSDV achieves lowest energy consumption.

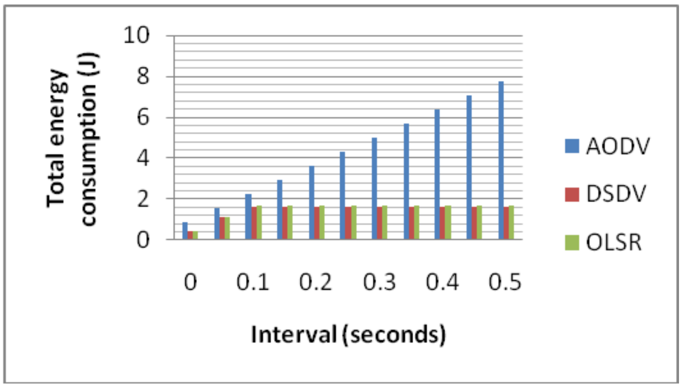

Fig. 5.109 Total Energy Consumed vs. Interval, Packet Size 1024, DSSS Rate 2 Mbps

Figure 5.110 shows that OLSR achieves lowest energy consumption than DSDV. Also, AODV shows worst results among all three protocols.

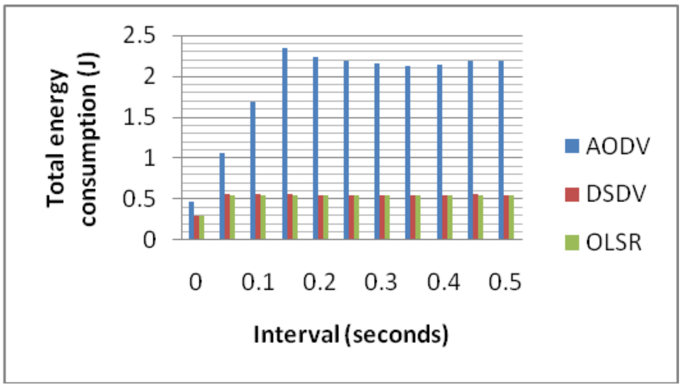

Fig. 5.110 Total Energy Consumed vs. Interval, Packet Size 1024, DSSS Rate 11 Mbps

In Fig. 5.111 DSDV achieves lowest energy consumption than OLSR. Also, AODV performance goes on degrading as the interval increases and hence it achieves highest enegy consumption.

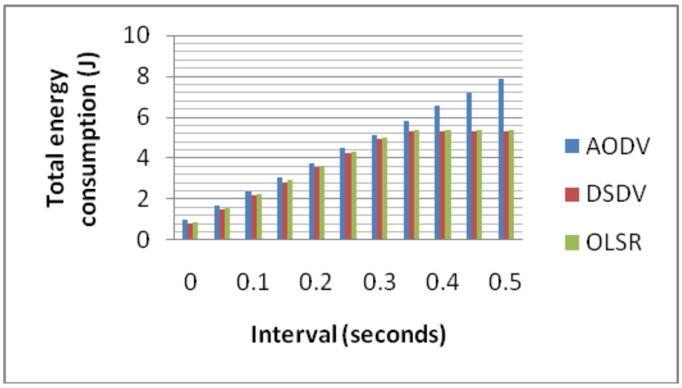

Fig. 5.111 Total Energy Consumed vs. Interval, Packet Size 2048, DSSS Rate 1 Mbps

Figure 5.112 shows that DSDV achieves lowest energy consumption than OLSR in all cases. Also, AODV has the highest energy consumption in every case.

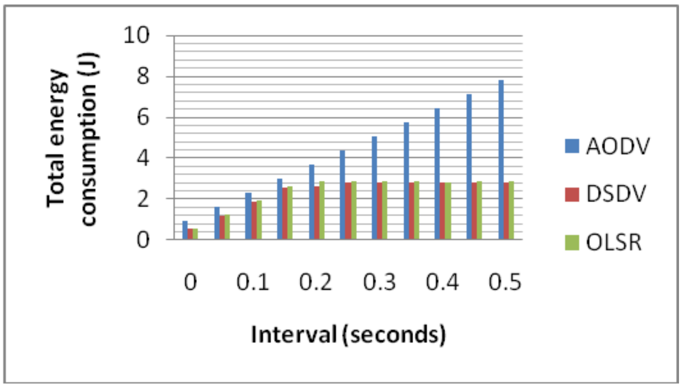

Fig. 5.112 Total Energy Consumed vs. Interval, Packet Size 2048, DSSS Rate 2 Mbps

Figure 5.113 shows that energy consumption of AODV is highest in all cases and also OLSR achieves lowest energy consumption than DSDV.

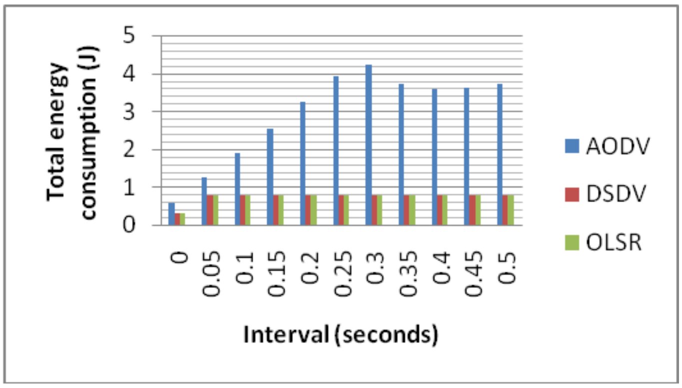

Fig. 5.113 Total Energy Consumed vs. Interval, Packet Size 2048, DSSS Rate 11 Mbps

In Fig. 5.114 total energy consumption is nearly same for all three protocols.When the interval is 0 and 0.05 seconds DSDV achieves lowest energy consumption and at interval of 0.1, 0.15, 0.25, 0.3, 0.35, 0.4, 0.45 and 0.5 seconds AODV achieves lowest energy consumption.

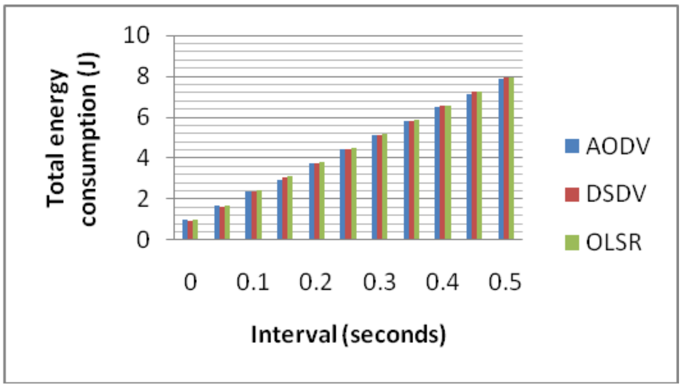

Fig. 5.114 Total Energy Consumed vs. Interval, Packet Size 4096, DSSS Rate 1 Mbps

In Fig. 5.115 AODV achieves maximum energy consumption. Also, DSDV outperforms OLSR in every cases.

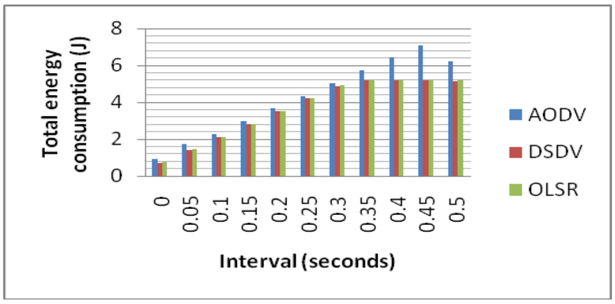

Fig. 5.115 Total Energy Consumed vs. Interval, Packet Size 4096, DSSS Rate 2 Mbps

In Fig. 5.116 it is observed that at the interval of 0, 0.1, 0.2 and 0.25 seconds OLSR achieves lowesrt energy consumption and in all other cases DSDV performs better than OLSR. It is also seen that AODV shows worst performance by achieving maximum energy consumption.

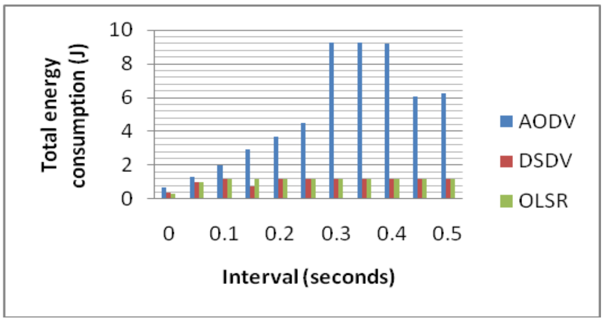

Fig. 5.116 Total Energy Consumed vs. Interval, Packet Size 4096, DSSS Rate 11 Mbps

6. Conclusions and Future Scope

Conclusions

In this thesis three routing protocols (AODV, DSDV and OLSR) are compared and their performance is examined in three real life scenarios by varying different simulation parameters in each scenario. Performance is measured using four performance metrics i.e. Packet delivery ratio (PDR), Throughput, Average delay and Total energy consumption.

In the first scenario (Historical site scenario), on considering the PDR, DSDV and OLSR performs better for lower DSSS Rates but AODV performs better for higher DSSS Rates. It is also concluded that in AODV, PDR is inversely proportional to the no. of nodes and no. of packets being send.When the size of the network increases i.e. above 20 nodes, performance of OLSR decreases. On considering the throughput, in AODV, the throughput does not reach high levels due to the low levels of PDR. Also, when the number of packets increases, linear relationship between throughput and number of nodes is observed. DSDV shows better results for bigger packet sizes. In OLSR, the throughput is increased linearly with the increase in number of nodes and packets being send. If delay is considered, average delay is variable in AODV but remains constant in OLSR and nearly constant in DSDV. In AODV, average delay is directly proportional to the number of packets being send. DSDV performs better for lower DSSS Rates and OLSR is independent of the network size i.e. the average delay is not affected by the number of nodes. And finally, on considering total energy consumption, in DSDV and OLSR, there is a linear relationship between the total energy consumption and network size along with number of packets being sent and in AODV, the higher the number of packets and nodes, the higher the total energy consumption.

In the second scenario, it is concluded that speed has no affect on the performance of DSDV and OLSR but it affects the performance of AODV but not in a certain pattern and particularly. Number of nodes affects the performance of all the three protocols. When the no. of nodes is increased, the throughput and PDR are decreased and the total energy consumption and average delay are increased. In every simulation metric OLSR shows the best performance with PDR (100%), Average delay (0.0064048 seconds), Throughput (568.072 kbps) and Total energy consumption (0.320609 J). Also, AODV never outperforms DSDV and OLSR.

In the third scenario, on considering the PDR, it is concluded that when the DSSS Rate is 2 Mbps or higher, OLSR always achieves the best results. When the DSSS rate is 1 Mbps and packet size is small, OLSR has best performance and as the packet size increases DSDV outperforms OLSR. Considering average delay, when the packet size is being increased DSDV shows better performance and on the other hand OLSR performs well during higher DSSS Rates. If we consider throughput, OLSR performs better than DSDV in almost all cases except when the DSSS Rate is 1 Mbps and packet size is increased. Finally, at last on considering the total energy consumption, DSDV outperforms OLSR at lower DSSS Rates and OLSR outperforms DSDV at higher DSSS Rates. AODV never outperforms DSDV and OLSR. So before choosing a routing protocol, their advantages and disadvantages should be considered.

Future Scope

1) There are many issues related to MANET that could be subject to further studies.

- An analysis on whether sending many small control packets are costly or fewer large control messages.
- Simulations which takes unidirectional links.
- IP-Sec authentication headers can be deployed as well as necessary key management to distribute keys to the members of MANET.
- Hand-over of real time traffic between nodes i.e. smoothly hand over the traffic to another node when a route goes down.
- Multicast routing can also be considered.
- Mobile IP can be integrated into ad-hoc networks.

2) Simulation environment could also be improved.

- More routing protocols for instance TORA, ZRP etc.
- Measurement of computing complexity.

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List of Publications

1. Supriya Singla and Sushma Jain, " Comparison of Routing Protocols of MANET in Real World Scenario Using NS3," *In Proc. of Inter. Conf. on Control, Instrumentation, Communication and Computational Technologies (ICCICCT-2014),* Tamil Nadu.
   [Accepted].
2. Supriya Singla and Sushma Jain, "Performance Comparison of Routing Protocols of MANET In Real World Scenario using NS3" published in *International Journal Of Computer Applications (IJCA),* vol. 99, August 2014.