CHAPTER 1

INTRODUCTION AND PREVIEW

The outlook of the wireless network is changing dramatically because of the fast advancement in wireless technologies and the requirement of the new wireless services and applications. For example, the third-generation of the cellular networks is an emerging technology in networking, which has significantly improved the speed of data transmission. Also, supports various mobile data services with a variety of higher rates. Meantime, various new standards like Wi-Fi (802.11), HiperLan2, Infrared, WPAN, Bluetooth, WiMAX (802.16) etc. are supporting to extend the network by providing short-range radio. The extension of a network through different new standards enables wireless industries for the various new applications such as home networking and enterprises, tactical operations, automated vehicle etc.

1.1 Overview of Wireless Networks Evolution

In this section, the development of wireless technology has been traced in a chronological manner. Further, this section also helps to understand, why infrastructure less or ad-hoc networks are becoming popular among researchers in the evolution of future wireless networks.

In the era of 70's, the rapid advancement in radio technology stimulated the growth of mobile communication systems that enabled the users for connectivity while roaming [J.J.-N. Liu, *et al.*, 2004]. Initially, there was a requirement to have connectivity while away from the fixed backbone or in roaming. The first generation of wireless networks that supported analog cellular phones, which had a speed up to 2.4Kbps based on FDMA technique, fulfilled the above requirement. However, this technique was relatively unsophisticated because of different standards for mobile phones, adopted in the different parts of the world. Therefore, it allowed users to make the voice call within one country only. For examples, first generation phones (1G) which were used in North America, were Advanced Mobile Phone Service (AMPS), and in Europe were Nordic Mobile Telephony (NMT) & Total Access Communications System (TACS) [W. Stallings, 2005].

The second generation (2G) of wireless network technology came in the market during the era of the late 80's and was over in the late 90's [A.K. Mishra, 2004; & A. Goldsmith, 2005]. The key features of this technique are that it digitizes the mobile communication system, and users are using it even today. This second wave of wireless evolution was more promoted because it provided the facility to connect the internet from the mobile terminals for various services, such as e-mail, web access, conferencing, and so on. The devices of this generation are attached with WLANs technology (IEEE 802.11) and data cellular services (e.g. UTMS, GPRS etc). The 2G based devices support voice transmission with a digital signal and with the transmission rate upto 64Kbps. Many 2G based devices use TDMA and few uses CDMA technique. Again, the plethora of standards was available in various part of the world. For examples, North America uses a mix of GSM, CDMA and TDMA, whereas Asia and Europe use GSM as 2G technologies. 2.5G is an extended version of 2G systems that supports data transmission rates up to 384 Kbps. It is usually associated with the General Packet Radio Services (GPRS) that provided the location based services.

The third generation of the wireless system started to be deployed in the late 90's, and still modifications are there [F. Adachi, 2001; & A.K. Mishra, 2004]. In other words, current efforts are being made in the transition of the wireless industry from a second generation to the third generation networks [J.J.-N. Liu, *et al.*, 2004]. The third generation of wireless systems adheres common standards around the world and allows users for global roaming across multiple wireless networks. It also accepts IP interoperability for the seamless mobile internet. Moreover, the third generation provides various services like super voice quality and video conferencing, purchasing (online shopping, games, banking etc), data services, add-on services (e-mail, personal organizer), web surfing etc. Mostly, devices of this generation are based on CDMA technique. The supported transmission speed of this network is from 125 Kbps to 2 Mbps for various mobile and stationary applications. In this generation, again different standards are being promoted by the different countries as Enhanced Data for GSM Evolution or Enhanced Data for Global Evolution (EDGE) and Wideband Code Division Multiplexing Access (W-CDMA) by Europe and Asia, whereas America supports cdma2000 [J.J.-N. Liu, *et al.*, 2004]. Furthermore, in 2005, the third generation was prepared for collaborating with computer networking (WLAN, Bluetooth etc.).

In this third wave of wireless evolution, the researchers used “Ad-hoc Networks” for providing the connectivity among participants. However, ad-hoc network holds future promises to further contribute significantly to the next generation of wireless networks. The aim of this type of network is very different from internet access and mobile telephony [M. Gerla, 2005]. The premier objective of an ad-hoc network has been to provide the connectivity for specialized, customized, extemporaneous applications in the region where setting up of fixed access points and backbone infrastructure is not feasible, like:

- Infrastructure may not be possible such as in disaster zone, in combat or emergency situations etc.
- Infrastructure has broken down (e.g. earthquake etc).
- No pre-existing infrastructure (e.g. jungle exploration etc).

- Infrastructure may not be practical for short-range radios like Bluetooth (range ~ 10m) etc or may not sufficient for present demands (interconnection of low energy environmental sensors etc).

The support and integration of ad-hoc networks play a vital role in these types of situations.

1.2 Kinds of Wireless Networks

At present, different kinds of the wireless networks are recently available, and can be classified in various ways as discussed below which is shown in figure (1.1).

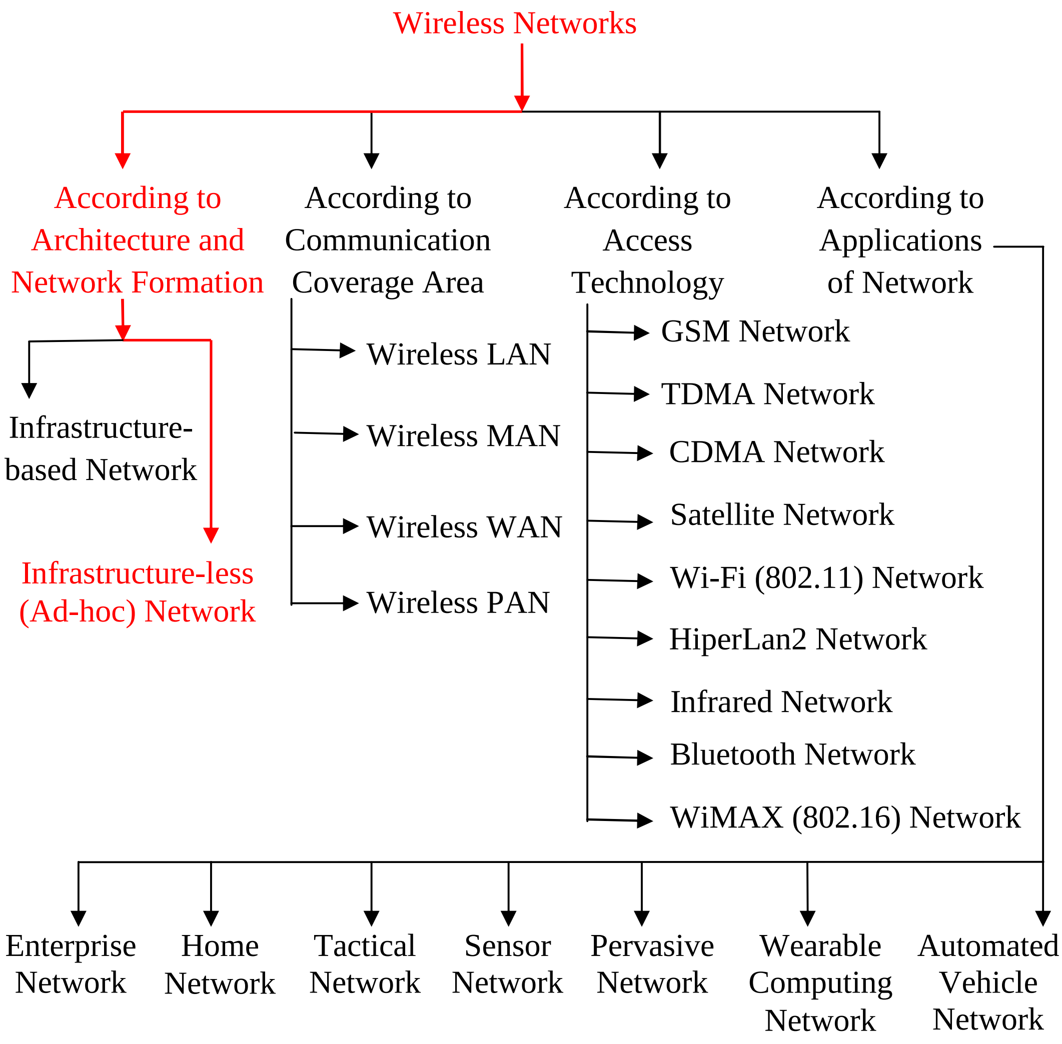

Figure 1.1: Different kinds of wireless networks

According to Architecture and Network Formation: In this category (according to network construction and network architecture), the wireless networks can be classified in mainly two ways as follows:

Infrastructure-based Network: This type of network has a static backbone that is constructed with fixed and wired network nodes and gateways. In other words, the infrastructure-based network has fixed, pre-located cell sites and base station. Key features of this network are stable connectivity and caring environment. The cellular networks are an example of infrastructure-based network that is built from PSTN backbone switches, MSCs, base stations, and mobile hosts [Y.B. Lin, *et al.*, 2000]. Here, a mobile host communicates with a bridge in the network (called base station) within its communication radius. The mobile unit can move geographically while it is communicating. The wireless LANs is also an example of this network, which is shown in figure (1.2).

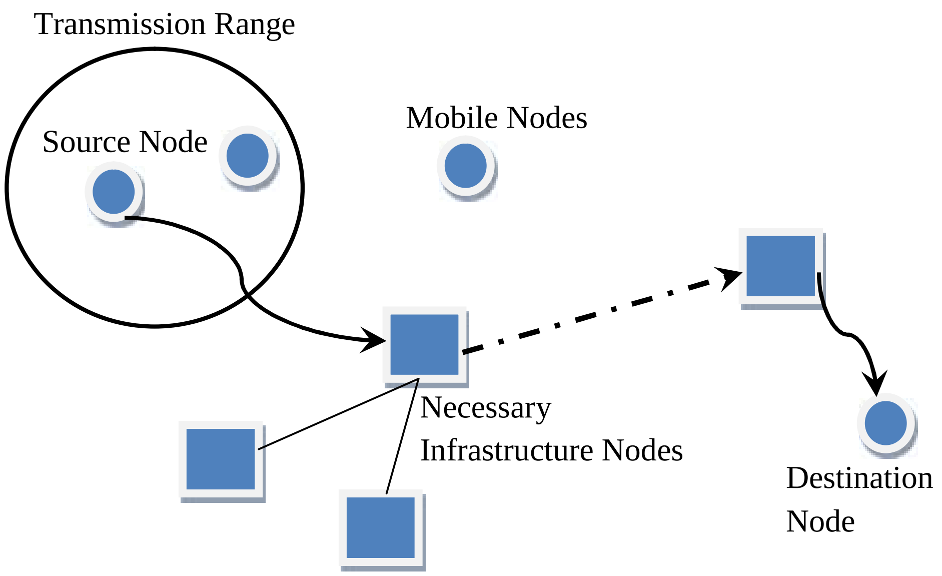

Figure 1.2: Example of an infrastructure network (WLAN)

Infrastructure-less (Ad-hoc) Network: In contrast to infrastructure based wireless network, all nodes are mobile in an ad-hoc network and these nodes can be connected dynamically in an arbitrary manner. An ad-hoc network is a collection of wireless mobile nodes forming a temporary network without using any existing infrastructure or any administrative support [M. Frodigh, *et al.*, 2000; & M. Gerla, 2005]. The wireless ad-hoc network is self-creating, self-organizing and self-administrating. The nodes in an ad-hoc network can be a laptop, cell phone, PDA or any other device capable of communicating with those nodes located within its transmission range. In this network, nodes can function as routers, which discover and maintain routes to other nodes. In an ad-hoc network, the dynamic routing protocol must be needed to keep the record of a high degree of node mobility, which often changes the network topology dynamically and unpredictably. The example of an infrastructure-less/ad-hoc network is shown in figure (1.3).

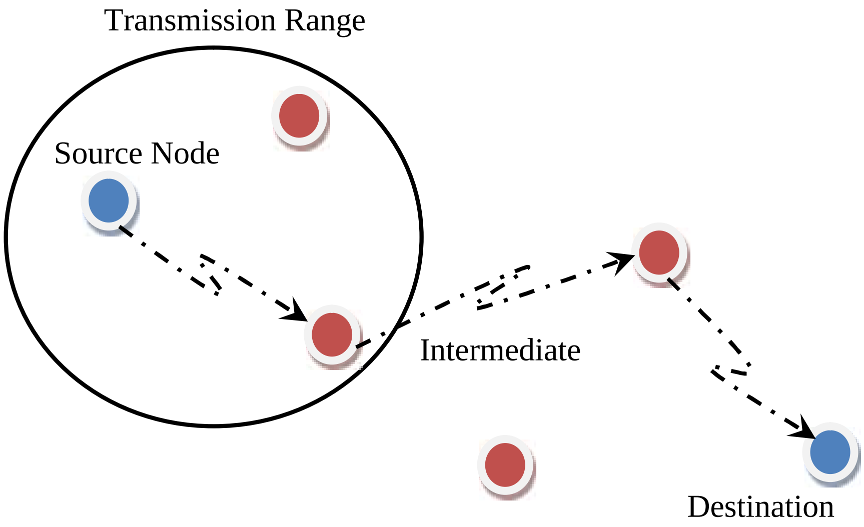

Figure 1.3: Example of an infrastructure-less (ad-hoc) network

According to Communication Coverage Area: The networks either with wired or wireless can also be categorized based on their propagation distances or coverage areas over which data is transmitted:

Wireless Local Area Network (WLAN): It is one of the fastest growing technologies because of the demand for connecting devices without the use of cable is increasing everywhere [A. Goldsmith, 2005; & W. Stallings, 2005]. WLAN allows users to setup wireless connections within a local area, such as within a corporate/campus building and in a public space, like an airport, stadium etc. The coverage area of WLAN is within a 100 m for building, 10 m for a room [D-Link WLAN, 2002; & I. Chlamtac, *et al.*, 1994]. It can be operated in two modes that are infrastructure-based or in ad-hoc mode. In infrastructure mode, Access Point (AP) is used to deploy the network, whereas, an ad-hoc mode does not use AP and have no connection to the internet. The group of IEEE standard 802.11 X and HiperLan2 specifies the WLAN technologies, and its transmission speeds are between 11 Mbps to 54 Mbps [D.L. Lough, *et al.*, 2000; & L. Goldberg, 1995].

Wireless Metropolitan Area Network (WMAN): It is also referred to the fixed wireless network. It allows the user for wireless connection among multiple spots within a metropolitan area without using high-cost fiber or copper cabling [D-Link WLAN, 2002]. Moreover, it can also serve as the backup for wired networks. Data transmission technique of WMAN is both radio waves and infrared light. This technique allows a maximum data speed up to 70 Mbps within transmission ranges of near about 40 Km. The most well know technology WiMAX (IEEE 802.16) belongs from this group [IEEE 802.16; & W. Stallings, 2005].

Wireless Wide Area Network (WWAN): This network provides the connectivity wirelessly to deliver services over large geographical areas that may comprise of a country, continent or even the whole world [D-Link WLAN, 2002]. Along with this, it can play the role of Local Multipoint Distribution Services (LMDS) or Wi-Fi to provide internet services. To offer services over large geographical areas, WWAN uses multiple antenna or satellite systems that are take care by the service provider. The good examples of WWAN are CDMA, GSM and satellite networks [W. Stallings, 2005].

Wireless Personal Area Network (WPAN): It can be defined by IEEE standard 802.15, which uses the Bluetooth wireless technology (cable replacement technology, here data is transmitted by using radio waves) [Official Bluetooth; W. Stallings, 2005; & IEEE 802.15]. In this network information are conveyed over a short distance (typically, near about range of 10m) among the group of the local participants such as laptops, PDAs or cellular phones. This network uses no or less infrastructure or direct connectivity to deliver services among participants. WPAN is gaining more importance because of its power efficiency, less complexity, interoperability with 802.11 networks, and inexpensive solutions provided for many devices. WPAN supports the maximum data speed up to 250 Kbps.

According to Access Technology [J.J.-N. Liu, *et al.*, 2004]**:** The wireless networks can also be differentiated according to its access technology that is based on the frequency, usage of the spectrum and specific standards, as follows:

1. GSM Network
2. TDMA Network
3. CDMA Network
4. Satellite Network
5. Wi-Fi (802.11) Network
6. HiperLan2 Network
7. Infrared Network
8. Bluetooth Network
9. WiMAX (802.16) Network etc

According to Applications of Network [J.J.-N. Liu, *et al.*, 2004]**:** The wireless networks may also be categorized according to its usage and applications, these include:

1. Enterprise Network
2. Home Network
3. Tactical Network
4. Sensor Network
5. Pervasive Network
6. Wearable Computing Network
7. Automated Vehicle Network

1.3 Ad-hoc Network

In the past few years, wireless technologies have experienced unexcelled growth. One of the most vibrant and rapidly growing fields today is the ad-hoc network. And, it is also known as mobile multi-hop wireless network or mobile packet radio network. In this area, the significant research has been going on since last nearly 40 years.

In this section, the evolutionary history of ad-hoc network has been explained in a chronological manner. Moreover, this section has also attempted to describe the fundamental concepts and major attributes of the ad-hoc network.

1.3.1 Evolutionary History

The concept of ad-hoc network is not a new one. In early 70's, it was first time introduced in the market and was known as the Packet Radio Network, which had been supported by the Defense Advanced Research Projects Agency (DARPA) [M. Frodigh, *et al.*, 2000; R. Ramanathan, *et al.*, 2002; & M. Gerla, 2005]. This project name had been given packet radio, where numbers of wireless participants could make connectivity on combat zone.

The complete life cycle of ad-hoc network could be presented to the first generation, second generation, and the third generation. Currently, the third generation of ad-hoc network is going on.

First Generation: The first generation of ad-hoc network can be traced back to the 72's. The DARPA started research on the feasibility of using packet-switched radio communications to give the reliable computer communications. And, finally came up it with the name of the DARPA Packet Radio Network (PRNET) [J.A. Freebersyser, *et al.*, 2001; C.K. Toh, 2001; & J. Jubin, *et al.*, 1987]. In this generation, the ALOHA (Arial Locations of Hazardous Atmospheres) and CSMA (Carrier Sense Medium Access) techniques were combined together for the medium access control. In addition, Distance-Vector routing protocol was used as a routing protocol to have communications on battlefields. Later on, the concept of automatic and distributed network management facility was also incorporated in this DARPA PRNET project. Initially, the great challenge in this field was radio coverage. However, this restriction was eliminated by the multi-hop Store/Forward routing concept, which enables multi-user to have connectivity within a very wide geographical zone.

Second Generation: The considered time of second generation is during 1980 to 1993. In which DARPA introduced Survivable Radio Networks (SURANs) after further enhancement of the ad-hoc networks. SURAN came up with the concept of packet switched networking which provided infrastructure-less environments in the combat fields [J.A. Freebersyser, *et al.*, 2001]. Moreover, under SURAN program radios' performances were significantly improved by making them cheaper, power-thrifty, smaller, and scalability of algorithms and resilience to electronic attacks. At the same time, the DARPA Global Mobile Information Systems (GloMo) [B.M. Leiner, *et al.*, 1996], and the Near-Term Digital Radio (NTDR) [R. Ruppe, *et al.*, 1997] projects were introduced by the Department of Defence (DoD), US. The facility of Ethernet-Type Multimedia connectivity among wireless users was provided by GloMo project that could be set up anytime and anywhere. Here, CSMA/CA and TDMA technique were used for media access control and various techniques were introduced for the topology control and routing. The NTDR gives self-organizing, self-healing capabilities to the network. Moreover, the network management terminal provides the network management facility for the network. Its primary purpose is to offer the data transport for the army battle. NTDR project uses the link state and clustering routing, and still the US Army uses it.

Third Generation: The third generation of ad-hoc network has been considered since 90's. In earlier generations (first and second), the ad-hoc network was only known for military applications. However, in this generation, it has been introduced for non-military applications also and has become a vibrant area of research among the researchers. Ad-hoc network has mainly attracted the researchers since 95's in the conference session of the Internet Engineering Task Force (IETF) [IETF MANET]. At the same time, the concept of a collection of mobile nodes was introduced in research conference by several researchers and the term "Ad-Hoc Network" has been adopted by the IEEE 802.11 subcommittee [R. Ramanathan, *et al.*, 2002]. Recently (near about 97's and 98's), newer techniques such as Bluetooth, Wi-Fi, and HiperLan2 have been introduced, and the deployment of ad-hoc network concept has significantly made possible to the outside of the military realm. As a result, the applications of an ad-hoc network have been seen in many fields like a personal area and home networking, search and rescue operations, commercial and educational applications, sensor networks, and so on [J.J.-N. Liu, *et al.*, 2004; & M. Gerla, 2005]. The best of all possible present and the future applications of the ad-hoc network have been shown in table (1.1). The medium access protocol of this generation is based on CSMA/CA and tolerated hidden terminals, which have been standardized by the IEEE 802.11 subcommittee.

It is expected that the coming generation of mobile communications will have both prestigious infrastructure wireless networks and novel infrastructure-less ad-hoc networks.

Table 1.1: Present and future applications of the ad-hoc network

S. No.	Name of applications	Descriptions of various services
1.	Tactical environments	Military communications, Military operations, Automated battlefield operations (unmanned fighting vehicles) etc.
2.	Business zones	Conferencing, Requirement of the collaborative computing inside and outside of the office etc.
3.	Emergency operations	Search-and-rescue in the jungle, in the mountain, in the desert, and so on. Replacement of backbone in case of environmental disasters such as earthquakes, hurricanes etc. Hospitals: supporting doctors and nurses Firing, Policing etc.
4.	Location aware services	Automatic Call forwarding, Advertise location specific services, Location–dependent travel guide etc.
5.	Extension of coverage	Tie-up with the internet, intranet, and so on Expansion of the cellular network and wireless hotspots etc.
6.	Entertainment	Multi-user games, Robotics pets etc.
7.	Education	Setup virtual class & conference rooms, Universities, and campus settings etc.
8.	Home and enterprise	Home/office wireless networking, PAN: using PDAs, laptops, and handphones etc.

9.	Sensor network [I. Chlamtac, 1996]	Remote sensors for Weathers, Earth activities, Sensors for manufacturing equipment etc.
10.	Commercial	E-Commerce: Electronic payments in bank, in taxi etc Vehicular services: Road conditions, Weather, Road/accidents guidance etc.
12.	Civilian environments	Taxi cab networks, Meeting area, Sports stadium, Boats and small air crafts etc.

1.3.2 Fundamental Concepts

The term "Ad-hoc network" has been taken from the Latin, which means "for this purpose" or "for this only". More often, ad-hoc network is deployed for a particular one-time purpose. Actually, ad-hoc network is a collection of wireless mobile nodes that can exchange the message among nodes without the help of any pre-existing infrastructure or centralized administrations [C.K. Toh, 2001; & M. Frodigh, *et al.*, 2000]. In an ad-hoc network, all nodes are mobile and connected dynamically in an arbitrary manner, node movement is random, and are capable of organizing themselves. Hence, owing to this nature of an ad-hoc network, the changes to topology are more common and unpredictable. In this network, due to a limited transmission range of nodes, one communication session is completed by the several intermediate/relay nodes, or may need multiple hops to reach the destination as shown in figure (1.3) and figure (1.4). In other words, it can be said that the intermediate nodes play a significant role in order to establish the connection between a source and the destination node. Hence, this network could also be called multi-hop wireless ad-hoc network. As, in this network, nodes can act both as a host as well as a router and can also accomplish a task of network management. Therefore, deployment of this network is easier than the other kind of networks like infrastructure etc, and has a number of applications as discussed in the table (1.1).

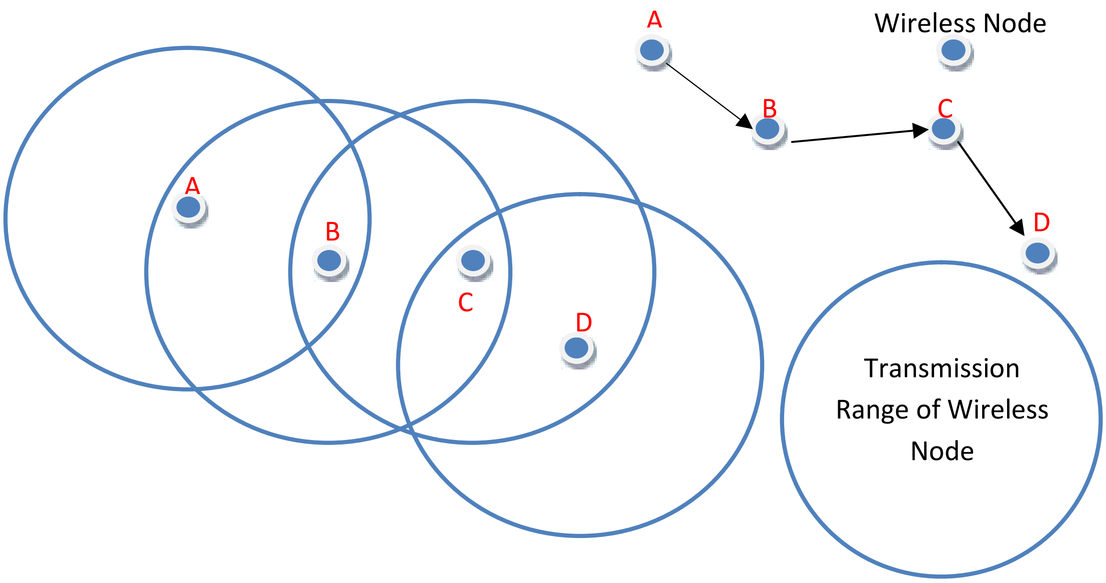

Figure 1.4: Multi-hop wireless ad-hoc network

1.3.3 Major Attributes [L. Qin, 2001]

Although, ad-hoc network possesses a number of advantages because of robust, scalable and adaptive nature, also have some major attributes that create challenges for researchers to deploy this kind of network. According to the IETF RFC 2501 [S. Corson, *et al.*, 1999], the major attributes of ad-hoc network are as follows:

Autonomous Terminal: In an ad-hoc network, each individual terminal is an autonomous node that may play the role of both, whether as a host or as a router. I.e. along with basic function as a host, node of ad-hoc networks may also execute the switching functions as a router.

Distributed Operation: Due to the lack of central administration or fixed backbone, an ad-hoc network is a self-configuring, self-organizing along with self-administering network. Therefore, the network controls operation as network controls, network managements etc are distributed among the terminals.

Dynamic Topology: All nodes of an ad-hoc network are mobile and move with the varying velocities. Hence, the topology of the network may change randomly and rapidly at unpredictable. Therefore, the phenomenon of frequent link breakage is quite common. In this case, always few nodes try to join the network or few existing nodes attempts to leave the network. Thus, the dynamic changes in the network topology pose the biggest challenge to routing in ad-hoc network.

Asymmetrical Communication: In the ad-hoc network environment, each node has different characteristics of antennas and therefore symmetric, bi-directional communication over the same link is not possible always. In some cases, only unidirectional communication is possible.

Energy Limitations: Each node of the ad-hoc network is generally battery operated. Therefore, energy conservation techniques and energy-aware routing in this network become necessary considerations.

Multi-hops Routing: The routing algorithm of ad-hoc network can be classified as single-hop and multi-hop based on their different features of link layer and routing protocols. If the source and destination nodes are out of the direct wireless transmission range, then the packets may use multiple hops to reach the destination node during the transmission. In other words, packets could be forwarded via multiple intermediate /relay nodes.

Fluctuating Link Capacity: In ad-hoc networks, generally, one end-to-end path or communication session can be completed by the multiple sessions. Channels through which wireless nodes are communicating are subjected to noise, fading, interference and have a smaller bandwidth than wired networks. Here, high bit error rate nature of the wireless link is more profound.

Bandwidth Limitations: Since the nodes communicate via wireless links, the realized throughput in this network, when compared to a wired network of similar size is quite small. The relatively low capacity of the wireless links is not able to facilitate real-time transmission. Therefore, leads to delay in packet transmission. Moreover, the wireless links are quite error-prone, which may further degrade throughput due to upper layer retransmissions etc.

Lightweight Terminals: The wireless nodes of the ad-hoc network are generally with less CPU processing capability, small size of memory, and less power storage capacity. Hence, these devices required optimized algorithms and mechanisms that implement the functionality of computing and communicating.

1.4 Background and State of The Art (SOTA)

This section describes the various key aspects of an ad-hoc network such as Routing Protocols, Mobility Models (MB), Medium Access Control (MAC), Quality of Service (QoS) and Simulation Software. Moreover, at the end of this section, some available studies related to the ad-hoc networks have been reviewed. After that, on the basis of the review, it may be concluded that major researchers have considered the mobility pattern, node mobility, network size, numbers of the node, while a few have also worked on route maintenance parameters but ART has only been considered. However, the present study marks a shift from the previous studies in which it considers ART, DPC along with determining factors like mobility, transmission range, NLD and ANs/SD pair.

1.4.1 Routing Protocols [E.M. Royer, *et al.*, 1999; D.A. Maltz, *et al.*, 1999; J. Broch, *et al.*, 1998; M. Gerla, *et al.*, 2002; & S.R. Das, *et al.*, 2000]**:**

In order to facilitate communication within a network, a routing protocol is used to discover the routes between nodes. The primary goal of a routing protocol is the establishment of an efficient and correct route between node pairs. Therefore, that packet could be successfully delivered to the intended node promptly. The formation of routes should be done with the minimum consumption of bandwidth and overhead [E.M. Royer, *et al.*, 1991]. In an ad-hoc network, the number of routing algorithms has already been addressed, and a traditional algorithm cannot be used here.

Owing to the highly dynamic nature and absence of backbone makes packet routing a challenging task in ad-hoc networks. The suggested routing techniques of ad-hoc networks can be divided into single and multi-path routing [P. Kuosmanen, 2003] as shown in figure (1.5).

The single path routing of this network, firstly understands all available routes and then finally chooses one best route to the destination. Further, single path routing can be split into the parts: based on topology and based on location. The topology based routing forwards packet based on links information that exists in the network. Further, they can be categorized as proactive/table-driven, reactive/on-demand driven, hybrid (combination of both proactive and reactive), hierarchical, and flow-oriented techniques.

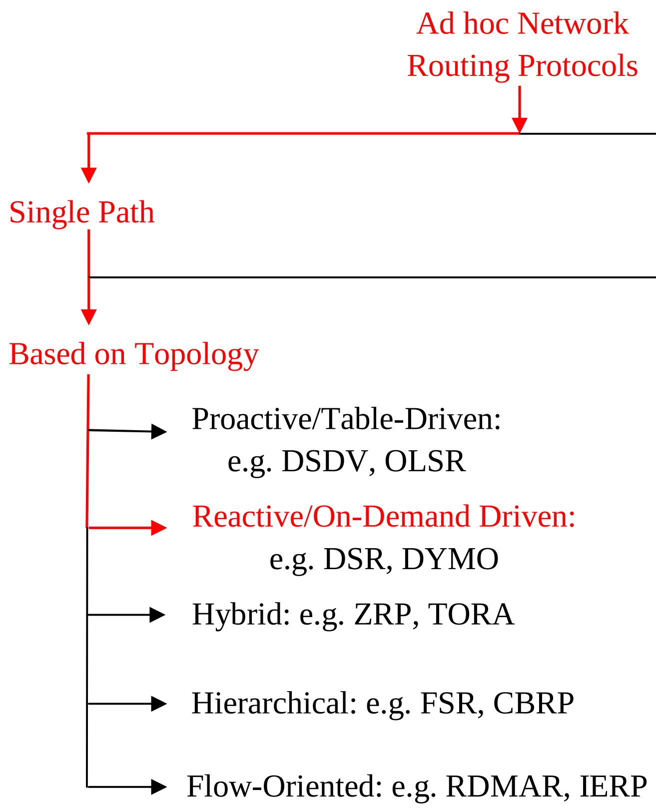

Figure 1.5: Classification of routing protocols in ad-hoc networks

Proactive/Table-Driven Routing Protocols [C.K. Toh, 2001; M. Abolhasan, et al., 2004; & C. Liu, et al., 2005]:

The idea of proactive routing protocols is based on traditional routing approaches like DSDV is related to distance vector routing or OLSR is related to a link state routing. In this routing, each and every mobile node maintains the routes towards each and every possible destination in the network. Here, updated routing tables are forwarded periodically throughout the network to maintain the up-to-date list of destinations. Therefore, there is little or no delay in route determination process. The major drawback of this protocol is that it also maintains the topological information about nodes with which it may never communicate, overhead in periodic/triggered routing table updates, and low convergence rate. Examples of proactive routing protocols are DSDV, TORA etc.

Reactive/On-Demand Driven Routing Protocols [M. Abolhasan, et al., 2004; & C. Liu, et al., 2005]:

Like proactive routing protocols, reactive routing protocols do not maintain the routes to all the possible destinations, and it is also known as on-demand routing protocols. Its name implies that routes are determined on-demand by flooding route request packets in the network, i.e. whenever a route is required for the communication, then only the reactive routing protocol will start to search for a route to the particular destination. In this routing protocol, employ flooding or global search techniques are used for the route discovery process. It maintains only those routes that are presently in use. The best examples of these routing protocols are DSR, AODV, and DYMO. Due to the features of on-demand nature, routes overheads are minimized in this technique. However, they still have some inherent limitations that are as follows;

- High latency in the route finding i.e. as, it is known that here routes are determined when it is needed. Hence, the significant delay may present in the network [L. Cheng-Ying, 1999].
- Excessive flooding can lead to network clogging i.e. due to large flooding lower overhead may be there.
- Finally, packets en-route to the destination are likely to be lost if the destination route is changed.

Hybrid (both Pro-active and Reactive) Routing Protocols [M. Abolhasan, et al., 2004; A.K. Pandey, et al., 2005; & C. Liu, et al., 2005]:

Hybrid routing protocols have been introduced to take the advantages of both proactive and reactive routing protocols, and overcome their drawbacks in order to achieve a higher level of efficiency and scalability. It uses the concept of traditional distance vector and link state routing and merges them into new protocols. In the beginning, it is set up for the proactive aim and after that it serves for the reactive purpose. However, even a combination of both approaches still needs to maintain at least those network paths that are presently in use, limiting the amount of topological changes that can be tolerated within a given amount of time. Examples of this category are ZRP, TORA etc.

Hierarchical Routing Protocols [L. Kleinrock, et al., 1977; J. Westcott, et al., 1984; & G.S. Lauer, 1986]:

Again, this routing protocol uses the concept of proactive and reactive routing and organizes hierarchically based on their relative proximity to one another. This routing protocol significantly enhances the scalability of routing in an ad-hoc network environment by strengthening the route robustness. The selection of proactive and reactive routing is based on a level of nodes in which it is laid in the hierarchy. The proactive routing concept is implemented for the higher levels of nodes after that reactive routing are flooded on the lower levels. Here, the depth of addressing and nesting scheme are the major factors, and it reduces the size of routing table by using hierarchy information. The example of these routing protocols is FSH and CBRP.

Flow-Oriented Routing Protocols [W. Su, et al., 1999 & 2001]:

Flow-Oriented Routing Protocol is one of the best stable path unicast routing protocol and finds a route in the network based on on-demand. In this routing, while promoting a new link consecutively unicast when data are forwarding. Moreover, for predicting a route expiry time, it uses the mobility and location information of the nodes. Exploring new routes without prior knowledge takes a long time that is the drawback of this routing. IERP and RDMAR belong from this group.

Location based Routing Protocols [Y.-B. Ko, et al., 2000; M.-T. Sun, et al., 2002; & C. Liu, et al., 2005]:

Location-Aided Routing (LAR) is the best example of these protocols, which eliminates some of the restrictions of topology-based routing by using additional information. This routing has GPS or some other kind of positioning service features so that each node in this network can determine its position. Whenever any node wants to send packets, it uses simply location services to determine destination position and includes it in the packet's destination address. Therefore, the decision of routing at each node is based on the destination's position contained in the packet and the position of the forwarding node's neighbors. Owing to these location-based features in this routing, the establishment or maintenance techniques for routes are not required, unlike other routing procedure. Besides, for acquiring node's location information, nodes need neither to store routing tables nor to send packets to keep routing tables up to date. Moreover, this routing can transmit the packets to all nodes in the entire network in a natural way. As a result, it can be said that this routing protocol works more efficiently in case of frequent route changes, and are more scalable to the larger network size.

Multi-paths Routing [S.J. Lee, et al., 2000; & A. Nasipuri, et al., 1999]:

Again, this type of routing protocol recognizes all available paths in the entire network as the single path routing protocol and may select more than one best route to the destination. Due to the selection of multiple best paths towards the destination, this routing protocol is more capable of balancing load throughout the network, which eventually leads to fault tolerance.

1.4.1.1 Some Popular Routing Protocols

This subsection discusses some popular routing algorithms proposed for the ad-hoc network.

Dynamic Source Routing (DSR) Protocol [J. Broch, et al., 1998]:

DSR has entirely on-demand behavior and its working principle is based on source routing. The key point of source routing concept is that relay nodes do not require to keep up-to-date routing information to route the packets they forwarded. Here, almost all the information about a route is maintained at the source node and this information is continuously updated. This fact, owing to the on-demand nature, DSR eliminates the requirement of the periodic route advertisement and the neighboring detection packets, which are present in other protocols. The major drawback of this protocol is the less feasibility of scalability because of the random broadcasting of packets in order to find the routes. Its performance may be affected in case of high node mobility and more traffic due to its on-demand nature. Moreover, the considerable amount of routing overhead is presented in DSR routing due to employ by the source routing mechanism. In this routing overhead is directly proportional to the path length. The DSR implements two phases to accomplish its job (i.e. establish the route between two entities), one of the phase is route discovery and the second is route maintenance.

Dynamic MANET On-demand (DYMO) Protocol [I. Chakeres, et al., 2006; & R.E. Thorup, et al., 2007]:

The DYMO allows dynamic, reactive/on-demand, multi-hop, unicast routing between participating nodes wishing to communicate. It is a memory concerned routing protocol and stores minimal routing information. Therefore, in this routing, the control packets are only generated whenever a node receives the data packets. The principal operations of this protocol are again route discovery and route management process. In route discovery, the source node starts to spread out the Route Request (RREQ) packet throughout the network in order to find the destination nodes. During the RREQ spreading process, each relay node records a route to the source node. The target node sends a Route Reply (RREP) packet towards the node of a source when it receives the RREQ. Once the source node receives the RREP packet, then the routes get established between the source and the destination node in both directions. In this routing, nodes maintain their routes and monitor their links to act fast in case of network topology changes. The source node is informed, whenever a data packet is received for a route that is no longer available. A Route Error (RERR) packet is sent to the source node to indicate that the current route is broken. Once the source node receives the RERR packet, it can perform route discovery process if it still has packets to deliver.

The DYMO protocol is generally preferred because it is energy efficient when the network is large and shows a high mobility environment. Also, the packet overhead decreases with increased network sizes and high mobility. However, DYMO does not deliver best in a case of low mobility environment. Moreover, the control packet overhead for such scenarios is also high. Another restriction of the DYMO protocol lies in its applicability as stated in its IETF draft i.e. it performs well when traffic is directed from one part of the network to another part. It shows a degraded performance when there is very low traffic randomly and routing overhead outruns the actual traffic.

Destination- Sequenced Distance-Vector (DSDV) [C.E. Perkins, et al., 1994]:

It is a table-driven or proactive kind of routing protocol and based on classical Bellman-Ford routing algorithm with certain improvement. In this routing protocol, each mobile node maintains the route towards each possible destination in the network.

In order to maintain the route, every mobile node retains the routing table that comprises the number of information like next hop, the number of hops to reach the destination, sequence number of the destination originated by the destination node etc. Here, the concept of sequence numbers is a key point that distinguishes the old routes from fresh one and assures the loop-free route in the network. DSDV is also based on distance vector routing and thus uses bi-directional links. A limitation of DSDV is that it provides only one route for a source/destination pair.

It uses both the periodic and triggered routing updates to maintain the routing table consistency. The triggered routing updates are used whenever the changes in network topology are found so that routing information could be propagated as soon as possible. Moreover, DSDV routing has two ways to send routing table updates, i.e. by the full dump or by incremental. In a full dump update, packets carry all available routing information. An incremental update, in contrast to full dump, comprises only those entries with metrics that have been changed since the last update was sent. Also, the incremental update can fit in one packet. The major drawbacks of DSDV routing protocols are as follows:

- It requires a regular update of its routing tables, which uses up battery power and a small amount of bandwidth even when the network is idle.
- Whenever the topology of the network changes, a new sequence number is necessary before the network re-converges. Thus, DSDV is not suitable for highly dynamic networks.

Optimized Link State Routing Protocol (OLSR) [T. Clausen, et al., 2003]:

OLSR is developed for mobile ad-hoc networks, but can also be used on other wireless ad-hoc networks. It is a proactive or table-driven routing protocol like DSDV, i.e., it exchanges topology information with other nodes of the network, regularly.

Moreover, it is an optimization of the classical link state algorithm. The key idea of this routing protocol is that of Multipoint Relays (MPRs). The MPRs are selected nodes, which are responsible for forwarding the broadcast packets during the flooding process. This technique provides an efficient mechanism for flooding the broadcast packets and substantially reduces the packet overhead as compared to a classical flooding mechanism. In this routing, the information of link state is only generated by nodes, which are selected as MPRs. Thus, a second optimization is accomplished by reducing the number of control packets flooded in the network. As a third optimization, the MPRs node may choose to report only links between itself and its MPR selectors. Hence, in OLSR protocol, partial information of link state is distributed in the network as compared to the classic link state algorithm. After that, this information is then utilized to calculate the route. OLSR provides optimal routes (in terms of a number of hops), and it is particularly suitable for large and dense networks as the MPRs technique works well in this circumstance. It increases the protocol suitability for ad-hoc network with the quick changes of the source and destination pair. Moreover, this routing protocol is well suited for the application where long delays in the transmission of data packets are not allowed. OLSR needs considerable time to re-discovering the broken link that is the major drawback of this routing. Furthermore, it requires more processing power while discovering an alternate route.

Temporally Ordered Routing Algorithm (TORA) [V.D. Park, et al., Apr 1997 & Nov 1997]:

TORA is a distributed routing protocol for mobile, multi-hop wireless networks. The key concept of this routing is that it decouples the generation of potentially far-reaching control packet propagation from the dynamics of the network topology. TORA is based on neither distance-vector nor link-state routing; basically, it is based on link reversal algorithms. TORA is supposed to reduce the control message in dynamic ad-hoc networks. Moreover, it is designed for loop-free, multipath routing, which is used for forwarding traffic to a given destination. It can support both reactive routing for some destinations that is source initiated, and proactive routing to other destinations that is destination initiated. In TORA, a node has to send a query message by the flooding method when it has to transfer some data from a source to the destination. Since the shortest route finding is not a priority in TORA. Therefore, longer paths may lead to some delay or even loss of some data than usual. Here, longer route is chosen mainly to avoid overhead in the process of finding new routes. This routing protocol is highly scalable, adaptive, efficient, and works well in case of a large & dense network. Also, it creates multiple paths between source and destination pairs. Generally, it is not preferred since DSR and AODV outperform TORA. Moreover, in this routing, performance degrades with an increase in mobility.

Ad-hoc On-Demand Distance Vector Routing (AODV) [C. Perkins, 1997]:

AODV mainly belongs to the reactive kind of routing protocol i.e. on-demand routing. In this routing, the route is determined between a source node and the destination node whenever it is needed. AODV routing is the main inclination of this thesis work, which has deeply been discussed in Chapter-2.

1.4.2 Mobility Models (MB) [T. Camp, *et al.*, 2002; F. Bai, *et al.*, 2003; & Q. Zheng, *et al.*, 2004]

The mobility model represents the movement of wireless nodes along with how their location, velocity, and acceleration change over time. In the performance evaluation of ad-hoc network routing protocol, the protocol should be experimented under realistic movements of the wireless users i.e. a mobility pattern. The choice of mobility pattern may play a considerable role in deciding the routing protocol performance; it is desirable for mobility models to emulate the wireless users' movement pattern for the targeted real life applications in a proper way.

The various mobility models have been proposed for the ad-hoc network, and it can be categorized according to the entity and group mobility model as outlined in figure (1.6). The entity mobility models reflect the behavior of an individual wireless node, i.e. in this case, the movement of mobile nodes is independent of each other whereas the second case represents the group mobility characteristics. The first one is only considered when the individual terminal performance is of concern.

One of the entity models, the random waypoint model (RWP), which has two variants (the random walk model and the random direction model), is regarded as a benchmark because of its simplicity and availability in many simulations. Therefore, this thesis work has adopted the random waypoint mobility model to analyze the network performance.

[T. Camp, *et al.*, 2002; F. Bai, *et al.*, 2003; & Q. Zheng, *et al.*, 2004]; They did an exhaustive survey on mobility models.

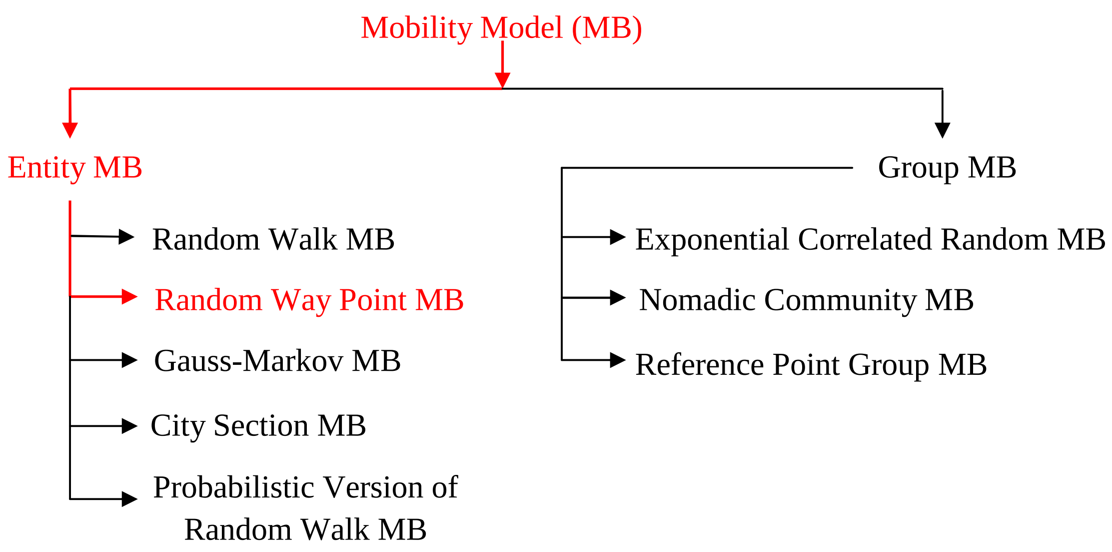

Figure 1.6: Classification of mobility model

Random Walk MB: In this mobility model, the movement of mobile nodes is entirely based on random directions and speeds.

Gauss-Markov MB: It has been designed to adapt to the varying degree of randomness via one tuning parameter.

City Section MB: In this mobility model, a simulation area represents the street within a city.

Probabilistic Version of Random Walk MB: This mobility model utilizes a set of probabilities to find out the next position of a mobile node in the simulation area.

Exponential Correlated Random MB: This mobility model puts relative distances of nodes within a group roughly constant.

Nomadic Community MB: In this model, groups of mobile nodes that collectively move from one point to another. Here, within each group of mobile nodes, individuals maintain their own personal where they move in random ways.

Reference Point Group MB: This model shows the random movement of a group of mobile nodes as well as the random movement of each individual mobile node within the group.

1.4.2.1 Random Way Point Mobility (RWPM) Model [T. Camp, *et al.*, 2002]

Johnson and Maltz [D.B. Johnson, *et al.*, 1996]: first time introduced the RWPM. Actually, RWPM and its variants have been invented to mimic the movement of mobile nodes. Very soon, RWPM became a benchmark to evaluate the ad-hoc network routing protocols because of its simplicity of implementation & analysis, and wide availability.

The RWPM model includes pause times between changes in direction and/or speed. As the simulation begins, each mobile node randomly chooses one location in the simulation area as the destination. After that, it starts to move towards this destination with the constant speed that is selected randomly from the uniformly distributed array

[V_{min}, V_{max}], where Vmax is the maximum speed, which can be acquired by any node. Here, chosen direction and speed of a node are independent of each other. Upon arrival at the destination, the mobile node stays for a certain duration (i.e. pause time), and this pause time is randomly selected from the array [0, T_{Pause}]. Once this pause time expires, again mobile node chooses another destination randomly in the simulation area and travels towards it. The above process is repeated until the simulation time is over. The mobile node-travelling pattern under RWPM model is shown in figure (1.7).

In RWPM model, [V_{min}, V_{max}] and [0, T_{Pause}] are the two important array which plays a significant role to determine the mobility pattern of nodes. If V is small and T_{Pause} is long, the ad-hoc network topology becomes relatively stable. On the other side, if V is large (i.e. highly mobile environment) and T_{Pause} is small, the topology is expected to be highly dynamic. The RWPM can generate various mobility scenarios with different levels of nodal speed by varying these two parameters, especially V parameter.

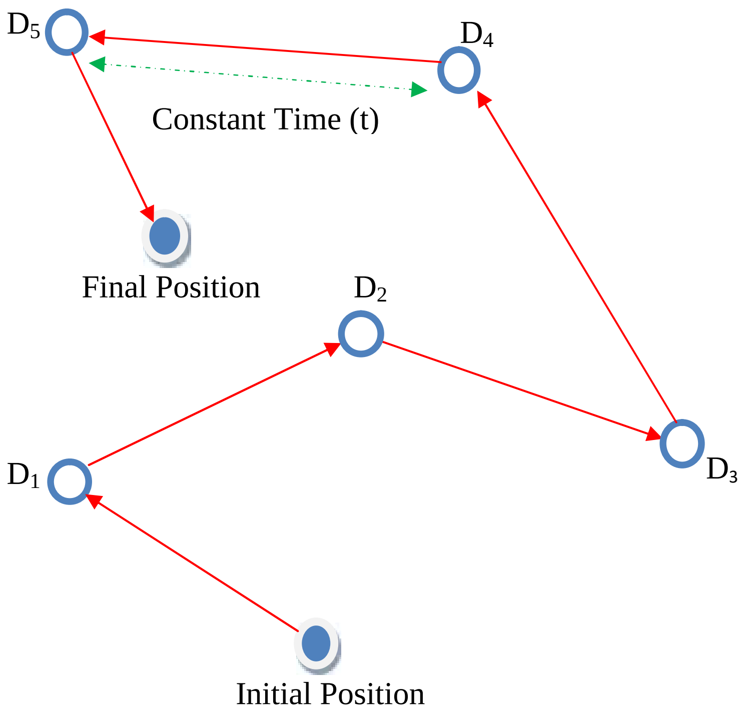

Figure 1.7: Movement of nodes under RWPM

1.4.3 Medium Access Control (MAC) [J. Walrand, 1998; & J.M. Capone *et al.*, 1999]

Since each mobile node uses the same frequency spectrum or physical channel, hence the MAC protocol plays a significant role to coordinate channel access among the mobile nodes in the ad-hoc network environment so that information could pass from one node to another node. The primary aim of MAC protocol is to achieve high throughput, highly reliable data delivery, and continuous network connection etc.

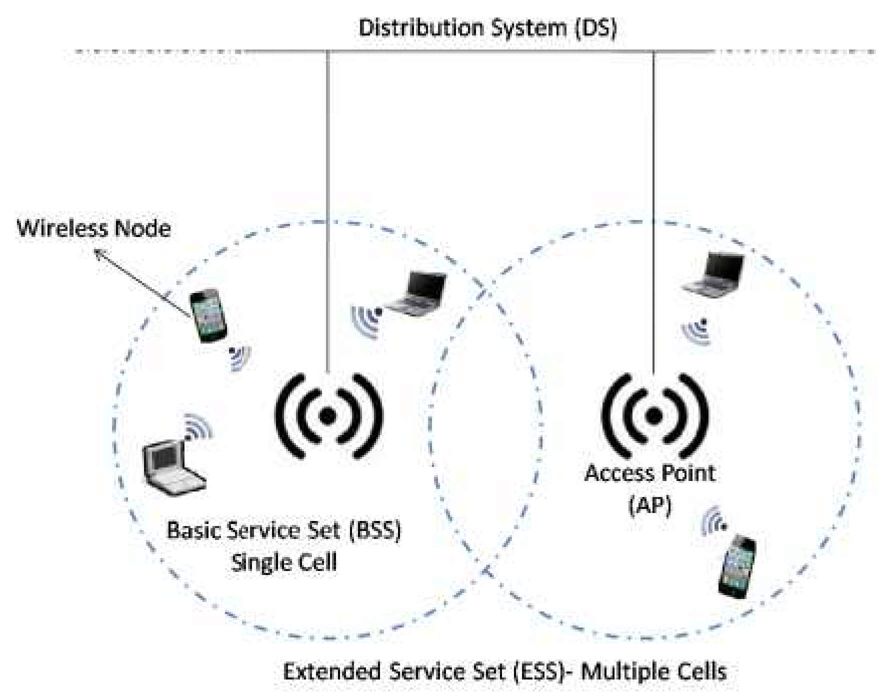

Figure 1.8: Infrastructure mode

The standard IEEE 802.11 was adopted in 1997. It defines the various versions such as 802.11a, 802.11b, 802.11g, 802.11e, 802.11f, 802.11i etc. And, describes two operating modes for MAC protocol that is Point Coordination Function (PCF) mode (for infrastructure mode) and Distributed Coordination Function (DCF) mode (for IEEE ad-hoc mode). The DCF mode of IEEE 802.11 is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol [L. Kleinrock, *et al.*, 1975; & F.A. Tobagi, *et al.*, 1975] that combines the both CSMA and Multiple Access Collision

Avoidance (MACA) techniques [P. Karn, 1990]. The CSMA/CA protocol uses the RTS-CTS-DATA-ACK sequence for message transmission. Moreover, in spite of the concept of the physical carrier sensing, it also introduces the novel idea of virtual carrier sensing that is implemented in the form of Network Allocation Vector (NAV). NAV represents the time duration up to which the wireless medium is expected to be busy because of transmission by other nodes. In this thesis work version "b" of IEEE 802.11 standard has been used as an MAC protocol, which also specifies mainly two operating modes; Infrastructure (using a fixed Access Point (AP)) and Ad-hoc mode. One can understand the concept of these both modes from the figure (1.8) and figure (1.9).

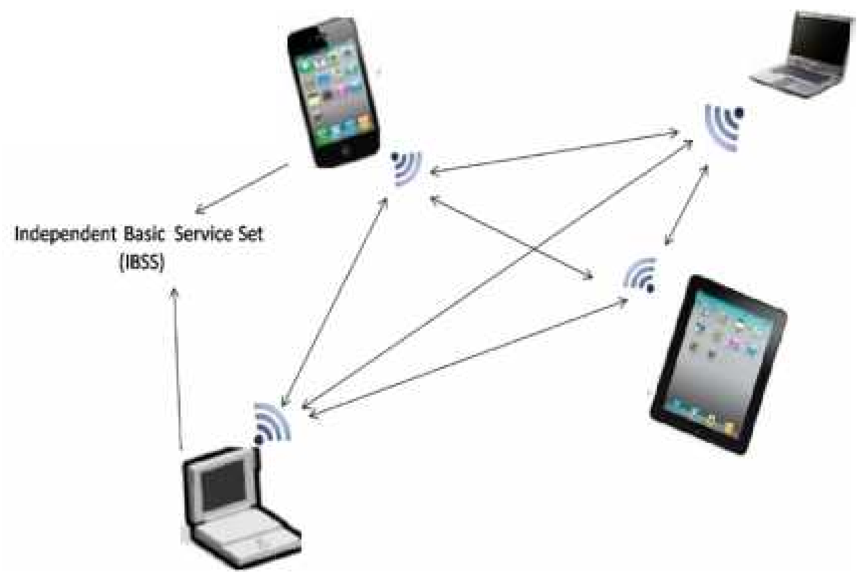

Figure 1.9: IEEE ad-hoc mode

1.4.4 Quality of Service (QoS) [ITU-T (E.800); S. Shenker, *et al.*, 1997; S.-B. Lee, *et al.*, 2000; C.E. Perkins, 2001; & J. Tsai, *et al.*, 1997]

The support of QoS for the design of ad-hoc networks is an indispensable part. The QoS attributes for each link, and a complete end-to-end path is affected by the channel quality fluctuations. Moreover, the interference from no neighboring nodes also affects the link quality. Thus, QoS is the essential integral of the ad-hoc network.

QoS can be used as a measurement of the level of service that any particular data gets on the network. In other words, it can be defined as “the collective effect of service performance, which decides the level of satisfaction of a user of the service”. It is expected from the network to guarantee a set of measurable pre-specified service attributes of the users, like Packet Delivery Ratio (PDR), delay, delay variance (jitter), throughput, bandwidth, a probability of packet loss, and so forth. The power consumption in another QoS attributes, which is more precise to ad-hoc networks. For any protocol to provide better QoS, it must be able to find a new route quickly with minimum bandwidth utilization.

Actually, QoS refers to different notions at various layers. At the physical layer, QoS mentions to the data rate and packet loss rate on wireless links that is a function of the channel quality. It is impossible to maintain constant data rate and low packet loss rate, in the continuously varying channel environment. At the MAC layer, it is related to the time, which is taken by a node to access medium successfully and transmits a packet. At the routing layer, end-to-end QoS metrics depends on the each hop metric of a multi-hop route. This layer must try to compute and maintain routes, which satisfy the QoS requirement for the lifetime of a connection. The transport and upper layers could include support for QoS if the routing layer is not able to meet the QoS requirements.

1.4.4.1 Defining Attribute for QoS Metrics

In this section, the various attributes are described, which has been used in this thesis work to analyze the network performance. The attributes are as follows:

Throughput [Y. Chen, et al., 2003; & M. Grossglauser, et al., 2002]: It is related to the channel capacity of the network, and it can be defined as the average rate of packets that has been delivered successfully over a communication channel under ideal circumstances in a particular time interval. It is quantitatively defined as the ratio of the total amount of data that reaches a receiver from a sender in a total time period. It is expressed in bits per second or packets per second. The network with high throughput is desirable. Generally, in a wireless channel, links are unreliable, and unreliability increases with distance.

Throughput =Total amount of Data received / Total time.

*End-to-End Delay [*S. Shenker, *et al.*, 1997*]:* The end-to-end delay of the packet depends on the source traffic characteristics and the scheduling algorithm at the network switches. It is a difference of time moment at which packets are actually transmitted from the point of origin and at what moment the receiving point actually receives it. In other words, it is an overall average time taken by the packets to reach the receiving point from a source point. Alternatively, it can be said that the average time that packets take to traverse the network, and it is expressed in seconds. It, therefore, includes all the delays in the network such as buffer queues, the transmission time, delays induced by routing activities and MAC control exchanges etc. Any network mainly experiences delay due to route discovery process, queuing, propagation and transfer time etc. Moreover, three kinds of delay are possible in the networks that are propagation delay, handling delay and queuing delay. For better performance, the delay should be less.

$$\text{Average end-to-end delay} = \Sigma\, (t_r - t_s)\, / P_r$$

where t_s is the packet sending time, t_r is the packet receiving time and P_r is total packet received at the receiving point.

*Delay Variation (Jitter) [*S. Shenker, *et al.*, 1997*]:* It is the displacement or variation in the time between packets arriving at the receiving point. In other words, network with constant latency has no variation or jitter. The presence of jitter in any network is caused by network congestion, timing drift or route changes. A jitter buffer can be used to handle jitter, and its value should be minimized for better performance of the network. If the jitter is so large that it causes packets to be received out of the range of the buffer, then the out-of-range packets get discarded and dropout. The congestion can occur either at the router interfaces or in a provider or carrier network if the circuit has not been provisioned correctly. It is one of the important metrics for any routing protocol and is expressed in seconds.

Packet Delivery Ratio (PDR) [S. Chen, et al., 1999]: PDR is the ratio of total packets received by the destination of total packets sent by the source. The better packet delivery ratio provides complete and correct routing protocol.

$$\text{PDR} = \sum \text{Number of packets received} / \sum \text{Number of packets sent}$$

Percentage of Drop (Loss) Packets: It is a measurement of a percentage of the total packets dropped with respect to packets sent during the whole simulation. Channel congestion typically causes the packet loss. Moreover, it may be a presence in the network due to severe delay in overall transmission, weak radio signal because of distance or multipath fading, faulty networking hardware, and faulty network driver.

The routers might fail or drop to deliver some packets if they arrive when their buffers are already full. Some, none or all of the packets might be dropped, depending on the state of the network.

$$\text{Percentage of Packet loss} = \{(\text{Number of sent packets} - \text{Number of received packets}) / (\text{Number of sent packets})\} \times 100$$

Power Consumption [V. Rodoplu, et al., 1999; S. Banerjee, et al., 2002; & J. Gomez, et al., 2001]: One of the critical issues in an ad-hoc network is the energy conservation because each node is battery operated in this environment and the capacity of these batteries is limited by the weight and volume restrictions of the nodes. Therefore, it becomes a necessary consideration to minimize the energy consumption of the node in an ad-hoc network. Moreover, in multi-hop ad-hoc network environment, each node may act as a router. Thus, the failure of a node due to energy exhaustion may influence the performance of the whole network.

The attributes of the metrics in this thesis work have been summarized in the table (1.2). It can be noticed, two metrics throughput and the PDR are grouped into the “maximum for better” category, while the other four metrics end-to-end delay, jitter, a percentage of drop (loss) packets and power consumption are assigned to the “minimum for better” category.

Table 1.2: Criteria and attribute

Criterion	**Description**
Throughput	Maximum for better
End-to-End Delay	Minimum for better
Delay Variance (i.e. Jitter)	Minimum for better
Packet Delivery Ratio (PDR)	Maximum for better
Percentage of drop (loss) packets	Minimum for better
Power Consumption	Minimum for better

1.4.5 Simulation Software

The simulation is one of the foremost technologies in modern time. It is the imitation of the operation of a real-world process or system over time. In other words, it can be said that the computer simulation can model hypothetical and real-life objects so that, it could be further implemented in the real benchmark. To simulate something on a computer system, firstly a model should be developed, which represents the essential features or functions of that model. The model itself represents the system, whereas the simulation represents the operation of the system over time. It is used in many contexts, such as performance optimization, safety engineering, testing, training, education etc. It can be used to show the eventual real effects of alternative conditions and courses of action.

The primary advantages of simulators, they can give users with practical feedback when designing in real world systems. A simulator allows the designer to determine the correctness and efficiency of a design before the system is actually constructed. As a result, the user can explore the merits of alternative designs without implementation in the real world. Another benefit of simulators is that they permit system designers to study a problem at several different levels of abstraction.

Network Simulation Tool [S. Kurkowski, *et al.*, 2005; & J. Pan, *et al.*, 2008]:

The simulation tool for networking is a cost-effective technique for developing, deploying and managing the network behavior throughout an entire life cycle of it. The fundamental c of a network and test combinations of network features can be evaluated that are likely to work. It is a technique of implementing the network on the computer. Through this, the behavior of the network is calculated either by network entities interconnection using mathematical formulas or by capturing and playing back observations from a production network.

To date, there are several different simulation tools such as NS-2 [NS-2], NS-3 [NS-3], QualNet [QUALNET], GloMoSim [L. Bajaj, *et al.*, 1999], OpNet [OPNET; & Opnet Technologies], NETSIM [NETSIM], OMNET++ [OMNeT], and MATLAB [MATLAB] have been developed for wireless and ad-hoc network simulations. This thesis work uses the NS-3 and QualNet simulation tool for the simulation purposes, which are described below.

Network Simulator-3 (NS-3) [NS-3]:

The NS-3 simulator is a discrete-event network simulator for internet systems, targeted primarily for research and educational use. The NS-3 project started in 2006, is free software, licensed under the GNU GPLv2 license, and is publicly available for research, development and use. The NS-3 simulation core supports research on both IP and non-IP based networks. However, the large majority of its users focus on wireless/IP simulations, which involve models for Wi-Fi, WiMAX, or LTE for layers 1 and 2 and a variety of static or dynamic routing protocols such as OLSR and AODV for IP-based applications.

NS-3 is a C++ library, which provides a set of network simulation models implemented as C++ objects and wrapped through python. The users normally interact with this library by writing a C++ or a python application which instantiates a set of simulation models to set up the simulation scenario of interest, enters the main simulation loop, and exits when the simulation is completed. The flowchart and component diagram of NS-3 are shown in figure (1.10) and figure (1.11), respectively.

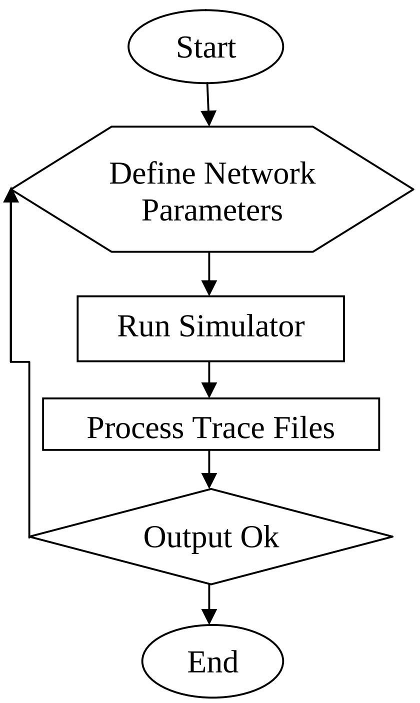

Figure 1.10: Flowchart for NS-3

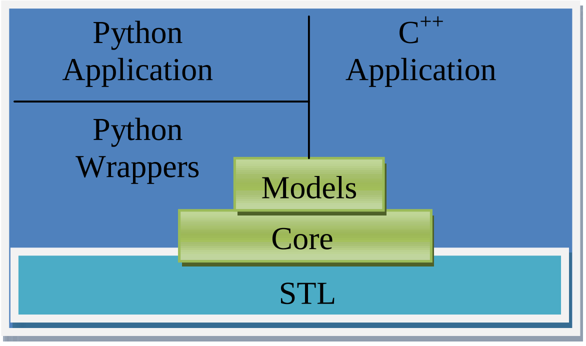

Figure 1.11: Architecture of NS-3

QualNet [QualNet Simulator Version 7.1, 2013]:

QualNet is a commercial simulator that grew out of GloMoSim, which was developed at the University of California, Los Angeles, UCLA, and is distributed by Scalable Network Technologies (SNT). It is a C++ based tool; therefore, all protocols are implemented in a series of C++ files and are called by the simulation kernel. It must be noted that QualNet is a discrete event simulator, which provides a good balance between ease of use, extensibility and power in terms of what scenarios can be simulated. Also, it does not have as much complexity as some tools, which results in a shorter learning curve. Here, speed and scalability have been optimized on one processor. Therefore, it can execute equivalent scenarios 5-10 times faster than the other commercial alternatives. Finally, it has quite advanced wireless modules with new technologies being incorporated into the tool relatively quickly.

The GUI based QualNet simulation software is planning, testing, and training tool that demonstrates the character of a real communication network. The QualNet simulation tool provides a platform to create & animate the network scenarios, to design the protocols and to analyze their performance. The architecture of the QualNet and scenario-based simulation are illustrated in figure (1.12) and figure (1.13) respectively, and it is composed of the following components as follows:

- *Architect:* A graphical experimental design and visualization tool, and has two modes: *Design Mode*- for designing experiments, and *Visualize Mode*- for running and visualizing experiments.
- *Analyzer:* It is a graphical statistic-analyzing tool.
- *Packet Tracer:* A graphical tool to display and analyze packet traces.
- *File Editor:* A text-editing tool.
- *Command Line Interface:* It is used to access the simulator from a command line.

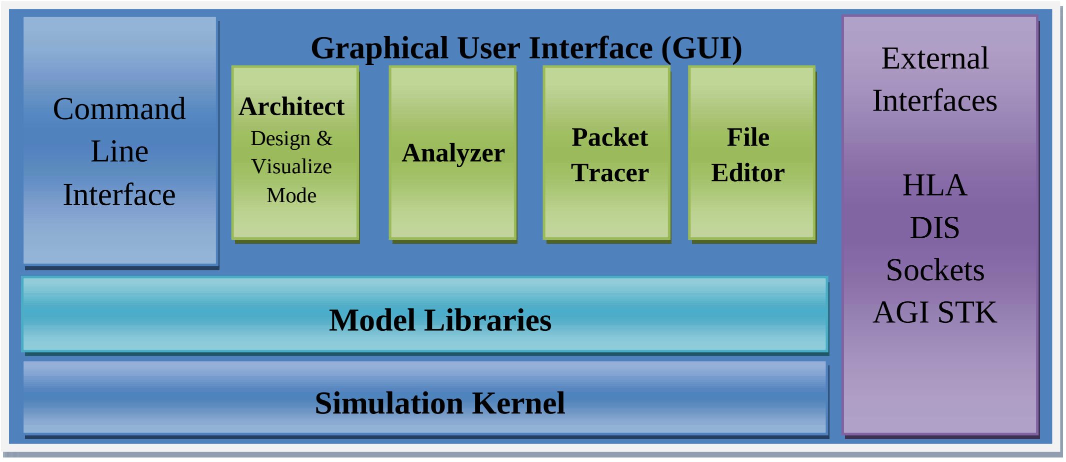

Figure 1.12: QualNet architecture

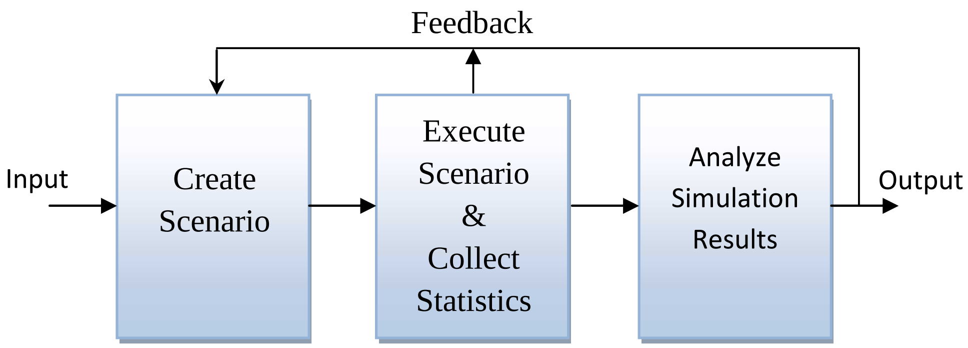

Figure 1.13: Scenario based simulation

- QualNet enables users to:
  - Design new protocol models.
  - Optimize new and existing models.

- Design large wired and wireless networks using pre-configured or user developed models.
- Analyze performance of networks and perform what-if analysis to optimize them.

❖ The key features of QualNet that enable creating a virtual network environment are:

- *Speed:* It can support real-time speed to enable software in the loop, network emulation, and human in the loop modeling. The faster speed enables model developers and network designers to run multiple "what-if" analyzes of varying models, network, and traffic parameters in a short time.
- *Scalability:* It can model thousands of nodes by taking advantage of the latest hardware and parallel computing techniques. Moreover, it can run on clusters, multi-core, and multi-processor systems to model large networks with high fidelity.
- *Model Fidelity:* It uses highly detailed standards-based implementation of protocol models. It also includes advanced models for the wireless environment to enable more accurate modeling of real-world networks.
- *Portability:* It runs on a vast array of platforms, including Windows and Linux operating systems, distributed and parallel cluster architectures, and both 32- and 64-bit computing platforms. Users can now develop a protocol model or design a network in QualNet on their desktop or laptop windows computer and then transfer it to a powerful multi-processor Linux server to run capacity, performance, and scalability analysis.
- *Extensibility:* It can connect to other hardware and software applications, such as OTB, real networks, and third party visualization software, for greatly facilitating the value of the network model.

1.4.6 State of The ART (SOTA)

In the last few years, ad-hoc networks have become the most sought topic among the researchers in the arena of networking. The ad-hoc networks are resource constrained and hence routing in ad-hoc networks is the most challenging task. AODV routing protocol is one of the well-known ad-hoc network routing protocols. It is designed to improve the network routing performance by the creation and maintenance of routes. AODV decreases the control overhead by minimizing the number of broadcasts while using a pure on-demand a route acquisition method. However, it has some limitations in terms of QoS constraints. Many modifications have been suggested towards the improvement in AODV performance to meet QoS challenges through focusing on bandwidth, packet delivery ratio, energy and mechanism overheads etc.

Several researchers have done the qualitative and quantitative analysis to analyze the characteristics of different routing protocols by means of different performance metrics of ad-hoc networks for various applications. However, they have used different simulators for this purpose.

[S.R. Das, *et al.*, 1998]: In this case, used simulator was MaRS (Maryland Routing Simulator). They compared AODV, DSR, TORA, DSDV, EXBF and SPF. According to them, it was the first attempt towards a comprehensive performance evaluation of routing protocols for mobile, ad-hoc networks. Here, performance in terms of packets delivered, delay and routing load have been considered as the performance metrics. The observation was that although the routing load was lowered in new protocols, the link state and distance vector protocols gave a better performance in terms of packet delivery and end-to-end delay. However, the impact of memory used by the protocols has not been considered in their study, as it is important in the ad-hoc network environment because of small size and low power devices.

[X. Hong, *et al.*, 1999]: In this paper, a survey of mobility models for both cellular and multi-hop networks has been presented. As per the authors, the group motion frequently occurs in ad-hoc environments and based on this they designed a group mobility model called RPGM (Reference Point Group Mobility model). The used simulator was Maisie that is a parallel simulation language. The node density was fixed at 100 and protocols compared were DSDV, AODV, and HSR. For the first time, they showed that the performance of routing protocol depends on the choice of the mobility model. Further, terrain models must be considered for both constrain movements and for influencing the propagation models.

[S.-J. Lee, *et al.*, 2000]: They have evaluated the performance of five multi-cast protocols; AMRoute, ODMRP, AMRIS, CAMP, and flooding which are proposed for ad-hoc networks. For this purpose, GloMoSim library has been used. The simulator has enabled for performing, fair and accurate comparisons of the multi-cast protocols under a realistic wireless environment for a broad range of parameters including mobility, number of senders, multi-cast group size, and traffic load. ODMRP performance was very effective and efficient in most of the simulation scenarios. However, a trend of rapidly increasing overhead as the number of senders increased can be seen.

[S.R. Das, *et al.*, 2000]: This work was an extended version of "S.R. Das, *et al.*, 1998" for more cases of node speed and density within the same set of protocols.

[E.M. Royer, *et al.*, 2001]: They investigated the nature of transmission power trade-off in ad-hoc network to determine the optimum node density for delivering the maximum number of data packets. It is shown that there does not exist a global optimum density, but in order to achieve this maximum, the node density should be increased as the rate of node movement increases. In this study, open air and the free space environment has been assumed. However, the physical world like terrain and atmospheric conditions exists, which affects the network connectivity. Further, it is required to study for determining the effects of these variables on the optimal node transmission levels.

[A. Nasipuri, *et al.*, 2001]: In this paper, the multipath extension for the popular on-demand routing protocol DSR has been reported. This extension gives alternate routes, which can be useful in case of the primary route breakage. Two variations are explored. In the first, only the source gets multiple alternate routes while in the second, each intermediate node on the primary route gets an alternate route. They provide a framework for analytical modeling of the time interval between successive route discoveries for on-demand protocols based on simple assumptions on the lifetime of a single wireless link. Later on, it was validated through simulation results, carried out by MaRS (packet-level simulation tool). Qualitative observations are similar to analytic modeling, and results presented a subtle tradeoff between delay and routing load.

[C.L. Barrett, *et al.*, 2002]: They conducted a comparative analysis of IEEE 802.11, CSMA and MACA media access protocols. They considered only static ad-hoc networks. The GloMoSim simulator was used to obtain a number of received packets, average latency of each packet, long-term fairness, and throughput. They concluded that typically, all protocols degrade significantly at higher packet injection rate.

[T. Clausen, *et al.*, 2002]: They studied CBR and TCP performance on OLSR and AODV protocols. The variation was done for traffic, density and mobility. The commonly used traffic type for MANET is CBR, but the Internet uses TCP. The number of nodes was fixed at 50, and random waypoint mobility model was used. The simulator used was NS-2. The metrics studied were control traffic overhead, delivery ratio, path length, delay, total transfer time and normalized routing load. The conclusion of the paper was, protocols may perform comparatively when exposed to CBR, but when the same scenario is exposed to TCP, it significantly affects the performance.

[Y.-C. Tseng, *et al.*, 2003]: The probability distribution of the lifetime of a given routing path has been derived based on discrete-time and random walk model, in a MANET environment. They measured the scalability of a MANET and evaluated routing paths during route selection procedure. However, a single mobility model cannot characterize the human's roaming pattern. Therefore, the route lifetime prediction is still a challenging question for roaming patterns other than the random walk model. Moreover, the route lifetime could also be enhanced by choosing an optimal value of the route maintenance parameters as per the applications.

[F. Bai, *et al.*, 2003]: To analyze the impact of mobility on the performance of routing protocols for ad-hoc networks, a framework named IMPORTANT was proposed. Mobility models used were RWP, RPGM, Freeway, and Manhattan. The density of nodes was fixed at 40, and NS-2 was used for simulation. Considered routing protocols were DSR, AODV, and DSDV. It was concluded that the performance of protocol shows drastic variations across mobility models. Performance rankings of protocols will change with a change in the mobility model.

[T. Kunz, 2003]: They provided an in-depth study of one-to-one and many-to-many communication in MANET. The protocols studied were unicast routing protocols (DSR and AODV), Multi-cast routing protocols (ADMR, ODMRP, and Extension of AODV) and Broadcast protocols (FLOOD and BCAST). Simulations were conducted on NS-2, and the number of nodes was fixed at 50. The performance metrics included packet delivery ratio and latency. It was concluded that the overall BCAST protocol achieved high packet delivery, at the cost of an increase in packet latency.

[B.-R. Chen, *et al.*, 2003]: They compared AODV, DSR, TORA and DSDV, based on energy. The mobility models employed were Random Waypoint, RPGM and Manhattan grid model. The simulator used was NS-2, and node density was fixed at 50. The authors concluded that reactive protocols are more sensitive to speed than proactive protocols. It is more challenging to route packets over Manhattan grid model over the others. For group movement, reactive protocols are better than proactive protocols. Moreover, among the evaluated protocols, DSR gives better performance than others except for the high-speed in case of Manhattan Grid model.

[K.K. Vadde, *et al.*, 2004]: They used a statistical design of experiments (DOE) to analyze the impact of factors and their interaction on the service delivery in a MANET. The considered factors were QoS architecture, routing protocol, medium access control protocol, offered load, and node mobility. The real-time throughput, total throughput, and average delay were taken as the measures of service delivery. The simulation was conducted through NS-2 and used 30 mobile nodes for analysis. They concluded it for an average delay, the MAC protocol and its interaction with the routing protocol were the most significant. Also, for both real-time and total throughput, the impact of routing protocol was not apparent except as it interacts with other factors, and the factor interactions were not as extensive as for the delay.

[C. Richard, *et al.*, 2005]: AODV routing protocol attempts to minimize the route discovery overhead by acquiring the route information for some period after a connection expires. How long each node should keep this route state information is set a priori and usually arbitrarily. These factors have been discussed in this paper. NS-2 obtained the preliminary results. And, 100 nodes were used for the simulation. However, in the case of a highly dynamic network, setting up of a priori route information for a long time may not show the proper utilization of memory. Moreover, they do not pay attention to the other route maintenance parameters like DPC etc. for the analysis.

[H.-C. Liao, *et al.*, 2005]: In this paper, the Ant mobility model was implemented, which was based on the actual movement of a group of ants. The effect of this mobility model was analyzed on DSDV, DSR, and AODV. For the worthiness of the model, ant mobility was compared to random waypoint model for the same set of protocols. The simulator used was NS-2. The number of nodes in the simulation was 50. It was concluded that trace models like ant mobility are more accurate than synthetic models like random waypoint mobility. However, this accuracy comes at a cost of the difficult and time-consuming process.

[E. Atsan, *et al.*, 2006]: They implemented the random direction and boundless simulation area models on SWANS and used AODV protocol for these as well as the random walk and random waypoint models. Here, 50 mobile nodes were taken and distributed randomly during the initialization. According to this paper, the performance of the ad-hoc network can be hugely affected when the mobility behavior of nodes change. The performance of the random waypoint mobility was not much good. However, it is the most consistent one for varying simulation values. In the case of the boundless simulation area model, AODV performed remarkably well for some performance metrics. Random direction and random walk model, showed the worst performances for AODV routing.

[J. Haerri, *et al.*, 2006]: AODV and OLSR were simulated for varying metrics such as node mobility and vehicle density with varying traffic rates. Here, the Vehicular Mobility Model (VMM) handled the traffic regulations and the vehicle characteristics. The goal was to provide a qualitative assessment of the applicability of the protocols in different vehicular scenarios. The used simulator was NS-2, and the number of nodes considered 40, 50, 60, 70, and 80. The paper concluded that clustering effects created by cars aggregating at intersections have remarkable impacts on evaluation and performance metrics.

[A.A. Pirzada, *et al.*, 2006]: They compared the performance of multi-path AODV and DSR protocols in hybrid mesh networks. NS-2 was the preferred simulator. The number of mesh clients was fixed at 50, and the number of mesh routers was set at 16. The random waypoint model was considered for mobility. The packet loss, aggregate goodput, percentage of packet delivery, routing packet overhead, average latency and path optimality were the calculated metrics. It was concluded that mesh networks have observed the better performance with an inclusion of mesh router i.e. reduce the packet losses, improve the packet delivery ratio and lower the latency of the network.

[S. Marinoni, *et al.*, 2006]: A realistic simulation based study of MANET protocols was made. They proposed a new and realistic Urban Mobility Model (UMM), which models, realistic user motion and signal propagation in a city-like scenario. The mobility models, namely RWP, UMMoff (UMM with radio constraints activated) and UMMon (UMM with radio constraints deactivated) were applied in DSR protocol. The number of sender/receiver was 20 pairs for all experiments. NS-2 was used for simulation, and calculated metrics were the packet delivery ratio, end-to-end delay, path length, and routing overhead. The authors concluded that trivial RWP was too simplistic and too narrow in its scope. Hence, a realistic model like UMM can be a better choice.

[I. Khider, *et al.*, 2007]: The authors presented random waypoint and a Manhattan mobility model for vehicular and pedestrian movement in urban (indoor and outdoor) environments. They evaluated the node movement under different parameters and compared ad-hoc routing protocols (AODV and DSDV) performance metrics like, throughput, PDR, and dropped packets. Moreover, the simulations were run by changing different running parameters in two categories: movement scenarios and communication patterns. In the movement scenarios, simulation results were highly dependent on the movement behavior of mobile node supported by base stations. Here, the NS-2 simulation tool was used to carry out outcomes and 10 wireless nodes were used to form an ad-hoc network.

[W. Al-Mandhari, *et al.*, 2008]: They evaluated the performance of changing ART parameter on AODV routing. In this paper, two main scenarios were simulated; ART vs PDR for different station movement speed, and station movement speeds vs PDR for the various numbers of stations like 50, 60, and 70. OPNET Modeler 11.0 was used for simulation purpose. They concluded that at the default value of ART parameters, the PDR values were very low especially at high station movement speeds. Moreover, reducing the ART value resulted in a better performance, especially for higher speed values. They have taken only CBR traffic generator. However, it could be extended to VBR traffic as in real-time applications.

[G. Jayakumar, *et al.*, 2008]: They compared the performance of DSR and AODV to random waypoint model by using NS-2. The node density was fixed at 50 nodes. Here, MAC and physical layer models were used to study the interlayer interactions and their performance implications. The performance metrics included packet delivery fraction, average end-to-end delay, normalized routing load, and normalized MAC load. The authors observed a very clear trend between mobility metric, connectivity, and performance. It was found that for lower loads DSR is more efficient while AODV is more effective for higher loads.

[L. Rosati, *et al.*, 2008]: They proposed novel Distributed Ant Routing (DAR), which is inspired by the behavior of the ant colonies in locating and storing food. Here, mathematical proofs supported DAR and demonstrated by a comparison with AODV algorithm. This method is suitable for the study of those scenarios where fast communication establishment and lower signaling overheads are required. Simulations were done by using the Network Simulator software NS-2. The number of mobile nodes was fixed at 30. However, the present paper does not focus on a situation where stable communication is required without route failure issues.

[L. Xia, *et al.*, 2009]: They presented an improved AODV that was the AODV-I. It was an extension of traditional AODV by adding congestion control processing and the route repair mechanism, which reduced the packet loss rate and end-to-end latency. It also increased the resource utilization. Here, a simulation was conducted to analyze the network performance. For above aim, the NS-2 simulator was used, and there 100 nodes were randomly placed.

[A.B. Arbia, *et al.*, 2009]: The authors proposed an adaptive version of AODV (A2ODV) where the protocol adopts the routing decision based on the state of behavior and the state of the networks. They used a NS-2 simulation tool and random waypoint mobility model. The source traffic generators were CBR, and 99 nodes were spread over an area. The speed of each node was uniformly distributed between 4 and 15 m/s. In this case, the mobility model was specified without pause time. A2ODV proved as improved AODV, which incorporates the reliability of routes during the route discovery process. A2ODV performs better than AODV. Moreover, A2ODV scales better than AODV in critical networks.

[Z. Sun, *et al.*, 2009]: They proposed AODV-ZFA routing protocol, which is a based on flooding and AODV. The proposed protocol has higher reliability and lower overhead than AODV. AODV-ZFA can be suited for dynamic topology. However, the end-to-end delay of the protocol has not been improved effectively. Moreover, it was concluded that with the help of dynamic cluster head selection techniques, the application scope of AODV-ZFA could be expanded. In the simulation, the numbers of nodes were 20, 30, 40, 50, and 60, and the NS-2 simulator was used to carry out the results.

[Y. Yang, *et al.*, 2009]: In this paper, the performance of IAODV (hybrid routing protocol for MANETs) was compared with AODV by OPNET simulations, and the network was made up of 100 nodes. The authors tried to reduce delay and improve the packet delivery ratio by merging multipath and path accumulation with AODV routing protocol. They also reduced the routing overhead by reducing the frequency of the route discovery process.

[I. Khan, *et al.*, 2009]: The performance of AODV and OLSR routing protocols were evaluated under realistic radio channel characteristics using NS-2 with Nakagami fading model. The number of nodes was 30, 50, 70, 90, and 120. It was observed that both routing protocols fail to provide an acceptable packet delivery ratio. Overall, OLSR, with short intervals of control messages, performed better than AODV in urban environments.

[S. Barakovic, *et al.*, 2010]: They compared the performance of MANET routing protocols; AODV, DSR, and DSDV. Simulations were carried on NS-2. PDR, average end-to-end delay, and normalized routing load were the performance metrics. The numbers of source nodes varied from 10 to 30. Random waypoint model defined the mobility of nodes. The conclusion from the study was that all the protocols reacted in similar ways to low mobility and low load conditions while DSR outperformed AODV and DSDV with increasing mobility and load.

[Z. Che-Aron, *et al.*, 2010]: The author addressed the issue of reliability by designing and developing an enhanced fault tolerance mechanism of the AODV routing protocol for WSNs called ENhanced FAult-Tolerant AODV (ENFAT-AODV). The basic scheme used in ENFAT-AODV, utilized the backup route techniques for improving reliable data packet delivery. They used QualNet simulator to simulate the ENFAT-AODV routing protocol, and its performance was compared with original AODV. Moreover, in this simulation, 100 sensor nodes were used. It was concluded that ENFAT-AODV routing protocol delivered better in terms of reliability, availability and fault-tolerant ability of the network. They also found that ENFAT-AODV was greatly suitable for high failure rate WSN.

[A. Tuteja, *et al.*, 2010]: In this paper, a comparative performance analysis of DSDV, AODV, and DSR routing protocols were done by using NS-2. The metrics included packet delivery ratio, throughput, end-to-end delay and routing overhead. Here, 25 nodes were considered for the simulation, and random waypoint model was used for defining movements of the node. It was concluded that performance got degraded with an increase in the mobility of nodes irrespective of the choice of the three discussed protocols. Moreover, it was also found that AODV and DSR protocols perform better at less packet size.

[F. Ullah, *et al.*, 2010]: They simulated AODV and DSDV routing protocols for the dynamic wireless sensor network and compared their performance based on end-to-end delay and total performance. It was concluded that AODV performed better than DSDV and AODV were more suited to sensor network applications. The NS-2 simulation tool was used, and three sensor nodes were taken for the analysis.

[S.P. Setty, *et al.*, 2010]: They evaluated the performance of existing wireless routing protocol AODV in various node placement models like the grid, random and uniform using QualNet 5.0. The simulation results showed that AODV achieves better performance in the grid environment.

[S. Sethi, *et al.*, 2010]: They proposed effective and scalable AODV (called as AODV-ES) for Wireless Ad-hoc Sensor Networks (WASN) by using the third party reply model, n-hop local ring, and time-to-live based local recovery. AODV-ES were proposed to control the overhead and minimize the time delay with improved effectiveness. NS-2 simulator under Linux operating system was used, and the number of nodes was taken 100 for simulation. It performs better than AODV in terms of PDR, end-to-end delay, and NRL for all mobility rates. Therefore, it was concluded that AODV-ES protocol was suitable for WASN, where effectiveness with scalability and time sensitivity were the important issues.

[W.-W. Fang, *et al.*, 2010]: They proposed the congestion avoidance, detection, and alleviation (CADA) scheme in Wireless Sensor Networks (WSNs) because congestion in WSNs not only causes severe information loss but also leads to excessive energy consumption. The key objective of this paper was to provide high transmission quality of the data traffic under conditions of congestion. The simulations have been performed by NS-2 that confirmed the advantages of CADA and demonstrated significant performance improvements over existing schemes. However, the paper does not address the dynamic behavior of a network such as a node mobility and link failure etc.

[S.K. Debnath, *et al.*, 2010]: Unicast and broadcast routing protocols of MANET were evaluated. Here, both one-to-one and many-to-many communications were addressed in detail. DSR and BCAST protocol were simulated on NS-2. The number of nodes was fixed at 50, and mobility model was random waypoint mobility. The performance metrics included packet delivery ratio, packet latency, normalized routing load, normalized MAC load, and throughput. The authors concluded that BCAST protocol worked well in most scenarios and was robust even with high traffic environments.

[S. Mohapatra, *et al.*, 2011]: Here, comparative performance analysis like delay, throughput, control overhead, and PDR was done over protocols such as AODV, OLSR, and DSDV through NS-2 Simulator. It was claimed that with the help these parameters a proper routing protocol could be designed for an efficient MANET environment. In this paper, the nodes were varied from 10 to 50 with an increment of 10 nodes. They concluded that OLSR delivered better PDR in the case of higher mobility than the other protocols, i.e. it was suitable for the highly random mobile network. It was also concluded that for better network size analysis, all three protocols behave almost same in the PDR, whereas DSDV could be the better choice if the data delivery is more important.

[R. Kachhoria, *et al.*, 2011]: They recommend a dynamic version of AODV i.e. ARTO-AODV in which active route timeout was varied from one second to many seconds. It can be used in large, middle and small networks depending upon the type of application such as a battlefield monitoring system, hospital monitoring, wireless remote meter-reading etc. Here, the simulation was done with QualNet tool. The number of sensor nodes and mobile nodes (vehicles) were taken 100 and 3, respectively. It was concluded that ARTO-AODV was clearly outperformed for PDR, throughput, average end-to-end delay. In this paper, AODV was simulated as a function ART only for the constant WSN environment, especially for the CBR traffic. However, it could be extended for DPC and dynamic ad-hoc network environment for various traffic generators like VBR.

[D. Singh, *et al.*, 2011]: The performance comparison was made of four popular routing protocols, i.e. LANMAR, LAR1, DYMO and ZRP in variable pause time. The QualNet simulation tool was used. The performance analysis was based on different network metrics such as average jitter, PDR, average end-to-end delay and throughput. 50 nodes were considered for the scenario. The authors concluded that LANMAR is the best scheme in terms of end-to-end delay & jitter while LAR1 is best in terms of packet delivery ratio & throughput. Also, it was found that ZRP performed worst in a case of PDR while DYMO did the worst performance for average jitter.

[B. Paul, *et al.*, 2011]: Here, differences between AODV and DSR were illustrated based on TCP and CBR connection with various network parameters in VANET environment. The NS-2 simulator was used, and the number of cars was taken 30, 60, 90, 120, and 150. It was concluded that for low density with the low speed, the PDR of TCP and CBR connection for both the protocols is high. In that scenario, an average end-to-end delay was high for TCP connection but low for CBR connection.

[R. Jain, *et al.*, 2011]: They analyzed the performance of AODV and DSR with path loss propagation model (Free Space & Two Ray Ground) based on various performance metrics. Here, the QualNet simulation tool was used, and 75 nodes were spread randomly. They concluded that overall performance of DSR was better in both models, whereas AODV performed better in an average end-to-end delay in the two-ray ground model.

[K. Zahedi, *et al.*, 2011]: Here, a new approach to solving the problem of link breakages was proposed and implemented in the DSR protocol. In this method, the Received Signal Strength Indicator (RSSI) value was used by a node along an active route to predict a link breakage in its link with its next hop to the source node of this active path. The idea behind this was to reduce the probability of constructing a route with bad connections, which can break during or directly after the construction of a new route. However, this approach is only suitable for DSR with CBR traffic model. For other routing protocols and traffic models, network utilizations are poor. To carry out the simulation results, NCTUns simulator was used, and the number of nodes per route was 10 to 100.

[P. Li, *et al.*, 2012]: The author tried to solve reliable broadcast and multi-cast lifetime maximization problem in the energy-constrained wireless ad-hoc network environment. The tree-based algorithm was adopted to find an optimal solution for the lifetime maximization problem. The results illustrated that the proposed algorithms can significantly increase the network lifetime as compared with the traditional algorithms under various distributions of error probability on faulty wireless links.

[M. Tripathi, *et al.*, 2012]: They analyzed the performance of the AODV routing protocol by varying ART value from one second to several seconds with the mobility of sensor nodes. The QualNet simulation tool was used to carry out the results. The number of sensors and mobile nodes was taken 100 and 5 respectively. It was observed that AODV provided maximum throughput when ART value was exactly 1 second. When the ART value was varied from 1 to 5 seconds, throughput remained almost same throughout the range as the routes were being cached during this period. Later on, throughput was starting to decrease because of more link failures.

[A. Hinds, *et al.*, 2013]: They discussed a pair of survey papers from which they identified early reactive and proactive MANET routing protocols. Their review focuses on protocols developed by Perkins, namely the Destination-Sequenced Distance Vector (DSDV) and Ad-hoc On-demand Distance Vector (AODV), researchers claim that these are most popular MANET routing protocol. Due to the popularity of the AODV protocol, the number of variations and improvements in the core protocol has been proposed to address specific issues with the protocol. They investigated the evolution of the AODV protocol by reviewing works based upon the Multi-cast Ad-hoc On-demand Distance Vector (MAODV), this protocol adds multi-casting support to the core AODV protocol.

[K.H. Almotairi, *et al.*, 2014]: They investigated the deficiency of uncontrolled asymmetrical transmission power over multiple channels in an ad-hoc network environment. The DPL protocol was presented to overcome the uncontrolled asymmetrical transmission power problem. Hence, interference was reduced over channels because the nodes that require higher transmission power were being separated. Therefore, they were not allowed to interfere with the nodes that need lower transmission power. The proposed protocol was implemented on NS-2. Two different types of topologies were considered for the simulation; chain topology kept 30 nodes, and random topology included 50 wireless nodes. It was concluded that the proposed protocol effectively prevented the uncontrolled asymmetrical transmission power problem, and achieved higher throughput.

[R.A. Uthra, *et al.*, 2014]: The authors argued that any node of WSN is a resource constrained in terms of memory, bandwidth, and energy that leads to a large number of packet drops, low throughput and wastage of energy due to re-transmission. Hence, they presented a novel approach to predict and to control the congestion using a probabilistic and new rate control methods, respectively. It was concluded from the presented schemes that throughput got increased, and energy got reduced by avoiding packet drops.

[D.G. Reina, *et al.*, 2015]: The authors discussed that broadcast or flooding is a dispute technique in the wireless ad-hoc networks. The broadcast scheme is widely used within routing protocols by a wide range of wireless ad-hoc networks such as mobile ad-hoc networks, vehicular ad-hoc networks, and wireless sensor networks. It is used to spread emergency messages in critical scenarios after a disaster and/or accidents. Hence, broadcast schemes are used to play a significant role in the performance of the network. Therefore, it should be selected carefully. Although, several kinds of broadcast schemes have been offered, probabilistic broadcast schemes are also seen as suitable for wireless ad-hoc networks. Because it provides a range of benefits such as low overhead, balanced energy consumption, robustness against failures and the mobility of nodes. Hence, this paper reviews a classification of the probabilistic schemes and an exhaustive evaluation methodology, including their performance metrics and types of network simulators along with their comparisons. Further, this paper also presents some examples of real implementation of this scheme.

A close analysis of the studies as mentioned above establishes a research gap that the effect of changing of route maintenance parameters; ART, DPC on the performance of the AODV routing protocol for different traffic generators like CBR, VBR has not been studied, so far. Hence, the present study makes a candid attempt to analyze and compare the AODV routing performance in the vast range of scenarios for different traffic generators by considering route maintenance parameters like ART and DPC.

1.5 Motivation and Research Objectives

Recently, ad-hoc networks have gained a lot of importance in the arena of wireless networking. Ad-hoc networks, due to its potential applications in tactical operations, emergency situations and various fields as mentioned in table (1.1) has become a vibrant area of research among researchers. It is precisely the contemporary relevance and future promise of ad-hoc network in the next generation of wireless networks, which has indeed motivated the author of the present thesis to select this area as his research work.

An ad-hoc network is vulnerable because of its fundamental characteristics, such as open medium, dynamic topology, distributed operation and constrained capability. Hence, stable routing is the challenging task in this network. However, routing in ad-hoc network is highly complex due to node mobility, limited node transmission range and security issues. Therefore, the author has been motivated to analyze and observe the performance of routing protocol (especially AODV) in the wide range of scenarios. An attempt is also made to observe the effect of simulators under different scenarios.

AODV routing protocol comes under the on-demand routing. Hence, in AODV routing, the route maintenance parameters for route discovery and route maintenance process is a key concept which deals with the topology changes and provides the stable path. Therefore, the route maintenance parameters; ART, DPC, and the determining factors like node mobility, node transmission range, NLD and ANs/SD pairs are the main variables for this thesis, which may affect the AODV routing stability.

The main objective of this research work is to provide more stable routing in AODV ad-hoc network environment. For doing so, it is important to take into consideration the timeout value for cached routes (i.e. lifetime of cached routes; if a data packet is not sent during this timeout interval, the route is considered to be expired) and timeout value after which an expired cached routes are completely deleted from the routing table. These two timeout values are known as ART and Delete Period (DP) respectively, and they minimize the route failure issues by providing alternative routes for data packets. ART and DPC (where DPC denotes the multiple for DP, i.e. "DP= *DPC X Max {ART or Hello_Interval}*") are termed as route maintenance parameters and are being used to improve the performance of the AODV routing protocol in this thesis.

From the section '1.4.6', one may observe that most of the time researchers' deal with mobility, number of nodes, size of the network, transmission range etc while very few have also chosen ART for their study but not DPC. Therefore, it is needed to explore in depth the impact of various route maintenance parameters on the performance of the AODV routing protocol. Here, the AODV routing protocol's performance is also evaluated by using two different simulators (NS-3 and QualNet).

One can also notice from the section '1.4.6' that the comparative studies between CBR and VBR traffic generator under the influence of the route maintenance parameters are not carried out yet. Therefore, in this research work, by making a few reasonable assumptions, the AODV routing performance for CBR and VBR traffic generators has been analyzed and compared under the influence of the route maintenance parameters. This section also makes an effort to point out an optimal relation between the route maintenance parameters (ART & DPC) and both traffic generators (CBR & VBR) in which AODV network provides stable routing.

From the SOTA section (1.4.6), it can also be seen that several researchers have attempted to observe the AODV routing performance by considering various factors like size of network, number of nodes in the given area, transmission range, mobility etc. However, they were restricted to only these factors and few of them separately considered the route maintenance parameters only, but the combine study between the route maintenance parameters and determining factors has not been studied, so far. Therefore, in this thesis, an attempt is also made to analyze how AODV routing performance is influenced, when various determining factors like mobility, transmission range, NLD and ANs/SD pairs are taken into account along with the route maintenance parameters.

It can also be easily noted from the SOTA section ‘1.4.6’ that several researchers have already conducted the number of studies in order to analyze and to compare the characteristics of different routing protocols through various QoS metrics for different situations and applications. However, they have considered the different set of routing protocols for their studies as chosen in this thesis. In this research work, the comparative performance analysis between the various routing protocols (like AODV, DSR, DYMO, IARP, and IERP) has been carried out under the varying pause time environment.

1.6 Organization of Thesis

The work embodied in the present thesis is organized into the following seven chapters, as follows:

Chapter 1: Introduction and preview:-

This chapter gives an overview of the wireless network evolution in which the development of wireless technology has been traced in a chronological manner. It also discusses the different wireless networks that are available at present. This chapter also illustrates the outlines of the ad-hoc network in which evolution history, general concepts, applications and major attributes of the ad-hoc network have been talked about. Moreover, the background and SOTA sections of this chapter depict the various key aspects of the ad-hoc network such as routing protocols, mobility model, medium access control, QoS and simulation software. At the end of this section, some available studies on the ad-hoc networks have also been reviewed and established the research gaps as mentioned in section 1.4. Finally, this chapter concludes with the motivation, research objectives, and descriptions about all chapters of the present thesis.

Chapter 2: Analysis of AODV, route maintenance parameters, and determining factors:-

This chapter explains the functioning of the AODV routing protocol in depth. In other words, this chapter presents the various key aspects that are related to the AODV routing procedure in detail. These various key aspects are different packets format (such as RREQ, RREP & RERR packets), and different steps involved in AODV routing operation (like pictorial presentation, route discovery & maintenance process, management of routing table & local connectivity). Moreover, this chapter also explores the various route maintenance/configuration parameters, and clearly depicts the concept of active route timeout & delete period constant. Finally, this chapter comes up with the various determining factors like mobility, transmission range, NLD, and ANs/SD pair, and explains how these various factors are affecting the AODV routing stability.

Chapter 3: ART & DPC on the performance of AODV routing for CBR traffic generator by using NS-3 & QualNet:-

In this chapter, the performance of the AODV routing protocol has been analyzed by variation in the route maintenance parameters from their default value. Here, it is tested under the random waypoint topology for a fixed number of nodes and is subjected to the IEEE 802.11 MAC protocol. Moreover, in this case, the provided traffic generators among the mobile nodes are CBR. This chapter mainly conducts two different simulation studies in order to have the substantial understanding of the AODV network behavior under different simulation tools (NS-3 & QualNet). First one simulation study is the AODV performance observation for the constant scenario by using NS-3. In this case, two different QoS metrics are taken for the performance observations that are net throughput and PDR. Moreover, the second simulation study is also the performance observation of the AODV routing protocol, but for different SD pairs and by using QualNet. Here, chosen QoS metrics are throughput, average end-to-end delay, average jitter and percentage (%) of loss/drop packet.

Chapter 4: In AODV routing: comparative studies for CBR & VBR traffic under the influence of route maintenance parameters:-

Due to the growth of mobile internet applications in the recent years, it is necessary to study to guarantee the QoS in a topology-varying ad-hoc network environment, especially for VBR traffic. For that reason, in this chapter, the performance of the AODV routing protocol is analyzed and compared to two different traffic generators (CBR & VBR). Again, in this section the comparative study between CBR & VBR has been made under the influence of route maintenance parameters. Here, the evaluation and comparison of AODV routing performance are based on three QoS parameters that are throughput, average end-to-end delay, and average jitter. The QualNet simulation tool has been used to carry out the results. This chapter mainly conducts two different simulation studies for both traffic generators in order to have a better understanding of the network behavior that is as follows:

- ✓ Analysis for variable ART at fixed "NLD & SD pair"
- ✓ Analysis for variable SD pair at fixed "NLD & ART"

Chapter 5: In AODV routing: determining factors along with the route maintenance parameters:-

The work presented in this chapter tries to analyze an optimal relation between the various determining factors (as NLD, mobility & transmission range) and route maintenance parameters (only ART is considered here) in which network gives stable routing (i.e. offers the best performance) while focusing on the AODV protocol, especially. Here, the performance of the AODV network is again subjected to IEEE 802.11 MAC protocol under random waypoint topology, but for the different NLD and a fixed number of SD pair. This chapter uses the QualNet simulation tool to carry out the results, and the CBR traffic generator has been provided to generate the traffic between the mobile nodes. Here, AODV performance observation is based on throughput, delay, and jitter metrics. In order to determine the best combination between the various determining factors and route maintenance parameters, this chapter creates two different scenarios, and each scenario presents two separate cases.

Chapter 6: Comparative performance analysis of various routing protocols under varying pause time environment:-

Although, in the ad-hoc network environment, there are various routing protocols available that are mainly responsible for establishing the connection between users, but it is not an easy task to decide which one routing protocol is efficiently best for the particular situations. Hence, it is the matter of further examine. Therefore, the prime concern of this chapter is subjected to the comparative performance analysis between five routing protocols, out of which four are reactive (AODV, DSR, DYMO, & IERP) or on-demand in nature and the remaining one is IARP that is proactive in nature. Here, this chapter is mainly showing its interest to see the performance differences between these five routing protocols in the variable pause time environment, where it is varied from 0 to 100 seconds in a regular interval of 20 seconds. The comparative performance evaluation has been done with the help of performance measuring metrics such as throughput, end-to-end delay, jitter, and packet delivery ratio (PDR) by using MAC and physical layer model.

Chapter 7: Summary and conclusion

Finally, in this chapter, the research work embodied in the present thesis has been summarized, and the significant conclusions have been drawn from the major findings. Furthermore, this chapter also includes the future prospective of current research work.

As the keywords of the present thesis are AODV, different types of route maintenance parameters, and the various determining factors. Therefore, all these keywords are clearly explained in depth in chapter 2.