CHAPTER 8

PERFORMANCE ANALYSIS OF ROUTING PROTOCOLS FOR WIRELESS AD HOC NETWORK USING RICIAN FADING PROPAGATION MODEL

8.1 OVERVIEW

In the last decade, major changes took place in the world of communication. Advances in technology and convergence from: analog to digital, wire line to wireless, narrowband to broadband, circuit switching to packet switching, etc. Wireless networking is an emerging technology that allows users to access information and services electronically, regardless of their geographic position. Mobile Ad-hoc Networks (MANETs) is a working group for Ad-hoc networking and research under the Internet Engineering Task Force (IETF). A variety of routing protocols for ad-hoc networks have been proposed. They can be classified into: proactive routing protocols (e.g.: DSDV, OLSR), reactive routing protocols (e.g.: AODV, DSR) and hybrid routing protocols (e.g.: ZRP) [26, 61, 74, 104,117].

Based on network parameters like varying data rates, network size and number of connections in the network we analyze and compare the performance of proactive routing protocols and reactive routing protocols. The simulation results bring out some important characteristic differences between the ad-hoc routing protocols. The different basic working mechanism of these protocols leads to differences in their performance in the network.

Routing is a challenging issue in ad hoc network since nodes are mobile and the topology of the networks is ever changing. Besides, all nodes need to communicate via wireless infrastructure. Routing metrics used such as shortest path, link quality, power conservation and position
location will reduce route discovery time and also message update cost. When compared to wired networks, mobile networks have unique characteristics. In mobile networks, node mobility may cause frequent network topology changes, which are rare in wired networks. In contrast to the stable link capacity of wired networks, wireless link capacity continually varies because of the impacts from transmission power, receiver sensitivity, noise, fading and interference. Additionally, wireless mobile networks have a high error rate, power restrictions and bandwidth limitations.

Mobile networks can be classified into infrastructure networks and mobile ad hoc networks [118] according to their dependence on fixed infrastructures. In an infrastructure mobile network, mobile nodes have wired access points (or base stations) within their transmission range. The access points compose the backbone for an infrastructure network. In contrast, mobile ad hoc networks are autonomously self-organized networks without infrastructure support. In a mobile ad hoc network, nodes move arbitrarily, therefore the network may experiences rapid and unpredictable topology changes. Additionally, because nodes in a mobile ad hoc network normally have limited transmission ranges, some nodes cannot communicate directly with each other. Hence, routing paths in mobile ad hoc networks potentially contain multiple hops, and every node in mobile ad hoc networks has the responsibility to act as a router. Being independent on pre-established infrastructure, mobile ad hoc networks have advantages such as rapid and ease of deployment, improved flexibility and reduced costs. Mobile ad hoc networks are appropriate for mobile applications either in hostile environments where no infrastructure is available, or temporarily established mobile applications which are cost crucial. In recent years, application domains of mobile ad hoc networks gain more and more importance in non-military public organizations and in commercial and industrial areas. The typical application scenarios
include the rescue missions, the law enforcement operations, the cooperating industrial robots, the traffic management, and the educational operations in campus.

Active research work for mobile ad hoc network is carrying on mainly in the fields of medium access control, routing, resource management, power control and security. Because of the importance of routing protocols in dynamic multi-hop networks, a lot of mobile ad hoc network routing protocols have been proposed in the last few years. There are some challenges that make the design of mobile ad hoc network routing protocols a tough task. Firstly, in mobile ad hoc networks, node mobility causes frequent topology changes and network partitions. Secondly, because of the variable and unpredictable capacity of wireless links, packet losses may happen frequently. Moreover, the broadcast nature of wireless medium introduces the hidden terminal and exposed terminal problems. Additionally, mobile nodes have restricted power, computing and bandwidth resources and require effective routing schemes.

8.2 LIMITATIONS OF TRADITIONAL ROUTING PROTOCOLS

Routing is a fundamental issue for networks. A lot of routing algorithms have been proposed for wired networks and also been widely deployed. Dynamic routing approaches are prevalent in wired networks. Distance Vector routing [119] and Link State routing [119] are the two most popular dynamic routing algorithms used in wired networks.

Distance Vector routing protocols [120] are based on the Bellman-Ford routing algorithm. In Distance Vector routing, every router maintains a routing table (i.e. vector), in which it stores the distance information to all reachable destinations. A router exchanges distance information with its neighbors periodically to update its routing table. The distance can be calculated based on metrics such like hop number, queue length or delay. If multiple paths exist, the shortest one will be selected. The main drawback of Distance Vector routing algorithm is the slow convergence.
Slow convergence leads to the "count-to-infinity" problem, i.e., some routers continuously increase the hop count to particular networks. The well-known Routing Information Protocol (RIP) [120] is based on Distance Vector Routing.

In Link State routing algorithm, each node periodically notifies its current status of links to all routers in the network. Whenever a link state change occurs, the respective notifications will be flooded throughout the whole network. After receiving the notifications, all routers re-compute their routes according to the fresh topology information. In this way, a router gets to know at least a partial picture of the whole network. In Link State routing, different metrics can be chosen, such like number of hops, link speed and traffic congestion. Shortest (or lowest cost) paths are calculated using Dijkstra's algorithm. Open Shortest Path First (OSPF) [121] is an example of a link-state routing protocol.

In wired networks, Distance Vector and Link State routing algorithms perform well because of the predictable network properties, such as static link quality and network topology. However, the dynamic features of mobile ad hoc networks deteriorate their effectiveness. In mobile ad hoc networks, when using a Distance Vector routing or Link State based routing protocol designed for wired networks, frequent topology changes will greatly increase the control overhead. Without remedy, the overhead may overuse scarce bandwidth of mobile ad hoc networks. Additionally, Distance Vector and Link State routing algorithms will cause routing information inconsistency and route loops when used for dynamic networks.

Multicast is required in applications where subsets of nodes have common interests for specific information. In such scenarios, multicast out-performs unicast due to the saving of bandwidth and computing resource. Multicast routing, together with multicast addressing and dynamic registration, provide supports for multicast in wired networks. The multicast routing protocol
avoids multiple transmissions of the same message to receivers belonging to the same subset. Many multicast routing schemes have been proposed for wired networks, both Internet and ATM. Multicast routing approaches, such as Distance Vector Multicast Routing Protocol (DVMRP) [122], Multicast Open Shortest Path First (MOSPF) [123], Protocol-Independent Multicast (PIM) [124, 125] have been widely used in wired networks. In most of them, distributed trees are built from the sender to receivers belonging to same group. DVMRP adopts reverse path forwarding and periodically applies flooding to discover new hosts that want to join a particular group. Some multicast routing protocols are dependent on specific unicast routing protocols. For example, Multicast OSPF (MOSPF) is an extension to the OSPF unicast routing protocol and includes multicast information in link state advertisements. Each MOSPF router knows all multicast groups currently residing in the network and builds a distribution tree for each source/group pair. Distribution trees must be re-computed either periodically or when there is a link state change. In contrast to MOSPF, the Protocol-Independent Multicast (PIM) was proposed to work with all existing unicast routing protocols. There are two types of PIM: the dense-model PIM and the sparse-model PIM. The dense-mode PIM was designed for environments where group members are packed relatively densely and enough bandwidth resource is available. Whereas the sparse-mode PIM refers to environments where group members are distributed across many regions of the network and bandwidth is scarce.

As in wired networks, multicast is also appealing for mobile ad hoc networks. Multicast is an appropriate communication scheme for many mobile applications and can save bandwidth resource of wireless channels. Additionally, the inherent broadcast property of wireless channels can be exploited to improve multicast performance in mobile ad hoc networks. Compared to unicast routing schemes, designing multicast routing protocols for mobile ad hoc networks is
more difficult. The node mobility makes keeping track of the multicast group membership more complicated and expensive than in wired networks. Also, a distribution tree suffers from frequent reconstruction because of node movements. Therefore, multicast routing schemes for mobile ad hoc networks must include mechanisms to cope with the difficulties incurred by node mobility and topology changes.

8.2.1 EVALUATION METHODS FOR ROUTING PROTOCOLS

There are numerous routing protocols have been proposed [119] for mobile ad hoc networks, there is no standard scheme that works well in scenarios with different network sizes, traffic overloads, and node mobility patterns. Moreover, those protocols are based on different design philosophies and proposed to meet specific requirements from different application domains. Thus, the performance of a mobile ad hoc routing protocol may vary dramatically with the variations of network status and traffic overhead. This comprehensive performance study with varying different parameters is carried out in our research work. The performance variations of mobile ad hoc network routing protocols make it a very difficult task to give a comprehensive performance comparison for a large number of routing protocols.

There are three different ways to evaluate and compare the performance of mobile ad hoc routing protocols. The first one is based on analysis and uses parameters such as time complexity, communication complexity for performance evaluation. In the second method, routing performance is compared based to simulation results. Network Simulator 2, GloMoSim, OPNET and QualNet are wildly used simulators. The simulation results heavily dependent on the selection of simulation tools and configuration of simulation parameters. The last method is implementing routing protocols and analyzing their performance using data from real-world implementations. This method is not suitable for comparison of a large number of routing
protocols. Considering the dynamic network features, metrics for evaluating performance of mobile ad hoc network routing protocols are proposed in [126]. Generally, a properly designed mobile ad hoc routing protocol should adapt to the dynamic network changes quickly with lower consumption of communication and computing resources.

8.2.2 Characteristics of Routing Protocols

MANET have so many characteristics that need to be study in order to understand it and as a guide line for designing routing protocol. The important characteristics are given below.

(i) Dynamic topologies

The network topology for MANET wills always changes. This is due to the nodes are free to move arbitrarily; thus, the network topology which is typically multi-hop may change randomly and rapidly at unpredictable times, and may consist of both bi-directional and unidirectional links. Energy constrained operation: Some or all of the nodes in a MANET may rely on batteries or other exhaustible means for their energy. For these nodes, the most important system computation must involve few, nodes only and not nodes that have no traffic. Furthermore, few nodes involvement means less energy usage or none at all at other nodes. Design criteria for optimization may be energy conservation.

(ii) Limited of Security

Compare to wired network, wireless network is much more difficult to handle the security. But for MANET, because of the decentralized nature of network control, it provides robustness against the single points of failure of more centralized approaches. As mobile node and a router for itself, something with physical peripheral or any protocol for MANET that need to be consider for security issue.

(iii) Bandwidth constrained with variable capacity links
For MANET, like any other wireless network, of course the bandwidth is constrained. In the other band, for these dynamic nodes, the number of nodes in certain bandwidth is always changing. Thus, the capacity of link also will always change. Since ad hoc network are self-organized, broadcasting to all nodes must be avoided because it will create flooding at the nodes. Alternative routes should also be identified to act as backup if a node failure occurs.

(iv) Power

Nodes in an ad hoc network rely on battery for their source of energy. Energy saving methods must be taken into account to sustain stability and connectivity of nodes.

(v) Security

Ad hoc network are exposed to eavesdropping and spoofing. But because of the decentralized nature of ad hoc network, node failure is a localized to the affected node only and minimal effect to the whole network.

8.3 CLASSIFICATION OF ROUTING PROTOCOLS

The limited resources in MANETs have made designing of an efficient and reliable routing strategy a very challenging issue. An intelligent routing strategy is required to efficiently use the limited resources while at the same time being adaptable to the changing network conditions such as: network size, traffic density and network partitioning. In parallel with this, the routing protocol may need to provide different levels of QoS to different types of applications and users. Prior to the increased interests in wireless networking, in wired networks two main algorithms were used. These algorithms are commonly referred to as the link-state and distance vector algorithms. In link-state routing, each node maintains an up-to-date view of the network by periodically broadcasting the link-state costs of its neighboring nodes to all other nodes using a flooding strategy. When each node receives an update packet, they update their view of the
network and their link-state information by applying a shortest-path algorithm to choose the next hop node for each destination. In distance-vector routing, for every destination \( x \), each node \( i \) maintains a set of distances \( D^x_{ij} \) where \( j \) ranges over the neighbors of node \( i \). Node \( i \) selects a neighbor, \( k \), to be the next hop for \( x \) if \( D^x_{ik} = \min_j \{D^x_{ij}\} \). This allows each node to select the shortest path to each destination. The distance-vector information is updated at each node by a periodical dissemination of the current estimate of the shortest distance to every node [127]. The traditional link-state and distance-vector algorithm do not scale in large MANETs. This is because periodic or frequent route updates in large networks may consume significant part of the available bandwidth, increase channel contention and may require each node to frequently recharge their power supply.

To overcome the problems associated with the link-state and distance-vector algorithms a number of routing protocols have been proposed for MANETs [128]. These protocols can be classified into three different groups:

- **Table driven /Proactive Routing Protocols**
- **On demand/Reactive Routing Protocols**
- **Hybrid Routing Protocols**

In proactive routing protocols, the routes to all the destination (or parts of the network) are determined at the start up, and maintained by using a periodic route update process.

In reactive protocols, routes are determined when they are required by the source using a route discovery process. Hybrid routing protocols combine the basic properties of the proactive and reactive routing protocols. That is, they are both reactive and proactive in nature. Each group has a number of different routing strategies, which employ a flat or a hierarchical routing structure.
8.3.1 Table driven or Proactive Routing Protocol

A proactive routing protocol is also called "table driven" routing protocol. Using a proactive routing protocol, nodes in a mobile ad hoc network continuously evaluate routes to all reachable nodes and attempt to maintain consistent, up-to-date routing information. Therefore, a source node can get a routing path immediately if it needs one.

In proactive routing protocols, all nodes need to maintain a consistent view of the network topology. When a network topology change occurs, respective updates must be propagated throughout the network to notify the change. Most proactive routing protocols proposed for mobile ad hoc networks have inherited properties from algorithms used in wired networks. To adapt to the dynamic features of mobile ad hoc networks, necessary modifications have been made on traditional wired network routing protocols. Using proactive routing algorithms, mobile nodes proactively update network state and maintain a route regardless of whether data traffic exists or not, the overhead to maintain up-to-date network topology information is high. In this research, popular proactive mobile ad hoc network routing protocols, such as the Destination Sequence Distance Vector (DSDV) [62] and Optimized link state routing (OLSR) [32] are used in designing Cross Layer Design Protocols.

8.3.2 On demand/Reactive Routing Protocols

Reactive routing protocols for mobile ad hoc networks are also called "on-demand" routing protocols. In a reactive routing protocol, routing paths are searched only when needed. A route discovery operation invokes a route-determination procedure. The discovery procedure terminates either when a route has been found or no route available after examination for all route permutations.
In a mobile ad hoc network, active routes may be disconnected due to node mobility. Therefore, route maintenance is an important operation of reactive routing protocols. Compared to the proactive routing protocols for mobile ad hoc networks, less control overhead is a distinct advantage of the reactive routing protocols. Thus, reactive routing protocols have better scalability than proactive routing protocols in mobile ad hoc networks. However, when using reactive routing protocols, source nodes may suffer from long delays for route searching before they can forward data packets. The Dynamic Source Routing (DSR) [26] and Ad hoc On-demand Distance Vector routing (AODV) [61], Temporally ordered routing algorithm (TORA) [75] are used in designing Cross Layer Design Protocols in this research work.

8.4 MOTIVATION

In [113] four different routing protocols AODV, Temporally Ordered Routing Algorithm (TORA), DSDV and DSR are compared. It is shown through simulation results that DSR generates less routing load than AODV. AODV suffers from end to end delay while TORA has very high routing overhead. The better performance of DSR is because it exploits caching aggressively and maintains multiple routes to the destinations.

Performance comparison of AODV and DSR routing protocols in a constrained situation is done in [114]. The authors claim that the AODV outperforms DSR in normal situation but in the constrained situation DSR outperforms AODV, where the degradation is as severe as 30% in AODV whereas DSR degrades marginally as 10% in constrained situations.

A comparison of Link State, AODV and DSR protocols for two different traffic classes in a selected environment is done in [115]. Based on the simulation results it is observed that AODV and DSR perform well when the network load is moderate and Link State routing protocol outperforms AODV and DSR when the network load is high.
Perkins et al [116] show the performance of two on demand routing protocols AODV and DSR. Though both AODV and DSR use on demand route discovery, they have different routing mechanisms. The authors observe that for application oriented metrics such as delays and throughput DSR outperforms AODV when the number of nodes in the network. AODV outperforms DSR when the number of nodes in the network is very large. The authors do show that DSR consistently generate less routing load than AODV.

S. Gowrishankar et al [112] compares the performance of two prominent routing protocols in MANET: Ad hoc On-Demand Distance Vector Routing (AODV) and Optimized Link State Routing (OLSR) protocol. The performance differentials are analyzed using various metrics like packet delivery ratio, end to end delay and number of nodes and are simulated using NS-2.

F. Bertocchi et al [115] makes a comparison of link state, AODV and DSR protocols for two different traffic classes in a selected environment. The classic Dijkstra is also reported as comparison term. As performance metric, packet delivery fraction, throughput, average delay and energy are considered. They state that AODV and DSR perform well when the network load is moderate, while, if the traffic load is heavy, simple link state outperforms the reactive protocols.

8.5 PERFORMANCE EVALUATION

8.5.1 Performance Metrics

Three performance metrics: packet delivery fraction, average end-to-end delay and routing load are used to analyze the performance of ad-hoc routing protocols.

*Packet Delivery Fraction (PDF)*: The total ratio of the data packets received at the destinations to those generated by CBR sources
Average end-to-end delay: It includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the Medium Access Control layer and propagation and transfer times of data packets.

Routing Load: The ratio of total packets used for routing (route discovery, route maintenance, route error) to the total number of packets generated (data packets + routing packets)

8.5.2 Simulation Setup

The simulation is carried out based on Network Simulator-2 (ver-2.33). Tool Command Language (TCL) is used along with C++ constructs to create the topology structure, to configure source nodes, intermediate nodes and destination nodes, to create the statistical data trace file, etc.

The simulation environment consisted of a mobile ad hoc network in a network area of 500 meters by 500 meters with simulation time of 200 seconds. The Physical Layer access is assumed as Shared Media interface with parameters to make it work like the 914MHz Lucent Wave LAN DSSS radio interface. Radio Propagation Model being used is Rician Fading. Proactive routing protocols: DSDV and OLSR are compared with reactive routing protocols: AODV and DSR. Two Medium Access Control (MAC) layer protocols: IEEE 802.11 and Time Division Multiple Access (TDMA) are used and the performance of ad-hoc routing protocols on each of these MAC protocols is compared.

Each ad-hoc routing protocol (proactive or reactive) is simulated for different node-densities keeping the number of connections constant. Data rates of 1 packet per second and 5 packets per second were used for the simulation study of every routing protocol. When simulating for different node-density scenarios, number of connections was kept 20 and number of nodes was varied in from 10 to 60 with an increment of 10 nodes each time.
8.6 RESULTS AND DISCUSSIONS

8.6.1 Effect of Node densities

In this simulation scenario the number of nodes is varied from 10 to 60 and the number of connections in the network is kept constant to 20. Simulations are carried out with two MAC protocols: IEEE 802.11 and TDMA. The impact of changing the number of nodes on the behavior of routing protocols is analyzed. Since number of connections is kept constant, the number of generated Data Packets remains almost constant while the number of nodes is changed.

8.6.2 Average end-to-end delay

![Figure 8.1: Average end-to-end delay v/s Number of nodes](image)

![Figure 8.2: Average end-to-end delay v/s Number of nodes](image)
Hence, changing the number of nodes mainly affects the routing packets and performance of the routing protocol used in the network.

![Figure 8.3: Average end-to-end delay v/s Number of nodes](image)

It can be seen from the figures 8.1-8.4 that average end-to-end delay increases gradually as increase in the number of nodes in the network. This increase in average end-to-end delay is because increasing number of nodes also increase the data as well as routing traffic hence congesting the network which in turn causes delay in transmission of packets. Also, increasing the number of nodes in the network increases the geographic distance between the nodes, thus increasing the number of intermediate hops due to which propagation delay and processing delay also adds up to the overall delay.
Proactive routing protocols perform reasonably better than reactive routing protocols at high data rate, signifying the benefit of their table-driven nature. As higher data rate increases the congestion in the network, it hinders and delays the route discovery and maintenance procedure of reactive routing protocols. Due to the table driven nature of the DSDV, it performs best in all the scenarios. OLSR performs poor because of its nature of flooding the network with topology control messages. DSR performs worst at higher data rate, while AODV performs better than DSR in most of the cases.

It is observed that the performance of routing protocols is poor with TDMA MAC protocol, with average delays up to 4 times higher than that with 802.11 architecture. The reason is the time-slot allocation mechanism of TDMA which restricts the protocols to perform only in their own time-slot and also delay introduced due to protocol procedures sitting idle during time-slot of another node.

8.6.3 Packet delivery fraction

![Packet Delivery Ratio vs Number of Nodes](image)

Figure 8.5: Packet delivery fraction v/s Number of nodes
At lower data rate, individual packet delivery fractions for each routing protocol is observed not to deviate much with increase in the number of nodes.
It is observed that reactive routing protocols have reasonably higher packet delivery fraction when data rate is low. At high data rate, the packet delivery fraction decreases with increase in number of hops. Because increasing the number of nodes in a congested network results in dropping of packets at intermediate hops.

Proactive routing protocols suffer from the periodic routing table maintainence procedures and when data rate is low, these maintenance procedures become the main cause of congestion which results in more packet drops. At high data rate proactive routing protocols outperform reactive routing protocol because the table driven nature of proactive routing protocols gives them an edge over reactive routing protocols in highly congested network.

It is observed that the performance of routing protocols is better with IEEE 802.11 MAC protocol because the RTC/CTS/DATA/ACK mechanism of this protocol which ensures the reliable delivery of frames at link layer, thus increasing the overall packet delivery fraction.

### 8.6.4 Routing Load

![Routing Overhead vs no of nodes (IEEE 802.11)-[Rate:1 pps]](image)

Figure 8.9: Routing load v/s Number of nodes

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Figure 8.10: Routing load v/s Number of nodes

Figure 8.11: Routing load v/s Number of nodes

Figure 8.12: Routing load v/s Number of nodes
It can be seen from all the above shown graphs that routing load increases gradually as we increase the number of nodes in the network since increase in number of nodes will put extra burden on routing protocols to discover route for more number of nodes well as overhead caused due to maintainance of large number of routes having more number of hops.

Since the number of data packets remains constant in the network (because the number of connections is fixed at 20 and only the number of nodes is varied), the routing overhead mainly increased due to increase in the number of routing packets (routing load is ratio of number of routing packets to number of total (routing + data) packets).

It is observed that DSR routing protocol performs better than all other routing protocols. AODV performs poor than DSR because it periodically transmits “Hello” messages that causes routing overhead. OLSR performs poor than DSDV because of its nature of flooding the network with topology control messages.

Routing load decreases with TDMA MAC protocol for reactive routing protocols whereas for proactive routing protocols, routing load increases with TDMA MAC protocol. Routing load increases with IEEE 802.11 MAC protocol for reactive routing protocols whereas for proactive routing protocols, routing load decreases with IEEE 802.11 MAC protocols.

8.7 SUMMARY

Reactive routing protocols perform better than proactive routing protocols at lower data rates when it comes to reliability of packet delivery, but at higher data rates proactive routing protocols gain their advantage of table-driven nature and perform better with packet delivery than reactive protocols. DSDV produces least average end-to-end delay whereas DSR produces maximum average end-to-end delay. DSR produces least routing load as compared to other
routing protocols whereas OLSR produces the maximum routing load due to its nature of flooding the network with topology control messages.

Overall, proactive protocols perform better than reactive with respect to average end-to-end delays and packet delivery fraction especially at higher data rates. Reactive routing protocols perform better in causing less routing load and better performance at lower data rates. DSDV shows the most consistent performance in most of the cases.

It is also observed that IEEE 802.11 MAC protocol is well suited for ad-hoc routing protocols when it comes to average end-to-end delay and packet delivery fraction. In case of routing load, IEEE 802.11 MAC protocol is well suited for proactive routing protocols whereas TDMA MAC protocol is well suited only for reactive routing protocols.