

Routing Protocols in MANET an NS-3 Performance-Centric Analysis of AODV, OLSR, and DSDV

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Abstract: Mobile Ad Hoc Networks (MANETs) are decentralized, self-configuring wireless systems. They are crucial in situations where quick setup and independence from existing infrastructure are important. These networks are commonly used in military communication, disaster relief, and IoT systems. MANETs work with dynamic topologies and multi-hop wireless links. Routing is a major challenge because of frequent changes in topology, limited bandwidth, and energy limits. A comparison of three key routing protocols, AODV, OLSR, and DSDV, was conducted using the NS-3 simulator. The evaluation measured performance metrics like packet delivery ratio, end-to-end delay, throughput, and routing overhead across different mobility levels and network sizes. AODV, which is reactive, demonstrated strong adaptability in high-mobility scenarios. OLSR, a proactive protocol, consistently provided low latency, making it a good fit for real-time applications. DSDV showed stable performance in smaller, less dynamic environments but had higher control overhead. Additional findings from simulations and previous evaluations of AOMDV, TORA, GRP, DAS, and RMQS-ua indicate that hybrid and intelligent approaches often find a better balance between efficiency and scalability. Therefore, choosing routing protocols in MANETs should match the specific needs of the application. Factors like mobility, energy availability, and network size play a crucial role in achieving the best communication performance.

Keywords: Mobile Ad Hoc Networks (MANETs), Routing Protocols, AODV, OLSR, DSDV, Performance Evaluation, NS-3 Simulation.

I. INTRODUCTION

Mobile Ad Hoc Networks (MANETs) are wireless networks made up of mobile nodes that can self-organize and communicate with one another using radio waves and do not rely on a fixed or centralized infrastructure. Each node in a MANET serves as a host and a router and forwards packets for other nodes. The important distinction of a MANET is that the network can be deployed quickly without the reliance on a fixed infrastructure, making them useful in situations where traditional network infrastructure does not exist or cannot be built, like in military scenarios, emergency disaster recovery scenarios, remote sensor networks, or vehicular ad hoc networks. A MANET has a set of unique features that distinguish it from other types of networks, these include dynamic topology, limited bandwidth, limited energy resources, and decentralized control [1]–[4]. Due to the lack of fixed backhaul infrastructure and the mobility of nodes, MANETs are highly flexible, but at the same time extremely unstable, meaning that the topology of the network changes nearly constantly. Routing in such a dynamic and decentralized environment presents unique challenges. Because nodes are constantly moving, it is difficult to maintain consistent and reliable routing paths. Because traditional routing protocols built for fixed networks cannot accept rapid topology changes; they cannot be used in MANETs. Frequent disconnections due to node mobility led to even greater route instability. It becomes even more complicated to find and maintain routes, given the multi-hop nature of nodes given that they each have a limited transmission range. Routing protocols in MANETs must provide a good packet delivery ratio with low end-to-end delay and overhead in order to conserve bandwidth and energy. The inability to trust a centralized authority makes trust management and security less feasible in a virtual context; and the changes in the topology make for hard to guarantee secure routes which increase difficulty in keeping nodes secure. Although there are a great number of routing protocols that will be considered for performance evaluation, in order to ensure the success of the MANET as a whole, routing performance metrics are important to evaluate, it is equally important to conceive and evaluate routing protocols which can successfully adapt to the MANET environment. Figure 1 shows a Mobile Ad Hoc Network (MANET) configuration. With mobile devices operated in a wireless network without any fixed infrastructure, mobile nodes automatically and dynamically advertise themselves through the network. For the configuration in this diagram, the GPS service provides location information for the mobile devices when required, and internet access is optional via the access point[5]–[11].

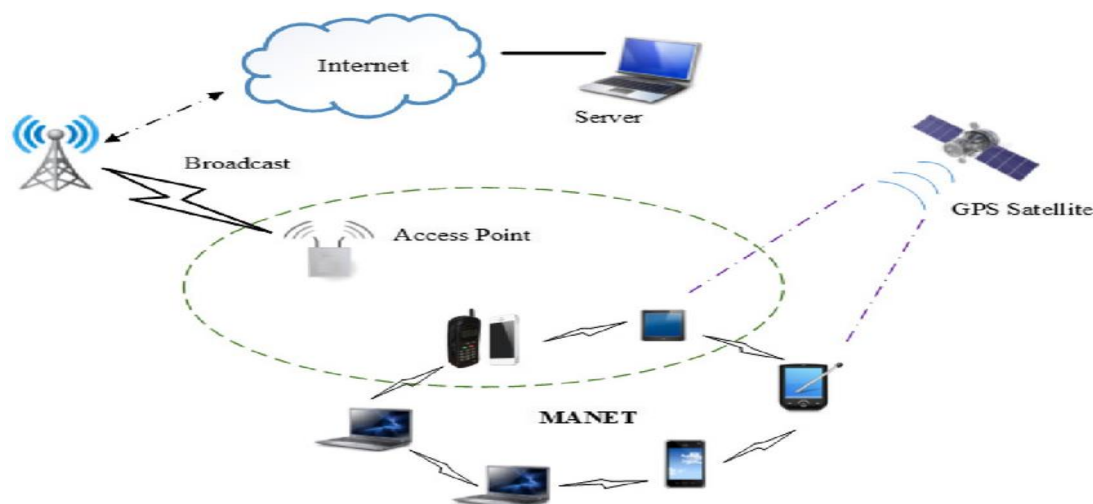


Figure 1 Basic MANET architecture [6].

II.OVERVIEW OF ROUTING IN MANET

Routing is the act of creating and maintaining communication paths between mobile nodes in a mobile ad hoc network (MANET) that does not have a fixed and anticipated structure. Each node in MANETs has two roles: the host (i.e., source and destination) and the router (i.e., each node forwards packets of data via multi-hop wireless transmission from one node to the next). The routing protocols fulfil the need to determine how to forward packets of data from source to destination through a series of wireless hops. Routing in this environment is particularly challenging because topology changes frequently due to node mobility (i.e., route breaks) and because wireless bandwidth is limited (and often shared), which can also impact the energy level of networking devices. Because of these challenges, different protocols can be used in experience, and these protocols can generally be categorized as being either proactive (i.e., DSDV, OLSR), reactive (i.e., AODV, DSR), or hybrid (i.e., ZRP). The importance of effective routing for communication in a decentralized environment, especially in terms of reliability, timeliness, and energy efficiency, cannot be overstated [12]–[14].

A. Classification of Routing Protocols

Routing protocols in MANETs are usually classified into three categories based on how they create and maintain routes. They are classified as reactive, proactive, or hybrid. Reactive protocols (also known as on-demand protocols) create routes only when the route is required for data transmission. Therefore, reactive protocols take advantage of congestion reduction in maintenance as well as bandwidth savings based on the constraints of the MANET [9]. Reactive protocols include AODV (Ad hoc On-demand Distance Vector) and DSR (Dynamic Source Routing). Reactive protocols have two major features: route discovery and route maintenance, which are initiated by the source node when the source node must conduct communication. Proactive protocols update the routing tables at all times by using control messages consistently regardless of the need for routes. This means that when you need a route, there is already one available which decreases the time to establish a route at the expense of some overhead associated with the constant updates [[15]–[18]]. Proactive protocols you may have heard of include OLSR (Optimized Link State Routing) and DSDV (Destination-Sequenced Distance Vector). Hybrid protocols are a combination of proactive and reactive protocols, which create a west coast solution to minimize control overhead and route discovery time. One example of a hybrid protocol is the Zone Routing Protocol (ZRP) which employs proactive routing in a local zone with reactive routing for inter-zone communication. Ultimately, you choose a protocol depending on the network size, mobility patterns, and application requirements.

B. Key Performance Metrics for Routing in MANETs

To evaluate MANET routing protocols, we use a number of performance metrics. One of the most significant metrics is called Packet Delivery Ratio (PDR). PDR refers to the ratio of successfully received data packets at the destination to all data packets sent by the source. A high PDR reflects successful delivery by the protocol and is essential for reliability and efficiency in many(a) sensitive applications. Another key metric is called End-to-End Delay. End-to-End Delay refers to the average time, measured in seconds, for a data packet to travel from the source to the destination. Delays need to be as low as possible for real time applications, such as voice or video communications etc. Throughput, which is the rate at which total data is successfully delivered over the network per unit time, demonstrates the routing protocol's total data handling ability in the face of high data traffic. Another important definition provided is routing overhead, which is the number of control packets produced during route discovery and route maintenance. A high routing overhead can consume valuable bandwidth and energy as well, which is often problematic in mobile ad-hoc networks (MANET) given limited resources. Another factor to consider for time critical applications is jitter (variation of packet delays), because it has an effect on the quality of service provided by the protocol. Additional routes for evaluating the performance of a protocol are hop count, route acquisition time, and energy consumption. The performance evaluation of routing protocols using these different parameters should give the researcher a good understanding of the relative merit and weaknesses of each protocol in a specific network situation and conditions [19]–[25].

C. Criteria for Protocol Comparison

When it comes to evaluate routing protocols in MANETs, it is important to evaluate them against a defined set of performance and technical criteria (for example, how the protocol performs under mobility, scalability, traffic load, and node density). For instance, since AODV is an on-demand protocol, it can be designed to work better in more dynamic conditions, while OLSR will more likely perform better in stability scenarios as mobility may cause unnecessary overhead to the proactive route updates. Route stability is another important parameter in performance testing protocols since topology is constantly changing, route stability identifies how capable the routing protocol is able to maintain routes, considering there will be more frequent route breaking in high-mobility situations that may adversely affect routing performance. Different protocols may also be analyzed based on energy consumption, latency, and overall utility (resource efficiency) for battery-powered or resource-limited nodes. Security and resilience are also increasingly being used in comparing protocols, since MANETs are generally open-to-attack and considered vulnerable to a variety of attacks. Finally, the complexity of protocol implementation and congruence of the potential protocol with real world applications (e.g., vehicular networks and disaster recovery) may be a factor in selecting what protocol one would like to use. The evaluation of the five components from above provides a solid basis for selecting or designing a routing protocol to meet the needs of a specific MANET application. Figure 2 shows how MANET routing protocols can be divided into categories based on routing decisions, with examples based on location-based category, topology-based category (also on-demand, table-driven, and hybrid), and energy-aware category [6], [9], [10], [26], [27].

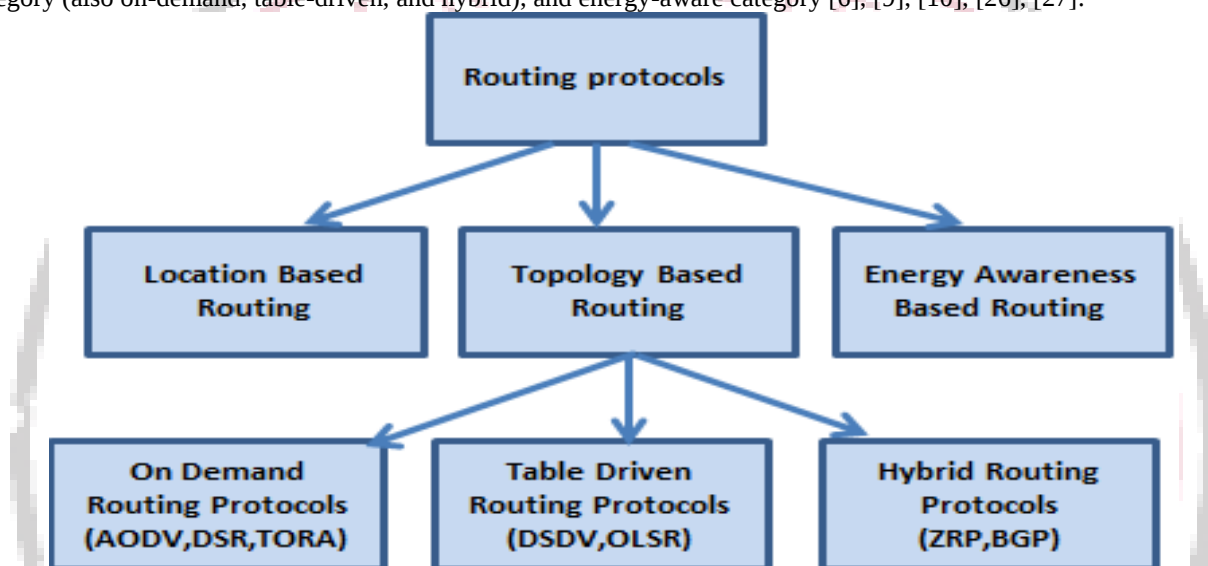


Figure 2 Routing Protocols in MANET [19]

III. DESCRIPTION OF SELECTED ROUTING PROTOCOLS

AODV, OLSR, and DSDV are mobile ad hoc network (MANET) routing protocols employing different strategies. AODV is reactive, creating routes only when they are needed, which is better for conserving bandwidth, but may be subject to initial latency with high overhead in dynamic environments. OLSR is proactive, using Multipoint Relays (MPRs) to eliminate control packet overhead and created low latency. OLSR has low latency and is scalable, but it utilizes consistent bandwidth and energy to keep routes over a given period of time active, while AODV only uses bandwidth and power when creating the route, which may be better for low traffic or very mobile scenarios. DSDV is also a proactive MANET routing protocol, defining loops for network protocols by using periodic routing updates and sequence numbers. DSDV gives you quick access to routing but uses large amounts of control overhead, especially for a larger network and a fast-trained protocol, in which size and change are considered more [12], [16], [18], [25].

A. Ad hoc On-Demand Distance Vector (AODV)

AODV is a reactive (on-demand) routing protocol because it only creates routes when needed by source nodes. In the scenario where a node must send data to a destination node in the network for which the node does not have a route, the node broadcasts a Route Request (RREQ) message through the network. Each intermediate node receiving the RREQ will reply with a Route Reply (RREP) message if it has a valid route to the destination. Otherwise, the RREQ propagates until it reaches the destination node [20]. When the source node receives the RREP, a route has been established and data can be sent. In AODV, sequence numbers are used to ensure the freshness of routing information and prevent routing loops. AODV handles route maintenance with Route Error (RERR) messages that are generated when a node detects a link break. Figure 3 shows a multi-hop wireless communication system where data sources or destinations are transferred in between by relay nodes (R1 and R2).

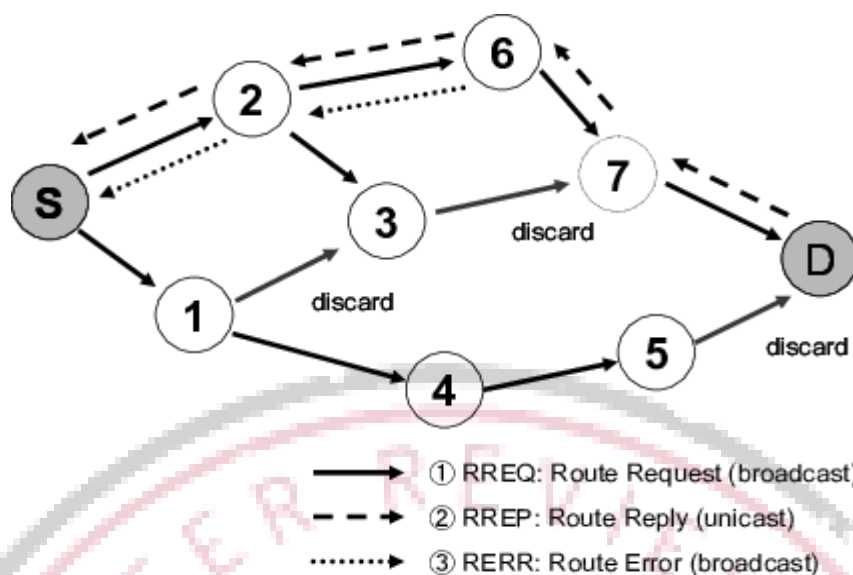


Figure 3 Overview of AODV protocol

AODV uses little bandwidth because it does not keep any useless routing information ahead of time with overhead in dynamic networks. AODV is loop-free with destination sequence numbers, and has multicast routing capability, making it useful for applications that require communication between groups of nodes. However, AODV will use flooding for the routes which leads to high initial latency and congestion in larger or dense networks. In addition, AODV will have more overhead and battery consumption, especially for an intermediate node that is handling more than one route request during the route discovery process, in a high-mobility environment for example, or if there are frequent route discoveries.

B. Optimized Link State Routing (OLSR)

OLSR operates in a proactive manner meaning it always maintains consistent routing tables with information on the current network topology. It is link-state routing in nature, and to reduce overhead, it uses the mechanism of MPRs. Control messages are only forwarded by some selected nodes, MPRs, during route updating, thus greatly cutting down on redundant transmissions. All nodes periodically interchange HELLO messages with their neighbors to determine whether links are up or down, and the nodes broadcast the link-state information through TC messages. Hence, routes can be optimally calculated at any time by all nodes without an end-to-end route discovery procedure being initiated by any one of them. Figure 4 explains the OLSR Multipoint Relay concept: the nodes selected to act as MPRs (in blue color) are the only ones to retransmit broadcast messages. This reduces control traffic and hence increases routing efficiency.

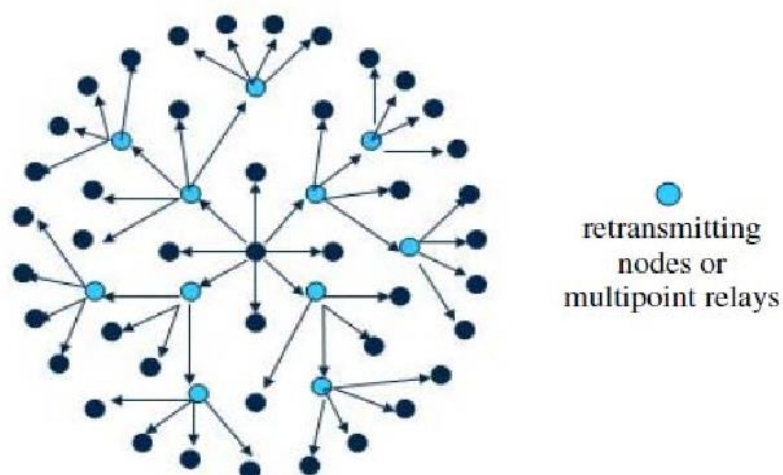


Figure 4 OLSR Routing mechanism [27]

OLSR offers low latency: routes are immediately available whenever needed, thus real-time applications such as VoIP and streaming benefit from it. Employing MPRs increased scalability over standard link-state protocols, thus minimizing unneeded traffic. Being a proactive protocol, control messages are sent back and forth all the time, wasting bandwidth and increasing power consumption even if there is no data transmission. This is bad OLSR efficiency-wise for resource-starved or low-population networks. Also, in areas of heavy mobility, OLSR can be difficult to operate, as it requires constant update cycles to remain an accurate topology with possible delays.

C. Destination-Sequenced Distance Vector (DSDV)

DSDV is a proactive routing protocol based on the Bellman-Ford algorithm with enhancements to eliminate routing loops with the incorporation of destination sequence numbers. Every node keeps a routing table that contains every

possible destination, the number of hops to each destination, and the sequence number assigned by the destination node. The routing tables are updated periodically, and the updates are broadcasted to neighbouring nodes; the updates can be full dumps (the whole table) or incremental updates (only the changes). When a route to a destination changes, the node increments the sequence number and propagates the updated information on all neighbours to ensure consistency across the network.

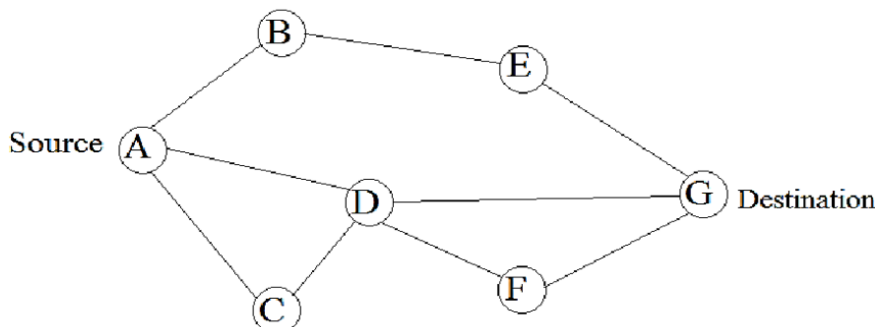


Figure 4 Distance sequenced distance vector (DSDV) [31]

DSDV provides loop-free routes and ensures route consistency due to its use of sequence numbers. It is well-suited for small to medium-sized networks with relatively low mobility, as it offers quick route availability without needing a discovery process. However, its periodic updates can lead to high control overhead, especially in large or highly mobile networks where topological changes occur frequently. This can result in wasted bandwidth and increased energy consumption. Moreover, maintaining routes to all destinations at all times can be inefficient if only a few routes are actively used, limiting its scalability and adaptability in dynamic environments.

IV. PERFORMANCE METRICS

In a comparative analysis derived from simulation results, the operational behaviour of various MANET routing protocols, including AODV, OLSR, and DSDV, can be objectively analysed in the same network conditions by simulating them using the NS-3 simulator. Once the simulation parameters, namely the number of nodes, area size, traffic patterns, and types of mobility models are held the same, the routing protocol behaviour can be compared in terms of various metrics. This exercise will show strengths and weaknesses among protocols and, ultimately, what protocol is able to perform more reliably, efficiently, and quickly in mobilized changing environments.

Packet Delivery Ratio (PDR) is another important metric used in assessing MANET performance, as it provides information about routing protocol efficiency and reliability. PDR is defined as the ratio of packets successfully received by the destination to the number of packets sent by source, and the value should be high in order to indicate a route that is stable and consistently delivers the packets despite mobility or wireless link condition changes. In reactive protocols the PDR tends to stay high even through movement with AODV, for example, changing the routing information when required and not being stagnant with an established path and therefore reduces the chances of having a stale route to send packets. Proactive protocols such as DSDV or OLSR may have a lower PDR if the routing mechanism cannot keep up with the amount of movement or amount of frequency the topology is changing. At the same time, in cases of little mobility or static networks, proactive protocols would have potential to perform equal to or better than the PDR of reactive protocols, as they have pre-computed routes available that are stable. In general, of these performance metrics, PDR is usually considered to be one of the most indicative productivity and performance assessment metrics for a protocol that has to function in a real operating environment.

Average end-to-end delay is defined as the time taken for a packet of data to traverse the network from the source node to the destination node on average. It includes all delays such as: delay in route discovery; queuing at the interface queues; retransmission delay due to MAC sublayer; propagation delay, and processing delays. Low end-to-end delay is desirable for time-sensitive applications, such as voice over internet protocol, video conferencing, and emergency communications, because the amount of lag can further reduce the user's experience. Simulation results have shown that proactive protocols like OLSR usually incur less end-to-end delay because the routing tables are blindly populated and valid routes prior to the sending the packet. When the sending node forwards the packet, the packet does not need to go through a delay of discovering time-sensitive routes. Conversely, reactive protocols such as Ad Hoc On-Demand Vector may incur higher end-to-end delay due to the necessity of discovering routes when the user need to transmit the packets. However, with mobility, the end-to-end delay could fluctuate in a proactive protocol due to the high frequency of exchanging control messages and frequent broken links, but AODV may have improved end-to-end delay if the route discovery procedure remains efficient. Therefore, end-to-end delay is a significant metric when considering a protocol for delay-sensitive applications in MANET environments.

Mobile Ad Hoc Network (MANET) is a user-driven, decentralized, and infrastructure-less wireless network designed for applications such as disaster relief, military mission coordination, and IoT systems. Due to the highly dynamic topologies of a MANET, efficient, as well as scalable, routing of data is a major challenge. There have been numerous studies that have evaluated the performance of different routing protocols under various conditions utilizing simulation environments, such as OMNeT++ and NS-3.27, to name a few. Network protocols such as OLSR can work effectively with low or moderate density and relative stability [39]. DSDV is a stable routing protocol, but it is limited to being most

effective in a static network of a small or medium size. In projects with high mobility and large-scale networks have favoured AODV and AOMDV protocols due to their willingness to self-adapt. DSR performed best when terrain dimensions were small with less than low mobility [40]. TORA performed well with dynamic topologies, but with moderate overhead limitations [41]. Deep reinforcement learning methods have been used to extend the lifetime of WSN-based MANETs by balancing node load [41]. Studies with NS-3.27 have shown that terrain dimensions greatly affect protocol suitability, with AODV performing well in larger areas [42]. The MAENA simulator with dynamic spectrum management (DSM) also improves performance under complex traffic models [43]. Better routing classification based on QoS, discovery, and maintenance offers deeper insights into protocols [44]. MSLD allows for lightweight and efficient service discovery with low overhead, making it suitable for IoT-based MANETs [45]. Cooperative multicast routing schemes have been evaluated to enhance multicast delay performance [46]. Lastly, the DAS protocol improves MANET security through energy-aware clustering and surpasses existing QoS-aware protocols [47]. RMQS-ua focuses on link quality and stability for urban MANET situations [48].

Table 1 Comparative studies of MANET Routing Protocols

Reference	Study	Type	Best Use Case	Performance Highlights	Simulation Environment	Routing Overhead	Scalability
[39]	OLSR	Proactive	Low-density, stable environments	Low latency, high delivery in stable networks	OMNeT++	High	Low to Moderate
[40]	DSDV	Proactive	Small/Medium terrain, static networks	Stable routing, moderate throughput	NS-3.27	High	Low
[41]	AODV	Reactive	High-mobility, large terrain	High throughput and delivery in mobile networks	NS-3.27	Low	High
[41]	DSR	Reactive	Small terrain, low mobility	Efficient in low-density and low mobility	NS-3.27	Low	Moderate
[42]	AOMDV	Reactive	Dynamic, high mobility	Multipath routing with better packet delivery	OMNeT++	Moderate	High
[43]	TORA	Reactive	High-mobility environments	Responsive to frequent topology changes	OMNeT++	Moderate	High

[44]	ZRP	Hybrid	Moderate mobility and scalability	Combines proactive and reactive strengths	OMNeT++	Moderate	High
[45]	GRP	Hybrid	Energy-efficient, balanced performance	30% lower energy use, high PDR	OMNeT++	Low	High
[46]	MSLD	Service Disc.	Service discovery with low overhead	High service availability, low latency	IFIP conf (Custom)	Very Low	High
[48]	RMQS-ua	Multipath	Urban areas with noisy channels	Improved reliability using link quality & stability	MAENA	Low	High
[47]	DAS	Security	Secured MANET with energy efficiency	High PDR (98.7%), low delay (15.81ms), secure, energy aware	Custom (DBSCAN-based)	Low	High

V.CONCLUSION

The dynamic and decentralized nature of MANETs requires strong routing protocols that can handle frequent changes in topology, limited bandwidth, and energy restrictions. This study shows that each routing protocol has distinct strengths based on the network context. AODV provides good adaptability and high packet delivery in mobile environments, but it may experience delays during initial route discovery. OLSR maintains consistent low latency and is beneficial for delay-sensitive applications, although it incurs continuous overhead. DSDV is stable in static networks, yet it has issues with scalability and frequent topology changes. Comparative studies from recent research support these conclusions and highlight that hybrid protocols like GRP and ZRP offer a better balance between latency and overhead, particularly in mixed mobility situations. Moreover, newer intelligent approaches, such as Deep Reinforcement Learning (DRL)-based routing and security-focused protocols like DAS, show promising results for energy efficiency and secure data delivery. Overall, the best routing protocol choice in MANETs depends on specific deployment scenarios, whether the focus is on mobility, energy conservation, security, or throughput. This study serves as a basis for researchers and developers to make informed choices about protocols and to further investigate adaptive or hybrid solutions for evolving MANET applications.

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