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A Comparative Study of Routing Protocols and Artificial Intelligence in Manets

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Abstract

Decentralized networks called Mobile Ad hoc Networks (MANETs) allow mobile nodes to dynamically connect to one another without the need for fixed infrastructure. An overview of MANETs is given in this work, along with a discussion of their features, uses, and difficulties. It explores how routing protocols, such as proactive, reactive, and hybrid protocols, are categorized in MANETs and provides examples and features for each. It also examines the performance measures, including packet delivery ratio, throughput, packet loss, latency, routing overhead, energy consumption, and jitter that are used to assess routing protocols in MANETs. Furthermore, the study discusses how AI-driven systems enhance intrusion detection, reaction speed, and huge data management, emphasizing the significance of AI in improving security in MANETs.

Keywords: MANETs, Artificial Intelligence, Routing Protocols, Performance Metrics.

INTRODUCTION

Mobile Ad hoc Networks (MANETs) represent a class of network where mobile devices connect spontaneously, forming a network without the need for established infrastructure. This flexibility allows nodes to join or leave the network at will, without the reliance on a fixed structure, enabling them to act both as data hosts and pathway routers. Unlike conventional networks that depend on predetermined infrastructure, MANETs operate independently, making them ideal for environments where deploying fixed networks is unfeasible or impractical. Examples of their application include instant communication systems like walkie-talkies, which do not require infrastructure to facilitate device-to-device communication. Such networks find utility across various fields, including emergency services, military applications, educational contexts, and sensor networks due to their infrastructure-less nature.

MANETs are characterized by their ability to adapt to dynamic topologies and create self-configuring networks, addressing the growing demand for internet connectivity in today's fast-moving world. With the advent of 5G technologies, these networks are exploring new possibilities within their operational spectrum. However, they face challenges such as the need for routing protocols to swiftly adapt to changes in network topology. Communication between sources and destinations might necessitate intermediary nodes because of the nodes' limited bandwidth, leading to issues like asymmetric connections, routing overhead, signal interference, and the inherently dynamic nature of their topology [1–4].

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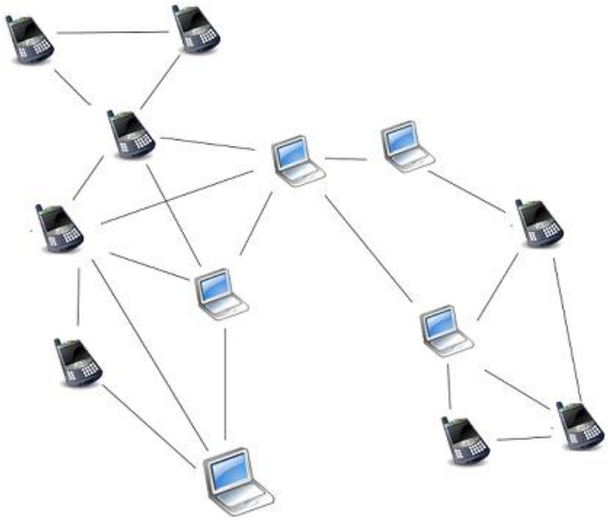

Figure 1. Mobile Ad-hoc Network [6].

Mobile Ad Hoc Networks (MANETs) are a focal point of contemporary research, addressing the challenges and leveraging the opportunities inherent in their dynamic, infrastructure-less setup (Figure 1). This interest spans several key areas, including Medium Access Control (MAC), routing, resource management, power control, and security, due to the critical role these elements play in the network's performance and reliability. MANETs enable Mobile Nodes (MNs) to autonomously establish networks and manage packet routing without the need for fixed infrastructure, making them invaluable in scenarios where traditional networks are impractical, such as military operations or disaster recovery situations [5, 6].

The formulation of routing protocols within MANETs is particularly challenging due to the network's inherently dynamic topology. Node mobility, constrained by the limited wireless transmission range, frequently alters the network's structure, necessitating constant updates to routing information. This volatility can lead to traffic congestion, increased network overhead, and higher consumption of critical resources, including processing power, memory, and battery life [5, 6].

Security stands out as a significant concern within MANETs. The network's open and mobile nature exposes it to various security threats, highlighting the importance of robust security measures to protect communication channels and data against potential attacks [7]. The adaptability of MANETs to hostile environments and their capacity for self-organization, despite these challenges, make them a potent solution in contexts devoid of traditional infrastructure.

Nevertheless, MANETs might not be the go-to solution for everyday mobile usage that demands stable internet connectivity, typically facilitated by access points and wired networks [8]. Instead, their strength lies in scenarios devoid of infrastructural support or where internet access is not critical. This includes military operations, emergency responses, sensor networks, and vehicle-to-vehicle communications, where MANETs can offer a viable communication framework [8].

Classification of Routing Protocols

Routing protocols have traditionally been divided into three categories in the context of Mobile Ad hoc Networks (MANETs): proactive (table-driven), reactive (on-demand), and hybrid. These protocols are especially made to deal with problems like highly mobile nodes, dynamically changing network topologies, and energy or transmission power limitations. By establishing routes only when necessary, reactive routing protocols—such as AODV (Ad hoc On-Demand Distance Vector)—strive to reduce control overhead. Although this method lowers overhead, the time needed to create routes on-demand may cause it to perform poorly in contexts with substantial node mobility [9–13].

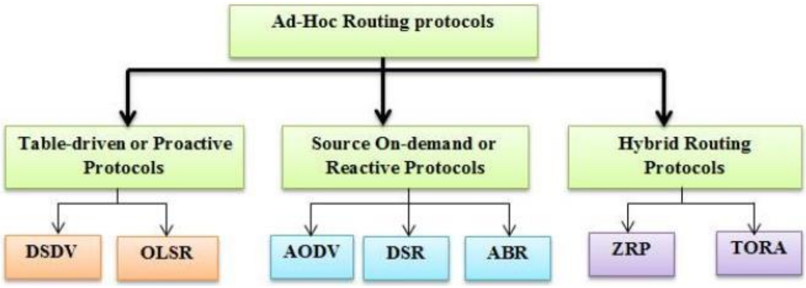

Figure 2. Classification of Ad-hoc Routing Protocols [13].

On the other hand, location awareness is achieved by geographic routing protocols through the use of GPS sensors or localization algorithms (Figure 2). These protocols use non-flooding-based route discovery algorithms and provide scalable routing based on node placements in large-scale networks. Geographic routing methods do not call for specific route management or connection maintenance procedures, in contrast to certain classical protocols. They do, however, rely on nodes being aware of their locations prior to sending out "Hello" messages. Even so, for dynamic networks, routing decisions that are based only on position information are reliable and efficient. However, problems like poor GPS reception, especially in enclosed spaces like tunnels, might cause errors in node locations, which can hinder the efficiency of geographic routing. Furthermore, excessive node mobility in MANETs might change the density of the network, leading to more frequent connection failures and less accurate neighbor awareness. No matter what kind of protocol they are, these modifications may have further effects on how good they are at routing. Therefore, even though MANET routing protocols provide answers to a variety of problems, mobility and environmental factors might affect how well they function in practical situations.

Table Driven/Proactive Routing Protocols

The Destination Sequenced Distance Vector (DSDV) protocol represents a proactive approach tailored for Mobile Ad Hoc Networks (MANETs), aiming to ensure stable and loop-free routing amidst the network's inherent fluctuations. Utilizing sequence numbers to enhance the integrity and reliability of routing information, DSDV mandates that each node maintains an up-to-date routing table, which is refreshed periodically or in response to topological changes [9]. This protocol amalgamates traditional distance vector routing principles with modifications suited to the dynamic context of MANETs. Its framework includes hop-by-hop routing for packet forwarding, periodic updates for topology adaptation, sequence numbers for route validation, stability protocols to curb route oscillations, and loop prevention mechanisms to avert routing loops. Collectively, these features elevate the efficiency and reliability of routing within MANETs, positioning DSDV as a significant contribution to mobile ad hoc networking technology.

The Optimized Link State Routing (OLSR) protocol is another proactive, table-driven strategy employed in MANETs. It operates on the principle of periodic link information exchange among nodes, with each node rebroadcasting this data. This constant exchange enables nodes to optimize routing efficiency by maintaining updated link state information and determining optimal hops for each destination. A key innovation within OLSR is the MultiPoint Relaying (MPR) strategy, which selects a subset of neighbor nodes as relays to propagate control packets, effectively minimizing message overhead. OLSR's advantages include reduced end-to-end latency, straightforward implementation, adaptability to network changes, scalability, support for multiple routes, and reduced network overhead, making it well-suited for dynamic network environments [10]. However, OLSR faces challenges such as the necessity to upkeep comprehensive routing tables, increased overhead with more mobile hosts, latency in reestablishing disrupted links, scalability issues in expansive networks, security vulnerabilities, limited Quality of Service (QoS) support, and complex configurations. Despite these drawbacks, OLSR remains a valuable MANET routing protocol, adept at balancing its strengths against the intricacies of dynamic, self-organizing networks.

Source on Demand Routing Protocols

The Ad hoc On-Demand Distance Vector (AODV) protocol exemplifies a reactive routing methodology within Mobile Ad Hoc Networks (MANETs), where routes are established only as needed. AODV minimizes the need for routine network-wide broadcasts by maintaining routes only for active paths, with unused routes being removed after a certain period. Each node possesses a routing table for next-hop information towards active destinations. The protocol employs three primary message types for route management: Route Request (RREQ), Route Reply (RREP), and Route Error (RERR). RREQ messages initiate the route discovery process, RREP establishes the route by retracing the RREQ's path, and RERR notifies the network of route failures. This reactive nature allows AODV to efficiently manage routing information, conserving network resources by reducing overhead compared to proactive protocols [11].

Dynamic Source Routing (DSR) is another reactive protocol that identifies routes on an as-needed basis, foregoing the maintenance of separate routing tables. Instead, DSR utilizes a Route Discovery Mechanism to dynamically identify the most efficient paths through the network. A distinctive feature of DSR is its route discovery process, wherein the destination node identifies the most direct route and communicates it back to the source, ensuring a single, optimized path for data transmission. DSR's advantages include high routing efficiency, reduced bandwidth consumption, and effective route discovery. However, challenges such as potential delays in route discovery, route maintenance difficulties upon link failures, and scalability issues in large networks due to packet header size constraints are notable [12].

Associativity-Based Routing (ABR) offers a unique approach designed for wireless ad hoc networks, including MANETs. ABR operates through three phases: route discovery, route reconstruction, and route deletion. In the discovery phase, search packets identify stable routes based on node associativity and stability. The destination selects the best route and informs the source. Route reconstruction allows for localized repairs to maintain route integrity, while route deletion removes obsolete paths either through explicit Route Delete (RD) packets from the source or by allowing inactive routes to expire. ABR's methodology ensures efficient and timely route establishment and maintenance, adapting to the dynamic conditions of ad hoc networks [12].

These protocols, AODV, DSR, and ABR, each address the unique challenges of routing in MANETs, offering tailored solutions to balance efficiency, resource conservation, and adaptability to network dynamics.

Hybrid Routing Protocols

The Zone Routing Protocol (ZRP) was introduced by Haas and Pearlman in 1997 as an innovative hybrid routing strategy for Mobile Ad Hoc Networks (MANETs), blending elements of both reactive and proactive routing methods. ZRP optimizes routing efficiency by implementing a proactive scheme, the Intra zone Routing Protocol (IARP), within a node's immediate neighborhood, while adopting a reactive approach, the Inter zone Routing Protocol (IERP), for communications between different zones. This segmentation into zones, where each zone's extent is defined by a hop count radius, facilitates reduced control message overhead compared to purely reactive or proactive protocols. Additionally, the Broadcast Resolution Protocol (BRP) within ZRP enhances route request forwarding across these zones. Despite its advantages, ZRP faces challenges such as potential delays in route discovery due to its hybrid nature [13].

The Temporally Ordered Routing Algorithm (TORA) is a dynamic, distributed routing protocol designed specifically for the decentralized and fluid nature of MANETs. TORA stands out for its capability to rapidly adapt to topological changes, making it highly suitable for environments with high mobility. It operates through three key phases: Route Creation, Route Maintenance, and Route Erasure, ensuring a loop-free routing experience by leveraging directed acyclic graphs for path establishment. This design contributes to TORA's scalability and efficient bandwidth utilization. However, TORA is not without its limitations, which include the potential for increased overhead due to frequent topological updates, sensitivity to specific parameters, concerns regarding security vulnerabilities, and energy consumption. The protocol's effectiveness in diverse scenarios hinges on its integration with complementary protocols, necessitating a balanced consideration of its strengths and weaknesses for optimal performance in MANET settings [14]. Both ZRP and TORA offer valuable contributions to the field of MANET routing, providing solutions tailored to address the unique challenges of dynamic network topologies. Their development underscores the ongoing evolution of routing protocols, aiming to optimize network performance, reliability, and adaptability in the face of MANETs' inherent complexities (Table 1).

PERFORMANCE METRICS OF ROUTING PROTOCOLS IN MANETS

A variety of metrics are used to evaluate the reliability and efficacy of routing protocols in Mobile Ad hoc Networks (MANETs) [15, 16]. PDR, or packet delivery ratio: This gauges the effectiveness of packet delivery; End-to-End Delay: This gauges the duration of a packet's transmission; Routing Overhead: This counts the number of extra control packets that are produced; Network throughput: This gauges how quickly data is sent; Packet Loss Rate: This indicates what percentage of packets are dropped; Scalability: the ability of a network to function well as it grows in size; Energy Efficiency: This gauges how much energy is used; Robustness and Resilience: This gauges the network's capacity to adjust to changes. Security: This gauges defense against dangers; and the Overhead-to-Benefit Ratio, which compares the advantages to the cost of resources [17–19]. Researchers may gain a better understanding of the protocol's ability to handle problems such node mobility, changes in network architecture, and energy constraints by integrating these measurements. For MANETs operating in a range of circumstances, routing protocols can be developed using this information (Table 2).

Table 1. Comparative analysis of routing protocols.

Feature	**Proactive (Table-Driven) Routing Protocols**	**Reactive (On-Demand) Routing Protocols**	**Hybrid Routing Protocols**
Operation	Constantly maintain routing information in tables for all nodes in the network.	Establish routes only when needed, typically in response to a specific data packet transmission request.	Combine elements of both proactive and reactive approaches to provide a balance between route establishment delay and routing table overhead.
Routing Table Updates	Routing tables are updated regularly to reflect changes in network topology.	Routing tables are updated dynamically in response to route discovery requests or changes in network topology.	Routing tables are updated both proactively and reactively, depending on network conditions and traffic requirements.
Overhead	Higher control overhead due to continuous updating of routing tables.	Lower control overhead as routes are established only when needed.	Moderate control overhead, balancing between proactive and reactive approaches.
Scalability	Generally less scalable for larger networks due to increased routing table size.	More scalable as routing information is obtained only when needed, reducing routing table size.	Scalability varies based on the implementation, with some hybrid protocols offering improved scalability compared to purely proactive or reactive protocols.
Route Discovery	Routes are available for all nodes in the network without delay.	Route discovery occurs only when a node needs to send data to a destination with an unknown route.	Routes may be available for some destinations proactively, while others are discovered reactively.
Adaptability to Network Changes	Proactively updates routing tables in anticipation of network changes.	Reacts dynamically to changes in network topology or route requests.	Combines proactive updating with reactive responses to network changes, offering adaptability to varying network conditions.
Examples	OLSR (Optimized Link State Routing), OSPF (Open Shortest Path First).	AODV (Ad hoc On-Demand Distance Vector), DSR (Dynamic Source Routing).	ZRP (Zone Routing Protocol), TORA (Temporally Ordered Routing Algorithm).

Table 2. Comparative analysis of performance metrics.

Ref.	Routing Protocols Used	Simulation Parameters	Performance Metrics	Performance Metric Values
[17]	AODV, AOMDV, DSDV	1000 m × 1000 m, Two-ray and random motion	PDR, Throughput, Packet Loss, Delay, Routing Overhead	***PDR***: AOMDV - 60.09%, AODV - 57.42%, DSDV - 38.86% ; ***Throughput:*** AODV - 368 Kbps, AOMDV - 278.5 Kbps, DSDV - 201.42 Kbps; ***Packet Loss***: AOMDV - 39.9%, AODV - 42.58%, DSDV - 61.14% ***Delay:*** DSDV - 27.8 milliseconds, AOMDV - 61.19 milliseconds, AODV - 102.83 milliseconds; ***Routing Overhead:*** AODV - 1809 packets, DSDV - 139586 packets, AOMDV - 171464 packets
[18]	AODV, DSDV	1000 m × 1000 m, Two-ray and random motion	Throughput, PDR, EED, PLR, Energy Consumption	***Throughput:*** DSDV (average) - 601 to 715 Kbps, AODV (average) - 525 to 691 Kbps ***PDR:*** AODV (average) - 1513 to 626, DSDV (average) - 846 to 312***;EED***: AODV (average) - 354 to 942 ms, DSDV (average) - 373 to 992 ms ; ***PLR***: AODV (average) - 525 to 691, DSDV (average) - 601 to 691***; Energy Consumption***: DSDV (average) - consistent with slight variations, AODV (average) - fluctuates with node count.
[19]	AODV, DSDV, DSR		Packet delivery rate, % Lost packets, Throughput, Jitter	***PDR:*** AODV – 97, DSDV – 97.8, DSR – 99; ***Throughput :*** AODV – 251.77, DSDV –154.32, DSR – 292.4; ***Packet Loss Ratio :*** AODV – 2.2, DSDV – 3.0, DSR –0.8

Research papers evaluating various routing protocols in Mobile Ad Hoc Networks (MANETs) are summarized in the table. It contains information about the reference, the routing protocols (AODV, AOMDV, DSDV, DSR) that were used, the simulation parameters (such as the mobility model and simulation area), the performance metrics (such as the packet delivery rate, throughput, packet loss, delay, routing overhead, energy consumption, and jitter), and the specific performance metric values that were found in the related studies[19].

ROLE OF ARTIFICIAL INTELLIGENCE IN MANETS

Network activities, such as packet transmission and the implementation of routing protocols, are fundamentally dependent on security, particularly when developing applications with strict security specifications. Through the use of machine learning techniques, prediction models that have been trained on particular cyberattack patterns may be created. These models are then tested using new data sets to see if they are effective at recognizing new attack patterns. Mobile Ad Hoc Networks (MANETs) are vulnerable to a range of security threats due to their inherent openness, including floods, Denial of Service (DoS) assaults, and more advanced vulnerabilities including wormhole, black hole, and grey hole attacks. Because data packets in MANETs must pass through a number of intermediate nodes in order to reach their destination, a cooperative architecture for node communication is required. Assessing the reliability of nodes is therefore vital to safeguard against forwarding packets to malicious or unreliable parties, with numerous methodologies proposed in scholarly works to bolster MANET security through trust evaluation. Security strategies within MANETs can be categorized for effective application [20].

Artificial Intelligence (AI) offers strong solutions to improve MANET security by enabling self-managing networks with little assistance from humans. The development of artificial intelligence (AI)-powered security systems seeks to dramatically lower mistake rates in two main ways: by taking the place of human supervision in network administration and by continuously improving the adaptability and resilience of these systems. There are various benefits to using AI approaches in MANET security [21–23].

Improved Intrusion Detection: Artificial Intelligence (AI) enhances intrusion detection systems (IDS) by giving them the ability to more accurately identify, categorize, and detect hostile activity within networks. It provides an extra layer of intelligence for well-informed decision-making by evaluating threat probability through the analysis of user and network behavior patterns.

Accelerated Response Time: When compared to conventional ways, AI-driven technologies provide for a speedier and more accurate resolution of security issues. By protecting data logs and using a variety of alert mechanisms, it expedites the threat analysis process.

Effective Data Management: Handling the massive volumes of data produced by MANETs, such as system log files and warnings, is a difficult task. Due to the sheer complexities and quantity of the created data, operations like data sifting and security measures are difficult to complete manually. AI helps with these duties.

CONCLUSION

Grasping MANET routing protocols is key to enhancing communication in these dynamic networks. Reactive protocols like AODV excel in mobile environments by establishing routes on-demand, while proactive protocols like DSDV ensure stable, continuous routing. ZRP, a hybrid protocol, combines the best of both approaches for optimal performance. Evaluating these protocols involves looking at metrics such as packet delivery ratio, throughput, and energy efficiency. Additionally, integrating AI into MANET security offers advantages like improved intrusion detection, faster response to threats, and efficient management of large data volumes, significantly enhancing network security and performance.

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