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MANETs their Challenges and, Applications along with Routing Protocols Classifications

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Abstract: Decentralized wireless networks called Mobile Adhoc Networks (MANETs) are made up of mobile nodes that self-organize dynamically without the need for fixed infrastructure. Independent peer-to-peer nodes interact together with other nodes for a specific goal is the foundation of a MANET. Every device in the network plays the same job, and no previous base station or organization is specified. Since the network's nodes are provided, there are no pre-defined roles like routers or gateways; instead, any device can function as both a node and a router simultaneously. In other words, it exhibits independent behaviour and sporadic nodal connection. Efficient routing in MANETs is a key challenge due to high node mobility, dynamic topologies, limited bandwidth, and energy constraints. This paper presents an overview of MANETs, its challenges, future trends, its applications. It also presents brief review of categorisation of routing protocols in MANETs e.g. proactive, reactive, and hybrid approaches. An alaysis is also being represented to shows the abilities, strength, weakness of the different routing protocols falling under different categories of MANET.

Keywords: MANET, DSDV, OLSR, DSR, AODV, ZRP, HWMP

1. Introduction

A **MANET (Mobile Ad-Hoc Network)** is a self-adjusting, wireless network of wireless moving devices that don't require fixed infrastructure like base stations or routers. Nodes act as both end hosts and routers, communicating over radio frequencies to relay data, creating a dynamic, decentralized network [1]. Key features include autonomous operation, self-healing capabilities, and a constantly changing topology due to node mobility, making MANETs suitable for emergency services, military operations, and sensor networks where infrastructure is impractical.

MANETs have gained significant attention in military communication, disaster recovery, vehicular networks, and IoT systems due to their infrastructure-less and self-configuring nature. Routing plays a central role in ensuring reliable communication among nodes, but MANETs face challenges like frequent topology changes, scalability, security threats, and energy consumption [2]. This review evaluates existing routing protocols and highlights future research directions.

Due to reason of freely moving nodes, MANET nodes may enter and exit the network, causing their linkages and topology to fluctuate. Furthermore, the connections among nodes may be unidirectional or bidirectional. Furthermore, the connections among nodes may be unidirectional or bidirectional. However, this characteristic results in a high user density and high user mobility [2].

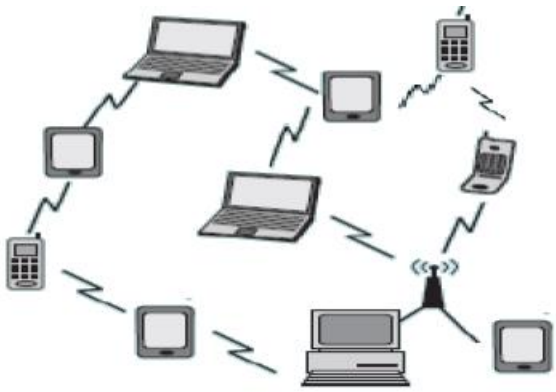

Figure 1: Scenario of Mobile Ad Hoc Network

The above shown figure 1 portrays the typical formation of a self-configured network i.e. infrastructure-less network and is called a MANET. The nodes within the network serve as both hosts and routers, transferring data from one node to another within the network. Every node in the MANET utilizes a wireless interface for communication with other nodes. These networks are entirely decentralized and can operate anywhere without the need for any permanent infrastructure like access points or base stations. These create a highly dynamic self-organizing structure featuring one or more distinct transceivers among nodes. The primary obstacle for the MANET is to enable each device to consistently retain the information necessary for effective traffic routing [3] [4]. MANETs are networks that are self-forming, self-healing, and operate on a peer-to-peer basis.

These mobile networks possess the following characteristics [5]:

- The connection between the nodes without wires is very susceptible. This occurs because nodes are in constant motion, leading to frequent link disruptions.
- The constant creation and breakdown of wireless links results in a highly dynamic network structure.
- These wireless networks are bandwidth constrained, meaning that the nodes constantly move in and out of each other's range.
- Because each node depends on battery power, which is limited, an energy-efficient operation is required.

MANET's goal is to deliver communication functionalities in regions with little or no established communication infrastructures. MANET possesses various notable features [6] [7] [8].

- Dynamic topologies: The network topology can fluctuate at any time due to nodes' ability to travel in any direction at different rates. As they move, the MANET's nodes dynamically establish routes between one another to construct their own network.
- Small Weight Terminals: Small computing devices like laptops and smartphones make up the majority of the nodes in the MANET. These devices have tiny memory, low power consumption, and limited CPU capabilities.
- Bandwidth constrained links: Wireless links have significantly lower capacity then their hardwired counterparts. Over time, a wireless link's capacity deteriorates due to multiple access, noise, and interference circumstances, and the effective throughput may fall short of the radio's maximum transmission capacity.

- Energy constrained operation: All operations require the intensive use of battery. Because devices are light weight so they also have limited battery life means they have limited energy.
- Limited physical security: Wireless links increased MANET's vulnerability to physical layer attacks such Denial of Service (DoS), spoofing, jamming, and eavesdropping. Nonetheless, MANETs are more resilient to single failure spots because to their decentralized architecture. However, compared to infra-structured networks, mobile wireless networks are more vulnerable to attacks.

Identifying the right Routing protocols is among the challenging and interesting areas of research. The goal of routing protocols is to find short routes because of the dynamic characteristics of MANETs like moving nodes, frequent loss of connections, limited battery life or many more. The following sections describes the categories of routing

2. Classification of MANET Routing Protocols

Routing is the method of identifying the optimal route for data packets to move from their origin to their endpoint within a network [9]. It entails making choices grounded in network protocols and algorithms to effectively route data through diverse network equipment like routers, switches, and gateways. The goal of routing is to ensure that data packets reach their intended destination reliably and in a timely manner.

The rules that determine the path taken by message packets as they move from a source to a destination inside a network are known as routing protocols [10] [11]. Nodes need some intermediary nodes to relay their data packets if they are not in direct range of one another, but they can connect and interact directly if they are. A number of variables, including network size, complexity, scalability, dependability requirements, and the kind of data being transferred, affect the choice of routing algorithm.

Different routing protocols categories among MANETs are broadly categorized into three categories:

2.1 Proactive (Table-Driven) Protocols

Another name for proactive routing systems are called as table-driven routing protocols. Every node in this kind of routing keeps a table known as a routing table. The complete details of every node in the network are included in this table [12]. After a brief amount of time, the routing tables are updated on a regular basis. Large networks cannot use these kinds of protocols since they must preserve complete information about every node in the network. This results in increased routing table overhead, which raises bandwidth usage.

In nutshell these type of routing algorithms maintains up-to-date routing tables at each node at every time. The following are some example of table-driven routing MANET protocols.

- **Optimized Link State Routing (OLSR)**
- **Destination-Sequenced Distance Vector (DSDV)**

The advantages of proactive routing protocols are low latency and consistent routing info. The disadvantages of such protocols are high control overhead, less efficient in highly dynamic networks.

2.2 Reactive (On-Demand) Protocols

In contrast to proactive protocols, which maintain routes continually, reactive (on-demand) protocols create network routes only when data has to be transferred [13]. This implies that routes are created only when required. A node does not need a route to a destination until it will be the sink of the data packets that the node transmits there; reactive protocols employ a lazy method in which nodes only find routes to destinations when asked to do so. The route discovery procedure is started by flooding the mobile network with route request packets. Route maintenance and route discovery are its two main phases. Route maintenance and route discovery are its two main phases. Route discovery determines the most efficient method of transmitting data packets between the source and destination mobile nodes. Due to the dynamic nature of the mobile ad-hoc network topology and the frequent occurrence of link failures that result in network failure between the mobile nodes, the route maintenance phase handles route maintenance. The route identification procedure may cause delays, but this on-demand method lowers overhead and is effective in low-traffic situations.

Common examples in reactive routing protocols include following.

- **Dynamic Source Routing (DSR)**
- **Ad hoc On-demand Distance Vector (AODV)**

The advantages of on-demand routing protocols are Lower overhead, scalability. Whereas disadvantages in this category are latency in route discovery, flooding and more overheads in larger network with large traffic.

2.3 Hybrid Routing Protocols

Reactive and proactive routing techniques are combined to form hybrid routing protocols in MANET [14]. By employing proactive routing within a node's zone, these protocols partition the network into zones and reactive routing for communication to nodes in other zones, offering improved scalability and performance compared to pure reactive or proactive methods. Because of their adaptive nature, these protocols change based on the location and zone of the destination and source mobile nodes. Hybrid routing methods are thought to be the most successful in MANET because they combine proactive and reactive strategies.

The following are the few examples of hybrid MANET routing protocols:

- **Hybrid Wireless Mesh Protocol (HWMP)**
- **Zone Routing Protocol (ZRP)**

The main advantages of hybrid routing protocols are balanced overhead and latency. Whereas the disadvantage of this category is complexity in the implementation of hybrid routing protocols.

3. Comparative Analysis of Routing Protocols

The comparative analysis of the above-mentioned routing protocols [15] under different categories are mentioned as below in Table 1.

Table 1: Comparative Analysis of various routing protocols

Protocol	Category	Key Mechanism	Strengths	Weaknesses	Best Use Case
DSDV	Proactive	Distance vector with sequence numbers	Low latency	High overhead	Small, stable networks
OLSR	Proactive	Multipoint relays (MPRs)	Efficient flooding	Scalability issues	Dense MANETs
AODV	Reactive	Route request/reply (RREQ/RREP)	Scalable, efficient	Delay in discovery	Large dynamic networks
DSR	Reactive	Source routing	Low control overhead	Packet header overhead	Medium mobility networks
ZRP	Hybrid	Zone-based routing	Balanced	Complex to configure	Large heterogeneous MANETs
HWMP	Hybrid	Tree-based routing	Balanced	Works on MAC protocol only	Peer Link Management Protocols

4. Challenges in MANET Routing

Despite the appealing applications and various features of MANET, there are several challenges and issues that need to be thoroughly examined before widespread commercial implementation can be anticipated. The MANET environment must tackle these problems and obstacles. These challenges signify the unresolved problems and open issues. MANETs have been a favored area of research over the past few years. Nearly every facet of the network has been investigated in various ways across different levels of issues [16]. The key challenges and latest research trends of the MANET are outlined below

- **High Mobility**: Frequent link breakages.
- **Energy Constraints**: Limited battery resources.
- **Scalability**: Performance degrades with large node count.
- **Security Threats**: Vulnerable to blackhole, wormhole, and Sybil attacks.
- **QoS Support**: Delay-sensitive applications need optimized routing.
- **Variable Link Capacity / Bandwidth Constraints:** Wireless connections linking the MANET nodes possess significantly lower bandwidth compared to wired ones.
- **Light-Weight Terminals / Constrained Resources:** The majority of MANET devices are compact, portable, and possess restricted power (battery-powered) processing abilities and storage limits.
- **Heterogeneity in Node and Link Capabilities:** Each node in the network can possess one or more distinct radio interfaces that exhibit differing transmitting and receiving abilities.
- **Hidden Terminal Problem:** The collision of packets at a receiving node caused by the simultaneous transmission of nodes outside the sender's direct transmission range is known as the "hidden terminal problem."

5. Emerging Trends and Future Directions

The effective implementation and utilization of MANET in real-world scenarios is proving to be a challenging endeavor [17]. Nonetheless, creating and assessing a dependable MANET presents a significant challenge, as the necessary expertise spans numerous subjects, including network intricacy, optimization of routing problems, QoS, scalability, Variability, dependability, mobility management, grouping, security, bandwidth allocation, and more.

- **Energy-Aware Routing**: Protocols minimizing power consumption.
- **QoS-Aware Routing**: Supporting real-time multimedia communication.
- **Secure Routing**: Incorporating cryptographic and trust-based mechanisms.
- **AI & ML-based Routing**: Using reinforcement learning and predictive models.
- **Cross-layer Design**: Joint optimization of MAC, routing, and transport layers.

6. Applications Areas of MANET

- **Military Operations:** MANETs provide essential communication in dynamic battlefield environments where infrastructure is scarce.
- **Disaster Response & Emergency Services:** They enable rapid network establishment for first responders and emergency personnel to coordinate efforts in damaged area infrastructure or absence of infrastructure.
- **Public Safety:** Police and fire departments can use MANETs for real-time coordination and communication during emergency situations.
- **Healthcare:** MANETs facilitate communication to facilitate real-time consultations with medical experts and allow for remote patient monitoring, especially in remote areas.
- **Sensor Networks:** A large number of small, mobile sensors can form a MANET to collect and transmit data on various properties like temperature, pressure, and toxins.
- **Vehicular Networks (VANETs):** MANET routing protocols are applied in vehicular networks to coordinate communication between vehicles and infrastructure to improve traffic flow.
- **Internet of Things (IoT):** The decentralized nature of MANETs makes them suitable for dynamic and self-organizing IoT systems.
- **Industrial and Mining Operations:** They are used for communication and monitoring in challenging industrial environments, requiring a central point for coordination.
- **Real-time Multimedia Streaming**: MANET routing protocols can be tailored for applications like video streaming, balancing metrics related to performance such as delay and throughput.
- **Environmental Monitoring:** MANETs and sensor data are used in real-time applications, such as detecting and monitoring forest fires.

6. Conclusion

Because of their dynamic and resource-constrained contexts, routing in MANETs is still a difficult issue. Reactive methods lower control burden but add delay, proactive protocols provide low latency but suffer from overhead, and hybrid protocols seek to strike a compromise between the two. Future research is moving toward intelligent, energy-efficient, and secure routing solutions that can support next-generation MANET applications in IoT, VANETs, and emergency communications.

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