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Review of Routing Protocols for Mobile Ad Hoc Networks

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ABSTRACT

Research on Mobile Ad Hoc Networks is of great significance in various fields including military, emergency response, Internet of Things (IoT), vehicular networking, aviation, and scientific research. This research contributes to the advancement and application of mobile communication technologies. Both domestic and international researchers have conducted in-depth studies on routing protocol design, which encompasses various aspects such as protocol design, topology management, link quality estimation, security, and energy efficiency. These areas represent current research hotspots and challenges. With the continuous development of wireless communication technologies and increasing demands for application, research on routing in Mobile Ad Hoc Networks remains highly significant with broad prospects for development. Therefore, research on routing strategies for Mobile Ad Hoc Networks has garnered widespread attention in academic circles worldwide, leading to numerous valuable research outcomes. This paper comprehensively analyzes the requirements related to the design of routing protocols for mobile self-organizing networks and comprehensively investigates the existing routing protocols, and classifies and investigates the routing protocols for mobile self-organizing networks in order to promote the research of next-generation mobile self-organizing network routing in China, which provides a reference.

KEYWORDS

Ad Hoc network; Routing policy; Proactive routing; Reactive routing; Clustering routing

1. INTRODUCTION

Mobile Ad Hoc Network (MANET) is a self-organizing communication network among autonomous nodes without the need for infrastructure support [1]. In such networks, each node is free to move and can join or leave the network at any time without prior planning or configuration. This self-organizing nature makes MANETs highly applicable in temporary or adverse environments such as military battlefields, natural disaster sites, and mobile fleets [2]. The concept of MANETs dates back to the 1990s when military applications and mobile computing began to emerge [3]. Traditional communication networks are inadequate for these scenarios because they rely on fixed infrastructure, which may be impractical or unavailable under mobile, temporary, or adverse conditions. Hence, researchers began exploring a new form of self-organizing network, known as a Mobile Ad Hoc Network.

Research on routing strategies for highly dynamic ad hoc networks is not only about addressing current challenges in network communication but also about providing reliable and efficient communication services for various high-dynamic scenarios of future mobile ad hoc networks [4]. Suitable routing strategies can help networks adapt to rapidly changing topologies, improving routing stability and communication reliability.

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By optimizing routing selection and path maintenance, communication interruptions and data loss caused by node mobility can be minimized, ensuring timely and reliable transmission of communication data [5]. Well-designed routing strategies can reduce data transmission latency and packet loss, enhancing the efficiency and speed of data transmission. Through optimized routing selection and communication paths, network resources can be maximally utilized, improving network throughput and performance stability. Routing strategies for highly dynamic ad hoc networks can enhance the efficiency of data transmission, reduce transmission.

2. TYPICAL MOBILE AD HOC NETWORK ROUTING STRATEGY

In the context of mobile ad hoc network (MANET) routing protocols, there are various classifications found in different literature sources. This article categorizes them into three main types: topology-based routing protocols, location-based routing protocols, and cluster-based routing protocols [6]. The detailed classification is illustrated in Figure 1.

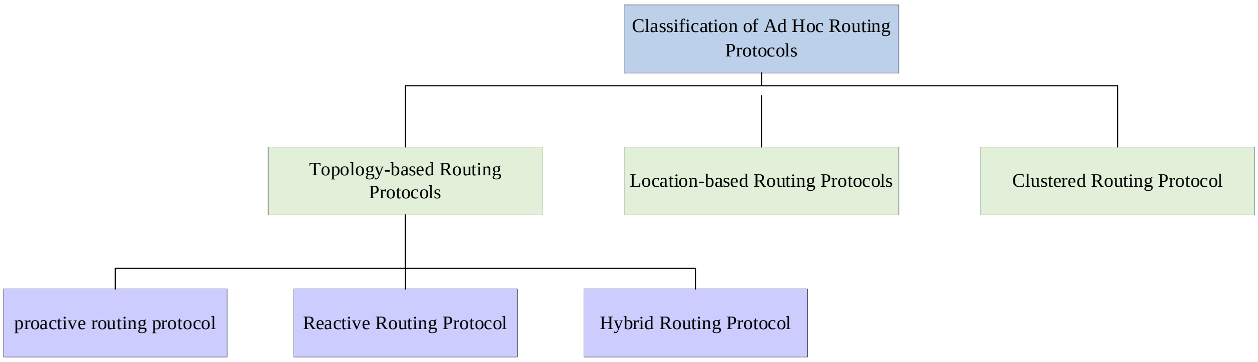

Figure 1. Routing protocol classification diagram

2.1. Topology-Based Routing Protocols

Topology-based routing protocols can be categorized into three types based on whether they require the maintenance of global routing information: proactive routing protocols, reactive routing protocols, and hybrid routing protocols.

2.1.1. Proactive Routing Protocols

In proactive routing protocols, nodes periodically send control messages to maintain global topology information. Regardless of whether communication is needed, each node regularly updates its routing table information. Nodes continuously exchange information using the respective routing algorithms to obtain routing paths to all other nodes and update and maintain their own routing tables, which contain routing information from the node to other nodes. Therefore, this protocol reacts very quickly with low communication latency but requires sending a large number of control signals to periodically maintain network topology information, thus increasing control signal overhead. Typical proactive routing protocols include OLSR and DSDV.

Optimized Link State Routing is a type of global routing algorithm, where global routing selection means that all nodes possess a complete network topology view and can obtain the status of all links, including the costs of all links. Using the respective routing algorithms, each node can compute the routing path from itself to other nodes, and then maintain its routing table based on this path information. This table includes the next hop and the total metric from the node to all other destination nodes. A traditional link state algorithm is an example of a global routing algorithm, where each node can access the entire network connectivity status. Nodes broadcast their own information and information about neighboring nodes, and based on the network topology and link weight information, they use algorithms like Dijkstra's algorithm to compute and update routing tables.

Link state algorithms have faster convergence speeds and are less prone to routing loops compared to distance vector algorithms, but they require more CPU power and memory. Additionally, link state algorithms are more scalable; by introducing different parameters into the link state calculations, various functionalities can be achieved. When there are changes in link states in this algorithm, messages are flooded to neighboring nodes, resulting in significant control signal overhead. Moreover, the algorithm requires computation of the shortest path to all other nodes each time a change occurs, which can be computationally intensive

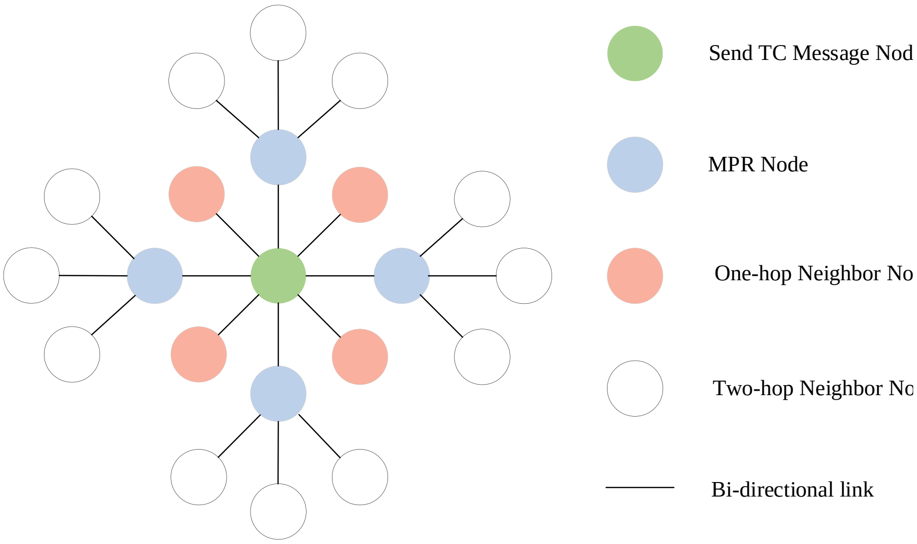

Figure 2. Multipoint relay diagram

OLSR (Optimized Link State Routing) was developed to adapt to mobile ad hoc networks (MANETs), improving upon traditional link state algorithms. Due to its proactive nature, OLSR requires periodic transmission of control messages, including Hello and Topology Control (TC) messages. Hello messages are used to identify neighboring nodes within communication range and maintain and update neighbor tables. TC messages are periodically sent to maintain the network's overall topology information. The main concept of OLSR is the use of Multi-Point Relays (MPRs), as depicted in Figure 2. When a node needs to broadcast TC messages, it only needs to relay them through MPR nodes, rather than every node, reducing control signal overhead compared to classic flooding mechanisms. This approach also helps in reducing battery consumption for mobile hosts. One of the advantages of the OLSR protocol is its proactive nature, where nodes periodically maintain routing tables, enabling immediate use of routes when communication is required, thereby reducing communication latency. However, a significant drawback is the large amount of data that needs to be maintained, which can lead to slow reaction times in cases requiring reconstruction or during failures.

Unlike the OLSR protocol, DSDV (Destination-Sequenced Distance Vector) is a distributed routing algorithm [7]. Distributed routing algorithms do not possess complete network information, including network topology and link states. Nodes can only obtain routing information about neighboring nodes. Unlike global routing algorithms, distributed routing algorithms compute shortest path routes through iterative methods, where nodes only exchange information with their neighbors.

Distance vector routing is a typical example of a distributed routing algorithm. In this algorithm, each router maintains a distance vector table. When a node detects changes in the path cost to other nodes, it updates its routing table and broadcasts this information to neighboring nodes. The control signal overhead of distance vector algorithms is relatively low since they only need to send control messages between neighboring nodes, making them easier to implement and maintain. However, due to their iterative nature, these algorithms have slower convergence speeds and are prone to forming routing loops.

Building upon distance vector routing, DSDV introduces sequence numbers to differentiate between new and old routes. During updates, DSDV selects route information with a higher sequence number to update its routing table, thereby avoiding routing loops. Each node must periodically update its routing table, which includes all reachable destination nodes, the path metrics to these nodes, and the sequence numbers assigned to destination nodes. Even if the network topology remains unchanged, nodes need to maintain routing entries that do not require updates to keep the distance vector simple.

DSDV uses sequence numbers to update routing information, ensuring no loops and reducing additional traffic consumption through incremental updates. However, regular updates can lead to significant communication overhead, making it unsuitable for large-scale networks.

2.1.2. Reactive Routing

Reactive routing protocols, also known as on-demand routing protocols, as the name suggests, only seek a route to the destination node from the source node when communication is required. Nodes do not possess information about the entire network and do not need to broadcast control signals, resulting in lower communication overhead. However, because the routing process begins only when data transmission is needed, this leads to increased latency and may hinder real-time communication. Prominent examples of reactive routing protocols include AODV and DSR.

AODV (Ad Hoc On-Demand Distance Vector) is a distributed routing algorithm where nodes periodically send Hello messages to detect neighboring nodes. Unlike DSDV, in the AODV protocol, when a source node has a communication need, it initiates a route discovery process. The source node broadcasts a RREQ message to neighboring nodes. If a node receives a valid RREQ message, it unicasts a RREP message back to the source node, establishing a path to the destination for data packet transmission. If the RREQ is invalid or incomplete, the node will rebroadcast the RREQ message. AODV also utilizes Route ERR or (RERR) messages to indicate routing errors. Upon detecting a failure, each node sequentially sends RERR messages to its predecessors to delete all routes using the failed link.

To avoid rapid changes in the network topology that may prevent route replies from reaching the source node, a study proposed Energy-Aware Q-learning AODV Routing (EAQ-AODV). EAQ-AODV utilizes a Q-learning-based reward mechanism for cluster head selection and establishes routing paths based on various parameters such as residual energy, shared channels, hop count, licensed channels, communication range, and trust factor, using the AODV-enabled routing protocol [8].

2.1.3. Hybrid Routing

Hybrid routing protocols initially proactively predict routes to establish initial routing and then fulfill additional node demands through reactive flooding in an on-demand routing manner. Hybrid routing combines the advantages of proactive and reactive routing, resulting in lower communication latency and reduced network control overhead. In hybrid routing protocols, the network is divided into regions, with different routing protocols used for different areas. Typically, intra-zone routing uses proactive routing protocols, while inter-zone routing employs reactive routing protocols.

The Zone Routing Protocol (ZRP) is a typical hybrid routing protocol that integrates proactive link-state routing and reactive routing [9]. In ZRP, each node sets up a zone defined by a pre-defined range. The proactive link-state routing protocol manages routes within the radius (zone), and when information needs to be sent outside the zone, the reactive routing protocol requests routes to destinations outside the area. ZRP refers to the local proactive routing component as the Intra-zone Routing Protocol (IARP) and the global reactive routing component as the Inter-zone Routing Protocol (IERP). Both IARP and IERP are sets of routing protocols rather than specific protocols.

IARP consists of a series of proactive link-state routing protocols used to maintain routing information for nodes within the zone. Similarly, IERP, built on IARP, enhances route discovery and maintenance functionalities. The advantages of this protocol include accelerated route discovery by reducing retransmissions, thereby reducing signaling overhead. However, the protocol's limitations arise from its behavior as a proactive protocol for larger routing areas and a reactive protocol for smaller routing areas, often resulting in overlapping regions.

2.2. Location-Based Routing Protocols

Location-based routing protocols are a relatively novel type of routing protocol that aids in routing decisions by leveraging the geographical location information of nodes within the network. Greedy Perimeter Stateless Routing (GPSR) is a typical location-based routing protocol [10]. Each node in the network can obtain its own location information through a positioning system and continuously interact with neighbors to obtain the location of the target node. The protocol forwards data packets to the neighbor closest to the target node within the communication range. If a node cannot obtain the location of the target node, it forwards the packet to the neighbor closest to its communication boundary. GPSR does not require the maintenance of routing tables and exhibits good scalability and routing overhead performance. However, it tends to perform poorly in networks with rapidly changing topologies and sparsely distributed nodes, often resulting in routing voids.

Rodrigues et al. [11] addressed the high mobility of unmanned aerial vehicle (UAV) nodes by predicting node locations to calculate contact duration between nodes. They measured uncertainty values by assessing the progress of a node's flight plan using neighbors, integrating these factors to improve GPSR. Experimental results showed reduced transmission latency and overhead, along with improved packet delivery rates.

Another improvement on GPSR is the Utility Function-based Greedy Perimeter Stateless Routing (UF-GPSR), proposed by literature. This protocol optimizes the greedy forwarding strategy by considering critical parameters of multiple nodes, such as remaining energy ratio, distance degree, movement direction, link risk level, and speed, using a utility function. UF-GPSR selects the best next-hop within communication range to enhance routing performance [12].

Usman et al. [13] introduced an Adaptive Reliable Link-based Location Routing Protocol for flying ad-hoc networks. This protocol establishes a forwarding zone toward the target node's direction within the communication range. Nodes within this zone select the next-hop node based on proximity to the target node, higher energy levels, stronger signal strength, and lower relative speed. This approach improves network connectivity and performance, extending network lifetime, reducing control message overhead for route discovery between source and destination nodes, and lowering network overhead.

Liu et al. [14] proposed a multi-objective optimization routing protocol for UAV ad-hoc networks based on Q-Learning. This protocol estimates the coefficient of neighbor relationships between nodes by predicting the next position of nodes and incorporates link quality between nodes as parameters in Q-Learning. By adaptively adjusting the parameters of Q-Learning to accommodate network dynamics, the protocol selects the optimal next-hop node, ensuring low-latency and low-energy consumption services.

Gharib et al. [15].introduced an optimized predictive adaptive routing protocol that calculates the link survival time between UAV nodes based on their position information and incorporates routing hop counts in route decision-making. Experimental results demonstrated reduced control overhead and latency, improved throughput, and packet delivery rate, maximizing network performance.

Sang et al. [16] proposed an opportunistic routing protocol based on trajectory prediction. This protocol predicts the next speed and position of UAV nodes using a Gaussian mixture model and calculates node trajectory metrics to avoid boundary effects and routing voids. By integrating node trajectory metrics, node energy, and node buffer size into route decision-making, the protocol selects the next-hop node. Experimental results showed excellent performance in packet delivery rate, hop count, latency, and overhead, making it suitable for dynamic network topologies in UAV ad-hoc networks.

Hussen et al. [17] presented a geographic multicast routing protocol for flying ad-hoc networks. When nodes need to send information to multiple destination nodes, they predict neighbor positions to obtain pairwise distances between neighbors and each target node, extracting the minimum value. If this value is less than the node's transmission radius, the node forwards the route through the neighbor. If the node cannot find a neighbor closer to the target node than itself, it performs boundary forwarding until finding a closer neighbor. Experimental results demonstrated reduced routing overhead.

Li et al. [18] proposed a mobile-aware gradient routing protocol where nodes define routing costs based on changes in distance from the source node, measuring the cost of gradient forwarding. When the distance decreases, the routing cost should be a small value, mitigating the impact of high UAV node mobility. Messages relay through a decreasing cost gradient from the source to the target node, rather than preselecting a fixed next-hop node. This routing protocol outperforms other unicast routing protocols in terms of average end-to-end delay, packet delivery rate, throughput, and routing overhead.

Location-based routing protocols do not require consideration of global link status in the network, enabling distributed, stateless route forwarding. They are more suitable for networks with frequently changing topologies but depend on the accuracy of the positioning system.

2.3. Cluster Routing Protocols

The advantages of hierarchical structures, known for their excellent scalability, are particularly suitable for large-scale, highly dynamic mobile ad-hoc networks. In a hierarchical network architecture, clustering is commonly employed to select cluster heads that collect information from all members within the cluster and facilitate inter-cluster communication, thereby reducing routing overhead and minimizing data transmission latency.

2.3.1. Cluster Based Routing Protocol (CBRP) [19]

CBRP is one of the early ad hoc clustering routing protocols proposed by the IETF for mobile ad hoc networks. It represents one of the earliest ad hoc clustering routing protocols. CBRP divides all nodes in the network into several clusters, and the selected cluster head nodes are responsible for intra-cluster and inter-cluster information transmission. Because this protocol only requires information exchange through cluster head nodes, the network transmission control overhead is significantly lower than traditional flooding-based routing strategies.

The protocol employs the Minimum ID Clustering Algorithm for cluster formation. Nodes in the network periodically broadcast HELLO messages to neighboring nodes, continuously updating the network topology. When a source node has a data transmission request, it first checks locally for an existing route to the destination node. If a route exists, data transmission occurs; otherwise, the source node broadcasts a Route Request (RREQ) message to initiate a new route discovery process.

Cluster head or gateway nodes forward received RREQ messages. Upon receiving RREQ messages, member nodes determine if the destination node is reachable within one hop; if so, they forward it to the destination node; otherwise, they discard the message.

Compared to other routing algorithms, the CBRP protocol has several advantages, including fewer participating nodes in route discovery, reduced network congestion for packet routing, lower overhead for routing control packets, and shorter path-seeking latency. In the CBRP protocol, the distributed nodes are organized into several clusters, which can be intersecting or separate, with each cluster controlled and supervised by a cluster head node. These cluster heads use "gateway nodes" to discover adjacent clusters and establish routing communication through relaying with neighboring cluster members.

Each node in the network periodically broadcasts Hello Messages for neighbor discovery. Through the interaction of Hello Messages, nodes gather information about nearby active nodes within one or two hops, thereby obtaining local topology information. This information serves as the basis for route discovery, forming a form of proactive routing.

2.3.2. Partition-based hierarchical link-state routing protocol (ZHLS)

The Zone-Based Hierarchical Link State Routing (ZHLS) protocol enhances network robustness by employing a hierarchical approach to route selection based on partitioned routing messages within zones [20]. ZHLS maintains two types of routing messages: intra-zone messages containing routing information for all nodes within a zone and only disseminated within the zone, and inter-zone messages containing inter-zone connectivity information propagated throughout the network. When there are changes in intra-zone network topology, the impact is limited to the zone; however, changes in inter-zone connectivity are disseminated using inter-zone messages, ensuring greater stability of inter-zone connections.

ZHLS adopts a two-tier topology structure comprising node-level and zone-level. When two zones are physically connected by one or more links, a virtual link is established to represent the inter-zone topology. Node-level topology information is locally disseminated, while zone-level topology information is propagated across the entire network, enabling each node to construct both intra-zone and inter-zone routing tables accordingly.

3. CONCLUSION

With the development of wireless network technology, the development of Mobile Ad Hoc Network (MANET) related technology has been favored by many researchers. However, the existing research results are not mature enough for the mobility characteristics of the nodes in Mobile Ad Hoc Networks (MANETs). Especially, the development of routing technology is one of the hot research topics of Mobile Ad Hoc Network (MANET). Due to the highly dynamic network characteristics of MANET, especially the routing protocols bring great challenges, therefore, the paper reviews and analyzes the existing routing protocols for MANET and summarizes the classification and research recent status of the routing protocols for MANET, so as to push forward the development of China's Mobile Ad Hoc Network (MANET).

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