# A Comparative Performance Evaluation of Routing Protocols for Mobile Ad-hoc Networks

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***Abstract*—Mobile Ad Hoc Network (MANET) is a group of wireless mobile nodes that can connect with each other over a number of hops without the need for centralized management or pre-existing infrastructure. MANET has been used in several commercial areas such as intelligent shipping systems, ad hoc gaming, and clever agriculture, and non-commercial areas such as army applications, disaster rescue, and wildlife observing domains. One of the main challenges in MANET is routing mobility management which affects the performance of MANET seriously. The routing protocols have been functionally classified into proactive routing protocols, reactive routing protocols, and hybrid routing protocols. The objective of this paper is to create observations about the advantages and disadvantages of these protocols. Thus, the aim of this paper is to conduct a comparative analysis of the three groups of MANET routing protocols by comparing their features and methods in terms of routing overhead, scalability, delay, and other factors. It was shown that the proactive protocols guarantee the availability of the routes. However, it suffers from scalability and overhead. Whereas, reactive protocols initiate route discovery only when data needs to be sent. However, reactive protocols introduce an undesirable delay due to route establishment, which affects the network performance. Hybrid protocols, attempt to utilize the beneficial features of both reactive and proactive protocols, hybrid protocols are suitable for large networks and keep up-to-date information, but they increase operational complexity. It was concluded that MANET needs enhancement with regard to routing in order to meet the required performance.**

***Keywords*—MANET; routing protocols; proactive protocols; reactive protocols; hybrid protocols; Ad Hoc Networks**

## I. Introduction

The routing process in MANET is responsible for discovering, establishing, and maintaining a route between two mobile nodes. Routing of packets can be performed using either a single-hop or a multi-hop paradigm [1]. In the single-hop paradigm, the destination node is assumed to be inside the communication range of the source node. Thus, the source node can connect with its destination directly. Within the multi-hop model, the source node can interact with its destination via intermediate nodes while the destination is outside the source node's communication range. MANET is regarded as a multi-hop network where mobile nodes in the network collaboratively help in forwarding the data or control packets between the source node and its destination. The mobile nodes are involved in the discovery of routes, and once found, the intermediate mobile nodes on the routes would have key roles in maintaining the routes. There are some difficulties in establishing a route between source and destination nodes through intermediate nodes including low bandwidth, limited coverage and connectivity due to limited transmission range, higher error rate, high possibility of interference, power consumption, no centralized mechanism for routing, and frequent network topology changes due to mobility. Mobility makes routing a more complex task in MANET. Routing protocols should be capable of managing routing in MANET efficiently; therefore, it is important to investigate the advantages and disadvantages of the different protocols for MANET to identify the performance evaluation of each routing protocol as the applications of MANET are strongly dependent upon the underlying routing protocol which must be reliable and robust to accommodate frequent disruptions in the communication between mobile node pairs due to node mobility, interference, and lack of infrastructure. These routing protocols can be categorized functionally and structurally based on their routing processes and structures; therefore, the main goal of this work is to perform a comparison between the routing protocol categories with respect to the common parametric evaluation metrics.

The remainder of this paper is structured as follows: Section II describes the general issues and challenges in MANET, routing structure and protocols in MANET are covered in Section III, and Section IV briefly describes the functional classification of routing protocols which includes table-driven, on-demand, and hybrid routing protocols. The structural classification of routing protocols is covered in Section V. The routing protocols are discussed in Section VI with their limitations. The discussion and studies are presented in Section VII. Finally, the conclusion and future works are discussed in Section VIII.

## II. General Issues and Challenges in MANET

Routing and mobility management are the two key issues with MANET. Routing becomes more challenging due to mobility in MANET, which generally consists of a group of decentralized mobile nodes, that move randomly and frequently causing topology changes [2], [3], [4]. The following are the subsections that summarize the major challenges and issues in MANET.

### A. Routing Traffic

Every node in MANET works as a source, a destination, or a router to send data to other nodes. Therefore, mobile nodes are equipped with a discovery function for their environment where a node can forward a message directly to nodes within range or to other unreachable nodes through the intermediate node(s) [5]. The main mechanism used to raise the whole network capacity and performance is multi-hopping. Thus, a node can send data to a specific destination on behalf of another node [6]. This means that even if a source is outside of the destination's radio range, the destination can still receive data from it. Packets travel through numerous wireless nodes to reach their destination. According to Minhas et al. [7], the multi-hopping mechanism helps in conserving energy resource conservation, interference reduction, and increasing the network throughput.

The network can stay operational by constructing new routes by flooding to deliver the data using a multi-hopping mechanism. In the flooding procedure, control packets are moving infinitely in the entire network. As a result, the flooding procedure consumes too much energy from the network resources when it is used for data transmission. Thus, controlling flooding is one of the major challenges to such networks.

### B. Nodes Mobility Management

In normal conditions, any two neighboring nodes can exchange data between them (see Fig. 1). Nevertheless, their connection will vanish if any of them leaves the transmission range of the other. Thus, in MANET with high mobility nodes, the probability of a link breaking between any two network neighbors is considerable. This is another significant obstacle to such networks. Due to MANET's dynamic nature, the network topology frequently changes, which therefore results in frequent connection failures [8], [9], [10]. The network must create new routes, just as in the case of broken links, to assure data transmission [11], [12]. A dynamic routing system is required to maintain routes between a source and its destination because of the frequent topology changes.

Therefore, the reliability and success of MANET depend on the effectiveness of the routing protocol and the attribute and usefulness of the collected data [13].

### C. Scalability and No Fixed Boundaries

MANET is subject to several challenges such as scalability and no fixed boundaries [14]. MANET is naturally dynamic where mobile nodes arrive and exit arbitrarily without control from a base station (BS) or other central points. Furthermore, as nodes in MANET join and leave arbitrarily, the number of nodes and the size of the network can grow erratically which introduces a heavy burden on the routing mechanism. Consequently, scalability becomes a major issue in MANET [15].

### D. Node Density

The density of nodes in regions such as a national or urban park, where high density is presented, compared to highways where the density is varied from high to low depending on rush hour times, should be considered [16] Modeling the mobile nodes and communication links is one of the problems in MANET. Such modeling can provide valuable information regarding the pattern or behaviors of the wireless transmission under different situations as wireless transmissions in a MANET functioning on a flat open environment can be different from such transmissions in an ad hoc network of nodes placed on a building [17].

The scatter or the distribution of nodes in a geographical area affects the efficiency of routing, especially when there are a lot of middle nodes between the source and the destination. In Fig. 2, where S and D denote the source node and the destination node correspondingly, the light gray area shows the potential flooding and the dark area shows the potential intermediate nodes involved in routing.

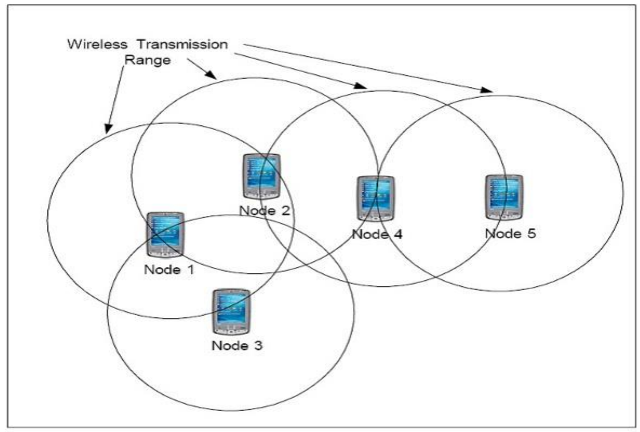


Fig. 1. Communications between adjacent mobile nodes.

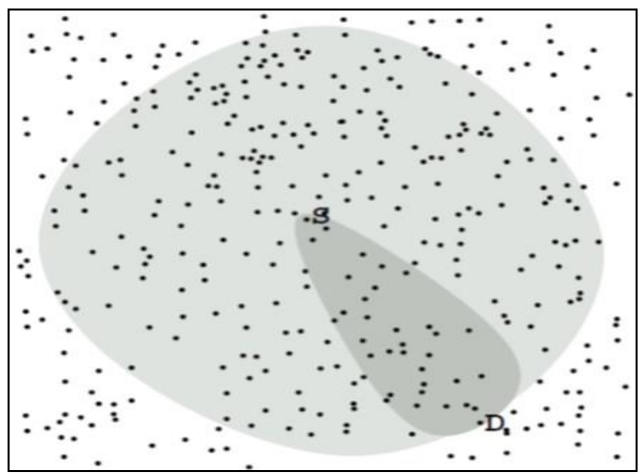


Fig. 2. Big number of nodes between the source and destination.

### E. Security Concerns

Besides the technical problems mentioned above, In MANET, where trust relationships must be established, security is a significant problem [18], [19]. It is crucial to note that using several hops can cause a problem because it enables unauthorized individuals to intercept data illegally. In addition, there is intentional electronic interference or unintentional interference occurring while many nodes share the same air interface domain. The major challenges and issues in MANET are shortened in Table I.

TABLE I. MAJOR CHALLENGES AND ISSUES IN MANET

| Issue | Description |
|---|---|
| Routing Traffic | The flooding procedure used in the discovery of new routes consumes too much energy from the network resources |
| Nodes Mobility Management | Nodes mobility causes frequent link breakages |
| Scalability and No Fixed Boundaries | As nodes in MANET join and leave arbitrarily, the size of the network can grow erratically which introduces a heavy burden on the routing mechanism |
| Node Density | The scatter or the distribution of nodes in a geographical area affects the efficiency of routing |
| Security Concerns | The use of multiple hops can be problematic since it makes it easier for an unauthorized person to intercept data. |

## III. ROUTING STRUCTURE AND PROTOCOLS IN MANET

The routing process in MANET is responsible for discovering, establishing, and maintaining a route between two mobile nodes. Routing of packets can be performed using either a single-hop or a multi-hop paradigm. In a single-hop paradigm, the destination node is assumed to be within the communication range of the source node. Thus, the source can communicate with its destination directly. Within the multi-hop paradigm, the source node can communicate with its destination through intermediate nodes as the destination is out of the communication range of the source node [20]. MANET is considered a multi-hop network where mobile nodes in the network collaboratively help in forwarding the data or control packets between the source node and its destination. The mobile nodes are involved in the discovery of routes, and once found, the intermediate mobile nodes on the routes would have key roles in maintaining the routes. Therefore, routing protocols should be capable of managing routing in MANET efficiently. There are some difficulties in establishing a route between source and destination nodes through intermediate nodes including low bandwidth, limited coverage and connectivity due to limited transmission range, higher error rate, high possibility of interference, power consumption, no centralized mechanism for routing, and frequent network topology changes due to mobility.

A lot of protocols have been developed for routing in MANET. These routing protocols can be classified functionally and structurally according to their routing processes and structures.

## IV. FUNCTIONAL CLASSIFICATION OF ROUTING PROTOCOLS

According to the methods that are used in discovering and maintaining routes, routing protocols in MANET are categorized into three groups; table-driven (proactive) routing protocols, on-demand (reactive) routing protocols, and hybrid routing protocols [4], [14], [21], [22].

### *A. Table Driven Routing Protocols*

Tables-driven protocols also called proactive protocols are developed depending on link state and distance vector routing techniques that are traditionally used on the Internet. The main characteristic of this type of protocol is that they are proactive in the sense that every mobile node maintains an updated routing table to any other node in the network. Therefore, each node should periodically communicate routing information with other nodes in order to maintain its routing table up-to-date on whether the routes are used or not [23], [24]. The frequency of updating the routing tables is crucial. Even though it can reflect the state of the network accurately, and the routing process would be robust to the dynamic changes in the network; however, the bandwidth usage for exchanging routing information will be high. This would leave not much bandwidth for delivering data packets, which affects throughput at the destination nodes considerably. Furthermore, it causes Broadcast Storm Problems (BSP) [25], [26], as the network will be flooded with routing information updates. Hence, the bandwidth for sending data packets will be reduced significantly; especially, in MANET with high node density. On the other hand, as table-driven protocols ensure that routes to destinations are always available, this would reduce the delay in sending data packets once required. In reaction to network topology changes, each proactive protocol reacts differently according to its routing structure, the size of the routing table, and the frequency of routing information updates.

### *B. On-demand Routing Protocols*

On-demand routing protocols also called reactive routing protocols were developed to improve scalability and overhead problems presented by table-driven routing protocols. The aim is to save bandwidth by reducing the number of control messages sent across the network. Therefore, a route to a destination is only looked up when the higher protocol levels demand it, compared with the periodic search for routes and updating them as with proactive protocols. Subsequently, the routing overhead is decreased significantly, which makes it more suitable for mobile network environments [15]. There are two main processes in reactive routing; which are route detection and route maintenance. When a Source node (S) needs to forward data, it first searches its routing table to examine whether it has a route to the desired Destination (D). If there is no route found, a route detection procedure is generated in order to discover a route to the destination. In route detection, the source node floods the network by broadcasting Route Request (RREQ) packets as shown in Fig. 3 [27]. When the destination or an intermediate node that has an active path to the destination receives the RREQ packet, it broadcasts or unicasts a Route Reply (RREP) back to the source node.

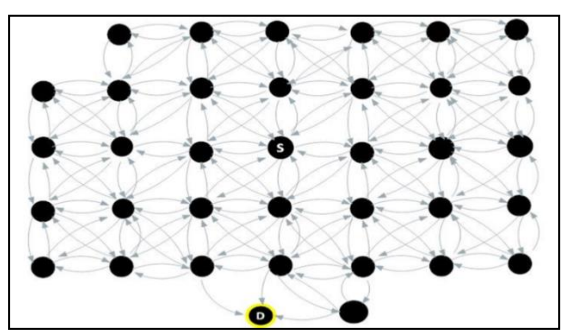


Fig. 3. Route detection in conventional on-demand routing protocol.

The route maintenance process starts when the route that is used currently to transport data is disconnected. The node that detects the route failure may repair the route using its local repair process, or otherwise, forward a Route Error (RERR) packet to the source node which will initiate a new route discovery attempt. The main difference between proactive and reactive routing methods in MANET is revealed in Table II [28].

TABLE II. DIFFERENCE BETWEEN PROACTIVE AND REACTIVE ROUTING METHODS IN MANET

| Parameter | Table Driven | On-Demand |
|---|---|---|
| Route availability | Constantly available | Calculated when needed |
| Periodic updates | Always required | Not required |
| Handling mobility | Updates happen at regular intervals | Use localized route discovery |
| Control traffic generated | Usually higher than on-demand | Growths with mobility of active routes |
| Storage requirements | Higher than on-demand | Depends on the number of routes maintained or needed |
| Scalability | Typically, up to 100 nodes | Frequently higher than table-driven |

Reactive routing protocols can be classified into two classes; which are hop-by-hop and source-based routing protocols. Source-based routing methods convey the whole path to the destination, while, hop-by-hop routing protocols hold only the destination and next hop addresses in their data packets header.

### C. Hybrid Routing Protocols

Hybrid routing is a combination of distance-vector routing and link-state routing. Thus, hybrid routing protocols share the properties and useful features of both reactive and proactive protocols. These protocols are developed to increase the scalability and improve routing in MANET by determining the optimal routes to a destination and reporting network topology when there is a change only [29]. In cases where connectivity to nearby nodes should be maintained, reactive routing is used, while proactive routing can be used if routes to remote nodes are required. This minimizes the periodic propagation of routing information and may provide accurate and reliable routes for transmitting data packets to their intended destination. Moreover, these protocols are able to reduce the number of rebroadcasting nodes in the network using different hierarchical strategies [30]. These strategies enable the nodes to organize themselves to provide effective routing where only selected nodes are used to perform route discovery. Nevertheless, the disadvantage of these protocols is that their efficiency depends on the number of nodes activated in the network. In addition, the gradient of traffic volume plays an important role in reacting to traffic demand. Compared to reactive or proactive protocols, hybrid routing protocols are naturally more complex and require a high computation level to investigate their performance in large MANET.

## V. STRUCTURAL CLASSIFICATION OF ROUTING PROTOCOLS

Based on their routing structures, routing protocols in MANET can be classified into three categories; flat, hierarchical, and geographic position routing protocols [31]. Every protocol in these categories performs routing whether proactively or reactively or both. For example, flat routing protocols can be reactive such as AODV and DSR, or proactive such as DSDV and OLSR. In hierarchical routing protocols such as ZRP, nodes are grouped into zones (cluster-based) or trees that would help in limiting the flooding area during the route discovery process. In hierarchical routing, the group leader is responsible for routing management within its group which can reduce the global exchange of routing information (overhead) and the size of routing tables [32]. In addition, hierarchical routing protocols scale better than flat routing protocols in large MANET. Nonetheless, these protocols cause high overhead in highly dynamic MANET due to the frequent reconstruction of zones and cluster head election [33]. Geographic position routing protocols such as ZHLS require that each mobile node must be equipped with GPS in order to acquire their location information when needed. In geographic position routing protocols, data are sent to all mobile nodes in a particular region using geographical information and routing. Hence, the propagation of routing information to the whole network is obviated. The use of geographical information makes those protocols adjust themselves to topology changes quickly. However, high overhead is introduced due to the mapping of address to location procedure.

## VI. LITERATURE REVIEW

This section discussed the previously mentioned routing methods along with their limitations in terms of the route discovery process.

Some of the table-driven routing protocols, like Optimized Link State Routing (OLSR) [34], [35], Mobility based OLSR (Mob-OLSR) [36], [37], and Fisheye State Routing (FSR) [38], [39], are developed based on link-state routing algorithm where nodes maintain link-state cost to their neighbouring nodes [40] Other routing protocols in this category, such as Destination Sequenced Distance Vector (DSDV) [41] and Wireless Routing Protocol (WRP) [42] developed based on distance vector routing were the shortest paths to a destination are checked and maintained periodically by every node.

DSDV routing protocol [41], which is a table-driven routing mechanism based on the Bellman-Ford algorithm [43], was developed to overcome the routing loop problems based on the sequence number of each route stored in the routing table that is announced by the destination. Hence, the data packets are routed through the route with the most recent sequence number. DSDV requires a consistent update of the routing tables [44] which utilizes some of the bandwidth even when the network is not used, which leads to fast depletion of battery power. DSDV is not appropriate for a very dynamic or large-scale MANET [45] as it needs a new sequence number whenever the network topology changes.

Similar to DSDV, WRP [42] was developed to diminish route loops and confirm reliable message exchange based on the Bellman-Ford algorithm. WRP preserves an up-to-date view of the network by using a set of tables. Maintaining multiple tables requires a significant amount of memory and greater processing power. As WRP uses hello messages to ensure connectivity with neighbours, in highly dynamic MANET, the control overhead involved in updating tables is high and more bandwidth and energy are consumed. Therefore, WRP is not suitable for large MANET since it suffers from limited scalability issues.

FSR [38], [39] is a link state-based routing protocol that controls the overhead by sending out information about mobile nodes that are within its range only. In FSR, a node maintains the link state for every destination in the network by periodically broadcasting update messages to its neighboring nodes. In addition, route updates related to closer nodes are propagated more frequently. FSR provides good packet delivery when mobility in a MANET is low. However, in highly dynamic MANET where the network topology changes repeatedly, FSR presents inaccurate routing information to the destination which makes it not suitable for large MANET.

OLSR [35], [46] is a proactive link-state routing protocol, which discovers and propagates information using Topology Control (TC) and hello messages. OLSR is a shortest-path first-based algorithm. OSPF (Optimize Shortest Path First) floods the topology data using a reliable algorithm that is not suitable for MANET nature. Accordingly, OLSR is considered an unreliable protocol for a highly dynamic MANET. Also, it does not sense the quality of the route; it just assumes that the route is active if some of the hello packets have been received properly. Furthermore, OLSR uses many network resources i.e., bandwidth and energy that are limited in MANET. It is the same for the enhanced version of OLSR where a new technique for node mobility measurement was proposed by [36].

The common on-demand routing protocols in practice are Dynamic Source Routing (DSR) [47], [48]. Ad-hoc On-Demand Distance Vector (AODV) [49], [50], Dynamic MANET On-demand (DYMO) [51], [52], Location-Aided Routing (LAR) [53], and Temporally-ordered routing algorithm (TORA) [54].

DSR [47] is an on-demand reactive routing protocol that uses source routing rather than depending on the routing table information at each intermediate node. DSR has two main mechanisms; which are route discovery and route maintenance. Route discovery is initiated when a node requests a route to a specific destination. Route maintenance is triggered when a link between two nodes that are involved in the active route breaks down. DSR, like other on-demand routing protocols, floods the network with RREQ packets during the route discovery process. In determining the route to a destination, the addresses of the intermediate nodes between the source and destination are accumulated during the route discovery process where each node caches the route information. The learned route is used to transmit data packets that contain the address of each node along the path to the destination. DSR controls the bandwidth consumed by control packets, eliminating the periodic update messages required in proactive routing. Load balancing is achieved by using multiple routes which can increase robustness as well DSR is beacon-less. Moreover, although DSR performs well in networks with low mobility, its performance degrades significantly in highly dynamic networks [55], [56], [57]. Furthermore, its route maintenance strategy does not locally repair a broken route. If routes in the cache are stale, it can cause incompatibility when the route is reconstructed. Also, the delay in establishing a connection is higher compared to that of table-driven protocols.

AODV [48], [58] is a hop-by-hop reactive routing protocol that broadcasts discovery packets only when needed. AODV applies destination sequence numbers to find the latest route to the destination, which also helps in avoiding the infinite loops problem. In addition to that, the delay of the connection establishment in AODV is lower. Overheads and contention are reduced since AODV maintains only active routes. However, having an old source sequence number in the intermediate nodes can lead to unreliable routes. Also, heavy control overhead can be caused by multiple RREP packets in response to a single RREQ and due to the use of periodic “HELLO” packets route maintenance. Furthermore, AODV uses periodic beaconing to keep routing tables updated, which results in unnecessary bandwidth consumption. Moreover, AODV shows better performance in terms of throughput and delay in small-size MANET with no node mobility; and in dense networks with minimum mobility [59]. However, the quality of its performance decreases as the node mobility increases. The mobility-aware approach was added to AODV [60] to improve the management of high mobility in MANET by avoiding the frequent link breakages associated with using unstable paths that contain high mobile nodes. This added feature has shown some enhancement compared to AODV [61].

DYMO (also known as AODVv2) [51] is designed for dynamic environments such as MANET where network topology changes frequently. DYMO shares many benefits of the operational structure of DSR and AODV. DYMO outperforms AODV and DSR protocols as it uses accumulative routing which reduces RREQs noticeably [62]. DYMO was improved by considering the energy and traffic parameters of the network and showed better performance compared to the original DYMO and AODV routing protocols [63].

LAR [53] is an on-demand routing protocol that uses geographical location information to limit the propagation of RREQ packets to a certain number of nodes rather than flooding the network, which in turn reduces the routing overhead considerably. The location of nodes is detected using Global Positioning System (GPS) information and defined in an area that is called a “Request Zone”. Only nodes in this zone are required to forward RREQ packets. This can help in avoiding the broadcast storm [20]. However, connection and tracking problems may appear with the use of LAR. It is because when a source node has to find a route to a destination, it should first get the coordinates of the destination from an external location service. LAR has been enhanced further to improve the link ability during routing [64], and to control the overhead found in LAR [65].

TORA [54] is an adaptive routing protocol designed to restrict the propagation of control messages in the highly dynamic context of mobile computing. In TORA, each node has to explicitly start a query when it needs to forward data to a specific destination. TORA tries to figure out what is known as a Directed Acyclic Graph (DAG) which is rooted at the destination. Even though TORA performs well in dense networks, it does not scale by any means. Several evaluation studies showed that DSR and AODV outperform TORA [66], [67]. It was enhanced to provide better packet delivery, and acceptable routing overhead and packet latency [66].

Location Update Routing Protocol (SLURP) [68], Zone Routing Protocol (ZRP) [40],[69] and Zone-based Hierarchical Link State (ZHL) [70],[71] routing protocols are among the common hybrid routing protocols served the base for the development of several protocols proposed later.

SLURP [68] uses GPS instead of a cluster head to manage the node location and coordinate the transmission of data packets. It utilizes the identification (ID) of the node and zone ID of the destination to perform routing. Therefore, SLURP shares the same advantages mentioned above. Moreover, it limits the need for flooding as the nodes within the zone maintain location information with each other. Thus, nodes know how to find an efficient route to destinations when required. SLURP limits the overhead of maintaining routing information further. This is achieved by restricting route discovery to the home region or specific zone assigned to each node in the network. The home region is determined by a static mapping function that is known to all nodes in the network. The drawback of SLURP is that it depends on a predefined static zone map.

ZRP [40], [69] was developed to speed up data delivery and reduce processing overhead. In ZRP, mobile nodes are clustered into zones where communications among nodes are performed according to their locations in the zone. ZRP maintains robust network connectivity within the routing zones using the reactive routing technique. Also, it reactively discovers remote routes faster. Nonetheless, ZRP behaves as a proactive protocol if the routing zone is too large. On the other hand, if the routing zone is too small, ZRP performs as a reactive protocol. Thus, it is important to set the value of the zone radius according to the density of nodes in the network.

In ZHLS [70], the nodes are divided into non-overlapping zones where each node is associated with two identifiers which are a node ID and a zone ID that is calculated using GPS. Traffic bottleneck is avoided in ZHLS as it does not require a cluster head to coordinate data transmission Therefore, there is no processing overhead necessary for electing the cluster and restructuring the zone in case of a single point of failure. Hence, the communication overhead is reduced significantly, compared to the flooding method in reactive protocols. Furthermore, ZHLS can adapt to the changes in network topology faster as it only requires the node ID and the zone ID of the destination when routing data packets. However, in ZHLS, for a node to function, it should have a static zone map, which is not practicable in networks like MANET where the geographical boundary is dynamic.

## VII. Discussion and Studies

This section discusses the advantages and disadvantages of the routing methods mentioned earlier and presents a comparison between different types of MANET routing protocols in terms of the common parametric evaluation metrics.

Proactive routing protocols have been evaluated theoretically and through simulation [23],[36],[44],[72], [73],[74],[75] and it was found that the main advantage of the proactive routing protocol is to ensure the availability of routes whenever needed with a minimum delay of data delivery, as every node should maintain routing information to every node in the network. The main disadvantages of this type of routing are the continuous discovery of routes and the broadcast of routing information which introduces high overhead and consumes high energy and bandwidth. Therefore, table-driven routing protocols are not appropriate for large and highly dynamic MANET since every node is required to maintain entries in the routing table about all nodes in the network. Because of the nature of MANET, a routing protocol designed for such networks should improve the scalability and decrease the routing overhead by restraining route computations to situations when a route is needed.

The evaluation of reactive routing protocols [17], [66],[76], [77] showed that reactive routing introduces lower overhead as loop free since routes are only constructed when required, which is a privilege of this type of the protocol compared to proactive routing. The disadvantages of reactive routing are that, due to the initial route discovery process, there is a critical delay between the time a source node requests a route for data transmission and the time when the actual transmission takes place. The source node must wait until a route is found then it can start transmitting its data. Rapid changes in a MANET topology due to mobility may break active routes and cause subsequent route discoveries which can substantially impact the network's performance. Additionally, the flooding technique utilized throughout the route discovery phase can result in a broadcast storm.

The performance evaluation of hybrid routing protocols [2], [29],[71],[78],[79] showed that, in comparison with reactive protocols, hybrid protocols can reduce the average length of the routes in terms of the number of nodes and the physical length of the route as well. It was found that the overhead cost in hybrid routing is tolerable in most of the evaluation scenarios. However, even though that hybrid protocols are suitable for large networks and make available up-to-date information, they increase operational complexity.

Table III [80] presents a methodological comparison between different categories of MANET routing protocols with respect to the corresponding parametric evaluation.

TABLE III. Comparison between Routing Protocols Categories

| Parameter | Reactive Routing Protocols | Proactive Routing Protocols | Hybrid Routing Protocols |
|---|---|---|---|
| Routing Structure | Flat | Flat, Hierarchical | Flat Hierarchical, Geographic |

| | | | |
|---|---|---|---|
| Routing Method | On-demand | Table driven | Both |
| Routing Overhead | Low | High | Medium |
| Delay | High-as a result of flooding | Low as a result of routing tables | Low inside the zone; high outside the zone |
| Scalability | Inappropriate for large-size MANET | Low | Suitable for large-size MANET |
| Route Availability | Required when needed | Always available in routing tables | Both |
| Periodic Updates | Not required | Required for updating on topology changes | Required inside the zone only |
| Storage | Low-depending on the routes number | The high-routing table can be large | High inside the zone |
| Mobility Management | Route maintenance | Periodic updates | Both |

## VIII. Conclusion and Future Works

This paper discusses that data packet routing is the main concern to improve the performance of MANET where nodes move arbitrarily with no central administration. This presents a heavy burden on the routing protocol in use. In regards to a functional classification of routing protocols discovering and maintaining routes are considered, the protocols have been classified into table-driven (proactive) routing protocols, on-demand (reactive) routing protocols, and hybrid routing protocols. It was shown that in proactive protocols, nodes should maintain a routing table for forwarding packets to any other node in the network. This enforces periodic exchange of information between mobile nodes to keep their routing table up-to-date. In this type of protocol, scalability and overhead become serious issues. Whereas, reactive protocols initiate route discovery only when there is data to send. However, it was recognized that such a process introduces an undesirable delay between the request for data transmission and the actual transmission of data before route establishment, which affects the network performance. Moreover, the flooding procedure used in the route discovery process can cause broadcast storms. Hybrid protocols, however, attempt to utilize the beneficial features of both reactive and proactive protocols to tackle these problems. Nonetheless, it was concluded that while hybrid protocols are suitable for large networks and keep up-to-date information, they increase operational complexity.

In this paper, in connection with the routing methods mentioned earlier, the routing protocols are also classified based on the structure of the network into flat, hierarchical, and geographical position routing protocols, along with a discussion on their performance in terms of some common evaluation metrics. It was concluded that MANET needs enhancement with regard to routing in order to satisfy the service quality requirements of the user applications with desirable performance. The insights gathered from this study will be useful to researchers, network designers, and professionals that work in this area as they design and optimize future MANETs. Future research should include recommendations for selecting the best routing protocol for various scenarios and conduct a comparative analysis of additional routing protocols, including their advantages and disadvantages. Furthermore, future research could be the investigation on how routing protocols in MANETs can be improved using machine learning and artificial intelligence techniques.

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