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Review Article

# A Review of Multipath Routing Protocols in Mobile Ad Hoc Networks (MANETS)

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## Abstract

In the recent past, the area of Mobile Ad Hoc Networks (MANETs) and its variant Vehicular Ad Hoc Network (VANET) are increasingly finding applications in the Internet of Things (IoT). MANETs have a particular characteristic of a rapidly changing network topology. This feature has an effect on: network connectivity, radio channel utilization and energy consumption of the network. Depending on the speed at which nodes are moving, designing routing protocol for MANET can be extremely challenging. Several works in literature have been proposed to address this problem. This paper provides a survey of the recent protocols proposed for MANETs which considers Mobility, Quality of Service (QoS) and Energy conservation network aspects. In this paper, special attention is paid to the contributions on multi-path mutation-based protocols and application scenarios.

**Keywords:** MANETS; M2M; QOS; AODV; AOMDV; TORA; DSR; ABR; Multi-hop; Multipath

## Introduction

Over the last few years, the number of mobile devices, especially those with data transmission capabilities has grown rapidly (smartphones, laptops, iPads, PDAs, etc) as well as the need to connect and transmit while 'Mobile' [1]. This means that reliability of the Quality of connection and transmission has become a key concern when speaking of Quality of Service (QoS). [2] estimates that by the year 2023 above 70% of the global population will have mobile devices that are connected and Machine - to - Machine (M2M) communications will be prevalent. The number of internet users is projected to grow up to 5.3 billion by 2023 and connected home applications such as home security, home automation, video surveillance as well as tracking applications will represent 48% of the total M2M connections.

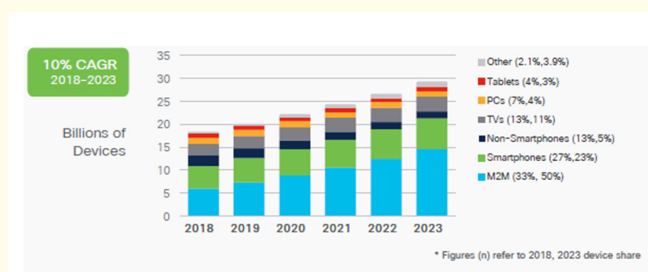


**Figure 1:** Global device and connections growth [2].

The number of mobile subscribers (for cellular service) has been growing at a rate of 2% since 2018 and is estimated to reach

5.7 billion subscribers by 2023 [2] where 71% of total global population will be penetrated. This is the reason why there have been research directions towards offloading some of the traffic from cellular networks (licensed) and also expand network coverage to places that have not been covered yet [3] via complementary access to network like Wi-Fi (unlicensed) [4].

In a Mobile Ad Hoc Network, mobile devices can join and leave the network at will and the topology keeps on changing. A Mobile Ad - Hoc Network (MANET) is an infrastructure - less set up of Mobile devices/nodes whereby there is no centralized administration of how the nodes would communicate [5]. This makes it decentralized. The network is also dynamic, in that, the nodes are continually moving and the topology of the network keeps on changing. Nodes work as both routers and hosts for the communications to remain active in the network. Each node in the network has the capability to communicate with nodes within its transmission radius ([6], hence there is always a need for the nodes to reroute packets to other nodes in order for the communication to complete from source S to destination D even when the two are not within a transmission range with each other.

Routing of packets towards the destination is executed by the mobile devices advancing packets to and from one another. Even though the source and destination nodes may be far from each other or beyond the transmission and sensing range of one another, each node can only communicate with its neighbours (those within its broadcast radius) and by this method a message packet is packet is passed from source to destination via multiple hops.

Due to the aspect of mobility and constant change in the network topology it becomes very difficult to ensure a constant path which is very important for network reliability and availability [7]. also, since this network is formed by battery - operated devices the power resources of the device become a concern [8]. This becomes a huge challenge when there is only one path that has been established to transfer data from Source S to destination D.

## Formation and working mechanism of MANETs

As the number of mobile users increases, so does the need for connectivity, and, sometimes it is in situations where the cost of installing the infrastructure may be prohibitively high or the situation itself does not allow installation, like in disaster recovery efforts. In such scenarios, for instance, a group of observers who would like to interact during the duration of a conference or a group of employees deployed for a rescue mission [9]. In such situations those mobile devices (phones) with network interfaces may be used to form a temporary network without the need of fixed infrastructure (like access point) or centralized management, which then becomes an Ad Hoc network ([10]. The nodes can transmit directly to one another or through other nodes depending on proximity [11].

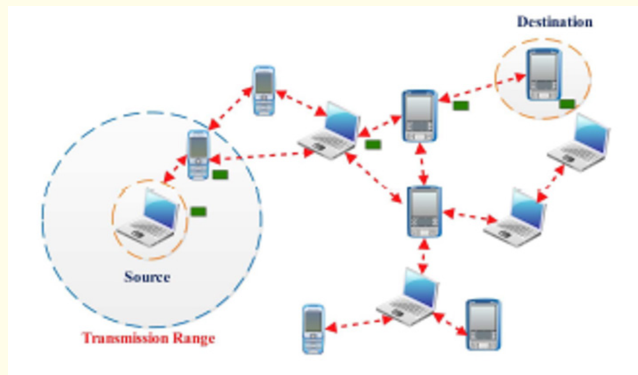


**Figure 2:** The working principle of Mobile Ad Hoc network [10].

Imagine a user would like to send a file from their mobile phone in one building in a University to a friend who is in another building 500 meters away in the same university. If there was a router or an access point connecting devices in that part of the university, things would be easy. In this case there isn't one, but in this case the assumption is that in the adjacent buildings there are devices, smartphones. What can be done is to connect the user's phone with the smartphone next building within its transmission range and the smartphone in the next building connects with the smartphone in the adjacent building, like that, until the destination is reached and the file is sent. So, the network which is created is an Ad - Hoc one and the file is sent through the connected devices rather than sending it to a central device (a router or access point) and then sending it back to the destination.

MANET can be said to be an infrastructure less network of mobile nodes that have wireless communication capabilities that are able to join anytime anyplace without any prior configuration (dynamically) [12]. This creates an independent system of mobile nodes that have no central control, making them access points or routers as well as the senders and receivers. Packets have to be forwarded from one node (hop) to another since they have limited transmission capability and through the multi hops they get to the destination.

MANETs are part of wireless networks whereby the wireless networks can be classified into two, that is, infrastructure networks and infrastructure less (Ad Hoc) networks.

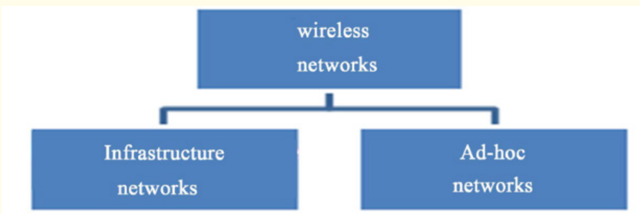


**Figure 3:** Classification of Wireless Networks [12].

In the infrastructure based wireless networks the wireless nodes communicate directly with the fixed infrastructure (Base station or access point) through electromagnetic waves, while, in infrastructure-fewer wireless networks there is no central intervention or management and functions are peer based. Some of the characteristics found in these include multi-hop routing, dynamic topologies and unconventional in link and node abilities.

## Routing in MANETs

In order to transfer packets from source to destination, routing has to take place due to the inherent nature of Mobile Ad Hoc networks of mobility and dynamic topologies. Nodes in a MANET have the ability to sense and discover a neighbouring node and one of their most important functions is to establish and maintain the network by use of routing protocols [13]. This means that the route established at the beginning of transmission may change before transmission is completed.

According to [13], "routing is the process of finding a path from a source to some arbitrary destination on the network." An important component in a routing protocol is the routing metric which now selects the best path to forward packets [11]. In order for that to take place, rules (protocol) governing the transfer have to be used since the data packet has to move through a number of nodes and their main function is to quickly respond to changes in the network topology. There are three categories of routing protocols that are normally used, namely, Proactive, Reactive and Hybrid, summarized in the figure below[14].

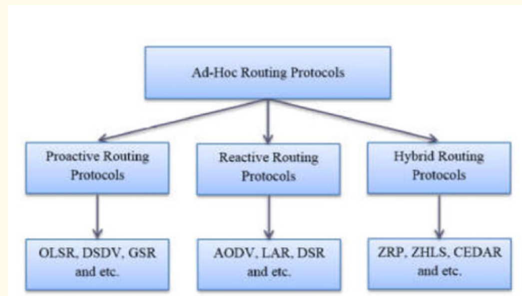


**Figure 4:** Classification of Routing Protocols [14].

In proactive protocols, the basis is on the classic Bellman-Ford Routing Algorithm (e.g. DSDV), whereby each node in the network maintains and updates a routing table with information on the routes to other nodes. Before nodes pass data packets in any route, there has to be an agreement between the two communicating nodes. So, nodes have to keep route information about the network which is up to date and updates have to be made from time to time, either when a change in topology occurs or periodically.

Reactive protocols are also referred to as on - demand routing protocols [15]. In these protocols, nodes do not need to keep routing information because a route generation mechanism will be used to create a route when a node needs to transmit data to a particular destination in the network. A node that needs to transmit sends a request to its immediate neighbour or neighbours checking if they are the destination. If not, the neighbours forward the request to their immediate neighbours and this process is repeated until the destination is reached and an acknowledgement of the route is made by the destination to the source. In these algorithms, a node will have the functions of route generation, route maintenance and route deletion. A node will also maintain a route cache to keep the routing information from source to destination once a route has been established.

In hybrid routing algorithms, attributes of both proactive and reactive routing algorithms are used. An instance is used in Zone Routing Protocol (ZRP) whereby nodes operate in zones and if a route is already in the routing table and it is valid, it will be used, meaning a reactive protocol is being used. If the route goes beyond the packet's originating zone, then a reactive protocol takes over to see if a destination is inside that zone, which reduces the overhead of checking the routing tables of nodes outside the sending node by just checking if the zones contain the destination [16]. The goal here is to improve on scalability and efficiency.

## Reactive routing protocols

Recent research has shown that reactive protocols are more dominant in performance when using Throughput, Packet delivery ratio and average end - to - end delay metrics for measuring [17]. This is because they are easier to execute and adapt in different conditions.

Reactive protocols are also divided into multipath (e.g. Ad Hoc On Demand Multipath Distance Vector (AOMDV) routing protocol) and single path (e.g. Ad Hoc On Demand Distance Vector (AODV) routing protocol and Dynamic Source Routing (DSR)) routing algorithms.

[18] proposed a multipath routing scheme based on DSR (Quality Aware Multipath DSR) whereby instead of doing a route discovery procedure when one fails, then a node can use another route from the list of discovered routes in its cache. This was in response to the problem of congestion which arises from route discovery procedures in the event a single route failed. This overhead can grow especially where there is high node mobility. This protocol uses source routing whereby the transmitting node has to determine the complete sequence of nodes through which to send a packet [19], that is, the sender lists the entire route in the packet header in order to identify all the hops in between that node and the destination node. The protocol is composed of two mechanisms - 'route discovery' and 'route maintenance' [20], whereby a route is launched by flooding the network with route requests and a response is given back to the source when a route has been discovered to the destination.

The challenge with this mechanism is that some of the routes discovered may not be disjoint and this has a problem of loops and collisions. Some of the benefits this algorithm offered include no periodic routing advertisement messages - which reduces network bandwidth overhead, and thereby, conserving battery power. This protocol performs very well in static and low mobility environments. However, the performance reduces with increasing mobility and a considerable routing overhead is involved due to source routing mechanism [21].

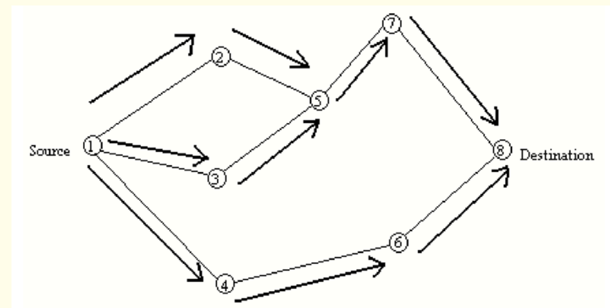


**Figure 5:** Propagation of route request [20].

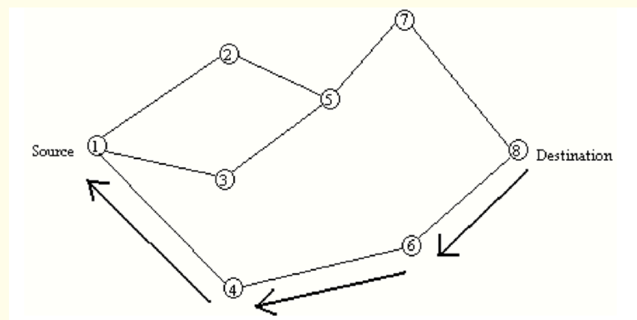


**Figure 6:** Path of route reply [20].

Ad - Hoc On-Demand Distance Vector (AODV) applies the request/wait for reply cycle to create a route from source to destination and applies the use of sequence numbers to ensure the freshness of routes [20]. This means that the route established by AODV from a destination and the sequence numbers can tell the latest route, which is most fresh and delay is reduced.

When there is a need for a route to a given destination, route search is initiated by the broadcast of a Route Request (RREQ) by the source. After receiving a RREQ, the intermediate node creates a reversed path to the source and the RREQ is forwarded only once (by each intermediate node) until the destination is reached or a node that has a recent path is attained. After that, a Route Replay (RREP) is forwarded towards the source to establish the transmission route. This is the mechanism used in AODV.

The main undoing of AODV is the aspect of intermediate nodes having higher sequence numbers than the source but not the latest destination sequence number which leads to inconsistent routes [20]. Also, the periodic beaconing to maintain a route leads to bandwidth consumption which is unnecessary. Hence, when there is frequent mobility of nodes in the network it causes transmission delay and overhead. This goes on to negatively affect the power and eventual lifetime of the network.

According to [22], Dynamic Source Routing (DSR) is a routing protocol in which, instead of memorizing the path in the intermediate nodes, it includes all the routing directives in RREQ/RREP and data messages. When a path disconnection is detected, it applies a packet recovering method to reroute packets towards the destination. Although this causes a lot of overhead, it reduces the routing operations and eliminates the need to memorize the routing decisions. This aspect of knowing the integrity of the path is a significant advantage especially for security insurance purposes. Which is why numerous security-oriented routing algorithms are based on DSR [23,24].

Both DSR and AODV employ different mechanisms to vary their performance levels in terms of packet delivery ratio, MAC load, routing load and average end - to - end delay by altering the number of sources, speed and pause time.

In order to improve on the route failures, Ad hoc On demand Multi - path Distance Vector (AOMDV) [22] and Temporally Ordered Routing Algorithm (TORA) [25] create many routes towards the same destination during route discovery. While applying AOMDV, during a path construction towards a single destination, a node accepts RREQs received from different links. Hence, resulting into the creation of disjoint reversed paths leading to the source. Afterwards, once the destination is located, the RREPs are forwarded to the source via the disjoint paths and all the unearthed paths are memorized although only one is used. Rather than restarting the search for the destination like AODV, AOMDV activates one of the alternative paths in case of a disconnection. This helps in reducing the end - to - end delay and energy wastage thus extending the network lifetime [26] - which can be used in streaming mobile videos in heterogeneous medium.

Another protocol that uses a metric-based mechanism to enhance the path stability is Associativity Based Routing (ABR) [27], whereby, each node in the network attributes an associativity degree to its neighbours by counting the number of HELLO messages received. During the search for the destination, the associativity degree of the explored links is included in the request messages. When the destination is reached, the path with the highest associativity degree is selected. Also, this protocol includes a local path repair feature. Although the local path repair is rewarding when the nodes are moving at a medium/low pace, this method amplifies the transmission delay when it fails.

In order to diminish the effect of node mobility on the network performance, Location Aided Routing (LAR) was designed [28]. While the location of the destination is forwarded regularly to the traffic source, this reactive protocol explores the existing geographical information about the destination (last known location, time elapsed since the last communication, speed and direction of movement) to near down the location where the destination might be found, in case of a path failure. First, the source calculates the relative distance that separates it from the destination and includes it in the request message. Then, the intermediate node receiving the request message will rebroadcast it only if the current node is closer to the destination than the previous one. In order to enlarge the search area, the distance separating the destination from the source is augmented at the beginning of the process. This way, the probability of finding the destination is increased. Additionally, the frequency to broadcast routing packets depends on the node mobility. The faster a node moves, the more it announces its location. However, supposing that the next hop leading to the destination is the closest one to it (geographically), can be false. As a result, the path repair mechanism can falsely fail which leads to restarting the search for the destination and including all the network in the process [17]. Additionally, building paths based on the geographical locations doesn't insure the creation of the shortest path.

### Multipath routing algorithms

[29] proposed a multipath minimum energy routing mechanism to minimize the overall energy consumption of the network. They modelled an ad hoc network by a set of nodes and links. Each link associates with an energy cost function which is a function of the total traffic flowing over this link. They focused on the problem of how to split traffic among multiple paths to minimize the sum of the links' energy cost.

| Protocol | Advantages | Disadvantages |
|---|---|---|
| AODV | Avoids routing loops by use of the destination sequence number.<br>Low complexity | When a path in current use is broken, the source is forced to restart the search for the destination from the beginning which increases the transmission delay |
| DSR | Avoids routing loops by including the entire path in the data messages and route request/reply<br>Requires less storage capacity/routing operations. | Generates high overhead |
| AOMDV/ TORA | Creates multiple paths to the same destination for a better adaptability to the topology changes.<br>Lowering the overhead caused by path failures. | Maintaining alternative paths requires extra processing. |
| ABR | Creates paths through the nodes that have a low state of mobility.<br>Applies a local repair mechanism to reduce the transmission delay. | When the local repair fails, the transmission delay is increased.<br>Local repair does not necessarily produce the shortest path. |
| LAR | Through the use of the geographical information, it minimizes the participants in the path recovery and accelerates the process. | If the next hop towards the destination is not the closest one to it (geographically), the path recovery can fail falsely. This would force the source to restart the search in the entire network.<br>Path construction based on the geographical locations does not necessarily produce the shortest path. |

**Table 1:** A Comparison of the reactive protocols [17].

### Mutation based routing algorithms

Genetic or mutation-based algorithms are mainly probabilistic algorithms that are based on the principle of natural selection and evolution [30]. The basic operational mechanism is generation of an initial population of all possible solutions of the problem at hand, in which case here is the route, called a chromosome. Every chromosome is evaluated by use of its fitness function and a new population is normally generated from the current population through selection, crossover, repair and mutation operations. The purpose of selection is in order to choose the fittest members/parents (genes) for crossover and mutation. Crossover is the function that causes the exchange of genetic materials between parents to form new offspring, then, mutation, incorporates new genetic materials in the offspring.

Due to the self - organizing nature of MANETs, their performance depends on the willingness of the nodes to contribute in the network traffic [17] and from a QOS perspective, managing selfish nodes is an important issue. In the recent past, upgrade versions of the initial routing protocols have been developed to achieve better QOS like the Honey Bee Algorithm, based on the Ant Colony Optimization (ACO) [31] and swarm intelligence [32]. Since the goal of the ACO meta - heuristic is to find the best path between the nest and the food source, this method connects well with the QOS routing problem. A good instance of this implementation is the Multi - Objective AODV (MAODV), which is an extension of AODV based on the ACO algorithm which takes into consideration multiple metrics (delay, load, path reliability) apart from hop count [33].

Since MANET components are normally equipped with restricted energy resources, several algorithms have also been developed towards increasing the Mobile nodes' lifetime hence increasing the network lifetime.

Essentially, AODV which is an upgrade synthesis between DSDV and Dynamic Source Routing (DSR) [17] initiates the request/ wait for a reply process when a path to a given place is necessary and during the search for a destination, the intermediate nodes re - broadcast a route request (RREQs) only once and memorise a reverse path towards the initiator. Then a route reply (RREP) is sent back to the source once the destination or path leading to it is found [34].

[35] have explained that the uptake of MANETs commercially has been derailed by the following challenges; (i) "special - purpose devices such as medical equipment and smartphones do not necessarily support the 802.11 ad - hoc mode or do not provide a user interface to support it. (ii) Supporting ad - hoc mode is insufficient for partaking in a MANET since every device must also support additional specialized MANET protocols for routing and address resolution. (iii) Mobile device vendors and operating system developers focus on the widely used 802.11 infrastructure mode and have little commercial incentive to provide full MANET functionality because of low customer interest. By extension lack of MANET support in devices has led to lack of demand in customers which has further been manifested in the lack of device support".

There is a possibility in creating MANETs in 802.11 infrastructure mode which is supported by every 802.11 compliant device and relies on plain IP routing. MA - Fi (Mobile Ad - Hoc Wi - Fi) is an example of such network [35]. The challenge comes in in the form of maintenance of the network and support for mobile clients since client configuration would be needed and name resolution on the network.

[36] proposed a new routing protocol for Mobile Ad - Hoc networks which can tolerate network delay. This algorithm utilizes information contained by packets in the network to choose the best routes. They employed a sliding window mechanism to update the average hop-count matrix dynamically. Too they have defined a heuristic function to estimate the prospective required hop-count between the current node and the destination node.

Research work done by [37] tries to come up with an algorithm to decrease location errors for routing; therefore, it proposes an on-demand routing protocol which takes location errors into consideration. To estimate accurate routes and route confidence in route discovery process, Kalman filter is employed. Since Kalman filter provides the root-mean-square error between the actual location and estimated location of a node, and considering the confidence level of links, this algorithm excludes unreliable links.

Work proposed by [38] recommends a machine learning based hybrid power-aware approach for handling critical nodes via load balancing. Using machine learning to the region of critical nodes for load balancing would serve as a profitable measure to prevent the critical nodes from energy depletion and improves the performance of the MANET. In this algorithm, the fundamental packet delivery is done via standard OSPF algorithm. Mobile nodes are clustered by learning their frequency and direction of packet exchange. Nodes that handle the same pattern of traffic are clustered together. This technique is known as self-similarity-based clustering.

The offered proposed solution by [39] puts forward a new mechanism to establish stable and sustainable paths between all pairs of nodes in a Mobile Ad hoc Network. In this mechanism, a stability function is utilized as the main path selection criterion which relies on the calculating mobility degree of a node corresponding to its neighbours. Authors applied this mechanism to the OLSR protocol to select stable and sustainable MultiPoint Relay (MPR) nodes. This mechanism significantly minimizes the recalculation of MPR and recalculation process for routing tables. Moreover, other QoS metrics such as packet loss and response time are guaranteed.

[40] proposed an energy management model and a power consumption control flowchart to control power consumption by reducing data transmission time. Simulation model is used for analysis of power consumption in mobile ad-hoc network. Power consumption is controlled by transmission time. Transmission time is directly proportional to slot time. Network life time is increased due to less transmission time. Optimization of power con-

sumption is possible by saving transition and receiving energy for mobile ad-hoc network.

The research work proposed by [41] applies a Reward-Based Routing Protocol (RBRP) for MANETs. This protocol employs a route strategy based on the Q-learning method to select a stable route to enhance system performance. The reward of a route is decided by four factors: hop-count, bandwidth, battery level, and node speed. Route discovery process usually finds multiple routes from the source to the destination node. Then, a path with the greatest reward value is selected for routing.

Another research work proposal [42] suggests a fuzzy logic-based on-demand routing protocol for mobile ad-hoc networks. The proposed algorithm exploits battery level and node speed as two criteria for route selection.

[43] have proposed new routing algorithms. The first proposed approach employs a classical logic approach for training all nodes in the network so that nodes will determine the link stability and finally determine the path stability rate by use of several factors such as available bandwidth, residual energy, mobility speed, and hop-count. In the second scenario, fuzzy logic is employed to train network nodes aiming at recognizing optimal paths. The third scenario, applies reinforcement learning to learn network nodes how to estimate path stability rate. In the fourth scenario, the fuzzy logic method is accompanied with reinforcement learning method to train nodes to estimate optimal paths.

[26] has proposed a routing scheme based on AOMDV which uses the fitness function (FFn) found in genetic algorithms to get the most optimal routes using the shortest route, maximum residual energy and less data traffic as the performance metrics. The routing mechanism makes use of the TCP congestion Control Enhancement for Random Loss (TCP CERL) in the FFn to optimize the efficient route. The algorithm focuses on energy utilization and the reduction of end - to - end delay as it tries to extend the network lifetime. However, the protocol requires more processing time to calculate the best route which increases the end - to - end delay, which is one of the goals of the protocol.

## Conclusion

Several routing algorithms have been reviewed in terms of their types and operational mechanisms and performance capabilities in terms of average end - to - end delay, throughput and packet delivery ratio. This review on the routing algorithms in MANETs and has gone ahead to specifically address routing challenges in this field. It has also looked at different routing algorithms up to the state-of-the-art routing algorithms such as the application of evolutionary algorithms for optimization problems in multi-hop ad hoc networks. In addition, it has shown why the use of evolutionary algorithms offers the best solutions and why the use of evolutionary algorithms in mobile multi-hop ad hoc network is still in an early stage of research. In the near future, the application of more powerful and distributed evolutionary algorithms will be possible thanks to the increment of computational power of embedded electronic devices.

The review has established that there is still a challenge in the existing routing algorithms in terms of routing updates, energy preservation and cost. This needs to be addressed properly.

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