Routing Methods for Mobile Ad-hoc Network: A Review and Comparison of Multi-criteria Approaches

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Abstract—In recent years, Mobile Ad-hoc Networks have been focused on research and strong applications in healthcare, military, disaster prevention, and IoT ecosystem. Due to the ad-hoc mobility characteristic of the network devices, the routing protocols are specifically designed to ensure factors such as energy efficiency, high performance, quality of service, as well as security-aware. In this article, we perform analytic routing protocols for mobile ad hoc networks to compare and evaluate the advantages and disadvantages of each protocol and propose the next research direction.

Index Terms—MANET, Routing Methods, Heuristic, AODV

I. Introduction

Mobile Ad-hoc Networks (MANETs) were advent in the 1970s. It is an organization of mobile wireless devices, capable of self-configuring, self-establishing parameters to communicate in-network without relying on base stations or pre-existing infrastructure [1]. Although limited in capabilities and ability [2]-[4], MANETs have proven superiority with series of applications was deployed in reality such as intelligent transport systems, military, smart agriculture, smart cities, healthcare, IoT ecosystems based on flexible communication infrastructure. It promising significant contributions to the development of the future Internet [5]-[9]. A diverse illustration of the MANET applications in the Smart Cities is indicated in Fig. 1. Because of the unstable and distributed network structure, routing is one of the most important problems of MANETs [10]-[11]. In recent years, many studies have focused to solve this problem [12]-[16]. However, the studies have proposed usually only suitable for a specific system or structure, so designing routing protocols more smart and flexible aim to improve MANETs performance always is an urgent and topical problem.

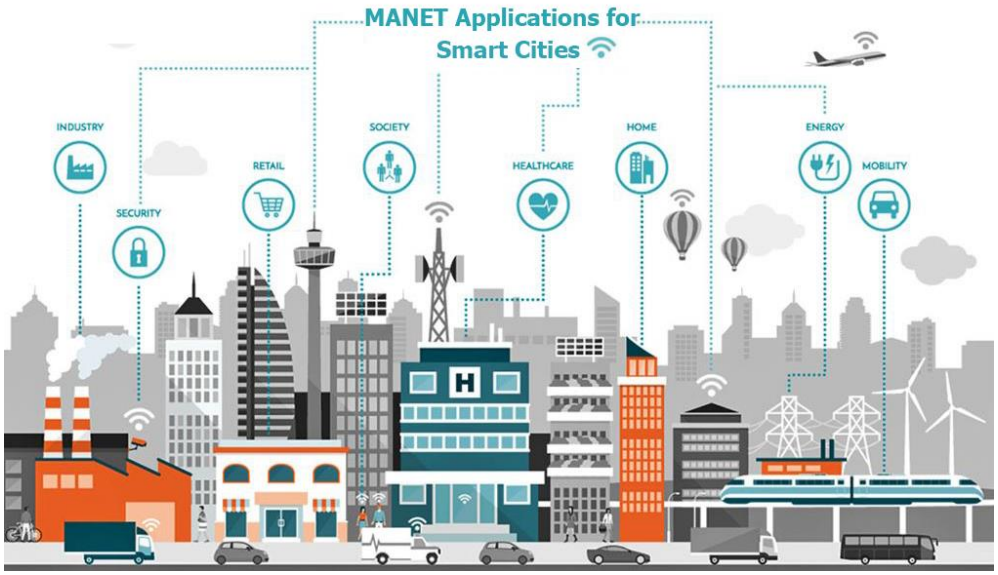

Fig. 1. Illustration of the MANET applications for smart cities

Survey of studies in this area [1]-[2], [9]-[10] showed that, based on the routing method, the routing protocols are divided into two categories: *proactive routing method* and *on-demand routing method*. Proactive routing allows each node to keep a routing table and periodically update information about all the routes in the network, while on-demand routing only finds and sets up a path from a source node to a destination node when it needs to transmit data.

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This article performs a survey to provide a brief study of the proposed routing protocols for MANETs as well as analyze the advantages and disadvantages of each protocol and suggest further research directions. The rest of the paper is presented as follows. In Section 2, we present the characteristic of the routing methods. In Section 3 we perform a comparison between some typical routing protocols and Section 4 is the conclusion and direction of our next research.

II. Routing Methods in MANETs

A. Link State-based Routing Method

Link State-based Routing (LSR) protocol [17] is the typical proactive routing protocol, determining the route based on the shortest path first algorithm (*Dijkstra Algorithm*). Specifically, each node has a routing table that stores the structure of the entire network. When the network structure is changed, the nodes use the Link State Packet (LSP) to broadcast to the entire network. This process ends when all nodes on the network have the same route map. Each node relies on the routing table to choose the best route in the network.

The LSR protocol has a fast route time, allowing nodes to have a complete view of all the routes in the network. As a result, it can find the most optimal routes as well as allow the construction of multiple redundant routes. Outstanding disadvantages of the LSR include power consumption and demanding hardware resources such as memory, large processors, while these are the limitations of mobile devices due to the limited battery power and low processing capacity.

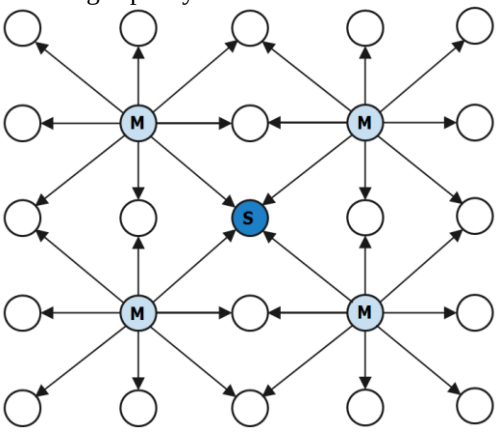

Fig. 2. The MPR elect mechanism in OLSR.

OLSR [18] is an improvement from the link-state protocol for multi-hop. Periodically, the nodes actively exchange information about the network architecture. OLSR has proposed an aim to reduce the overload caused by broadcast packets by electing some nodes which have played a role are center relay nodes. Only these nodes can forward the broadcast. As a result, it reduces the number of broadcast packets as well as the size of the control packet. In order to elect a Multi-Point Relay node (MPR), nodes send Hello packets to identify neighboring nodes, then these nodes perform MPR node election, described in Fig. 2. OLSR protocol enhances performance in the dense network environment and large data traffic. However, the limitation of this protocol is a lot of network resources consuming.

B. Distance Vector-based Routing Method

DSDV [19] is a proactive routing protocol that uses the hop number to making-decision select a route, it is proposed to solve the looping problem by adding a sequence number field to the routing table. Unlike the link-state-based routing method, the DSDV does not have a route map to all the nodes on the network. Each node maintains a routing table to the destination nodes it knows, and this information is exchanged and updated periodically. When selecting a route, DSDV prioritizes the route with the highest sequence number, in case there are multiple routes with the same sequence number, the protocol will prioritize the route with the lower cost. Due to the principle of periodically exchanging and updating routing information, in the Mobile Ad-hoc Network environment, DSDV often causes a waste of system resources in the event that the network architecture has little change and causes overloaded problems when the route that exists in the routing table is not in use.

C. On-demand-based Routing Method

The two typical IETF standardized protocols for MANETs are AODV [20] and DSR [21], which are on-demand routing protocols. Protocols operate based on principle as follows: When the source node needs to transmit data, it invokes the discovery procedure, in Fig. 2 to determine a route from the source node to the destination node by broadcast the router request messages, as in Fig. 3.

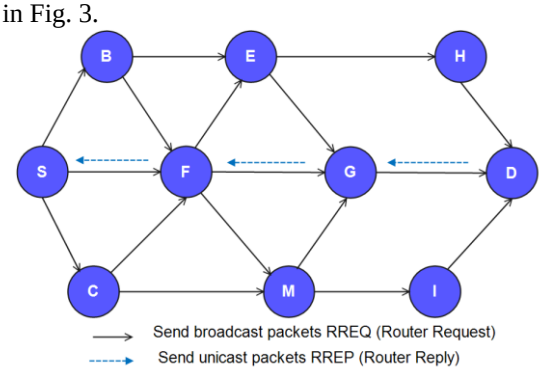

Fig. 3. The route discovery procedure of the on-demand method.

The destination node or the node that knows about the route to the destination will send a router reply message (RREP) to the source node. When the source node receives an RREP packet, the route will be established and data can begin to be transmitted. In addition to route discovery, AODV and DSR also have the route maintenance procedure based on the error messages.

The two main features of AODV are the route setting method and the sequence number property. AODV does not predetermine a route to transmit data from source to destination. The transmission route is decided by each network node when the data arrives based on the system

information status obtained by each node. Besides, AODV also uses the sequence number attribute to determine the time available value of the packet as well as to avoid the loop routing. Meanwhile, the main feature of DSR is the method of determining the route from the source node to determine the best route. Therefore, RREQ and RREP packets must contain information about the addresses of the intermediate nodes. While AODV does not store any routes, DSR maintains a cache of routes and uses the routes in memory until they are marked as invalid.

In the MANETs, the on-demand-based routing methods are much more energy-efficient than the proactive-based routing methods due to them not broadcast periodically control messages and routing tables. Therefore, proactive routing methods are suitable for the stable structure networks and on-demand routing methods is suitable for MANETs. AODV and DSR have been standardized into typical routing protocols for MANETs. They support well the features of ad-hoc network architectures such as self-organization, self-configuration, and mobility. They also have route maintenance procedures, which are used to deal with frequent connection changes. In a performance evaluation, AODV delivers over 90% of the packets, while the performance of DSR is highest in the low node number and decreases when network size increases. AODV is more suitable than DSR in a mobile ad-hoc network environment [22]. However, with limited ability and capabilities, the routing protocols more flexible and efficient for MANETs need to be studied.

D. Location-based Routing Method

LAR (Location Aided Routing) [23] uses location information, which is obtained through the Global Positioning System (GPS) as a routing metric to improve the performance of the network. The purpose of this solution aims to limit the calculation area to improve the performance network.

$$R = V \times (T_1 - T_0) \quad (1)$$

Suppose, at T_0 time, the S node already knows the D node is at L position; the D node has an average movement speed is V. Then, at the T_1 time, the S node will estimate a location area of the D node with the center of the circle at L point as in Equation (1). The discovery mechanism of the LAR similar to a flooding mechanism. A difference, it only flooding in limited scope. LAR minimizes the route discovery cost by shrinking the route definition area. The downside of LARs is that the nodes need to know their location information.

E. Security-aware Routing Protocol

SAR (Security Aware Routing Protocol) [24] is an on-demand routing protocol that adds security tasks. Due to the mobile ad-hoc characteristics of MANETs and the low reliability of the network nodes. In order to ensure that data is only sent on the trusted network nodes, the SAR adds security properties to the route discovery procedure. The source node sends the route request broadcast with the security attribute determined by the sender. Neighbor nodes can participate in routing if the required level of security is met. Nodes that do not meet of security level are removed from the routing process. Simulation results showed that the SAR has improved the level of information security. However, SAR has a high delay due to the node authentication period. Moreover, SAR alone is not enough to deal with the increasing risk of information insecurity increase.

F. Heuristic-based Routing Method

In the natural world, ants/bees colony are insects that have well-known socially organized. In particular, they have the ability to optimize route discovery from the nest to the food based on Swarm Intelligence (SI) [10]. Inspired by the ways to find food from the bee/ant colony, Ant / Bee colony optimization algorithm has been advent. Agents in a colony are the result of pheromone-based local communications.

In reality, pheromones are a chemical that has the ability to evaporate, left behind by ants/bees when they pass to affect other animals in the colony. When a bee/ant passes on the path, it leaves a pheromone trail for other animals to follow [25].

In the process of discovering the path from the nest to where there is food, some ants/bees may choose random paths without relying on pheromone concentrations. This is the most important feature of the shortest route discovery process of the optimization algorithms based on ACO / BCO. A performance analytic in [26] showed that ACO / BCO-based routing algorithms improved latency and throughput by up to 30% over traditional routing protocols in high mobility MANET scenarios. An illustrates of the route discovery process of an Ant colony is indicated in Fig. 4.

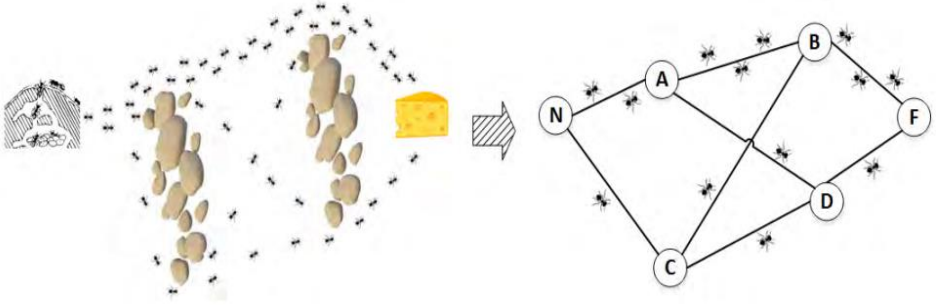

Fig. 4. An Illustration of the route discovery process of an ant colony

G. Hybrid Routing Method

PRISM (Privacy-Preserving Location-Based On-demand Routing in MANETs) [27] is a location-based on-demand routing protocol, improved from AODV and added security features. This protocol was developed to maintain privacy and ensure information security against attacks from both inside and outside the network on a mobile ad-hoc environment. PRISM only broadcast RREQ packets in the target geographic area and RREP packets are only returned by local nodes. Moreover, it enhances security by hashing control packets such as RREQ, RREP, and uses group signature methods for authentication to ensure data only passes through authenticated nodes. The advantage of this protocol is that it reduces system overload and reveals only a small part of the network architecture. However, this solution will limit the variety of candidate routes.

III. Comparison of Routing Protocols

According to the surveyed studies, we divided the surveyed routing protocols for MANETs into two sets, include: the proactive method and on-demand method as well as evaluation of the advantages and disadvantages of each protocol and summarized in Table I.

Table I. Comparison of the Proposed Routing Protocol for MANETs

Protocol	Routing Method	Advantages	Disadvantages
LSR [7]	Proactive	Improved delay, fast optimal route setting, QoS ensures.	The solution consumes a lot of system resources and energy.
DSDV [8]	Proactive	Improved delay, determine the fast optimal route, including redundancy route, QoS ensures.	The solution consumes a lot of system resources and energy, overload.
AODV [9]	On-demand	Saves energy, system resources, adapts well to mobile ad-hoc network environment characteristics.	Performance parameters need is improved to enhance performance and energy efficiency.
DSR [10]	On-demand		The source routing mechanism of the DSR has lower performance than AODV in high-density scenarios.
OLSR [11]	Proactive	Improved system overload thanks to the clustering mechanism and elect multi-point relay nodes.	The solution consumes much system resources and energy compared to the on-demand method. It is suitable for high-density scenarios.
LAR [12]	On-demand	Taken GPS information into making-decision choice route, lead to reduce the system overload.	Need to obtain location information of nodes via GPS system, lead to significantly increased delay.
SAR [13]	On-demand	Uses node authentication mechanism to ensure data only passes through authenticated nodes, against attacks in the ad-hoc network environment.	Latency and performance are significantly reduced compared to the AODV protocol.
PRISM [14]	On-demand	Use group signature mechanism to authenticate node to ensure data security in MANETs environment.	

Observe the results in Table I showed that the proactive-based routing protocols have high network performance, fast route determination time but use a lot of system resources and energy. In contrast, the on-demand-based routing protocols use limited system resources, save energy, but have low network performance.

The survey results also show that, in MANETs environment, due to the movement of network devices, combined with the limited battery capacity and resources of the network nodes, the routing protocols must face a variety of problems such as saving energy, improving performance, load balancing, support QoS, security, etc. Therefore, on-demand routing protocols are more suitable than active routing protocols, especially in large and dense networks. The survey results also showed that to guarantee the QoS, the routing algorithms often integrate the routing parameters into the cost function to making-decision select optimal routes.

$$F_P = \sum_{(i,j)\in P} \overline{distance_{ij}} + \sum_{(i,j)\in P} \overline{delay_{ij}} - \min_{(i,j)\in P}(bandwidth_{ij}) - \prod_{(i,j)\in P} \overline{reability_{ij}} \quad (2)$$

In order to select the optimal route based on multiple parameters, in this study we proposed a routing strategy that using a target maximizing function introduced in [25] with the parameters are considered to include: distance, delay, bandwidth, and reliability of link, we obtain the optimal function as Equation (2). Where, the i, j is a link on the the P path. $\overline{distance_{ij}}$ is the hop number of the node pair (i, j), $\overline{delay_{ij}}$ is the end-to-end delay of the node pair (i, j), $bandwidth_{ij}$ is the available bandwidth

of the node pair (i,j), and $reability_{ij}$ is the successful transmission probability of the of node pair (i,j).

In addition, the results also showed that to collect routing information, the on-demand routing protocols often add some fields into the header of control packets such as RREQ, RREP. As a result, the size of the packets will increase. This can increase the energy consumption of the entire system. However, studies have not specifically evaluated these issues. Therefore, in our opinion, this issue should be further considered in the next studies.

IV. Conclusion and Further Research Direction

In this research, we performed analytics and comparisons of the typical routing protocols proposed for Mobile Ad Hoc Network environments. Survey results showed that on-demand routing protocols saving energy, support well to routing in network environments that have structures constantly changing such as MANETs, especially the two protocols AODV and DSR. In reality, the performance of MANETs is rather low, especially in the high mobility MANET scenarios. Aim to the enhance performance of MANETs, research, and improvement of routing protocols need to continue to be studied. In further time, we will focus on research security-aware and support QoS routing solutions for the next generation MANETs.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

We have conducted the research, analyzed the data, and performed simulations together. All authors had approved the final version. Corresponding Author is Vu Khanh Quy.

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References

[1] V. K. Quy, V. H. Nam, D. M. Linh, *et al*., "A survey of QoS-aware routing protocols for the MANET-WSN convergence scenarios in IoT networks," *Wireless Personal Communications 120*, pp. 49-62, 2021.

[2] M. N. Khan, A. Rao, and S. Camtepe, "Lightweight cryptographic protocols for IoT-Constrained devices: A survey," *IEEE Internet of Things Journal*, vol. 8, no. 6, pp. 4132-4156, 2021.

[3] L. Qiu and G. Cao, "Popularity-Aware caching increases the capacity of wireless networks," *IEEE Transactions on Mobile Computing*, vol. 19, no. 1, pp. 173-187, 2020.

[4] J. Liu, Y. Xu, and Z. Li, "Resource allocation for performance enhancement in mobile ad hoc networks," *IEEE Access*, vol. 7, pp. 73790-73803, 2019.

[5] M. A. Al-Shareeda, M. Anbar, I. H. Hasbullah, and S. Manickam, "Survey of authentication and privacy schemes in vehicular ad hoc networks," *IEEE Sensors Journal*, vol. 21, no. 2, pp. 2422-2433, 2021.

[6] A M. M. Azari, G. Geraci, A. Garcia-Rodriguez, and S. Pollin, "UAV-to-UAV communications in cellular networks," *IEEE Transactions on Wireless Communications*, vol. 19, no. 9, pp. 6130-6144, 2020.

[7] J. S. Lee, Y. Yoo, H. S. Choi, T. Kim, and J. K. Choi, "Energy-Efficient TDMA scheduling for UVS tactical MANET," *IEEE Communications Letters*, vol. 23, no. 11, pp. 2126-2129, 2019.

[8] J. J. Astrain, F. Falcone, A. J. Lopez-Martin, P. Sanchis, J. Villadangos, and I. R. Matias, "Monitoring of electric buses within an urban smart city environment," *IEEE Sensors Journal*, 2021.

[9] A. M. Alberti, *et al*., "Platforms for smart environments and future internet design: A survey," *IEEE Access*, vol. 7, pp. 165748-165778, 2019.

[10] H. Zhang, X. Wang, P. Memarmoshrefi, and D. Hogrefe, "A survey of ant colony optimization based routing protocols for mobile ad hoc networks," *IEEE Access*, vol. 5, pp. 24139-24161, 2017.

[11] V. K. Quy, N. T. Ban, V. H. Nam, D. M. Tuan, and V. D. Han, "Survey of recent routing metrics and protocols for mobile ad hoc networks," *Journal of Communications*, vol. 14, no. 2, pp. 110-120, 2019.

[12] L. Deng, F. Liu, Y. Zhang, and W. S. Wong, "Delay-Constrained topology-transparent distributed scheduling for MANETs," *IEEE Transactions on Vehicular Technology*, vol. 70, no. 1, pp. 1083-1088, 2021.

[13] V. K. Quy, N. T. Ban, and N. D. Han, "A high performance and longer lasting network lifetime routing protocol for MANETs," in *Proc. International Conference on Advanced Technologies for Communications (ATC)*, 2018, pp. 237-241.

[14] Y. Song, H. Luo, S. Pi, C. Gui, and B. Sun, "Graph kernel based clustering algorithm in MANETs," *IEEE Access*, vol. 8, pp. 107650-107660, 2020.

[15] V. K. Quy and L. N. Hung, "A trade-off between energy efficiency and high-performance in routing for mobile ad hoc networks," *Journal of Communications*, vol. 15, no. 3, pp. 263-269, 2020.

[16] C. K. Toh, A. Le, and Y. Cho, "Load balanced routing protocols for ad hoc mobile wireless networks," *IEEE Communications Magazine*, vol. 47, no. 8, pp. 78-84, 2009.

[17] C. Adjih, E. Baccelli, and P. Jacquet, "Link state routing in wireless ad-hoc networks," in *Proc. IEEE Military Communications Conference (MILCOM 2003)*, 2003, pp. 1274-1279, vol. 2.

[18] Optimized Link State Routing Protocol (OLSR). [Online] Available: https://www.ietf.org/rfc/rfc3626

[19] C. Perkins and P. Bhagwat, "Highly dynamic destination sequenced distance vector routing (DSDV) for mobile computers," *ACM SIGCOMM*, pp. 234-244.

[20] Ad hoc On-Demand Distance Vector (AODV) Routing. [Online]. Available: https://www.ietf.org/rfc/rfc3561

[21] The Dynamic Source Routing Protocol (DSR) for Mobile Ad Hoc Networks for IPv4. [Online]. Available: https://www.ietf.org/rfc/rfc4728

[22] L. N. Hung, *et al*., "A review: Performance improvement routing protocols for MANETs," *Journal of Communications*, vol. 15, no. 5, pp. 439-446, 2020.
[23] Y. Ko and N. H. Vaidya, "Location-Aided Routing (LAR) in mobile ad hoc networks," *Wireless Networks*, vol. 6, pp. 307–321, 2000.
[24] S. Yi, P. Naldurg, and R. Kravets, "Security - Aware ad hoc routing for wireless networks," in *Proc. 2nd ACM International Symposium on Mobile Ad hoc Networking and Computing*, 2001, pp. 299-302.
[25] X. Chen, *et al*., "Artificial intelligence-empowered path selection: A survey of ant colony optimization for static and mobile sensor networks," *IEEE Access*, vol. 8, pp. 71497-71511, 2020.
[26] D. J. Persis and T. P. Robert, "Review of ad-hoc on-demand distance vector protocol and its swarm intelligent variants for mobile ad-hoc network," *IET Networks Journal*, vol. 6, no. 5, pp. 87-93, 2017.
[27] K. E. Defrawy and G. Tsudik, "Privacy-Preserving location-based on-demand routing in MANETs," *IEEE Journal on Selected Areas in Communications*, vol. 29, no. 10, pp. 1926-1934, 2011.

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