Performance Analysis of Routing Protocols for Mobile Ad Hoc Networks in Urban Scenarios

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Abstract —Device-to-Device (D2D) is one of the emerging technologies expected to have significant contributions to the future of the Internet. The combination of personal mobile devices and D2D communications forms the Mobile Ad-hoc Network architecture, called MANETs. Nowadays, due to the flexibility and simplicity of establishing data transmission, MANETs are applied in various areas such as healthcare, intelligent transportation systems, tactical, smart retail, and smart agriculture. In practice, due to the mobility of network nodes, the network structure often changes, and the performance of MANETs is relatively low. Routing is one of the significant challenges of MANETs. In this study, we perform a comprehensive analysis of the traditional routing protocols for MANETs. Based on the analysis results, we obtained a common framework for designing routing protocols for MANETs. To visualize the efficiencies of protocols under variable network traffic, we performed a simulation to compare the performance of typical protocols, including AODV, DSR, and OLSR. The obtained results again demonstrated that on-demand-based routing protocols are suitable for dynamic topology networks. We hope that this work will be an essential guide in researching and proposing energy-saving, secure, and QoS routing protocols for MANETs in the future.

Index Terms—High-Performance, Routing Protocol, MANETs.

I. INTRODUCTION

The 5th generation mobile network technology, the so-called 5G, is taking shape. It is expected to make outstanding contributions to the development of the future Internet. 5G enables the delivery of services with extremely high bandwidth and extremely low delay. According to *Boccardi et al.* [1], one of the breakout factors to provide the capabilities of 5G is the centric device architecture. Specifically, devices in 5G can self-establish parameters and communicate with other devices without relying on central devices such as base stations. It is the principle of forming Mobile Ad Hoc Networks (MANETs).

In recent years, wireless network technologies have been researched and applied in many fields to serve humanity. These networks can be divided into two main categories, includes:

1) *Infrastructure Networks* are network types that allow wireless devices to communicate with other devices relying on existing infrastructures such as access points or base stations to communication.

2) *Ad-hoc Networks* are organizations of wireless devices that can communicate without relying on the pre-existing network infrastructure or centralized management. When these devices can move, they form MANETs [2]. In MANETs, the nodes can be self-configured and self-established to communicate without reply on pre-existing infrastructures such as access points or base stations [3]. In MANETs, each network node acts as a router with a wireless transceiver. The network nodes move randomly and ad-hoc, so the network structure changes rapidly and unpredictably. The MANETs can operate independently or connect to infrastructure networks forming the known-well Internet-assisted MANET architecture [4].

Nowadays, because of this flexibility and convenience in establishing connections and transferring data, MANETs have been applied in many areas. Fig. 1 describes the applied MANET in intelligent transportation systems. Based on the equipped transceiver, vehicles, signal lights, and roadside units (RSUs) can be established D2D (Device-to-Device) communications to exchange information aim to more intelligent monitoring and control vehicles. The mobile ad-hoc network has some unique characteristics as follow [5]:

- Mobility: The network node can access data when it is moving, improving data retrieval efficiency.
- Deployment: Due to without cable, it can be installed fast and efficiently, it is feasible for emergency scenarios such as rescue, disaster recovery.
- *Flexibility*: It can be deployed quickly for small networks; network expansion is easy because communications only rely on personal wireless devices.
- *Cost*: Due to the use of existing personal devices and the communication relies on unlicensed wireless technology such as 802.11x, the cost to deploy MANETs is low.
- *Limitation*: MANETs have some constraints, such as the abilities and capacities of personal devices are low, leading to the unfeasible deployment of the

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optimal algorithms. Consequently, the MANETs face a series of challenges such as low performance, energy consumption, support QoS, and security-aware [6]-[9].

Fig. 1. An illustration of MANET applications for IoT ecosystems.

II. Several Typical Applications

Due to the flexibility in setting up and transmitting information, MANETs have a series of applications server humans, as follows:

Emergency Services: Anywhen and anywhere, in emergency scenarios, the combination of rescuers and MANETs is a feasible solution. In [10], *Ojetunde et al.* (2019) have proposed a mobile payment system that can help maintain online payment transactions even in emergency scenarios such as earthquakes based on MANETs. This study assumes a post-disaster scenario, where people need to buy necessities such as medicine, clothing, etc., while fixed and mobile network-based payment systems have been destroyed. The experiment results indicated that the proposed solution allows payment transactions to achieve a success rate of 65% to 90%, depending on specific conditions.

D2D Communication: One of the emerging communication technologies that are expected to make significant contributions to the future of the Internet is Device-to-Device (D2D). In [11], *Ahmed* (2021) proposed a new multi-hop routing protocol, improved from the DSR protocol of MANETs for D2D communications in 5G networks. The integration of MANETs into the 5G will allow the 5G mobile infrastructure to take a powerful advantage. The research results show that deploying MANETs to establish small-scale networks is a possible solution in 5G.

Smart Healthcare: One of the crucial applications of MANETs is to provide solutions for human health care. In [12], *Mukhopadhyay et al.* (2020) proposed a solution for emergency medical communication situations. According to their proposal, MANETs are formed based on a combination of personal devices, ambulance vehicles, and hospitals. These connections can be facilitated by Unmanned Aerial Vehicles (UAVs). Through this scenario, a communication system is established to connect patients, doctors, and ambulances in emergency medical relief situations during a disaster.

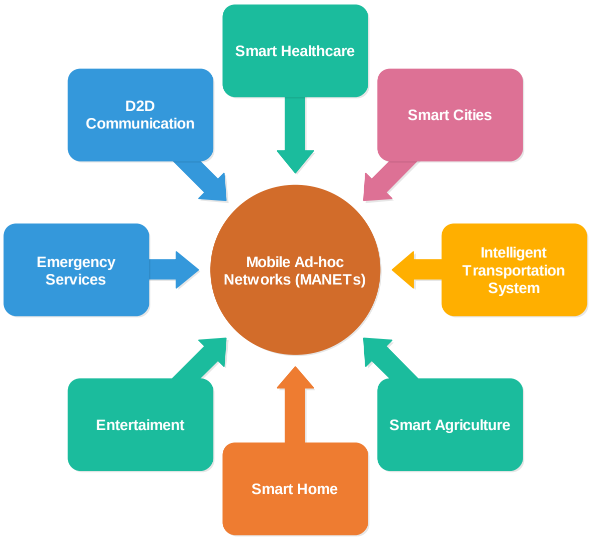

Fig. 2. An illustration of MANET Applications.

Smart Cities: The use of ad-hoc technology allows personal mobile devices to self-configure and transmission data. Consequently, smart applications based on MANETs can be easily deployed to forming smart homes, smart campuses. In [13], *Oubbati et al.* (2019) proposed a solution for vehicle-to-vehicle communication with the support of Unmanned Aerial Vehicles (UAVs) to provide reliable transportation services and applications in smart cities.

In addition, a series of detailed MANET applications are presented in the survey studies [14]-[15]. Fig. 2 illustrates a diverse of the applications of MANETs for humanity.

III. Routing Issues for MANET

For the purpose improve network performance, routing protocols must adapt to the characteristics of MANETs, including mobility and limited network resources. Therefore, the routing protocols of MANETs have several features [16]. We compare some common protocols based on these characteristics as in Table I.

TABLE I: A COMPARISON OF KEY FEATURES OF ROUTING PROTOCOLS

Protocols	DSDV	AODV	DSR	ZRP	TORA
Loop-Free	Yes	Yes	Yes	Yes	Yes
Distributed	Yes	Yes	Yes	Yes	Yes
On-demand	No	Yes	Yes	No	No
Support QoS	No	No	No	No	No
Security-aware	No	No	No	No	No
Saving Energy	No	Yes	Yes	Yes	No
Routing Overhead	High	Low	Low	Low	High

A. Characteristics

Routing protocols for MANETs have some characteristics as follows.

- $Distributed\ Operation$: It does not depend on a centralized control network node.
- $On-demand$: Minimize the portion of control information in the network.
- $Uni-direction\ links$: Due to mobility characteristics, routing methods should is uni-direction to improve performance.
- $Security$: The wireless environment is very vulnerable to attacks and information exploitation, the security should be flexibly deployed in MANET.
- $Saving\ Energy$: mobile devices use batteries as energy. Therefore, the routing protocol needs to use saving energy mechanisms.

$Quality\ of\ Service$: MANET applications usually guarantee QoS. Therefore, QoS guarantee solutions need to be integrated into the routing protocol.

B. Common Performance Metrics

For the purpose of the performance evaluation of routing protocols in different MANET scenarios, we define the performance evaluation criteria [17] as follows:

- $Packet\ Delivery\ Ratio$: Defined as the total number of the received packets by the destination node divided by the total number of the sent packets from the source node. Packet delivery ratio (PDR) reflects specifically the packet number lost in the transmission and prove the effectiveness of routing protocols:

$$PDR_{avg} = \frac{P_{receiving}}{P_{sending}} \times 100\% \quad (1)$$

- $Time\ Delay$: Defined as the period to transmit a packet from a source node to a destination node, unit: seconds (s). The average end-to-end delay (Delay) is determined as follows:

$$Delay_{avg} = \frac{\sum_{i=1}^{n}(t_{receiving} - t_{sending})}{P_{receiving}} \quad (2)$$

- $Throughput$: Defined as a multiplication of the total packet numbers and the packet size in a unit of time, unit: bit/second (bps). The following formula determines the throughput:

$$Thoughput_{avg} = \frac{P_{receiving} \times Size\ of\ Packet}{T} \quad (3)$$

- $Routing\ Load$: Defined as the ratio of the total number of the control packet and the total number of the received data packet numbers in a simulation. The NRL parameter shows how many control packets are needed, including route discovery and maintenance packets, to transmit a data packet successfully from the source node to the destination node. The following formula determines NRL:

$$Routing\ Load_{\boldsymbol{avg}} = \frac{P_{Control}}{P_{receiving}} \times 100\% \quad (4)$$

where:

$P_{receiving}$ is the received packet numbers by the destination node.

$P_{sending}$ is the sent packet numbers by the source node

$t_{receiving}$ is the time the received packet at the destination node.

$t_{sending}$ is the time the sent packet at the source node.

T is the time of the measurement process.

IV. ROUTING METHODS

The survey results indicated that aims to improve the abilities of MANETs applications, many routing protocols had been proposed. Based on the collected routing information method, we divided these protocols into three main categories: *On-demand*, *Link-state*, and *Location*. The detailed results are presented in the following subsections.

A. On-demand Routing Method

$AODV\ Protocol$ [18]: The typical routing protocol based on this method is AODV (Ad-hoc On-demand Distance Vector). AODV uses a variety of message formats to detect and maintain routes in the network. When a node wants to use or find a route to another node, it broadcasts the RREQ messages (Route Request) to all neighbour nodes. This RREQ message propagates across the network until it reaches the destination node or a node with a route to the destination. The RREP message is then sent back to the source node. In addition, AODV also uses HELLO messages to broadcast to neighbour nodes.

This message aims to find neighbour nodes. Suppose the node does not receive the HELLO message from a certain node A. In that case, it can be considered as it has moved out of the communication range with node A. The links to this node are considered broken. Then it also reports to the relevant nodes relying on Router Error (RRER) message.

DSR protocol [19]: The routing mechanism of the DSR protocol is similar to the AODV. A difference point, the destination node will decide to choose the suitable route. Based on the making-decision of the destination node, the RREP packet will be sent back to the source node. DSR also uses the on-demand routing method like AODV. Therefore, it does not broadcast routing information periodically.

Consequently, the number of control packets and bandwidth consumption is reduced, saving energy. Besides, DSR also uses two methods of route discovery and update like AODV. **Fig. 3** presents the route discovery procedure of the on-demand routing method.

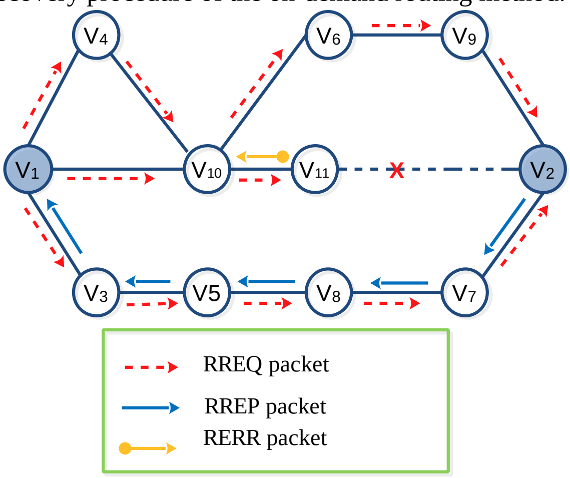

Fig. 3. An illustration of the route discovery procedure of the on-demand routing method.

B. Link State-based Routing Method

OLSR protocol [20]: According to this method, a typical routing protocol is the OLSR protocol. The OLSR protocol is an improvement of the traditional link-state routing protocol. One of the unique features of OLSR is using Multi-Point Relay nodes (MPRs) to limit the flooding of control packets in the network. Each node uses Hello packets to broadcast in two hops to find neighbour nodes. These nodes then elect an MPR node of the range. When a node needs to find a route, it only broadcast in two hops. Only MPRs can broadcast packets to the entire network. As a result, the number of control packets is significantly reduced, leading to improved throughput, power consumption, and other performance metrics.

DSDV protocol [21]: According to this method, a node has information about the path to the entire network based on the routing table. This table contains the destination IP address, destination sequence number, next-hop address, hop count, and setup time. DSDV also uses periodic event-based update tables. At certain intervals, each node will broadcast to neighbours its routing information so that other nodes can update their routing.

C. Location-based Routing Method

A typical routing protocol based on this method is *ZRP* (Zone Routing Protocol) [22]. This protocol divides the network into several routing zones and specifies two separate protocols between the routing zones. The IARP protocol performs local routing operations based on the shortest path algorithm. When there is a change in the network topology, the update information is only transmitted in a relevant routing region, not the entire network. The second IERP protocol is used for routing between areas. When the destination node is out of the coverage range, the protocol broadcasts the RREQ to all edge nodes of routing areas. This procedure is repeated until the requesting node is found and a reply packet is sent to the source node.

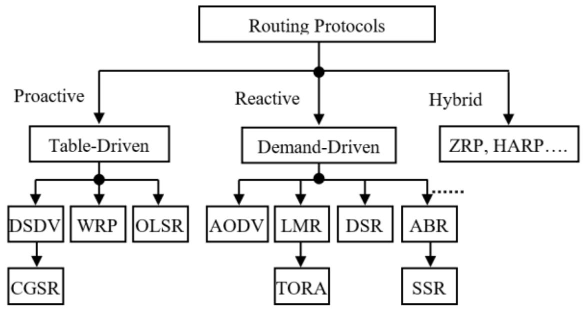

Fig. 4. Several proposed routing protocols for MANETs.

The survey results showed that a series of protocols are proposed for MANETs, as presented in Fig. 4. To visual present the effectiveness of protocols, we will focus on setting simulation parameters to evaluate the performance of the protocols. The detailed results are indicated in the next section.

V. Performance Analytic

TABLE II: SIMULATION PARAMETERS

Parameters	Value
Simulation area	2.000×2000 (m)
Number of nodes	200
Time simulation	200 (s)
Type traffic	CBR
Throughput	2 (Mbps)
Size of Packet	512 (byte)
MAC Layer	802.11
Transport Layer	UDP
Mobility Modern	Random Waypoint
Speed of Nodes	[5-11] (m/s)
Transmission Area	250 (m)

To consider the performance of the most common three routing protocols analyzed in section 4, including AODV, DSR, and OLSR, this work set up a simulation system on NS2 software compared to the performance of protocols under changes of network traffic. In these simulations, we established the CBR traffic with 200 mobile nodes distributed randomly in an area of 2.000 × 2.000 (m). The transmission area of the network nodes is set to 250 (m). The movement speed of each node is set up randomly in ranges [5-11] (m/s), corresponding to the average movement speed in urban areas from [18-40] (km). Moreover, we set the number of end-to-end connections to be: 5, 10, 15, 20, and 25, respectively. The remain simulation parameters are presented in Table II.

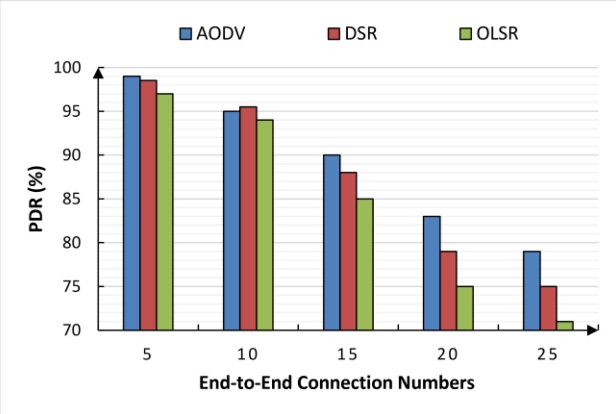

Fig. 5. Average packet delivery ratio & network traffic.

Observing figures in Fig. 5 have shown that protocols have a relatively high packet delivery ratio (PDR) (over 95%) when the number of end-to-end connections is low. The PDR tends to decrease as the number of terminal connections increases. These figures have shown that, as network traffic increases, collisions and re-transmissions will increase. Consequently, the PDR of the protocols will tend to decrease. The results also have shown that when the number of end-to-end connections increases above 15, the PDR of the OLSR protocol tends to decrease faster than the two protocols AODV and DSR. This result again demonstrates the adaptability of the on-demand routing method in MANETs scenarios.

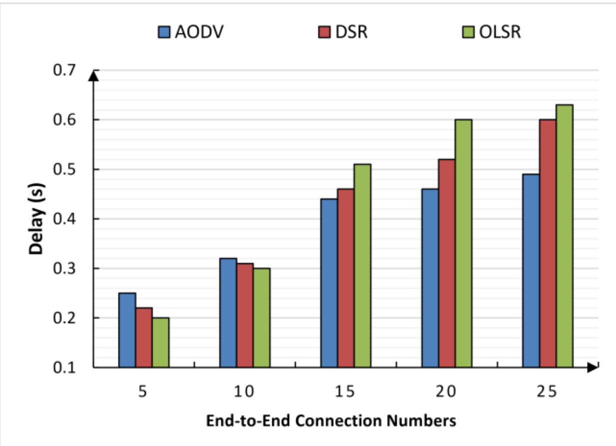

Fig. 6. Average delay & network traffic.

Fig. 6 presents the relationship between average delay and the number of end-to-end connections. Observing the figures has shown that when the number of end-to-end connections is low, the latency of the protocols is very low, less 0.25 (s), and the delay of OLSR is the lowest. The latency of protocols tends to increase as the number of end-to-end connections increases. When the number of end-to-end connections increases above 15, the delay of protocols starts to swap places, the delay of OLSR is higher than the delay of the remaining two protocols. These results are explained collisions and re-transmissions increase as network traffic increases. The figures also have shown that when the number of end-to-end connections increases to 25, the latency of OLSR is significantly higher compared to the remaining two protocols. These results demonstrate that active routing methods are suitable for networks with stable topologies, whereas on-demand routing methods are suitable for dynamic network topologies.

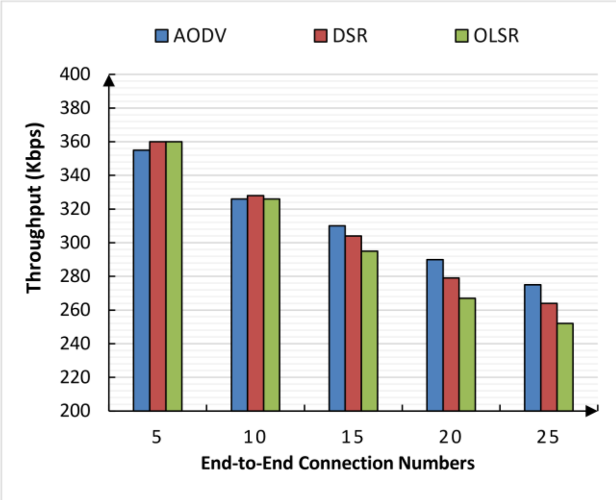

Fig. 7. Average throughput & network traffic.

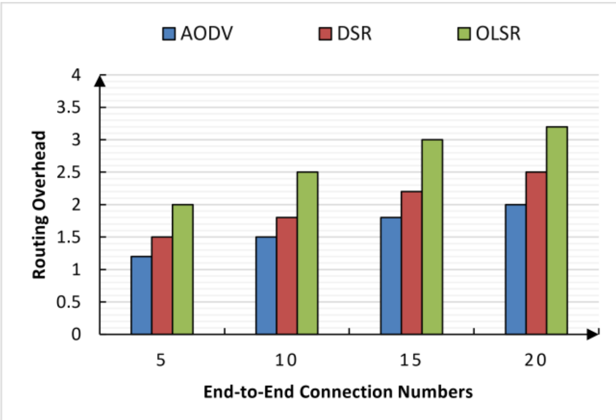

Fig. 8. Routing overhead & network traffic.

If the delay is considered the length of the path, then the throughput is considered the width of the path. Latency and throughput are the two most important metrics to evaluate the performance of a system. Observing the figures in Fig. 7 has shown that throughput tends to decrease as the number of end-to-end connections increases. When the number of end-to-end connections is low, the throughput of protocols is quite similar, the throughput of OLSR is the highest. When the number of end-to-end connections is higher than 15, the throughput of protocols swaps places, the throughput of AODV achieved 310Kbps, higher than the other two protocols. When the number of end-to-end connections increases due to changes in the network topology, collisions and re-transmissions increase. Consequently, the throughput of OLSR is significantly reduced compared to the other two protocols, reaching only about 250 (Kbps).

Routing Overhead is a critical metric that represents the efficiency of a routing protocol. The lower the Routing Overhead, the more efficient the protocol is. On the other hand, it means the cost to successfully deliver a data packet from the source to the destination. Observing the figures in Fig. 8 has shown that Routing Overhead increases when the number of end-to-end connections increases. The results also have shown that the Routing Overhead of OLSR is always higher than the other two protocols. These results can be explained as follows: Since OLSR routing is based on the active method, every time the network topology changes or is cyclical, it broadcasts routing information to the entire network. In the MANET environment, the frequent changes in the network structure led to the OLSR often has to send control packets to update the changes in the network structure. Consequently, the Routing Overhead of OLSR is always higher than the other two protocols and reaches approximately 3 when the number of end-to-end connections increases to 25.

This section focuses on analyzing the figures and simulation results to highlight the effectiveness of on-demand-based routing protocols. The results have demonstrated that when network traffic is low, the efficiency of routing protocols is quite similar. However, the reactive-based protocols improved the packet delivery ratio, throughput, and delay compared to the active-based protocols when the network traffic increases. The results have also indicated a possible research direction to improve the existing routing protocols to obtain a better protocol for MANETs in urban scenarios.

VI. Feasible Research Directions

Along with the development of society, the move demand for humans is increasing, especially in urban areas. As a result, the transportation systems are overloaded, and traffic jams and collisions often occur. To the adaptation of the vehicle-to-vehicle communication environment, the MANET has evolved into a VANET. However, the operating principle of VANET is still inherited from MANET. In recent times, the advent of 5G [23] has led to the formation of a series of VANET applications in the field of intelligent traffic, such as autonomous vehicle systems [24], collision warning [25]. However, smart transportation solutions still face a series of challenges such as service response time, security, and energy efficiency [26]. We point out a number of possible research directions, specifically as follows:

1) Nowadays, most applications are deployed based on the Cloud. The reliability and robustness of the Cloud have been demonstrated for decades. However, the disadvantage of Cloud is the high service response time. In urban and traffic environments, response time is a key factor of applications. Therefore, the reduced service response time of MANET and VANET applications in urban scenarios is an inevitable trend.
2) Data shared between devices and vehicles needs security and privacy. However, due to the limited capacity of mobile nodes, it is infeasible to implement full security algorithms on each device. Therefore, security and privacy on MANETs and VANETs in the urban scenarios are factors to consider.
3) The growing number of mobile devices leads to the consumption amount of huge energy. This is infeasible. Therefore, energy-saving routing algorithms and solutions need to continue to be researched.

VII. Conclusion

MANETs are organizations consisting of mobile wireless network nodes capable of self-configuring and establishing parameters to communicate with each other without relying on pre-established infrastructure. Thanks to these extremely flexible characteristics, MANETs have been applied in a series of areas of humans and promise significant contributions and development of humanity. The survey results have indicated that the performance of MANETs is relatively low. Moreover, due to the ability of mobile nodes, it is not feasible to implement robust security protocols. Therefore, designing flexible, intelligent, and security-aware routing protocols present significant challenges.

The development history of mobile communication systems has demonstrated that the evolution of things is always inherited from existing ones [27]. In this work, we performed a comprehensive analysis of the traditional routing protocols that have been proposed for MANETs. The analysis results presented a common framework to propose new routing protocols. Besides, the results also indicated some exciting results, including the feasibility of on-demand routing methods, clustering methods to limit broadcast packet flooding, or routing partitioning to improve performance and security perception. We hope that the results of this work will be vital guidelines for further studies for urban-MANETs areas.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Dang Van Anh, Vu Khanh Quy conducted the research; Nguyen Duy Tan and Cong-Doan Truong analyzed the data; Nguyen Van Hau proofread the manuscript; all authors had approved the final version. The corresponding author is Vu Khanh Quy.

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