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A Novel Routing Scheme for MANET-Assisted Smart Traffic Applications in 5G Networks

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Abstract—**Intelligent Transportation Systems (ITS) are being vigorously researched and developed. The advent of the 5th generation networks (so-called 5G) in the early 21st century led to the formation of a series of smart applications. Mobile Ad-Hoc Networks (MANETs) are one of the most common solutions for communication between smart traffic applications. With outstanding advantages in establishing flexible connection and communication, recent MANETs are applied in various fields serving humanity, such as healthcare, military, smart agriculture, and smart cities, and are expected to make important contributions to future Internet development. Due to the mobility of network nodes, performance is one of the main challenges of MANETs. Many routing protocols have been proposed for MANETs to solve this problem. In this paper, we propose an improved routing protocol from Dynamic Source Routing (DSR) for MANET-based smart traffic scenarios. The proposed protocol uses mobile agents to collect routing information. The simulation results demonstrate that the proposed protocol improves packet delivery ratio, delay time, and throughput compared to traditional routing protocols in low-speed ITS scenarios.**

***Keywords*—5G, Mobile Ad-Hoc Networks (MANETs), smart traffic, internet of things, mobile agents**

I. INTRODUCTION

Cisco predicts that by 2023, over 66% of the global population have mobile Internet connectivity. A person will have an average of 3.6 mobile devices [1]. The netizen expects seamless and high bandwidth Internet connectivity anytime, anywhere on any device. The 5th generation mobile networks (5G) are forming and are expected to become a revolution in the future Internet. In 5G networks, the device-centric architecture will replace the traditional base station-based network architecture [2]. Moreover, mobile devices are becoming intelligent, compact, and more robust in adapting to the network's central role. According to forecasts by Ericsson [3], more and more network devices are equipped with Mechanism-to-Mechanism (M2M) modules that establish short-range ad hoc connections, as presented in Fig. 1, which is the principle forming Mobile Ad-Hoc Networks (MANETs).

MANETs are mobile devices capable of self-configuring and establishing data-transmission connections without depending on pre-established infrastructure. In recent years, MANETs have demonstrated outstanding communication features with flexible infrastructure. They are applied in a series of sectors such as smart homes and cities [4], e-health [5], smart transportation systems [6], military [7], emergency and disaster recovery [8], and promising important contributions to the future Internet [9, 10].

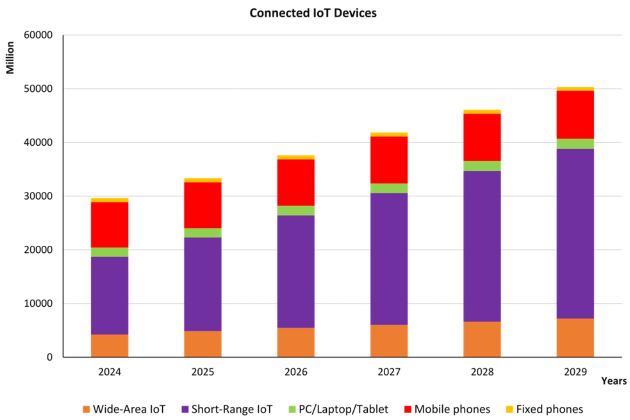

Fig. 1. Ericsson forecasts the number of connected devices to the Internet in the period [2024–2029].

However, in different scenarios, MANETs face challenging problems such as performance, Quality of Service (QoS), energy consumption, and privacy and security. The mobility features of network devices make an uncertain network topology. Consequently, the network performance is low and depends on factors such as topology, operation model, and wireless environment. The surveyed results have proven that routing protocols mainly improve network performance [11]. Therefore, designing efficient routing algorithms for MANETs is one of the challenges to solving this problem.

In this study, we propose a new routing protocol called Intelligence-Dynamic Source Routing (I-DSR). Our key idea is to use mobile agents to obtain routing information. The rest of this study is organized as follows. In Section II,

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we present the Intelligent Transportation Systems (ITS) systems in 5G. Section III shows the relationship of agents, routing, and vehicles. The traditional routing methods are introduced in Section IV. Our proposed protocol is given in Section V. Section VI is the results and analysis, and Section VII is the Conclusion.

II. The ITS Systems in 5G

Recently, Intelligent Transportation Systems (ITS) systems have emerged as a potential solution to the increasingly complex traffic problems of smart cities [12, 13]. In that context, the advent of 5G networks enables the provision of network services with ultra-high throughput and ultra-low latency [14]. In other words, 5G enables the realization of intelligent transportation applications. As a result, a series of intelligent traffic applications have been forming, such as autonomous vehicles [15], collision warning [16], traffic jam warning [17], smart parking [18], smart charging [19], and intelligent payment mechanisms [20]. A comprehensive survey of the standards, applications, and challenges of 5G-based ITS systems is presented in [21].

The architecture of traditional cloud-based ITS systems consists of two layers. The end-user layer includes sensors, vehicles, actuators, Roadside Units (RSUs), etc. This layer is responsible for collecting data and transferring it to the cloud. The cloud layer consists of powerful servers with handling, computing, and storage capabilities linked based on optical backhaul connections. The cloud layer is responsible for all storage, processing, and decision-making. A main feature of the cloud layer is the ability to provide everything as a service, including IaaS, SaaS, and PaaS [22]. The cloud's powerful, reliable computing capabilities have been proven by its resounding success over the past decades. Cloud computing has been applied to almost all human applications and domains [23, 24]. However, one of the biggest hurdles of the cloud is the high service response time [25].

Edge computing solutions have been proposed to address this problem [26]. Instead of just two layers, as in the existing cloud-based architecture, an edge layer is inserted between the cloud and end-user layers. The edge layer consists of servers and computing devices installed at the edge of networks. In ITS systems, edge devices are installed between vehicles and RSUs. A significant goal of Edge Computing (EC) is to shorten the distance between end-users and the database. In other words, it moves the capacity of the cloud to the edge of networks. As a result, service response times are reduced, and real-time ITS systems are realized [27, 28]. Moreover, it also improves energy consumption, privacy, security, and reliability. Fig. 2 presents an edge computing-based architecture for real-time smart traffic systems.

The volume of RSUs is limited, especially in smart cities. Therefore, to communicate between vehicles and the edge layer or cloud, information needs to transfer through multiple hops based on mobile ad-hoc routing protocols. As a result, each group of vehicles with self-connect and self-communicate abilities forms a Mobile Ad-Hoc Network (called MANETs), as described in Section I. The advantages and capabilities of MANETs are outlined in a series of recent applications [29, 30]. However, a major challenge for MANETs is low performance [31]. As a result, this creates a barrier to implementing of real-time ITS systems. Obviously, routing is one of the main challenges to improving system performance [32].

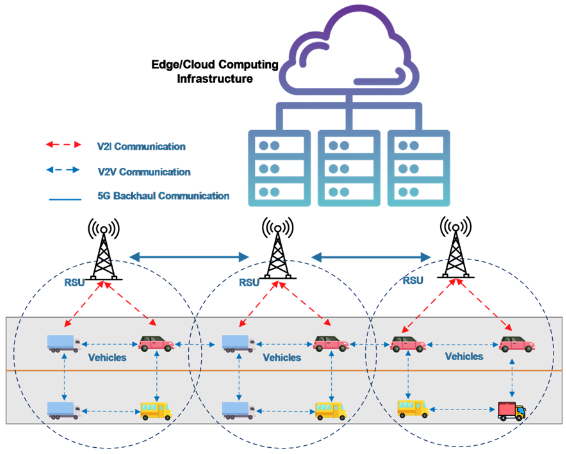

Fig. 2. An illustration of edge computing-based smart traffic architecture.

In this work, we propose a routing protocol for vehicles to improve the overall performance of ITS applications in the exploding development context of 5G applications. Our protocol uses mobile agents to collect routing information between vehicles. Then, based on these parameters, the vehicles can determine the optimal route to transfer data. The details are presented in the following sections.

III. Methods Agents, Routing and Vehicles

In reality, an agent is a physical or logical entity with autonomous ability and can be transparent in the system to perform tasks [33]. In this study, we use mobile agents to obtain flexible routing data and select optimal routes. It reduces network load and latency and improves performance and adaptation across complex heterogeneous 5G network environments for ITS systems. Fig. 3 presents an agents-based routing da-ta-collecting framework for ITS systems. Regarding related issues, several studies have proposed to enhance the performance problems of MANETs based on mobile agents and have achieved some possible results. We can summarize as follows.

In [34], the authors proposed a task distribution algorithm-based relationship of agents for mobile sensor networks. First, the authors determine the score and factors of mobile agents. Then, they combine these parameters in an exponential distribution-based mobility model. The simulation results have shown that this solution improved by 57.23% and 12.31% compared to existing algorithms.

In [35], the authors have considered the security problems of mobile agents for cloud computing. First, the authors compare existing security solutions. Then, they proposed a method to protect mobile agents against attacks on cloud environments by the mobile agent encapsulation and coding. The simulation results have shown that the proposed solution can deal with most attacks.

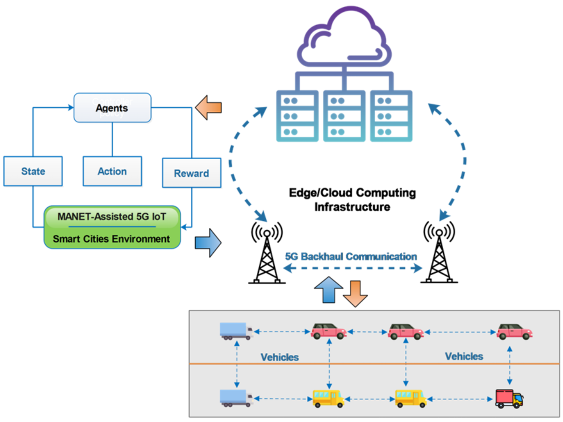

Fig. 3. An agents-based routing data-collecting framework for ITS systems.

In [36], the authors proposed a fuzzy-based method to determine the optimal migration of mobile agents for wireless sensor networks. The authors take hop count, energy, and several neighbor parameters to determine a suitable itinerary for mobile agents. The simulation results have shown that the proposed algorithm improved the success rate of mobile agent round-trips and enhanced the system's network lifetime.

In [37], the authors proposed a novel positioning solution based on mobile agents to provide the accurate position of network devices without relying on Global Positioning Systems (GPS). The authors propose a location estimation algorithm that requires each agent to measure the relative inter-agent distance. The simulation results have shown that the proposed solution improves energy consumption compared to previous algorithms.

In [38], the authors proposed a mobile agent-based coverage optimization solution to improve distributed parameter systems. The optimal moving direction of mobile agents is determined through parameter measurement of mobile agents. Then, motion control laws for mobile agents are established. The simulation results have shown that the proposed solution improves the stability and system performance compared to existing solutions.

In [39], the authors presented a survey of autonomous vehicles based on agents. The authors insist that autonomous vehicles will be the future of intelligent transportation systems. To enhance the ability of systems, they consider the potential of agent-based operating models to enhance systems' ability. This work has concluded that the smart transportation infrastructure should be more insight researched to realize autonomous vehicle systems.

The above studies have approached the use of mobile agents in aspects such as performance improvement, energy saving, security, and integration into ITS. However, in our opinion, heterogeneous 5G network infrastructures in smart cities will be one of the significant challenges for communication applications between vehicles [40]. Therefore, communication protocols need to be more flexible and intelligent. Designing routing protocols for ITS based on mobile agents is one possible approach. That is also the reason we conducted this study.

IV. TRADITIONAL ROUTING METHODS

The routing issue is challenging for mobile wireless networks [4, 6, 7]. Routing processing can happen before or during data transmission processing when a node requests data transmission. There are two typical routing methods: proactive and on-demand. In mobile ad hoc networks, the on-demand-based routing methods are suitable and provide high performance, as indicated in a series of studies [9–11]. In this method, DSR [41] and Ad Hoc On-Demand Distance Vector (AODV) [42] are typical protocols. In this section, we focus on analyzing the DSR routing protocol. Then, we integrate mobile agents into this protocol to obtain routing metrics to enhance performance.

A. DSR Protocol

The DSR protocol is one of the simplest and most efficient protocols for MANETs [43, 44]. It uses a dynamic source routing mechanism, which allows the mobile nodes to self-configure and establish communications without relying on fixed infrastructure, as presented in Fig. 4.

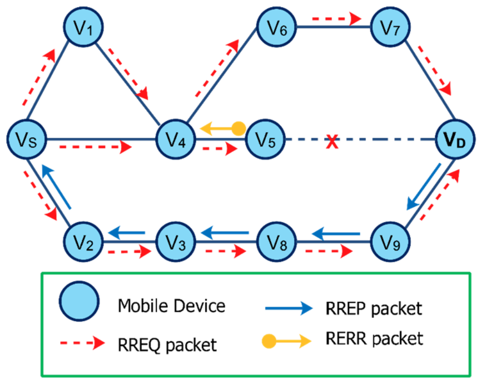

Fig. 4. The route discovery process of the DSR protocol [43].

The header of the data packet will store the order of the intermediate nodes of the path from the source node to the destination node. Therefore, intermediate nodes only need to communicate with their neighbors to forward packets. According to this protocol, each wireless node always maintains a cache memory for routing. On the contrary, when no path exists in the cache or invalid routes, DSR initiates a route discovery process by sending broadcast Router Request (RREQs) messages to neighboring nodes in-network. When a route is found, a Route Reply (RREP) packet containing the order of hops to the destination sends identifiers to the source node. After this stage, the data packets can be transmitted.

The operation of the traditional DSR protocol can be summarized into two phases as follows:

- Stage 1. The route discovery process.
- Stage 2. The routing information is maintained.

The route discovery process is performed as follows:

- Step 1: Check the ID field of RREQ packets. If this RREQ packet has been received, remove this packet and end the procedure. Otherwise, next to Step 2.
- Step 2: Check in the route cache. If the path to the destination node is valid, send the identified RREP packet to respond to the source node with a header of the RREP packet containing routing information. Otherwise, go to Step 3.
- Step 3: Check the destination node address that matches the current node address. If there is, send the identity back to the source node an RREP packet containing routing information and end procedure. Otherwise, send broadcast RREQs to neighboring nodes. The route discovery process continues until the received source node routing information to the destination or the TTL of a packet expires.

B. The Limitations of the DSR Protocol

Analysis of the operating mechanism of the DSR protocol in [31] provides some comments as follows:

- The route discovery process is based on RREQs broadcast and the RREP unicast transmission. All intermediate nodes store routing information. During the route discovery process, intermediate nodes have the learning ability to route to the destination node.
- Each node always maintains information about the entire route, so when there is an errored link or local congestion at a certain node, this route is impossible. The route discovery process is invoked.
- The DSR protocol uses a dynamic source routing method, which always responds to all routing requests. This method helps DSR collect more routes to the destination and better transmission capacity than AODV under low-mobility scenarios. In high-mobility scenarios, the link loss problem leads to a decrease in the MANETs' performance.

In summary, we have found that the routing information maintained by the DSR protocol does not care about the state of neighboring nodes in-route. When a request arrives, if there is a route in the cache, the transmission process is performed immediately, even in the congested intermediate nodes. This is an essential weakness that needs to be improved to further enhance the system's performance. And that's the motivation for our work.

This study is performed in the context of communication problems between vehicles in smart cities. In this context, the moving speed of the mobility devices is controlled under 50 kmph. In our opinion, applying improved protocols based on DSR for these scenarios is feasible.

C. Mobile Agent

In computer science, an agent is an entity that can perform a specific task [31–34] autonomously. In a wireless environment, a mobile agent is small packets sent periodically between neighboring nodes to collect information.

As discussed in Section III, the approach based on mobile agents is attracting the great interest of the scientific community. One of the solutions to improve MANET performance is to determine an optimal routing parameter that reflects the reliability and bandwidth of routes rather than the smallest hop count [31]. Furthermore, due to the uncertain nature of MANET topologies, which aim for nodes to update their information before making decisions [45], we propose a mobile agent pair to update this information. Fig. 5 presents the structure of proposed mobile agents. The meanings of the remaining fields are similar to those described in [45].

There are two types of agents, QA (Request Agent) and LA (Reply Agent), which correspond to two tasks: information request and information reply. We set it up so that every 1 second nodes send QA probe packets to their one-hops. When receiving the QA packet, these nodes return the LA packet to provide information to the requesting node. Based on the collected data, each node will decide on the most suitable route.

RQA	Type	Traffic Density	Hop Count	Dest_ID	Dest Seqno	Src ID
RLA	Type	Traffic Density	Hop Count	Dest_ID	Dest Seqno	SrcID

Fig. 5. The structure of mobile agents.

V. PROPOSED ROUTING PROTOCOL

This section presents the idea, operating principle, routing method, and our proposed protocol in detail. Firstly, we modeled MANETs by a weighted graph. Then, we conduct simulations to evaluate the performance of the proposed protocol and other traditional protocols for MANET through the Network Simulation 2 (NS2) simulation software, specifically as follows.

A. Idea of Proposal

The unbalanced distributed flow density may cause flow congestion problems in MANETs. In the route discovery process, some centric nodes contain many routes. To solve this issue, we use mobile in-network agents to update traffic density at each node. Our proposed solution's new idea is predicting nodes' congestion ability based on mobile agents. The aim is to reduce the traffic density passing through a node over the total routes in one-hops. Finally, our proposed protocol will select an optimal route based on the lowest density rate to limit congestion ability.

B. Protocol Specification

Our proposed protocol has the same operating principle as the traditional DSR protocol. The routing process consists of two stages, the route discovery process and the route maintaining process, as described in Subsection IV. A. A key difference of the proposed protocol is that instead of using the smallest hop count, we use an integrated metric from two metrics: hop count and traffic density. The method of obtaining and calculating parameters is presented as follows.

We set up a pair of mobile agents, called QA and LA to exchange traffic density information with neighbouring nodes in one hop, as presented in Subsection IV. C. The route discovery process is performed as in the traditional DSR protocol. RREQ packets are modified headers as follows {MaxTraffic|DSR RREQ Header}. Then, RREQs will reach the destination through intermediate nodes.

The packet forward mechanism is the main difference between this protocol compared with the traditional DSR protocol. When an intermediate node receives the RREQ packet, it invokes the Traffic-Density procedure, as presented in Fig. 6. This procedure obtains the traffic density of a path. Next, the estination network node will be obtained a set of candidate paths with parameters which are provided by RREQs. Then the destination node will then select the optimal route and send unicast the RREP packet to the source network node.

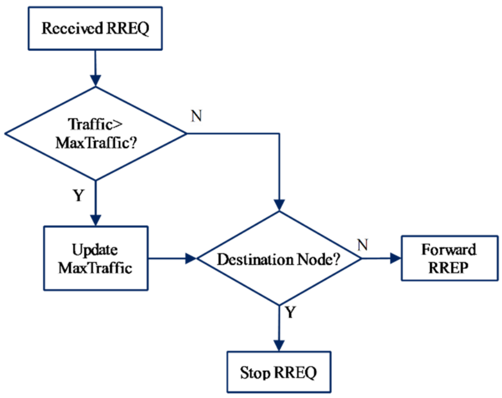

Fig. 6. The Traffic-density procedure.

C. Routing Method

The destination node obtains the candidate route set, with the routing parameters being the hops and the highest traffic density of the route. To select the optimal route, we define a cost function as follows.

1) The hop-count number of candidate routes must be within scope $[H^{max}, H^{min}]$. If a route has the hop-count number out of this scope, it will be discarded.

$$Hopnumber = [H^{max}, H^{min}] \tag{1}$$

where, H^{min} is the hop-count of the shortest candidate route. To discard the redundant routes, we have a constraint:

$$H^{max} = H^{min} + 2 \tag{2}$$

2) Symbol $Dist$ is the number of hop count, and D is the traffic density of the route. To determine a route that has the highest residual energy, we define the cost function:

$$CP_{(P)} = w.Dist + (1 - w).D \tag{3}$$

Accordingly, Eq. (3) determines the optimized route. Table I illustrates how to determine the routing cost with different values.

Assuming there exist nine routes between the S (Source) node and the D (Destination) node, as presented in each scenario (in Table I).

- In Scenario 1, we found that route 4 with P = 5 and D=3 will provide the smallest average traffic density in the entire route. Therefore, it is suitable.
- Scenario 2 has up to three suitable routes, including routes 1, 4, and 7. Consequently, whichever route among these three routes comes first will be selected.
- In Scenario 3, Route 9 has high hop count numbers, but the traffic density is lower than that of the existing routes. Therefore, it will be selected to transmit data.

TABLE I. THE METHOD CALCULATES TO OBTAIN THE ROUTING COSTS

Scenarios	Route	P	D	w	CP
Scenarios 1	1	4	5	0.5	4.5
	2	4	6	0.5	5.0
	3	4	7	0.5	5.5
	4	5	3	0.5	4.0
	5	5	5	0.5	5.0
	6	5	7	0.5	6.0
	7	6	3	0.5	4.5
	8	6	4	0.5	5.0
	9	6	5	0.5	5.5
Scenarios 2	1	4	5	0.5	4.5
	2	4	6	0.5	5.0
	3	4	7	0.5	5.5
	4	5	4	0.5	4.5
	5	5	5	0.5	5.0
	6	5	7	0.5	6.0
	7	6	3	0.5	4.5
	8	6	4	0.5	5.0
	9	6	5	0.5	5.5
Scenarios 3	1	4	5	0.5	4.5
	2	4	6	0.5	5.0
	3	4	7	0.5	5.5
	4	5	4	0.5	4.5
	5	5	5	0.5	5.0
	6	5	7	0.5	6.0
	7	6	3	0.5	4.5
	8	6	4	0.5	5.0
	9	6	2	0.5	4.0

VI. SIMULATION AND RESULT ANALYSIS

In this section, we provide simulation parameters, scenarios, and analyst results, specifically as follows.

A. Simulation Scenarios

In this subsection, we have performed simulations to evaluate the system performance under low mobility scenarios in smart cities on NS2 simulation software. We have established the mobility speed of the network nodes in the range [1–10] (m/s). We set up the end-to-end connection numbers in all simulations to 30 pairs. The system performance is considered to consist of three main parameters, including average end-to-end delay, average throughput, and average packet delivery ratio. Other parameters are presented in Table II.

TABLE II. SIMULATION PARAMETERS

Parameter	Value
Simulation Area	2,000 × 2,000 m
Number of Nodes	100
Type Traffic	Constant Bit Rate (CBR)
Bandwidth	11 Mbps
Size of Node	1,024 byte
Time Simulation	300 s
Mobility Model	Random Waypoint
MAC Layer	802.11 b
Transport Layer	User Datagram Protocol (UDP)
Mobility Speed	[1–10] (m/s)
Protocol	AODV, DSR, I-DSR

B. Results and Analysis

Fig. 7 presents the relationship between mobility speed and packet delivery ratio. The simulation results have shown that when the mobility speed of nodes is low, under 5 (m/s), the packet delivery ratio of protocols is high. When the mobility speed of nodes increases, the packet delivery ratio of I-DSR improves significantly compared to other protocols. This may be explained as follows: when mobility speed is low, the network topology is relatively stable, and break link rates are low, which leads to the packet delivery rate of high-performance protocols.

As the node speed increases, the network structure changes continuously, leading to high broken links and increased retransmission and collision rates. Therefore, the packet delivery ratio tends to decrease. The proposed protocol is based on a dynamic balancing mechanism, which allows the selection of different routes based on hops and traffic density to minimize collisions at nodes with high traffic density. Consequently, the I-DSR improves the packet delivery ratio compared to single metric-based protocols such as DSR and AODV in low-mobility MANET scenarios.

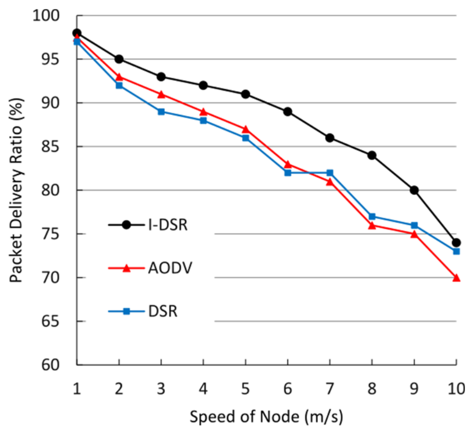

Fig. 7. Packet delivery ratio.

Fig. 8 presents the relation between mobility and average throughput. The simulation results have shown that when the mobility speed of the nodes is low, under 5 m/s, the throughput of protocols is relatively high. As the mobility speed of nodes increases, the throughput of protocols declines rapidly and markedly.

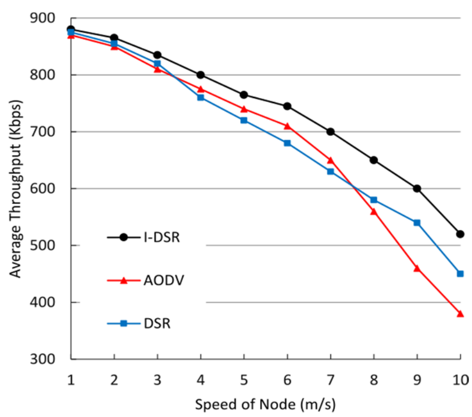

Fig. 8. Average throughput.

The throughput of I-DSR is significantly improved compared to other protocols. These results emphasize the significance of the dynamic balancing mechanism in our proposal. Thanks to this mechanism, the route between node pairs between source and destination is selected depending on the traffic state at each node, thus reducing the possibility of collisions and congestion at the crowded nodes. This opens up opportunities for applying this algorithm to traffic forecasting and coordination problems to limit traffic congestion in urban areas.

Fig. 9 presents the relation between mobility and average end-to-end delay. The simulation results have shown that the delay tends to increase when the mobility speed of nodes increases. Specifically, when the mobility speed of nodes is up to 6 (m/s), the end-to-end delay of protocols increases rapidly. The end-to-end delay of I-DSR is improved compared to other protocols. In addition to the dynamic balancing mechanism, another highlight of our proposed protocol is the ability to select candidate routes with minimal end-to-end delay. Observe scenario 2, Table I, when there are 3 candidate routes 1, 4, and 7, with the same cost of 4.5. The route with the lowest end-to-end delay will reach the source node first and be selected by the algorithm. As a result, I-DSR always selects the optimal route with low latency and avoids the generation of congested nodes to improve system performance.

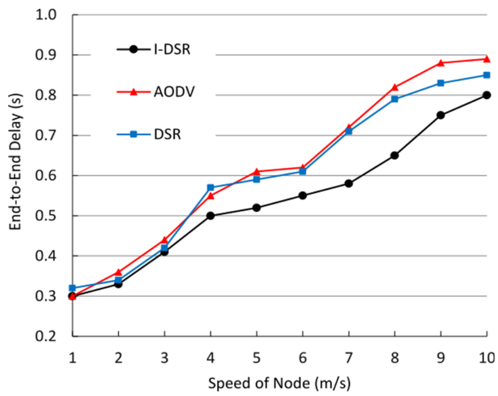

Fig. 9. End-to-end delay.

VII. CONCLUSION

In this study, we propose a routing protocol, improved from DSR, to enhance system performance for traffic scenarios based on 5G networks. Instead of relying on a single routing parameter, our protocol uses an integrated parameter based on hops number and traffic density. We use mobile agents to exchange information in one-hops to get traffic density. The simulation results have demonstrated that our proposed protocol significantly improves the system performance regarding packet delivery ratio, throughput, and end-to-end delay. In addition, we have also indicated the possibility of applying this protocol in traffic forecasting and coordination problems to limit traffic congestion in urban areas based on MANETs, which can be self-established quickly based on personal mobile devices. This approach is feasible and highly effective. A limitation of this work is that it has not been experimentally implemented in the real world.

Furthermore, routing decision-making needs to be optimized with the support of federated learning techniques and edge computing technologies. These issues will be solved in our future studies.

Conflict of Interest

The authors declare that they have no conflict of interest.

Author Contributions

N.M.Q and C.M.H conducted the research; N.M.Q made the system model and simulations; C.M.H analyzed the data. All authors had approved the final version.

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