An Adaptive On-demand Routing Protocol With QoS Support for urban-MANETs

Nguyen Minh Quy, Nguyen Tien Ban, Vu Khanh Quy

Abstract—**Mobile Ad Hoc Networks (MANETs) are organizations of mobile network devices that ability to self-configuring and self-setting parameters for effective in-network communication. Thanks to the intelligence and flexibility in connections and transferring data, MANETs have demonstrated outstanding capabilities and abilities in a wide range of fields serving humanity, such as healthcare, intelligent transportation systems, smart agriculture, smart retail, and IoT ecosystems. Due to the mobile characteristics of wireless nodes, the structure of MANETs changes frequently. Moreover, the operating principle of MANETs is distributed, not relying on central devices such as base stations, leading to the guarantee QoS problem is one of the main challenges of MANETs. In this study, we proposed a QoS-aware on-demand routing protocol (QoS-ADRP) for urban-MANET applications. To enhance the feasibility of the proposed solution, we establish a mechanism so that the proposed protocol can work on both Adaptive and Admission modes. The experiment results demonstrated that the QoS-ADRP improve the QoS flows, packet delivery ratio, latency, throughput compared to existing protocols.**

Index Terms—**QoS-aware, Routing Protocol, MANETs, Urban Environment**

I. Introduction

THE launches of 5^{th} generation mobile networks, also well-known as 5G in the early 2020s, firstly time allowed to realistic a comprehensive digital society of humanity. 5G supports to provide network services with ultra-low delay and ultra-high bandwidth [1]. The architecture of 5G will be heterogeneous networks, and network devices will be equipped with M2M (Machine-to-Machine) modules [2] that can establish direct communications between devices, and is the principle that forms the Mobile Ad Hoc Networks (MANETs).

MANETs are the organizations of mobile network nodes that ability self-configuration self-establish to efficiently communicate in-network without relying on pre-fixed infrastructure and centralized administrations [3]. Due to the nature of MANETs is the mobility of the nodes and the network architecture without relying on pre-installed centric devices such as base stations led to it has some disadvantages such as low performance, limited resources and not security [4]. However, the ability and capacity of MANETs are demonstrated in series of areas to serve humanity such as disaster recovery [5], military [6], healthcare [7], entertainment [8], and smart cities [9-10]. In [11] presented a diverse survey of MANET applications for different areas.

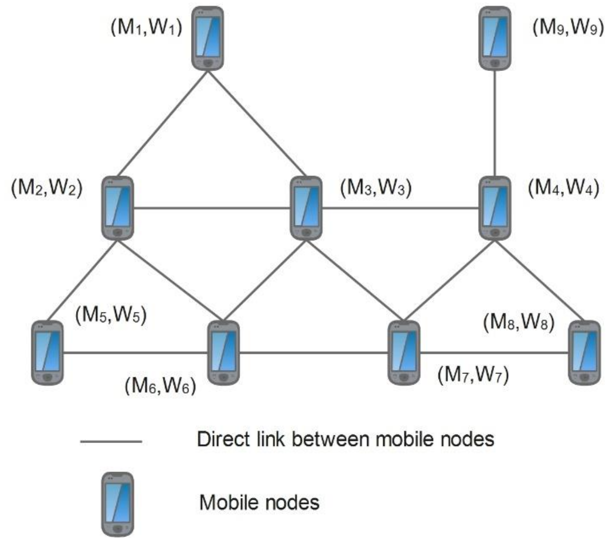

Fig. 1. An Illustrition MANET structrute.

In MANETs, all wireless nodes can transfer data with other network devices directly or indirectly through intermediate mobile network nodes. Due to the mobility characteristics of the nodes, the MANETs structure is unstable. The links usually are broken, and the probability of re-transmission packets is high. Consequently, system performance such as quality of service and throughput are low while latency and energy consumption are high. Hence, the routing problem is one of the main challenges of MANETs [1, 12].

Aim to improve the MANETs performance, a series of studies have been proposed in [5-8], [30-31]. Survey results of routing protocols indicated that the MANETs performance is relatively low and evaluated by primary metrics such as throughput, latency, and packet delivery ratio. A suitable routing protocol will have strong substantial to network performance, energy consumption, and quality of service of the whole system [13]. For those reasons, the design of high performance, guarantee QoS, and saving energy have always been a timely topical and the concern of researchers.

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The survey of the proposed routing solutions for MANETs indicated that routing protocols might be classified based on the routing method or the network architecture [9]-[10]. According to the routing method, the protocols are classified into $active\ routing$ and $reactive\ routing$. According to the network architecture, the protocols are classified into *hierarchical routing*, *flat routing*, and *location-based routing*. Surveys also presented that the reactive-based routing protocols save energy and are more suitable than active-based routing protocols [14-15]. Two typical on-demand protocols are Ad hoc On-demand Distance Vector (AODV) [16] and Dynamic Source Routing (DSR) [17] proposed by the IETF for MANETs. However, the MANETs performance is dependent on the MANETs structure, network size, and network traffic [2]-[4]. Currently, no class of solution or algorithm can solve all problems. Each method has different positives and limitations and is only suitable for some scenarios. For certain purposes, as in urban-MANET scenarios of this study, we can combine existing methods to make a more efficient solution.

In order to solve the problem, we design and deploy a reactive protocol for urban-MANETs. This protocol uses two routing metrics, are *throughput* and *hops* number, to make the decision aim to select the fit path. This protocol is improved from AODV with the main purpose of guarantee the quality of service of the network. Unlike the traditional protocols, the QoS-ADRP (QoS-aware on-demand routing protocol) integrates a costing function from two metrics: hops number and throughput to select the optimal route for data transmission.

The rest of the study is organized as follows: In the next section, we present the related work. Section 3 presents the proposed routing protocol. Section 4 presents different simulation results to verify the achievable performance of the proposed protocol, and Section 5 is Conclusions.

II. RELATED WORKS

The resource limitation of network nodes and mobility are the main factors that affect the performance of MANETs, especially in high movement speed scenarios. The mobility of network nodes will affect the stability of routes, so the design the smarter and flexible routing solutions to adapt to network topology changes and support QoS is necessary. Survey recent studies [18]-[25] indicated that the performance improvement and guarantee QoS research direction for communication solutions in urban are achieved certain results. The main approaches to this area may be summarized as follows.

In [18], *A. M. Mezher et al.* (2017) proposed a multi-metric routing method to send videos for urban-VANETs scenarions. This protocol uses five routing metrics, includes trajectory, distance, density, bandwidth, and MAC layer losses, to decision-making select optimal routes. The results have indicated that this solution decrease latency and enhance packet delivery ratio compared to traditional protocols.

In [19], *D. Lin et al.* (2017) designed a zone-based routing solution to transfer data between cars for VANETs. Specifically, they proposed each vehicle is equipped with a global positioning system to determine the real-time location information. Then, a routing algorithm combined with clustering techniques to decision-making select optimal routes aims to improve overall network performance. The results have indicated the proposed protocol significantly improves the routing load and packet delivery ratio compared to existing protocols.

In [20], *W. A. Jabbar et al.* (2018) proposed a hybrid routing protocol based on multi-metric for the purpose of energy-saving and support QoS in the MANET-WSN convergence scenarios of IoT networks. Specifically, they proposed a new rank method to rank network nodes based on energy and QoS metrics, include lifetime, residual energy, speed, and queue length. Besides, this protocol also proposed a multipoint relay node selection method based on energy and QoS metrics. The results have indicated that this solution improves performance, QoS, and reduced energy consumption compared to the traditional routing protocol under different MANET-WSN convergence scenarios of traffic and mobility.

In [21], $I. Kacem\ et\ al.$ (2018) introduced a novel routing method based on the fuzzy synchronized Petri Net model and ant optimization algorithm for MANETs. Specifically, they use Fuzzy Petri Nets to discover and decision-making select optimal routes, while ant algorithm is used to find a solution for uncertain events in the network. The results have indicated that the efficiency of the proposed solution in terms of performance and QoS compared to traditional solutions.

In [22], *Q. Zhang et al.* (2019) proposed a new multicast model based on genetic algorithms to guarantee QoS in MANETs. Specifically, they proposed the new model guarantees the duration time of a link in a multicast tree is longer than the delay time from the source node. The results have indicated that this model enahnces QoS flows and delay compared to the traditional methods in MANETs scenarios.

In [23], *M. Sivaram et al.* (2019) proposed the advanced routing protocol, improved from the existing DBTMA protocol for support QoS in MANETs. Specifically, they proposed two elements, namely: busy tones and RTS/CTS dialogues. These signals allow determining the faster re-transmission after the collision occurred by the nodes. The simulation results indicated that this protocol enhances system performance, quality of service, and decrease route discovery latency up to 38% compared to traditional protocols.

In [24], *Z. Chen et al.* (2020) proposed a multipath routing protocol to guarantee QoS for high mobile MANETs scenarios. Specifically, they proposed a mechanism to predict the disconnect of links. Then, they use a multi-metric routing algorithm based on parameters, such as remain energy, bandwidth, queue, and reliability. The simulation results have indicated that the proposed solution enhances system performance and QoS compared to traditional protocols in scenarios the movement speed of nodes up to 108 km/h.

In [25], *B. U. I. Khan et al.* (2020) proposed a routing approach relying on the game theory for guarantee QoS in MANETs. Specifically, they evaluate the repute of each node based on the collaboration level of a node aims to encourage the positive of nodes jointly in the data forward.

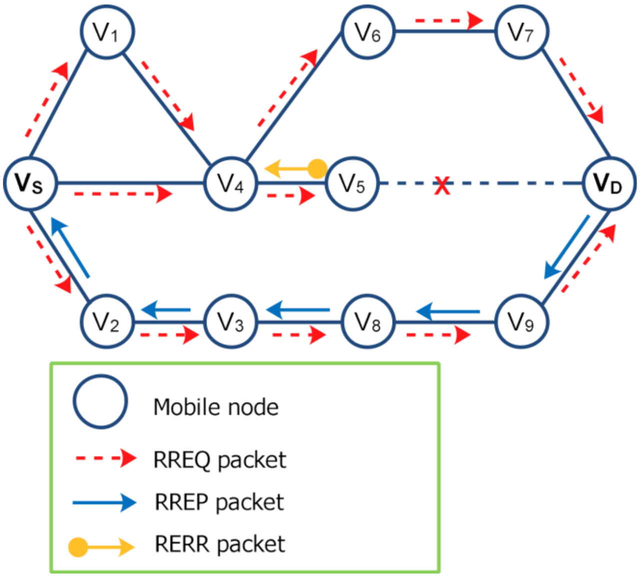

Fig. 2. Three operational states of the QoS-ADRP protocol.

The results have indicated that the proposed solution enhances system performance and QoS compared to traditional solutions.

According to this research direction, the existing protocol very close to this study was proposed in [26]. Some of the key differences are routing metrics, cost functions, and simulation scenarios. Specifically, instead of using an integrated metric between bandwidth and delay, in this study, we use an integrated metric of bandwidth and hop. These changes will reduce the complexity of determining the routing metric of each route. Furthermore, it also leads to a simpler and more efficient routing cost function. In addition, movement scenarios suitable for the urban environment are also used.

Although these above solutions enhanced the performance and quality of service of MANETs in specific scenarios, however, in the urban-MANETs environment, the system performance and QoS flows is affected by many factors such as dynamic network structure, mobility of network nodes, size of the network. Therefore, the QoS support and performance improvement problems are always timely and attract the attention of researchers.

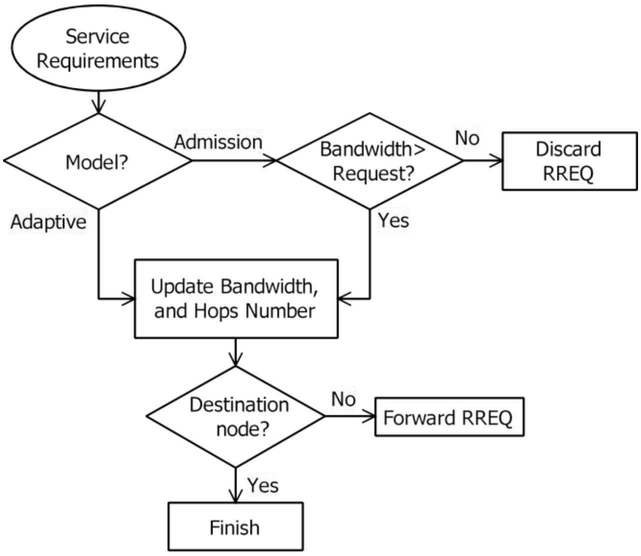

Fig. 3. *Bandwidth – Check* procedure.

III. PROPOSED ROUTING PROTOCOL

The main purpose of the QoS-ADRP protocol is to support QoS and enhance the whole system performance of urban-MANETs. We have improved the type traditional protocol is AODV to establish a more suitable one for scenarios. We approached this direction because survey results demonstrated that in the MANETs environment, reactive routing protocols are more suitable than proactive protocols [11-12]. Moreover, AODV always has performance stable and high in many different MANETs scenarios.

A. Protocol Description

Aim to support transportation applications in an urban environment, QoS-ADRP should is designed to smooth operation in both modes: Adaptive and Admission, as follows:

Adaptive mode: aim to provide a route with the best bandwidth.

Admission mode: aim to provide the guaranteed bandwidth.

The route selection procedure requires knowledge of the bandwidth of routes between a node pair (S, D). This information is obtained based on the route discovery process, as follows:

Like AODV, the QoS-ADRP routing protocol operates on the principle that whenever a wireless device needs to communicate, the source node will activate the route discovery procedure to find routes to the wireless device. The discovery procedure initializes with the *S* node sends the RREQ packets, with the header changed as follows {*Model-Flag, MinBandwidth, AODV RREQ Header*}. Then, RREQ packets are forwarded through intermediate nodes to reach the *D* node, such as in Fig. 2 (red line).

The *D* node or intermediate node (the node that knows the route to the *D* node) will respond by sends the RREP packet back to the *S* node, such as in Fig. 2 (green line). The main difference from the traditional AODV is the packet forwarding method. At each intermediate network node, when received the RREQ packet, these nodes perform a procedure called *Bandwidth-Check*. This procedure is described in Fig. 3, has two main tasks:

(1) To remove immediately routes not satisfy bandwidth conditions. This issue helps to decrease bandwidth, energy consumption as well as routing load spent in unnecessary operations.

(2) Identify the minimum bandwidth of the route. The bandwidth of each link is determined based on information of the *Hello* messages (see [27] for more details). Finally, the destination node will calculate the optimal path based on parameters provided by the RREQ packet and sends the RREP packet to the source node. Besides the path discovery procedure, our protocol also has path maintenance procedures that use RERR packets, such as in Fig. 2 (yellow line). In that way, the *S* node is received candidate routes to the *D* node.

B. Method of Route Selection

To enhance the performance of the proposed routing protocol, we consider parameters that affect the MANETs performance. The surveyed results in [11], [28-29] indicated that the key parameters that affect the MANETs performance are hop numbers, link quality, and queue length at nodes. Then, we make modify the AODV to establish the QoS-ADRP protocol.

We include the bandwidth parameter that the most affect the whole system performance into the cost function to decision-making choosing a suitable route. Common, the traditional routing protocols making-decision optimal route based on the smallest hopcount number. However, the shortest route may not provide the highest performance. Note that the performance usually is determined based on main criteria, include: delay time, throughput, and packet delivery ratio. To enhance the system performance, we introduce a cost function based on parameters as follows:

- $P_{(i)}$: the hopcount number which packets must go from the source to the destination on the i route.
- $Bandwidth_{(i,j)}$: the throughput of the link between a node pair (i, j)

After receiving a set of candidate routes by the route discovery procedure, we define and use a cost function to select the QoS guaranteed route, as follows:

Let $Bandwidth_{(i)}$ is the minimum bandwidth of the route i. Then, the cost function of the route i can be determined as follows:

$$Cost\_route_{(i)} = \frac{Bandwidth_{(i)}}{P_{(i)}} \tag{1}$$

Next, let Z and $Cost\_Set$ be the route number and the routing cost set of the candidate routes satisfying bandwidth condition, respectively as follows

$$CostSet = \begin{cases} Cost\_route_{(1)} \\ Cost\_route_{(2)} \\ . \\ . \\ . \\ Cost\_route_{(Z-1)} \\ Cost\_route_{(Z)} \end{cases} \tag{2}$$

$$Optimalpath = Max\ (CostSet) \tag{3}$$

Finally, the optimal route is determined by Eq. (3). The algorithm selects the optimal path of the QoS-ADRP protocol is presented in $Algorithm$ 1.

Algorithm 1: QoS-ADRP Route Selection Algorithm

```
routeset = shortest − route(S, D)
// Equation (2) & (3)
Cost = 0, Selectedroute = {∅}
for i = 1 to sizeof(routeset) do
    if Cost < Cost_route(i) then
        Cost = Cost_route(i)
        Selectedroute = routeset(i)
    end if
end for
return (Selectedroute, Cost)
```

C. Modifications of Control packet

To the QoS-ADRP protocol is received routing information, the route cost is calculated as in Eq. (1) and (2), and making the routing decision based on Eq. (3). We store the cost value $Bandwidth$ into the $Reserved$ field of the header of the RREQ (Router REQuest) packet. This method has been proposed in some recent research [11], [18-19], [22], [27]. The use of the $Reserved$ field in the header of the RREQ packet does not only allow the network nodes to determine the $Bandwidth$ cost but also not reduce performance or energy consumption for the system. Fig. 4 presents the RREQ packet structure after being changed.

Type	Reversed	Last hop	Hop count	Bandwidth
RREQ ID				
Destination IP Address				
Destination Sequence Number				
Originatior IP Address				
Originator Sequence Number				

Fig. 4. The header structure of the RREQ packet after the change.

IV. PERFORMANCE EVALUATION

In order to evaluate the system performance of the proposed protocol, in this section, we establish parameters, simulation, and analyze the results as follows:

A. The Metrics to Evaluation performance

In this study, the system performance is evaluated based on criteria as follows:

- $Packet\ Delivery\ Ratio\ (PDR)$: Defined as the percentage of total packets received over the total packets sent during the entire simulation.

$$PDR = \frac{P_r}{P_s} \times 100\% \tag{4}$$

- $Average\ End-to-End\ Delay\ (Delay)$: Defined as the total time from when the sent packet until the received packet on the total number of packets transmitted successfully during the entire simulation process.

$$Delay = \frac{\sum_{i=1}^{n}(t_r - t_s)}{P_r} \tag{5}$$

- $Throughput$: determined by multiplying the packet numbers are transmitted and the packet size per one second.

$$Throughput = \frac{P_r \times Size}{T} \tag{6}$$

- $Routing\ Overhead$: Defined as the ratio of the total control packet number per the total data packet numbers received by the source node:

$$Routing\ Overhead = \frac{Control\ Packets\ Number}{P_r} \tag{7}$$

where, P_s and P_r, respectively are the packet number sent by the source nodes and the packet number received by the destination nodes.

t_s and t_r, respectively are the time the packet is sent at the source node and the time the packet is received at the destination node.

T is the time of the measurement process.

$Size$ is the size of the packet.

B. Simulation Parameter

To compare the system performance of the QoS-ADRP with existing routing protocols, we establish simulations on NS2 version 2.34. The simulations are conducted under different scenarios in terms of mobility level in all two modes: *Adaptive* and *Admission*. In all scenarios, we randomly arrange 200 mobile network nodes that use the CBR traffic type. We also use the random waypoint model in an area of 2000×2000 (m). The transmission range is set up default value is 250 (m). Mobility velocities of network nodes are set randomly in the range $[0, V_{max}]$. Where, $V_{max} = [1 - 10]$ (m/s) (simulation of the real speed of vehicles in urban environments).

The system performance is evaluated in both *Adaptive* and *Admission* modes with the difference in terms of node numbers and velocity. The end-to-end connection numbers are established 50 pairs in all cases. In *Adaptive* mode, we observe performance metrics, including packet delivery ratio, throughput, and delay. In *Admission* mode, we observe performance metrics, including delay, throughput, and routing overhead. Simulation parameters are summarized in Table I.

TABLE I
SIMULATION PARAMETERS

Parameters	Value
Simulation Time	500s
Simulation Area	2.000m×2.000m
Number of Nodes	200
End-to-End Connection Number	50
MAC Layer	802.11
Traffic Type	CBR
Bandwidth	1 Mbit/s
Size of Packets	1024 byte
Transport Layer	UDP
Bandwidth Request	100 Kbps
Mobile Speed	(1-10) m/s
Communication Range	250 m
Mobility Model	Random Waypoint
Protocols	QoS-ADRP, AODV, DSR

C. *Adaptive Mode*

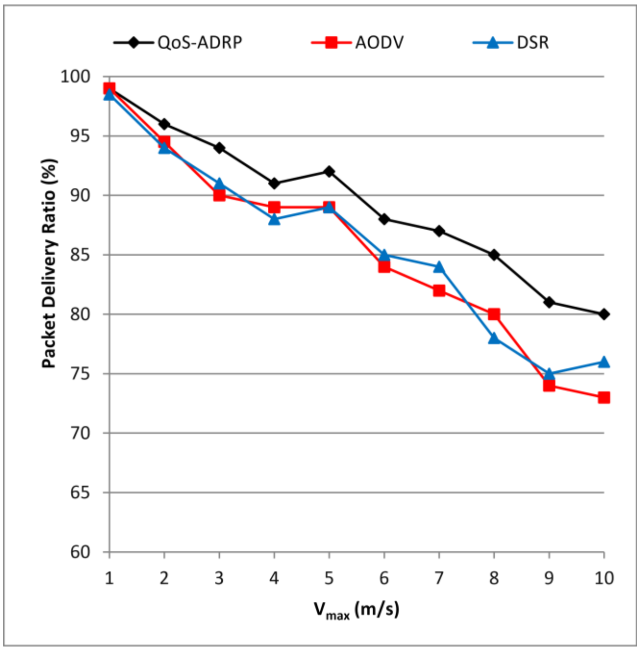

Fig. 5. Average packet delivery ratio in *Adaptive* mode.

In *adaptive* mode, we compare QoS-ADRP with two traditional routing protocols on the aspect of delay, average throughput, and average delivery ratio. Simulation results are presented in figures 5, 6, and 7 indicated that as the velocity of network nodes increases, the structure of the network changes more rapidly lead to a higher broken link ratio. As a result, the retransmit packet numbers will be more increased. This issue will lead to bandwidth consumptions and end-to-end delay increased as well as the average delivery ratio reduced.

Fig. 5 presents the average delivery ratio results of all three protocols in the *Adaptive* mode. The results indicated that as the velocity of network nodes increases, the packet delivery ratio decreases. However, the average delivery ratio of the QoS-ADRP is improved significantly compared to the AODV and DSR protocols. It is enhanced by over 7.5% at $V_{max} = 9$ (m/s).

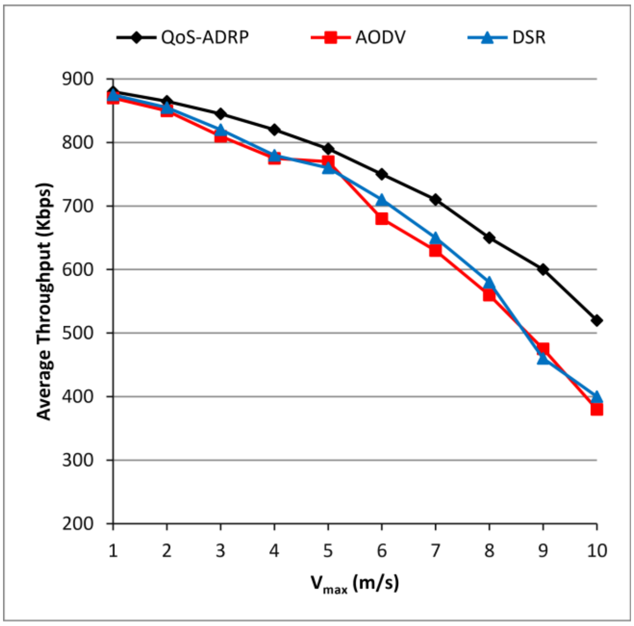

Fig. 6. Average throughput in *Adaptive* mode.

Fig. 6 presents throughput in *Adaptive* mode. When $V_{max} < 5$ (m/s), the throughput of all three protocols is rather high and not much different. When V_{max} increases,

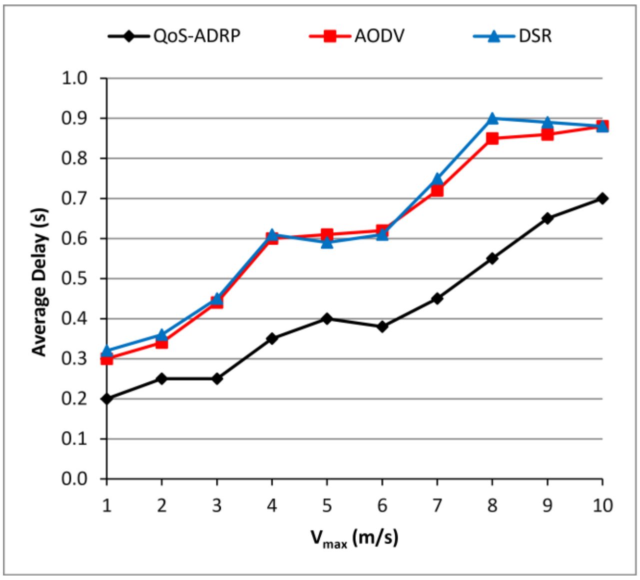

Fig. 7. Average delay in *Adaptive* mode.

the throughputs tend to decrease. However, due to the optimized routing method, the QoS-ADRP always selects routes with high throughput. Hence, the throughput of QoS-ADRP is better compared with other protocols. At V_{max} = 10 (m/s), the throughput of QoS-ADRP is higher by 20%.

Fig. 7 presents the end-to-end delay in *Adaptive* mode. The average latency of the three protocols tends to increase rapidly as the velocity of network nodes increases. However, due to the optimized routing method, the end-to-end delay of QoS-ADRP is always lower than the other protocols. At $V_{max} > 5$ (m/s), the average latency of QoS-ADRP is improved by 20% compared to the remaining routing protocols.

D. Admission Mode

In *Admission* mode, we compare QoS-ADRP with two traditional routing protocols in terms of packet delivery ratio, end-to-end delay, and routing overhead. Again note that a link is discarded immediately if the available bandwidth is lower than the requested bandwidth. As a result, the candidate route numbers are obtained in this mode will less than the adaptive mode. As a result, the routing packet numbers and the collision ability will decrease. We expected that the packet delivery ratio, end-to-end delay, and routing overhead of QoS-ADRP would improve significantly compared with other traditional protocols. In this mode, we still use the same network structure and simulation parameters. Simulation results are as follows:

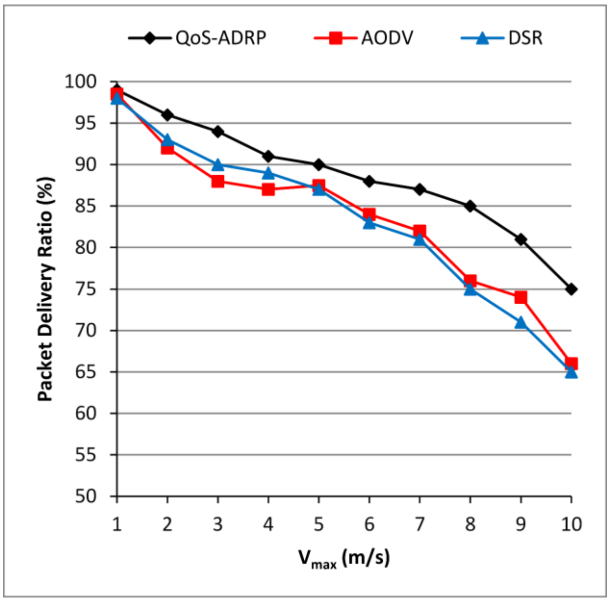

Fig. 8. Average packet delivery ratio in *Admission* mode.

Fig. 8 presents the packet delivery ratio in *Admission* mode. Simulation results indicated that the packet delivery ratio of three protocols tends to reduce when the velocity of network nodes increases. However, when considering these results in *Admission* mode compared to the *Adaptive* mode, we found that the average delivery ratio of QoS-ADRP was almost unchanged and better compared to the AODV and DSR protocols. At $V_{max} = 7$ (m/s), in the admission mode, the packet delivery ratio of the QoS-ADRP protocol is improved by 10% compared to the AODV and DSR protocols.

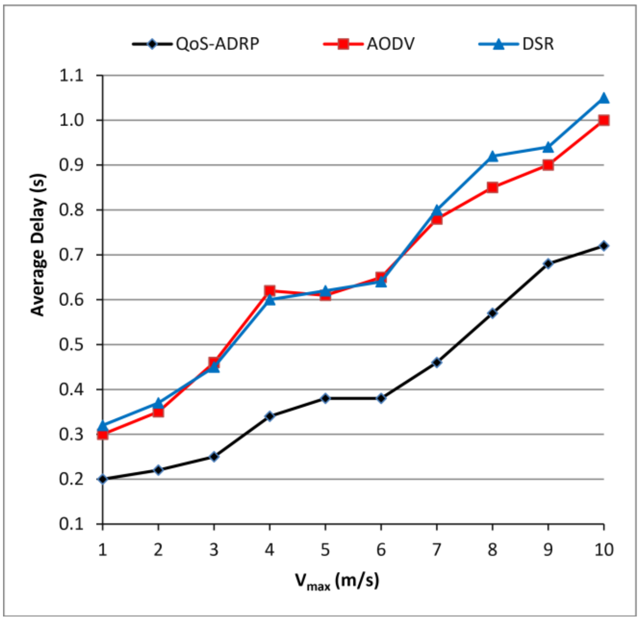

Fig. 9. Average delay in *Admission* mode.

Fig. 9 presents the end-to-end delay in *Admission* mode. Simulation results indicated that the end-to-end delay of three protocols tends to increase as the velocity of network nodes increases. However, when considering these results in Admission mode compared with *Adaptive* mode, similar to the packet delivery ratio, we find that the end-to-end delay of QoS-ADRP protocol was almost unchanged and improved compared to the other traditional protocols.

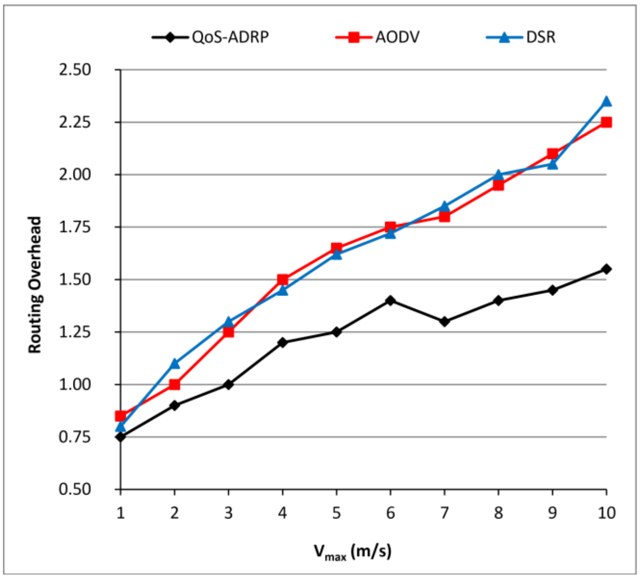

Fig. 10. Average routing overhead in *Admission* mode.

Fig. 10 presents the routing overhead in *Admission* mode. The results have indicated that the routing overhead of all protocols tends to increase when the velocity of the network nodes increases. However, the routing overhead of QoS-ADRP significantly improved compared to other protocols. This issue can be explained as follows: In the *Admission* model, the QoS-ADRP protocol will remove immediately the routes which do not ensure the bandwidth in the route discovery procedure. Consequently, only routes with high throughput will be found. Consequently, the average latency and throughput improved significantly.

V. CONCLUSION

In this work, we propose a QoS-aware routing protocol, namely QoS-ADRP, to support multimedia applications for MANETs in urban. Our proposed protocol performs well in both *Adaptive* and *Admission* modes. To performance evaluate the QoS-ADRP protocol, we set up several simulation scenarios under different changes in terms of the velocity of the mobile nodes. The results have demonstrated that the performance parameters such as QoS flow, average throughput, average latency, and average packet delivery ratio of QoS-ADRP are significantly improved compared to traditional routing protocols. For further studies, we will focus on optimizing routing algorithms for MANET-IoT systems in the urban environment.

APPENDIX

TABLE 2
ACRONYMS USED IN THE STUDY AND DEFINITIONS

Acronym	Definition
AODV	Ad hoc On-demand Distance Vector
D2D	Device to Device
DoS	Denial of Service
DSR	Dynamic Source Routing
IETF	Internet Engineering Task Force
IoT	Internet of Things
IoV	Internet of Vehicles
MANET	Mobile Ad Hoc Networks
QoS	Quality of Service
QoS-ADRP	QoS-Aware On-demand Routing Protocol
RREP	Router Reply
RREQ	Router Request
RTS/CTS	Ready To Send/Clear to Send
VANET	Vehicle Ad hoc Networks
WSN	Wireless Sensor Networks

AUTHOR CONTRIBUTION

Dr. Quy Nguyen Minh proposed the model and performed the simulation, Dr. Quy Vu Khanh wrote this manuscript; Prof. Ban Nguyen Tien proofreading this manuscript.

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