MultiRAT DYMO: Enhanced Routing Protocols for VANETs

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Abstract*—This paper describes our design of multihop multiRAT routing protocol based on the traditional DYMO (Dynamic MANET On Demand) routing protocol. Since the tradition routing protocols including DYMO only support singleRAT communications. With the increasing demand of multiRAT communications, there is a need for a multihop multiRAT routing protocol. Among the well-accepted routing protocols, DYMO is one of the popular routing protocols, which is also a successor of the widely-used AODV (Ad-Hoc on Demand Distance Vector). To support multiRAT, a route discovery process in DYMO is enhanced. A route request message RREQ will be broadcasted from the source to its neighbors through multiRAT instead of singleRAT as done traditionally. Then, the intermediate hosts also perform the same procedure by broadcasting the received RREQ to the next hop via all RATs they have in hands. The process continues until reaching the destination. The destination then sends a route reply message RREP back to the source through the reverse order of the intermediate hosts and the specified RATs. Therefore, a routing table stored on each host has be enhanced to include the information regarding the RAT used for each route entry, so that the RREP can be successfully sent through the right RATs along the discovered route back to the source. With the performance evaluation based on the simulation in OMNET++, the result shows that the proposed enhanced multiRAT DYMO achieves high QoS in terms of reception rate and end-to-end delay, and successfully create routes in multiRAT environment with the mix use of different RATs in each data route.

Keywords*— *DYMO, MultiRAT, Multihop, QoS, Routing Protocol, VANET, V2X

I. Introduction

Intelligent Transpiration System (ITS) has recently promoted several applications based on Vehicle-to-Everything communication (V2X) [1]. However, different applications require different Quality of Services (QoS) [2]. For example, in safety messaging application, it basically requires low end-to-end delay and high reliability. To achieve such requirements, it becomes really challenging due to unique characteristics of V2X, [3, 4].

Number of Vehicles: V2X covers a variety of network densities. For instance, the network density is normally sparser in rural area and denser in urban area. Time of the day also affect the network density. During the rush hour in the morning and evening, the vehicle network is expected to be much denser than that during the night time.

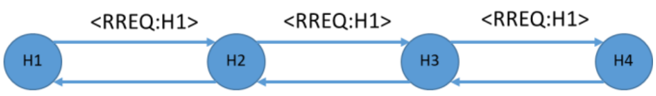
Dynamic Topology: In addition to the diversity of the network densities, the number and the members of the networks are normally changed drastically. One vehicle may join the network while the others are leaving and vice versa. Consequently, the topology of V2X becomes extremely dynamic.

Communication Constraints: Several V2X-based applications have different communication constraints. For example, the communications must meet several concrete constraints, such as delay and reliability constraints, in safety messaging, such as rescue application.

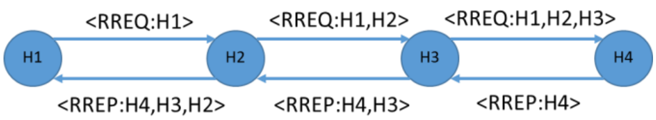
Ad-Hoc in Nature: In urban, V2X could rely on uplink and downlink communications (communications through base stations). However, in rural area, the infrastructure may not be available all the time. Therefore, most of the time, V2X must rely on sidelink communications, i.e. a direct communication between devices. This ad-hoc nature posts an additional challenge in terms of multihop communications, such as routing protocol.

Apart for V2X, with the recent advances in Multi-Radio Access Technology (MultiRAT), several RATs could coexist in the V2X communications [5]. Nowadays, there are various RATs, such as Wireless Fidelity (Wi-Fi), 4G Long-Term Evolution (4G LTE), 5G New Radio (5G NR). These RATs have been standardized, could provide different levels of QoS, and are concurrently deployed [6]. To achieve an optimal QoS in MultiRAT, several researchers [7, 8] are now focusing on optimal RAT selection algorithms.

In this work, we propose an enhancement of one of the well-known reactive or on demand routing protocol maned Dynamic MANET On Demand (DYMO) to support Multihop MultiRAT communications in V2X.



(a) AODV Route Information



(b) DYMO Route Information

Fig. 1. Route Information

Dest.	Next	Hop#	Seq#
10.0.0.1	10.0.0.1	1	1
10.0.0.6	10.0.0.4	3	120

Fig. 2. Routing Table

II. TRADITONAL DYMO

DYMO is basically a successor of Ad-Hoc on Demand Distance Vector (AODV) routing protocol, which is one of the most well-accepted routing protocol [9]. DYMO aims to achieve a simpler design compared to AODV. DYMO retains many mechanisms used in AODV such as the use of sequence numbers to enforce loop freedom. However, the main difference between DYMO and AODV is path accumulation, which is proposed in DYMO to reduce protocol overhead and required participation rate from the hosts shown in Fig. 1.

During the route discovering process, in AODV all intermediate hosts only learn about the source and the destination but no other intermediate hosts in the route. Therefore, only one route between source to destination is stored in all hosts illustrated in Fig. 1a. DYMO, in contrast, provides information about all intermediate hosts in addition to the information about the source and destination shown in Fig. 1b. Thus, DYMO allows all the hosts to additionally store route information among the intermediate hosts. In generally, DYMO contains three key characteristics as follows;

A. Routing Messages

There are three types of routing messages used in DYMO including Route Request (RREQ), Route Reply (RREP) and Route Error (RERR). RREQ is normally initiated by a source to request for a new route from the source to a destination. To set up a route from the source to the destination as well as to all other intermediate hosts, RREP will be replied by the destination through the intermediate hosts until reaching the source. When a route is broken, the message RERR will be used to indicate any invalid route entry from any intermediate hosts to the destination.

B. Route Discovery

DYMO performs a similar route discovery compared to AODV. There is only one difference, which is the path accumulation. When a source wants to find a route to a destination, it starts broadcasting a RREQ to its neighbors. If one of its neighbors already has a route to the destination, it replies to the source with a RREP. Otherwise, it appends its address into RREQ and broadcasts it to the next hop until reaching the destination. It is noted that all intermediate hosts that participate in broadcasting RREQ will concurrently learn and create the reverse route back to the source as well as update their routing tables shown in Fig. 2 accordingly. During this time, the source will wait for a RREP for a period of Time-to-Live (TTL). Once reaching the destination, the destination replies with RREP. The path accumulation is also performed while sending the RREP to confirm the route validity in both directions.

However, if the TTL expires before the source gets the RREP, the source will resend RREQ again. Similar to AODV, a unique sequence number associated to each host is used in DYMO to avoid loops in routing. In DYMO, low-energy hosts always have an option not to participate in route discovery process, but they can still learn from both received RREQ and RREP to update their routing tables.

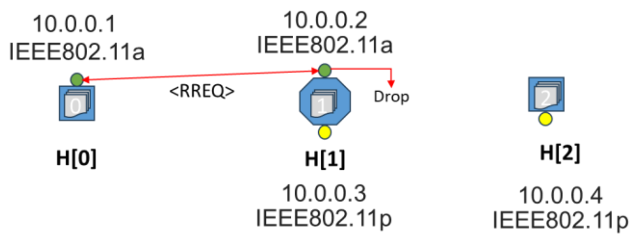
C. Route Maintenance

All routes in routing tables must be maintained by all hosts. If a link is founded broken, RERR will be multicasted by the host to all other hosts in the broken route. When received RERR, the hosts update their routing tables by deleting the broken route entry. If the route is no longer complete, the route discovery process will be initiated.

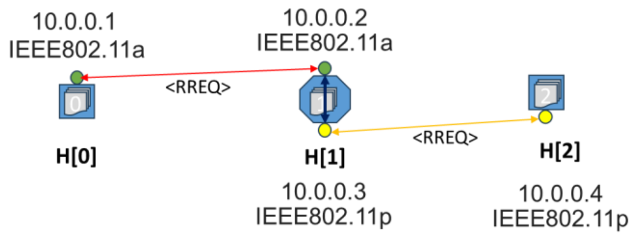
III. MULTIRAT DYMO

As it can be observed in the previous section, all routing protocols, including both DYMO and AODV, mainly operate on a specific single RAT. For example, if hosts have multiRAT capability, the hosts have to perform route discover process on each RAT individually one by one and each created route will consist of the hosts that contain the same RAT only. There will be no multiRAT route discovery provided by such traditional routing protocols. For example, there is no route that is a combination of different RATs shown in Fig. 3.

In Fig. 3a, H[0] initiates a route discovery process to H[2] through IEEE802.11a RAT. The RREQ sent by H[0] can reach only H[1], but not H[2]. This is because there is no connection from H[1] to H[2] via IEEE802.11a. Thus, the route discovery process is fail in this case.



(a)Traditional DYMO without MultiRAT Support

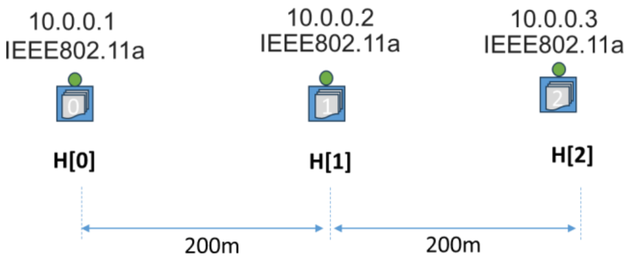


(b) Enhanced DYMO with MultiRAT Support

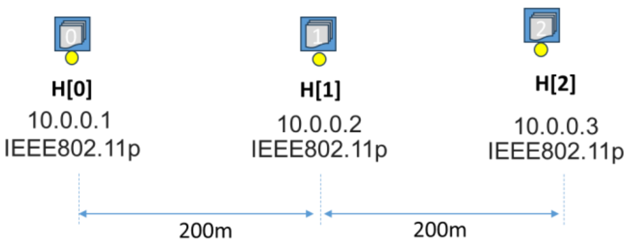
Fig. 3. DYMO without and with MultiRAT Support

Dest.	Next	Hop#	Seq#	RAT
10.0.0.1	10.0.0.1	1	1	IEEE802.11a
10.0.0.6	10.0.0.4	3	120	IEEE802.11p

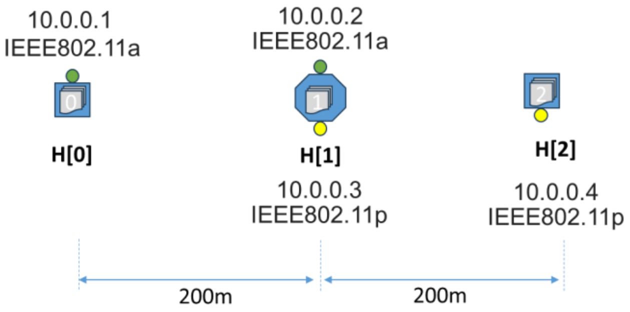
Fig. 4. Enhanced Routing Table



(a) S1: Only IEEE802.11a with Traditional DYMO



(b) S2: Only IEEE802.11p with Traditional DYMO



(c) S3-4: MultiRAT with Traditional DYMO and with MultiRAT DYMO

Fig. 5. Simulation Scenarios

Fig. 3b shows the route discovery result when the routing protocol supports multiRAT. When H[1] receives RREQ form H[0], instead of broadcasting the RREQ via IEEE802.11a only, it will broadcast RREQ through all RATs it has in hands, which are IEEE82.011a and IEEE802.11p. Consequently, the RREQ can go through H[1] and finally reach the destination H[2] through IEEE802.11p. In this case the route discovery process is successful and the discovered route is H[0], H[1], and H[2], which is a combination of both IEEE82.011a and IEEE802.11p RATs. It can be noticed that with multiRAT support, H[0] has more possibilities to communicate with other hosts in the network. Therefore, an enhancement of DYMO is proposed as follows to support multiRAT communications.

A. Routing Messages

In the enhanced DYMO, three types of routing messages which are RREQ, RREP, and RERR have the same role without any changes.

B. Route Discovery

The enhanced DYMO performs a similar route discovery compared to traditional DYMO. However, two main differences are as follows;

The first difference is when a source requests to find a route to a destination, instead of broadcasting a RREQ through one single RAT, the source must broadcast RREQ to its neighbors through all of its RATs. Its neighbors, which do not have a route to the destination, also have to broadcast the received RREQ to the next hop via all of their RATs. The process continues until one of the RREQ reaching the destination through one particular RAT. The destination then replies with RREP back to the source according to the reverse route and reverse sequence of RATs used by each intermediate hosts.

Therefore, the second difference between the enhanced and the traditional DYMO is the information stored in the routing table. RAT information must be included in to the routing tables of all hosts which are part of the discovered route shown in Fig. 4. This RAT information in the routing table is used by all hosts along the route to efficiently pass the RREP back to the source through the correct sequence of hosts and RATs. Other concepts such as the uses of a sequence number, TTL, path accumulation, and option to join route discovery process by the low-energy host are kept as same as the traditional DYMO.

C. Route Maintenance

In case of a link founded broken, RERR will be multicasted by the host to all the hosts in the broken route though a defined RATs stored in the routing table. The other hosts then delete the broken link from their routing tables and start a route discovery process if needed.

IV. Simulation Configurations and Performance Evaluation Results

A. Simulation Scenarios

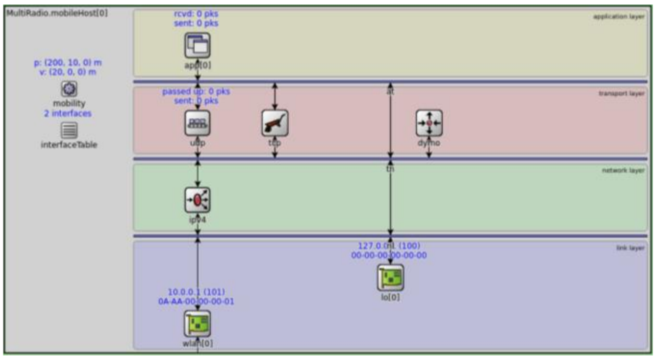
Performance of the enhanced DYMO is evaluated through the simulation based on OMNET++ simulator. There are 4 simulation scenarios shown in Fig. 5;

- Scenario1 (S1): IEEE802.11a with traditional DYMO
- Scenario2 (S2): IEEE802.11p with traditional DYMO
- Scenario3 (S3): MultiRAT with traditional DYMO
- Scenario4 (S4): MultiRAT with MultiRAT DYMO

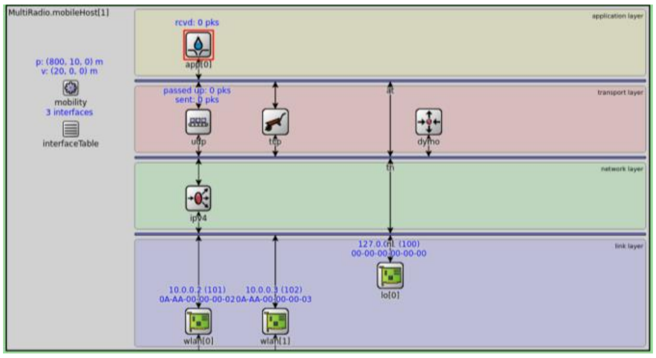
There are 3 hosts, i.e. H[0], H[1], H[2]. While H[0] is the source, H[2] is the destination of the communication. The distance between the source and the destination is 400m so that they cannot directly communicate with each other. Thus, one intermediate host H[1] is placed in the between both the source and destination with the distance of 200m from each side. H[1] will acts as a relay node for the communication.

TABLE I. RAT Characteristics

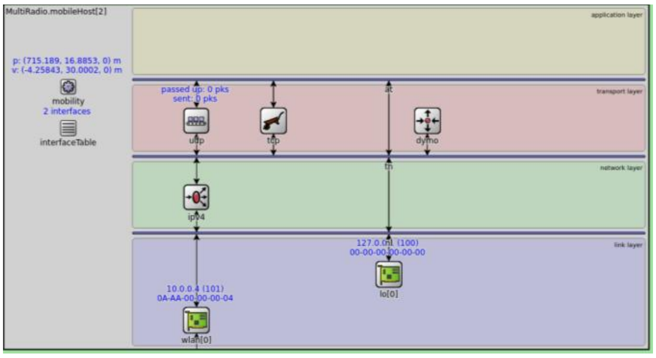
Parameter	IEEE802.11a	IEEE802.11p
Frequency	5.1-5.2 GHz	2.4-5 GHz
Channel Width	20 MHz	10 MHz
Modulation Scheme	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM
Available Data Rate	6, 9, 12, 18, 24, 36, 48, 54 Mbps	3, 4, 5, 6, 9, 12, 18, 24, 27 Mbps



(a) H[0] SingleRAT



(b) H[1] MultiRAT



(c) H[2] SingleRAT

Fig. 6. RAT Configuration in OMNET++

TABLE II. DEFAULT PARAMETER VALUES AND CONFIGURATIONS

Module	Parameters	Values
Mobility	Mobility Model	Linear
	Number of Vehicles	3
	Speed	80 km/h
	Heading Direction	0 Degree
DYMO Routing	RREQ Wait Time	0.5s
	RREQ Hold Down Time	1s
	Max Route Discovery Attempts	2
Source Application	H[1] Application	UdpBasicApp
	Message Length	1000 Bytes
	Start Time	1s
	Stop Time	100s
	Send Interval	2s
	Destination Port	1000
	Destination Addresses	H[2]
Destination Application	H[2] Application	UdpSink
	Local Port	1000
RAT	Wireless Lan	IEEE802.11a IEEE802.11p
	Bit Rate	54Mbps 27Mbps
Simulation	Simulation Time	100s

Fig. 5a shows the detailed configuration of scenario S1. All three hosts in S1 are equipped with only one RAT which is IEEE802.11a, while all the hosts in scenario S2 are also equipped with a single RAT which is IEEE802.11p as in Fig. 5b. Scenarios S3 and S4 are shown in Fig. 5c. In the last two scenarios, H[0] is equipped with only IEEE802.11a, H[2] is equipped with a single RAT IEEE802.11p. In contrast, H[1] is the only multiRAT host that have two RATs equipped, i.e. IEEE802.11a and IEEE802.11p shown in Fig. 6.

Both S3 and S4 have the same configuration setup, but will be evaluated with different versions of DYMO. The specification of RATs used in the simulation is briefly shown in Table I [10].

B. *Simulation Configurations and Scenarios*

The default parameter values and configurations of the simulation is summarized in Table II.

There are three vehicles in the simulation, i.e. H[0], H[1], and H[2]. All of them follow linear mobility model that represents movement of vehicle on a highway. The speed of all the vehicles is set to 80 km/h in the same direction to keep their distance constant. UdpBasicApp in OMNET++, which is the constant bit rate (CBR) UDP, is implemented as a sample communication between H[0] and H[2]. The message length is set to 1K Bytes. One UDP packet will be transmitted at every 2 second starting from the first second of the simulation. The transmission will be terminated at 100 second, which is also the total simulation time. The destination of the transmission is H[2] and the destination port is 1000. H[2], which is the destination host, implements UdpSink application to receive UDP packets sent from H[0] through port number 1000. Two RATs are implemented in the simulation including IEEE802.11a and IEEE802.11p which have 54 and 27 Mbps bit rate, respectively.

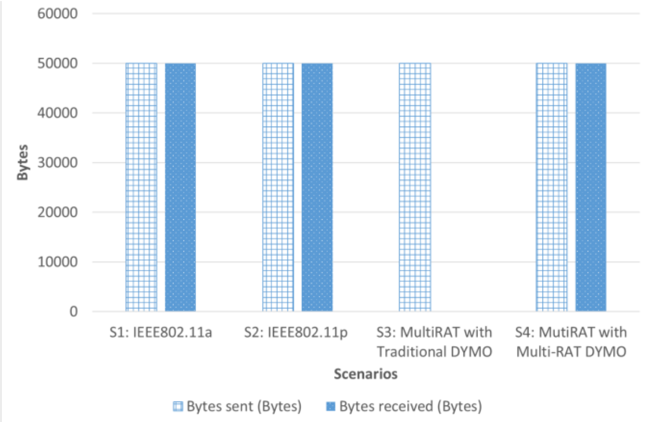


Fig. 7. Performance Comparison in terms of Sent and Received Data Byte

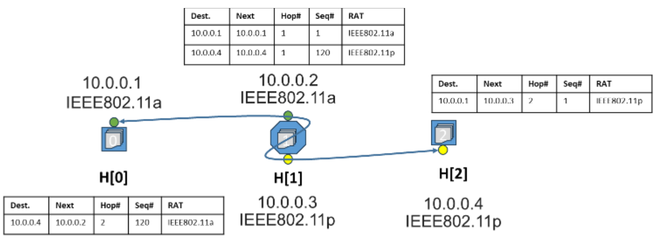


Fig. 8. Successfully Created Route in MultiRAT Network

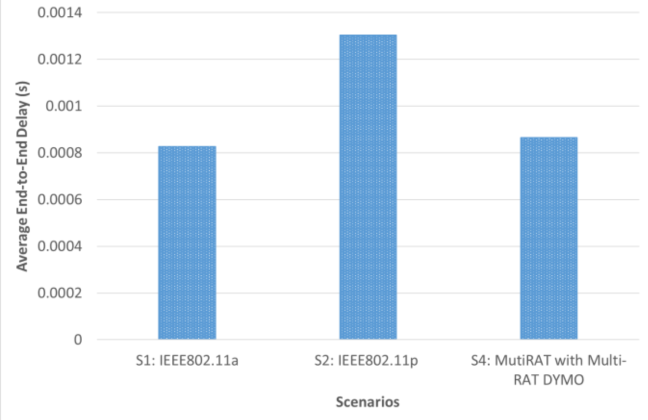


Fig. 9. Performance Comparison in terms of Average End-to-End Delay

C. Simulation Results and Discussions

In the section, we present simulation results for the enhanced DYMO in multihop multiRAT communications in terms of sent and received data Byte, end-to-end delay, number of routes created.

D. Simulation Results and Analysis

Fig. 7 shows performance comparison of all four scenarios in terms of sent and received data Byte. In scenarios S1 and S2, the data sent and received are equal representing 100% reception rate. This can be explained as in both scenarios there is a singleRAT that works well with the traditional DYMO routing protocol. Therefore, all data sent by H[0] is successfully routed to and received by H[2].

In the scenario S3, it can be observed that all sent data from H[0] cannot reach the destination H[2] at all yielding 0% reception rate. This is due to the fact that the source H[0] is equipped with only IEEE802.11a while the destination H[2] is equipped with another singleRAT which is IEEE802.11p. To make a successful communication between both hosts, it requires intermediate multiRAT host(s) that could bridge the connection between both IEEE802.11a and IEEE802.11p RATs. Actually, H[1] has this multiRAT capability. However, due to the use of the traditional DYMO that does not support multiRAT communication. H[1] cannot perform its job as a bridge. As the result, the reception rate in this scenario is 0%.

On the other hand, with the same configuration in scenario S4, but with the enhanced multiRAT DYMO, the route from H[0] to H[2] is successfully created with the combination of IEEE802.11a and IEEE802.11p shown in Fig. 8. Therefore, the reception rate in this case is 100%, i.e., sent and received data bytes are equal.

Fig. 9 shows performance comparison of 3 scenarios, i.e. S1, S2, and S4, in terms of end-to-end delay. The performance of the scenario S3 is excluded from this comparison because there is no end-to-end delay measured since all of the sent data packets fail to reach the destination as discussed previously. It can be seen that the end-to-end of the scenario S1 is the lower than that of the scenario S2. This is because IEEE802.11a has higher data rate of 54 Mbps compared to that of IEEE802.11p at 27 Mbps as shown in Table II. The end-to-end incurred in S1 becomes lower than that of S2 due to its larger bit rate. In S4 that contains multiRAT communication, the end-to-end delay is higher than S1, but lower than S2. This is quite expected. Since there are both IEEE802.11a and IEEE802.11p used in multiRAT environment in S4, the high data rate of IEEE802.11a is compromised by IEEE802.11p along the communication route. Therefore, the end-to-end delay in S4 lays in between those of both S1 and S2 scenarios.

V. CONCLUSION

Traditionally, the routing protocols including DYMO, operate on singleRAT communications. However, with the recent high demand for multiRAT communications, the traditional routing protocols are needed to be enhanced. In this investigation, we proposed an enhancement of the well-known routing protocol DYMO to support multiRAT communications. According to the investigation through the simulation via OMNET+++, with the modification of routing table to include RAT information and RREQ broadcasting through all RATs, the enhanced DYMO achieved 100% reception rate and successfully makes use of the multiRAT topology by crossly routing data packet through different RATs successfully when needed.

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