Network Mobility Protocol for Vehicular Ad Hoc Networks

Yuh-Shyan Chen and Ching-Hsueh Cheng
Department of Computer Science
and Information Engineering
National Taipei University
Taipei 237, Taiwan, R. O. C.
yschen@mail.ntpu.edu.tw

Chih-Shun Hsu
Department of Information Management
Shih Hsin University,
Taipei, 116 Taiwan, R. O. C.
cshsu@cc.shu.edu.tw

Ge-Ming Chiu
Department of Computer Science
and Information Engineering
National Taiwan University of
Science and Technology,
Taiwan, R.O.C.

***Abstract*—The goal of the network mobility (NEMO) management is to effectively reduce the complexity of handoff procedure and keep the mobile devices connected to the Internet. Vehicle is moving so fast that it may cause the handoff and packet loss problems. Both of the problems will lower down the throughput of the network. To overcome these problems, we propose a novel NEMO protocol for vehicular ad hoc network (VANET). In freeway, since every car is moving in a fixed direction with high moving speed, the car adopting our protocol can acquire IP address from the VANET through vehicle to vehicle communications. The vehicle can rely on the assistance of the front vehicle to execute the pre-handoff procedure or it may acquire its new IP address through multi-hop relays from the car on the lanes of the same or opposite direction and thus reduces the handoff delay and maintain the connectivity to the Internet. Simulation results have shown that the proposed scheme is able to reduce both handoff delay and packet loss rate.**

I. Introduction

Vehicles may acquire information and services through V2V (Vehicle to Vehicle) or I2V (Infrastructure to Vehicle) communications. The V2V communication is based on the Dedicated Short Range Communications (DSRC) technology; while the V2I communication is based on GPRS/3G, WiFi or WiMAX.

Since the moving speed of the vehicle in the VANET is so high that it is harder to maintain a seamless handoff and a stable connectivity to the Internet. To achieve seamless handoff for IP based communication, the IP of the mobile device must be assigned and reassigned efficiently. Mobile Internet Protocol version 4 (MIPv4) [1] has been proposed by the Internet Engineering Task Force (IETF). Since MIPv4 may face problems like the short of IP addresses and the weak security mechanism, MIPv6 [2] is proposed by IETF to alleviate the above problems. Mobile IP has an important characteristic that it configures IP address by neighbor discovery or auto-configuration. There are two auto-configuration mechanisms, including stateful and stateless mechanisms. Dynamic Host Configuration Protocol (DHCP) [3], which has been adopted in both IPv4 and IPv6, is a stateful auto-configuration mechanism that each IP address is auto configured and managed by the DHCP server [4]. The stateless auto-configure mechanism is adopted by IPv6, which creates link-local IPv6 address. Although MIPv6 can provide enough IP addresses and better security mechanism than MIPv4, it is not efficient enough. To improve the efficiency of MIPv6, IETF has proposed a hierarchical mobile Internet Protocol (HMIPv6) [6]. HMIPv6 adds a new component named as Mobility Anchor Point (MAP), which manages user's location. MAP provides two types of location management including the macro-mobility and micro-mobility managements, the later one can improve the handoff efficiency of MIPv6. MIPv4 and MIPv6 are designed to handle terminal mobility and are not suitable for handling network mobility. Therefore, the mobile working group at IETF extended MIPv6 to support Network Mobility (NEMO) [7]. According to this RFC (Request for Comments), mobile network nodes (MNNs) can only be accessed through mobile router (MR), in other words, all users are not allowed to access the base station directly. In mobile network, Each MR has a home network address. When a MR moves to the communication range of a new access router, it acquires its care-of Address (CoA) from the visited network. As long as the MR acquires its CoA, it sends the binding update message to its home agent (HA). The MR provides connections to MNNs. MNNs get IP addresses through MR by DHCP and network address translation (NAT) [8].

In this paper, we proposed a novel network mobility management protocol for VANETs. Each vehicle in the VANET is equipped with an MR with two interfaces, e.g. Wi-Fi and WiMAX. The basic idea of this paper, inspired by [9], is shown as follows: When a vehicle is leaving the communication region of its serving base station (BS) and is moving to the boundary of the target BS's communication region, it gets its new IP from the inbound vehicles by IP exchange or from the outbound vehicles by IP passing and it can assist the vehicle behind of it to perform pre-registration. By using the relay ability of each vehicle, we can significantly reduce the handoff delay time and the packet loss rate. Simulations results have shown that the proposed scheme can efficiently reduce handoff delay and packet loss rate.

The remainder of this paper is organized as follows. Section 2 overviews the system architecture, and the basic ideas of the proposed schemes. Section 3 describes the proposed NEMO

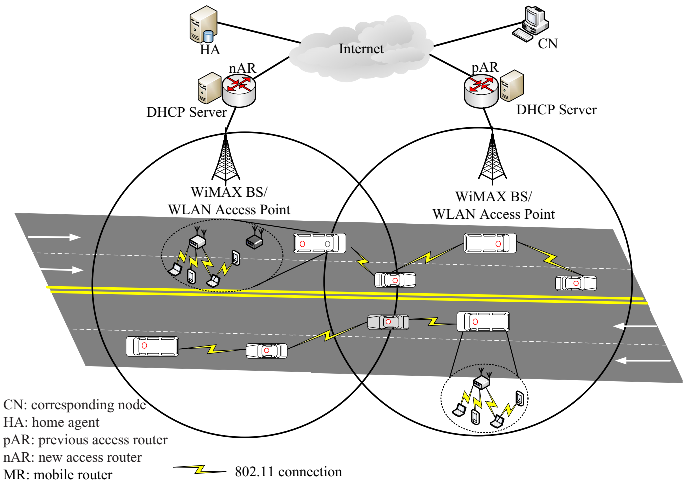

Fig. 1. System architecture

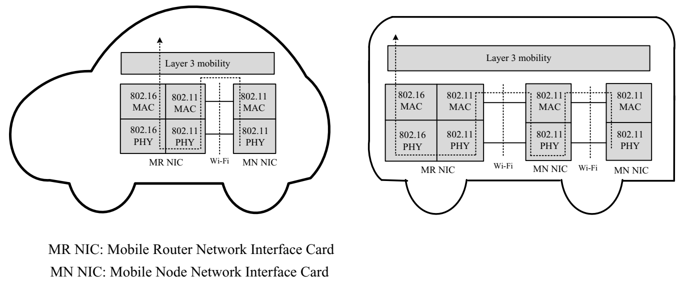

Fig. 2. Mobile router protocol stacks.

management scheme for VANETs. Performance evaluation is presented in Section 4. Section 5 concludes this paper.

II. Overview of the Protocol

A. System Architecture

A novel network mobility management protocol for VANETs is proposed in this paper, which assumes that each of the vehicle is equipped with at least a mobile router. The system architecture of our protocol is shown in Fig. 1. Our protocol, designed for vehicles on the highway, combines the network mobility (NEMO) concept and the property of multi-hop VANETs. In WiMAX or Wi-Fi environment, the base station (BS) (or Access point (AP)) is managed by the access router (AR). The home agent (HA) records the vehicle's new location and the Correspondence Node (CN) serves as a remote server e.g. FTP, Web server etc. The car and bus can connect to the Internet through the mobile router with the wireless communication technology e.g. IEEE 802.11 or 802.16. In our system architecture, the mobile router has a special function to assist the pre-handoff procedure, the details will be introduced later. Fig. 2 shows the protocol stack of the mobile router.

The protocol stacks of the vehicle and bus are shown as follows:

1) The protocol stack of a vehicle:
   Each vehicle is equipped with a mobile router, which is equipped with two communication interfaces, including the WiMAX and Wi-Fi interfaces. The mobile network node is equipped with only one communication interface, the Wi-Fi interface. Since the backbone is the WiMAX architecture and the mobile network node is not equipped with the WiMAX interface, the mobile network node connect to the MR via the Wi-Fi interface and then connects to the Internet via the MR's WiMAX interface.
2) The protocol stack of a bus:
   Each bus is equipped with one or more mobile routers. The mobile network node decides to adopt one hop or multi-hop communications to the mobile router according to the distance between the mobile network node and the mobile router.

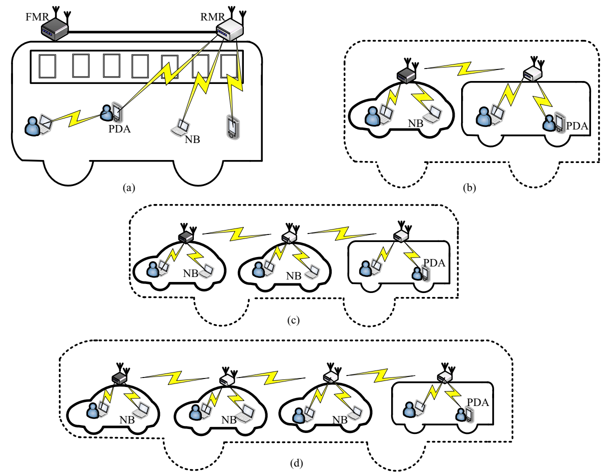

Fig. 3. Network mobility scenario: (a) NEMO on a real Bus (b)NEMO on a Virtual Bus with two vehicles (c) NEMO on a Virtual Bus with three vehicles (d) NEMO on a Virtual Bus with more than three vehicles

The network mobility scenarios of the proposed protocol are shown in Fig. 3. As shown in Fig. 3(a), the real bus is equipped with two mobile routers, the front mobile router (FMR) and the rear mobile router (RMR). The FMR and RMR are connected by wires. The users on the bus connect to the RMR either directly or via multi-hop wireless communications. As shown in Fig. 3(b), a front vehicle and a following small bus may form a virtual bus. The MR of the front vehicle serves as an FMR, while the MR of the following small bus serves as an RMR. However on a virtual bus, the FMR and RMR are connected via wireless communication. Fig. 3(c) and (d) shows two larger virtual buses.

B. Basic Idea and Challenges

When a mobile node moves to a new subnet, the mobile router (MR) will receive broadcast packet from the target BS and most importantly perform the handoff procedure. The handoff procedure contains signal measurement, network

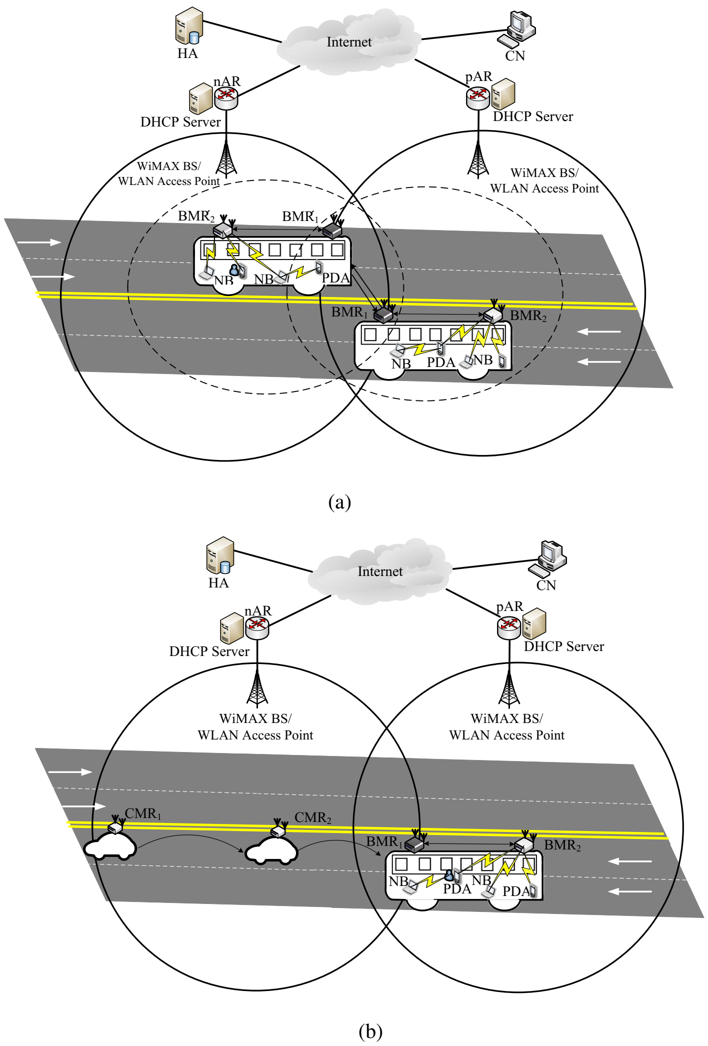

Fig. 4. (a) Acquire IP address from the lanes of the opposite direction. (b)Acquire IP address from the lanes of the same direction.

layer movement detection, the duplicate address detection (DAD) procedure and registration. The DAD procedure is time consuming and thus will cause the link to be disconnected. In VANETs, since the vehicle is moving so fast that the handoff procedure must be simplified. Our protocol, based on IP passing [10] or IP exchange, can acquire IP address faster than the traditional handoff procedure. The basic idea of our protocol is to perform the fast handoff by the assistance of other vehicles on the VANET.

Our idea comes from a real bus mentioned in Fig. 3(a). The bus is assumed to be equipped with the Wi-Fi and WiMAX interfaces, where the Wi-Fi interface is for V2V communication and the WiMAX interface is used to connect to the Internet. If there is any vehicle on the lanes of the opposite direction, the mobile router may acquire its IP address from the vehicle on the lanes of the opposite direction. For example in Fig. 4, the bus have two MRs, called BMR_1 and BMR_2. BMR_1 and BMR_2 are connected by a wire. When BMR_1 receives the advertisement of the target BS, it informs BMR_2 to prepare the handoff procedure. BMR_2 sends the request message called the get IP address packet to ask BMR_1 to assist its pre-handoff, and then BMR_1 replies an allowance message to BMR_2. As shown in Fig. 4(a), when a bus is entering into a new subnet, BMR_1 will assist BMR_2 to get its IP address. Since there is no neighboring vehicle on the lanes of the same direction released its IP address, BMR_1 may acquire the IP address from $BMR_1^{'}$ or $BMR_2^{'}$, which are the mobile routers of the bus on the lanes of the opposite direction. Initially, all mobile network nodes (PDA, NB) receive data form the correspondence node (CN) via the home agent (HA) and BMR_2. If BMR_2 performs pre-handoff, it will send a pre-handoff request to BMR_1. When two buses on the opposition direction are entering into the new subnet. Since they cannot acquire IP addresses from the vehicle on the lanes of the same direction, the MRs of the two buses BMR_1 and $BMR_1^{'}$ exchange the IP addresses.

However, if there is no neighboring vehicle on the lanes of the opposite direction, the mobile router may acquire the IP address from the vehicle on the lanes of the same direction. When the mobile router of a vehicle (CMR_1) is going to leave the target BS's communication region, it passes its IP address to CMR_2, which is the MR of the back vehicle, by multi-hop communications. For example in Fig. 4(b), when CMR_1 is going to leave the target BS's communication region, CMR_1 passes its IP address to BMR_1 through CMR_2 by multi-hop communications ($CMR_1 \rightarrow CMR_2 \rightarrow BMR_1$).

The concept of our protocol is similar to [11] [9] that the cooperative node can assist other mobile nodes to perform pre-handoff. However, the real bus scheme has two drawbacks: First, the distance between BMR_1 and BMR_2 is too short to reduce enough handoff latency through the pre-handoff procedure performed by BMR_1 and thus cannot provide a seamless handoff when the speed of the vehicle is high. Second, each vehicle needs to equip with two MRs in the real bus scheme and thus increases the hardware cost. To improve the real bus scheme, we propose a virtual bus scheme, which consists of at least two vehicles. Each vehicle only needs to equip with an MR and thus reduce the hardware cost. Since the distance between the front vehicle and rear vehicle is longer than the distance between BMR_1 and BMR_2, the pre-handoff procedure performed by the front vehicle can be done long before the rear vehicle leaving the serving BS and thus reduce more handoff latency.

III. A Network Mobility Protocol for VANETs

Since our NEMO protocol is based on the real bus scheme, we will introduce the real bus scheme first, followed by the virtual bus scheme. Each scheme is split into the following phases: the fast IP acquiring phase, the cooperation of mobile routers phase, the make before break phase, and the route redirection phase.

A. *Real Bus Network Mobility Protocol*

In this scheme, the bus is equipped with two mobile routers, the front mobile router (FMR) performs the pre-handoff procedure and the rear mobile router (RMR) serves the mobile nodes

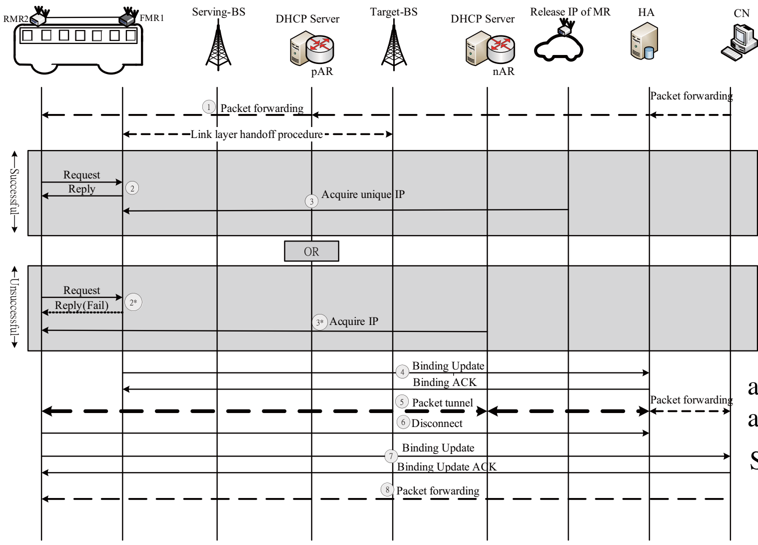

Fig. 5. The message flow diagram of the real bus scheme.

and maintain the connectivity to the Internet. The message flow diagram of the real bus scheme is shown in Fig. 5.

If there is any vehicle on the lanes of the opposite direction has available IP address, the per-handoff procedure is performed as follows:

S1: The mobile network nodes connect to Internet via RMR.

S2: $FMR \overset{ACQ\_IP-REQ}{\Longrightarrow} RMR$: If there is any vehicle on the lanes of the opposite direction, the mobile router acquire the IP address from the vehicle on the lanes of the opposite direction. When a bus enters a new subnet, FMR assists RMR to get IP address. FMR acquires the IP address from the bus on the lanes of the opposite direction. For example in Fig. 4(a), the mobile network nodes (PDA, NB) receive data form CN via the home agent (HA) and BMR_2. If BMR_2 is going to perform the pre-handoff procedure, BMR_2 sends the pre-handoff request to BMR_1. Similarly, when the bus on the lanes of the opposite direction enters a new subnet, $BMR_2^{'}$ is going to perform the pre-handoff procedure and it sends an acquire IP address request to $BMR_1^{'}$. If there is no any available IP address on the lanes of the same direction. Under such circumstance, two MRs (BMR_1 and $BMR_1^{'}$) of the two buses exchange the IP addresses.

When there is no neighboring vehicle on the lanes of the opposite direction, the per-handoff procedure is performed as follows:

S1: The mobile network nodes connect to the Internet via RMR.

S2: When there is no neighboring vehicle on the lanes of the opposite direction, the mobile router acquire the IP address from the vehicle on the lanes of the same direction. When FMR has received the advertisement of the target BS, it informs RMR to prepare for the handoff procedure. The RMR sends a request message called the get IP address packet to FMR and ask FMR to assist the pre-handoff procedure. The FMR then reply an allowance message to RMR. When the mobile router of a vehicle (CMR_1) is going to leave the target BS's communication region, it passes its IP address to the MR of another vehicle (CMR_2) behind of it by multi-hop communications. For example in Fig. 4(b), when BMR_2 has received the ready handoff message from BMR_1, BMR_2 will perform the handoff procedure by sending the acquire IP address request to BMR_1. The IP address of CMR_1 is passed to BMR_1 by multi-hop communications (CMR1 $\rightarrow$$CMR_2$ $\rightarrow$ BMR_1).

If the MR cannot acquire IP through the above steps, it acquires IP from the DHCP server. After acquired the IP address, the mobile router performs the following steps.

S3: $FMR \overset{PRE-BU}{\Longrightarrow} HA$: After FMR getting IP address, the FMR perform pre-binding update to home agent (HA) when RMR is added into a new subnet as show in Fig. 5(4) and (5).

S4: $RMR \overset{Disconnect}{\Longrightarrow} pAR$: When FMR helps RMR to perform the pre-handoff procedure, the RMR establishes connection to HA. Even RMR has entered the target BS's communication region, the old connection between the serving BS and RMR still exists until RMR is away from the serving BS's communication region, as show in Fig. 5(6) and (7).

S5: $RMR \overset{RR}{\Longrightarrow} CN$: The network mobility route redirection is similar to MIPv6. When RMR have moved to the communication region of the target BS, all of the packets from CN to HA and HA to nAR to mobile network nodes are via RMR, which may cause the network to be overloaded. Therefore, NEMO route redirection must be performed with CN. The packets form CN is directly transferred to RMR, not need to via HA again, as shown in Fig. 5(8).

B. Virtual Bus Network Mobility Protocol

In the virtual bus scheme, the vehicle is only equipped with a mobile router but still with WiMAX and Wi-Fi interfaces. Two or more neighboring vehicles on the lanes of the same direction may be grouping as a virtual bus according to the moving speed. If no vehicle on the lanes of the same direction is at the target BS's communication region and the mobile router of the virtual bus cannot acquire the target BS's IP address at the serving BS communication region, it gets the IP address from the DHCP server but this approach is costly.

The message flow diagram of the virtual bus scheme is shown in Fig. 6, which is very similar to the message flow diagram of the real bus scheme except that the communication between RMR and FMR is replaced by the communication between BMR and CMR.

IV. Simulation Results

To evaluate the performance of our protocol, we simulate the original network mobility basic support protocol [7], the fast network mobility protocol [12] and our protocols on Network Simulator-2 (ns-2)[13]. For the simplicity of describing the

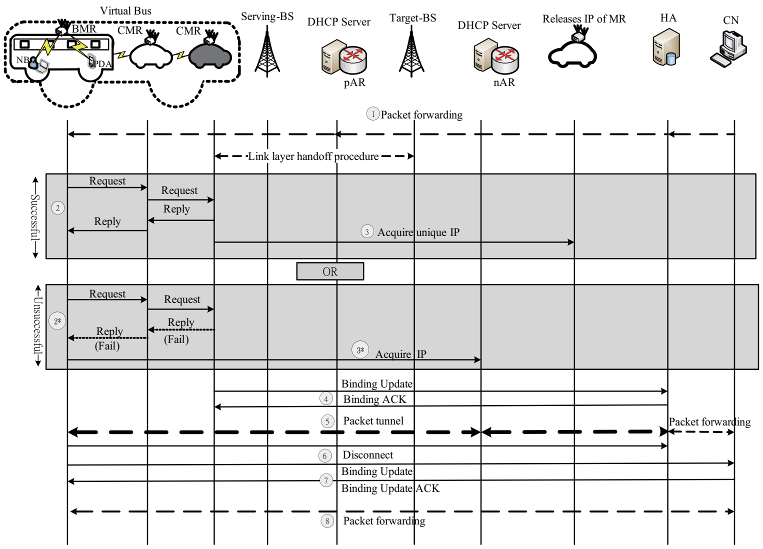

Fig. 6. The message flow diagram of the virtual bus scheme.

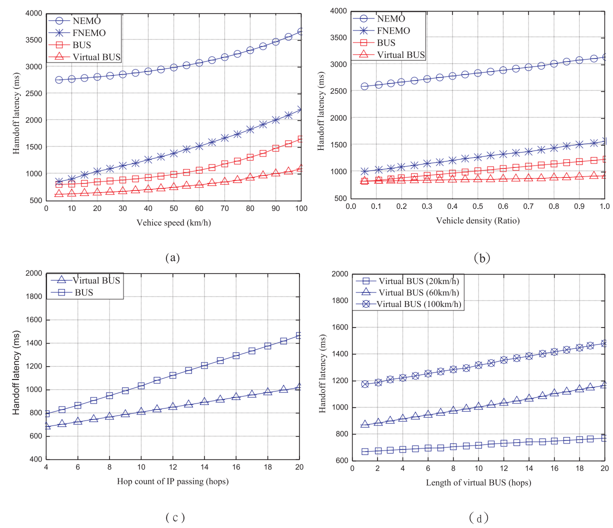

Fig. 7. (a) Handoff latency vs. vehicle speed. (b) Handoff latency vs. vehicle density.(c) Handoff latency vs. hop count of IP passing (hops). (d) Handoff latency vs. Length of virtual BUS (hops)

TABLE I
SIMULATION PARAMETERS

Network size	$1000m \times 1000m$
Number of vehicles	$0 \sim 100$
Vehicle speed	$5 \sim 100$ km/h
Transmission range of WiMAX	1000m
Transmission range of WLAN	300m
Packet size	320 bytes
Packet rate	100 packets/sec
Simulation Time	200sec

simulation results, the original network mobility basic support protocol is denoted as NEMO, the fast network mobility protocol is denoted as FNEMO, our protocol based on a real bus is denoted as Bus, and our protocol based on a virtual bus is denoted as Virtual Bus. Each simulation result is derived from the average of 10 simulations. The performance metrics we observed in our simulations are shown as follows:

- Handoff latency: The handoff latency is defined as the interval that the last packet is received from the pAR to the time that the first packet is received from the nAR.
- Packet loss rate: The total number of lost packets over the total number of transmitted packets.
- Message overhead: The total number of IP-passing packets and the packets to discover CV-MR (cooperative vehicle's mobile router).

Simulation parameters are shown in Table I.

A. Handoff latency

Fig. 7 shows the handoff latencies of the NEMO, FNEMO, Bus, and Virtual Bus schemes. The handoff latency of the Virtual Bus scheme is the lowest, followed by the Bus, FNEMO, and NEMO schemes. Fig. 7(a) illustrates the impact of vehicle speed to handoff latency. In this simulation, there are total 50 vehicles. As the vehicle speed increases, the handoff latency also increases. Both of the Bus and Virtual Bus schemes perform better than the FNEMO and NEMO schemes because the mobile router in our scheme can perform pre-handoff procedure and thus reduce the handoff latency. The handoff latency of the Virtual Bus scheme is lower than that of the Bus scheme because the MR on the front vehicle of the virtual bus can perform the pre-handoff procedure earlier than the FMR on the real bus and thus reduces more handoff latency. The FNEMO performs better than the NEMO scheme because the predictive fast handoff mode and reactive fast handoff mode of FNEMO can reduce a few handoff latency of the NEMO scheme. Fig. 7(b) illustrates the impact of vehicle density to handoff latency. The number of vehicles is tuned between $10 \sim 100$. Each vehicle is moving at a fixed speed (50km/h). As the vehicle density increase, the handoff latency also increases because higher vehicle density may incur more congestions and contentions and thus increases the handoff latency. The Virtual Bus scheme still performs the best, followed by the Bus, FNEMO, and NEMO schemes. Fig. 7(c) illustrates the impact of hop count of IP passing to handoff latency. As the hop count increases, the handoff latency also increases because more hop count may bring longer time to pass IP to the target MR and thus increases the handoff latency. The Virtual Bus scheme still performs better than the Bus scheme. Fig. 7(d) illustrates the impact of the length of virtual bus (hops) to handoff latency. As the length of virtual bus (hops) increases, the handoff latency also increases. Three vehicle speeds are considered, including 20km/h, 60km/h, and 100km/h. The lower the vehicle speed is the lower the handoff latency becomes.

B. Packet loss Rate

Fig. 8 shows the packet loss rates of the NEMO, FNEMO, Bus, and Virtual Bus schemes. The packet loss rate of the Virtual Bus scheme is the lowest, followed by the Bus, FNEMO, and NEMO schemes. As mentioned in the previous subsection, the handoff latency of the Virtual Bus scheme is the lowest. Therefore, the vehicle with lower handoff latency,

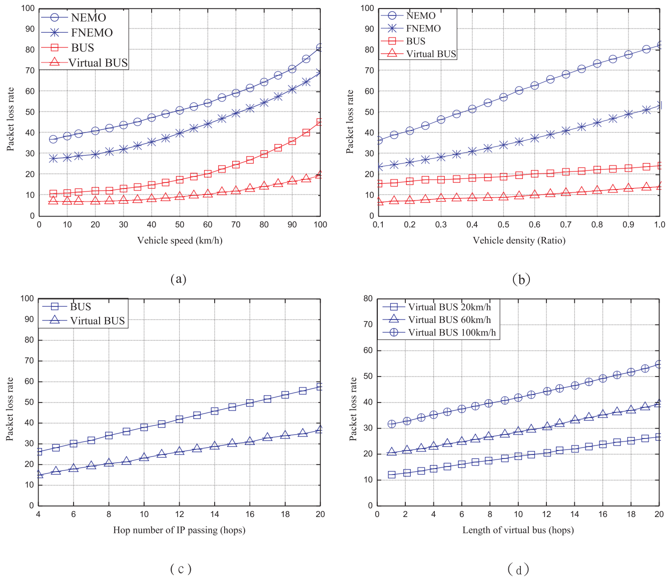

Fig. 8. (a)Packet loss rate vs. vehicle speed. (b) Packet loss rate vs. vehicle density.(c)Packet loss rate vs. hop count of IP passing (hops). (d) Packet loss rate vs. Length of virtual BUS (hops)

whose connection to the Internet is less likely to be broken during the handoff procedure, incurs lower packet loss rate.

C. Message overhead

Fig. 9 shows the message overhead of the Bus and Virtual Bus schemes. The message overhead of the Bus scheme is lower than that of the Virtual Bus scheme because on a real bus, the transmission between the RMR and FMR is single hop and via wires; while on a virtual bus, the transmission between the RMR and FMR may be more than a hop and is wireless. Fig. 9(a) illustrates the impact of vehicle speed to message overhead. As the vehicle speed increases, the message overhead of the Virtual Bus scheme also increases because of the nature of multi-hop wireless communications. The message overhead of the Bus scheme is insensitive to vehicle speed because the transmission between the RMR and FMR is through wires. Fig. 9(b) illustrates the impact of vehicle density to message overhead. As the vehicle density increases, the message overhead also increases because higher vehicle density may incur more congestions and contentions and thus increases the message overhead.

V. Conclusion

In this paper, we have proposed a novel network mobility management protocol for vehicular ad hoc networks. We make use of the cooperative vehicle's mobile router to perform pre-handoff procedure and the IP passing procedure to reduce handoff latency, while any vehicle is entering a new subnet. Both of the real bus and the virtual bus schemes can acquire IP addresses fast from the vehicle on the lanes of the same direction or opposite direction. When a vehicle is entering a new BS, the vehicle will find a mobile router of the cooperative vehicle to assist it to get the IP address and

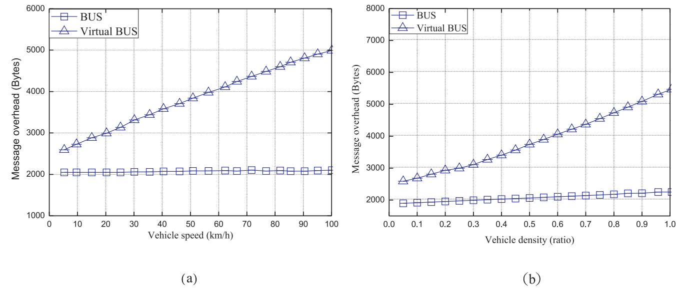

Fig. 9. (a)Message overhead vs. vehicle speed. (b)Message overhead vs. vehicle density.

perform binding update. Simulation results have shown that our protocol performs better than the original network mobility basic support protocol and the fast network mobility protocol in terms of handoff latency and packet loss rate.

Acknowledgment

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