IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received August 10, 2018, accepted September 12, 2018, date of publication September 28, 2018, date of current version October 25, 2018.

Digital Object Identifier 10.1109/ACCESS.2018.2872795

A Network-Based Seamless Handover Scheme for VANETs

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This work was supported by the National Research Foundation of Korea (NRF) through the Korean Government (MSIT) under Grant NRF-2018R1A2B6009122.

ABSTRACT Vehicular ad hoc network (VANET) standards, including IEEE 1609 WAVE and ETSI C-ITS, use IPv6 to interconnect VANET with the Internet. Considering the high vehicle speeds and short communication ranges of road side units (RSUs), such vehicles may suffer from frequent service interruptions. Several VANET IP mobility schemes have been proposed in order to mitigate this problem. However, these only support L3 handover, as the RSUs act as IPv6 access routers (ARs) for vehicles. Some VANET IP mobility schemes reduce the handover latency of the L3 handover but do not fundamentally mitigate the frequency of the L3 handover. As L3 handover indicates that the default router of the vehicle is changing, the vehicle must perform IPv6 configuration, including router discovery and neighbor unreachability detection. Since most L3 handover latency is caused by this IPv6 configuration, the L3 handover involves a higher signaling cost and longer handover latency than the L2 handover. We propose a network-based L2 extension handover scheme for VANET. It decouples the AR functions from the RSU. An AR connects several RSUs via L2 links within its coverage. In this configuration, most inter-AR handovers are replaced with intra-AR handovers, so that the frequency of the L3 handover is decreased substantially. Therefore, the service disruption time caused by default router switching is also reduced, and the deployment of VANET can be made more flexible by decoupling the RSU and the AR. Proxy Mobile IPv6 is adopted in order to support inter-AR handover in the proposed scheme. Furthermore, the scheme supports seamlessness in both the intra-AR and inter-AR handovers with buffering at the AR. The performance analysis and the simulation result reveal that the proposed scheme reduces the signaling cost and handover latency and also shows seamless packet delivery for vehicles.

INDEX TERMS Network-based seamless handover, vehicular ad-hoc networks.

I. INTRODUCTION

Over the last few years, vehicular ad hoc networks (VANETs) have been evolving and attracting increased attention from researchers due to their potential to increase road safety. The IEEE 1609 Wireless Access in Vehicular Environment (WAVE) [1] and the ETSI Cooperative Intelligent Transport System (C-ITS) [2] are the standards for VANET. These standards adopt IPv6 in order to connect to the Internet for infotainment applications [3], [4]. Considering the high mobility of vehicles and the short communications range of RSUs, a vehicle usually passes through the coverage of an RSU quickly; this may cause frequent interruption of IP connectivity. However, the IEEE WAVE reference model [5] only mentions references to the IETF IPv6 specification and does not address IP mobility. The ETSI C-ITS supports Mobile IPv6 (MIPv6) but excludes Proxy Mobile IPv6 (PMIPv6) by prohibiting the use of the unicast Router Advertisement (RA). However, the handover latency of the MIPv6 is affected substantially more by the wireless link condition than that of PMIPv6 [6].

A Road Side Unit(RSU) in VANET standards acts as an Access Router (AR). Therefore, a large number of routers exist within a narrow area, so handover events frequently occur between these routers. Several VANET IP mobility schemes [7]–[15] have been proposed based solely on L3 handover. Although some of these schemes aim to mitigate handover latency by predicting the movement of the vehicle, they do not fundamentally reduce the frequency of the L3 handover. Whenever the L3 handover occurs, the vehicle should perform IPv6 configuration, such as router discovery and Neighbor Unreachability Detection (NUD), in order to determine its default router. The vehicle should send a Router

Solicitation (RS) to search for the router, which may take up to 1000 ms [16]. In addition, the vehicle may confirm the unreachability of an old RSU before switching to a new RSU by using the NUD mechanism. The NUD requires at least a 3 sec delay [17]. Therefore, the L3 handover involves a higher signaling cost and longer handover latency than the L2 handover. This may incur risks, such as long service interruptions. These schemes also fail to consider the seamless packet delivery during the handover period.

Furthermore, most of these VANET IP mobility schemes require the vehicle to participate in the handover procedure itself, even if some of them adopt the network-based mobility protocol. The RSUs in these schemes detect the vehicle through separate messages sent by the vehicle, failing to take advantage of the fact that vehicles and RSUs already exchange safety beacons in VANET.

In this paper, we propose a network-based seamless handover scheme for VANET, which is applicable to both IEEE WAVE and ETSI C-ITS. The scheme decouples AR functions from RSUs. An AR connects several RSUs via L2 links, thereby expanding its coverage area. In this architecture, most inter-RSU handovers become intra-AR handovers rather than inter-AR handovers. The inter-AR handover incurs a higher signaling cost and longer handover latency than does the intra-AR handover. Therefore, the scheme significantly decreases the total costs of inter-RSU handovers and enables the more flexible deployment of VANET. The scheme employs the PMIPv6 to support the inter-AR handover. In addition, the scheme supports seamlessness for both intra-AR and inter-AR handover. RSUs use the safety beacons of vehicles to track them in its coverage, and they notify their AR of relevant significant events. An AR uses these notifications to buffer packets proactively before a vehicle leaves an RSU's coverage. Consequently, that vehicle is excluded from the mobility signaling, and no additional modification of the vehicle is required for it to be supported for a seamless IP mobility over a wide area.

II. RELATED WORK

IEEE WAVE [1] defines the following two types of channels: Control CHannel (CCH) and Service Channel (SCH). The safety related beacons generated by several VANET applications [18] are sent over the CCH. All involved vehicles and RSUs must monitor the CCH in order to detect the surrounding traffic environment. An RSU can detect vehicles when they emit safety beacons. The SCHs are employed by the IP to support the IP-based applications. However, while the WAVE standard recommends the use of the IPv6 standard [19], it does not describe the detailed operation [20].

In ETSI C-ITS, IPv6 packets are transmitted through the GeoNetworking (GN) [21] protocol. GN routes IP packets based on geographical position rather than IP address. Therefore, GeoNetworking to the IPv6 Adaptation Sub-Layer (GN6ASL) [22] is introduced in order to bridge the IPv6 and the GN. When the GN6ASL receives the RA, it creates a link-local multicast-capable virtual link referred to as the Static Geographical Virtual Links (SGVL). The SGVL extends the IPv6 link to a specific geographic area. ETSI C-ITS prompts the use of the MIPv6 in order to support mobility. On the other hand, the PMIPv6 cannot be applied, as the unicast RA is disabled in ETIS C-ITS. This restriction is introduced because unicast packet does not contains a geographical destination area that is used by the GN6ASL to create SGVL.

Several handover schemes for VANET [7]–[9] have been proposed. These schemes apply the host-based IP mobility protocols [23], [24] to VANET. In VFMIPv6 [7], each vehicle is assigned a unique global IPv6 address. Before a vehicle leaves the boundary of the current AR, it sends relevant Handover Assist Information (HAI) to the AR. The AR can then predict the candidate Target ARs (TARs) from the HAI and notifies the vehicle of these TARs. However, VFMIPv6 does not deal with reactive handover, which occurs when incorrectly predicting vehicle movement. Enhanced MMIP6 [8] is based on the principle of MIPv4 and supports IPv6 based vehicles. The vehicle in [8] also uses a global permanent IP address rather than a temporary Care-of-Address (CoA). Through eliminating the time required for CoA reassignment and Duplicate Address Detection (DAD) [25], the handover latency is reduced. Mussabbir *et al.* [9] improved the FMIPv6 by employing the Media Independent Handover (MIH) scheme [10] for VANET. This scheme uses MIH triggers to provoke predictive FMIPv6 handover, and it improves the handover accuracy by introducing a special cache that stores information regarding the neighbor access network. However, as these schemes are host-based, the vehicle must detect its movement and initiate the handover procedure.

Several proposals [11]–[15] have also been presented for the integration of VANETs with the PMIPv6. The PMIPv6, which is a well-known network-based IP mobility protocol, was applied to IEEE WAVE and ETSI C-ITS in [11] and [12]. In these schemes, a vehicle must determine the handover when it receives the RSU's RA, and sends a Router Solicitation (RS) to the RSU in order to indicate that the handover procedure can proceed. This conflicts with the concept of PMIPv6, which excludes the host from the mobility procedure. In addition, VIP-WAVE [11] requires modification of the Neighbor Discovery (ND) [16] protocol, and in [12], unicast RA is considered to be restricted in ETSI C-ITS. In [13] and [14], solutions that extend FPMIPv6 were proposed. Enhanced PFMIPv6 [13] employs a Global Positioning System (GPS) in order to achieve more accurate prediction considering geographical constraints when it determines candidate Mobility Access Gateway (MAGs). The serving MAG then pre-establishes tunnels with the candidate MAGs. However, as the serving MAG creates tunnels with all candidate MAGs, it causes tunnel overhead. In [14], a temporary binding between candidate MAG and Local Mobility Anchor (LMA) is proposed as the way to accelerate the handover procedure. However, when the prediction fails, the LMA, which is the network anchor point, wastes excessive resources. These schemes also require the vehicle to be

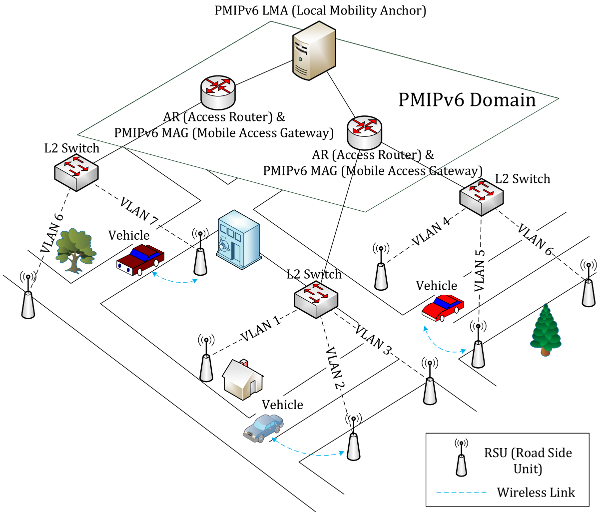


FIGURE 1. Proposed system architecture.

involved in handover signaling. In [15], the MIH service is employed in order to obtain the vehicle's information without route discovery as well as to predict the movement of the vehicles. However, packet loss may increase in this case due to incorrect predictions.

III. PROPOSED SCHEME

A. SYSTEM ARCHITECTURE

The overall system consists of VANET, an intra AR network that handles L2 handover, and an inter AR network that is responsible for L3 handover. Fig. 1 shows the simple configuration of this system.

VANET consists of vehicles and Road Side Units (RSUs). They communicate with existing VANET standards [1], [2]. The intra AR network consists of RSUs, an L2 switch, and an AR. In this domain, an L2-extension mechanism is proposed in order to extend the coverage of the AR via the connection of the RSUs with L2 switches. The RSUs and the AR cooperate in order to provide seamless intra AR handover to the vehicles within the AR's coverage area. The inter AR network is comprised of LMA and several ARs. The AR also acts as an MAG; it registers the vehicles and initiates an inter AR handover procedure. An LMA manages the information of the latest MAG where the vehicle is currently located and the previous MAG where the vehicle was previously located. The proposed scheme provides seamless inter AR handover to the vehicles. The existing PMIPv6 standard is applied, but a specific buffer is added at each of the ARs for seamless inter AR handover, which PMIPv6 does not support.

1) VEHICLE

The vehicles communicate with the RSUs or other vehicles using the VANET standards [1], [2]. The vehicle usually executes the safety applications [18] to disseminate its driving related information such as velocity, location, and direction.

TABLE 1. RSU cache table.

Vehicle MAC	Receive Time	Position
Vehicle A's MAC	10:15:38:19	30,33
Vehicle B's MAC	10:15:38:28	33,33

The RSU can track the location of the vehicle by employing this information.

2) L2 SWITCH

An L2 switch is an ordinary Ethernet switch with the function of a Virtual Local Area Network (VLAN). Each RSU/AR pair has a VLAN on the link. The VLAN is used to decouple the roles of the RSU and the AR in the proposed system. Each VLAN acts as a VANET interface [26], [27] in order to replace the embedded VANET interfaces of the AR that are required by the VANET standards.

3) ROAD SIDE UNIT (RSU)

An RSU is a vehicle-access point of the VANET that bridges the VANET with the Internet at the data-link layer. An RSU has two interfaces: one for the VANET and one for the Internet.

An RSU monitors the vehicles' safety beacons in order to gain information regarding the surrounding traffic conditions. According to the Crash Avoidance Metrics Partnership (CAMP), almost all of the used safety beacons contain at least the position and the directional information of a vehicle [29]. The RSU can passively know a vehicle's position and direction, and it stores this information in its RSU Cache Table (RCT). Each entry of the RCT contains the MAC address, the most recent receiving time, and the position information. Table 1 shows an example RCT entry.

For the support of a network-based seamless handover, the vehicles themselves should not be involved in the handover procedure, and the AR requires information on when a vehicle leaves the area covered by a serving RSU as well as on when it moves into another area covered by a new RSU; however, the AR is unable to discern the position of the vehicle due to the separation of the RSU and the AR. The RSU must therefore notify the AR about the vehicle's movements, although this information is limited to only the significant movements. In order to categorize the significance of vehicular movement, the RSU divides its coverage area into two zones: a normal zone and a handover zone. The normal zone refers to the section where the vehicle and the RSU communicate reliably. This section is calculated through preliminary experimentation, and the RSUs know the distance of the normal zone they provide. The handover zone is the external area beyond the normal zone. It is a section in which communication links are unstable and where packet loss can occur. Fig. 2 presents these two zones.

An RSU processes all incoming safety beacons with its RCT, and it sends a control message to the AR in only three cases: First, the RSU sends an Attachment Indication (AI) in the case that information on a vehicle moving toward

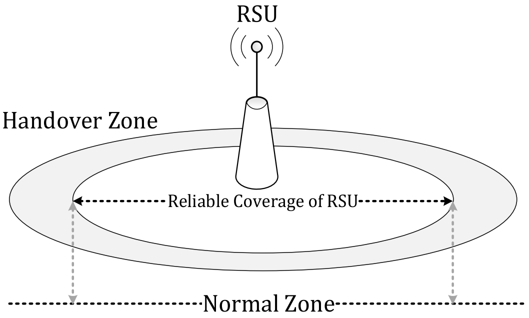


FIGURE 2. Division of communication area.

the RSU does not exist in the RCT. Second, the RSU sends a Handover Prepare (HP) message in the case that the vehicle reaches the handover zone and is moving away from the RSU. Third, it sends a Detachment Indication (DI) in the case where a beacon has not been received from the vehicle within a predefined time, or the RSU fails to deliver three consecutive frames to the vehicle.

If the vehicle is in the handover zone, packet transmission is not guaranteed, because the communication link is unstable. Therefore, the serving RSU continues attempting packet transmission to the vehicle, while the AR simultaneously begins to buffer the packets for seamless communication. Because of this unstable link condition, the already transmitted packets may be unnecessarily buffered in the AR's buffer. In order to mitigate the number of redundant buffered packets at the AR, the RSU and the AR interact in order to precisely buffer any undelivered packets. The RSU checks the packet transmission status through the IEEE 802.11 Automatic Repeat reQuest (ARQ) operation and informs the AR that the packet transmission has either failed or succeeded.

In order to add a bridging function at the RSU, the RSU must process the MAC frame, which has the AR's MAC address in the address-1 field. According to the current MAC operation procedures [28], in the case that the address-1 field does not match the RSU MAC address, the RSU does not process the MAC frame; therefore, the RSU needs to accept at least two MAC addresses: the first MAC address is the RSU's MAC address, and the second is the MAC address of the AR to which it is connected.

4) ACCESS ROUTER (AR)

An AR is the default router of the Internet for the VANET that connects several RSUs using L2 switches.

The AR makes handover decisions based on the control messages sent from the RSUs, and it maintains an AR Binding Table (ABT) for the purpose of storing the handover information ‘from the control messages. Each entry of the ABT contains the vehicular MAC address, RSU MAC address, VLAN ID (VID) and position information. Table 2 shows an example ABT entry. The AR has packet buffers in order to support seamless intra AR and inter AR handover for vehicles.

TABLE 2. AR binding table.

Vehicle MAC	Serving RSU MAC	VLAN ID	Position
Vehicle A's MAC	RSU A's MAC	1	30,33
Vehicle B's MAC	RSU B's MAC	2	33,33

From receiving the Attachment Indication (AI) message, the AR can detect the appearance of a new vehicle or the entrance of a vehicle into a new RSU coverage area. If the AR receives the AI and a vehicle is not registered in the ABT, it recognizes the vehicle as being new and creates an entry for that vehicle; the sending RSU is chosen as the serving RSU. If an AI arrives for a vehicle whose entry is already in the ABT, or if the buffer of the AR has buffered packets for the vehicle, it chooses the sending RSU as a new serving RSU. It then updates its entry in the ABT and sends the buffered packets to the new serving RSU where the vehicle has moved, if it has buffered packets for the vehicle.

When the vehicle reaches the handover zone of the serving RSU, the AR detects this event via the Handover Prepare (HP) message. The AR starts the packet buffering in order to prepare for the handover, but it still forwards packets to the vehicle via the serving RSU (sRSU) until a new RSU is selected, or until the sRSU can no longer reach the vehicle. The AR and the sRSU interact in order to precisely track the undelivered packet. The sRSU sends a Negative Acknowledgement ARQ (NACK-ARQ) message for each unsuccessful delivery along with part of the undelivered packet to the AR. The AR then attempts to match the packet in its buffer until it finds the matched packet, then deletes the packet from the front of the buffer to the matched packet, thereby mitigating redundant packet buffering. The AR does not then retransmit the undelivered packet, beacuse recovering lost packets is not the role of the AR. The sRSU may send an Acknowledgement (ACK-ARQ) for each delivered packet in order to reduce the number of buffered packets. The AR removes the front packet of the vehicle in its buffer whenever it receives the ACK-ARQ.

If the AR receives the Detachment Indication (DI) message, it stops the packet forwarding, then continues buffering until it receives the AI from another RSU, or until the predefined timer expires.

B. HANDOVER PROCEDURE

1) INTRA AR L2 HANDOVER

An intra AR handover occurs between the RSUs. The coverage areas of these two RSUs may be disjointed or overlapping, such as in the cases shown in Figs. 3(a) and 3(b). The handover procedures in both cases are almost identical, with the only difference being that the formal case includes the detachment event. Fig. 4 shows the complete intra AR handover procedure.

Event 1 [Detection (Section A)]: RSU 1 detects the entrance of a vehicle from the vehicle's safety beacon. It then generates an RCT entry and sends an AI to the AR. The AR creates a new entry for the vehicle and selects

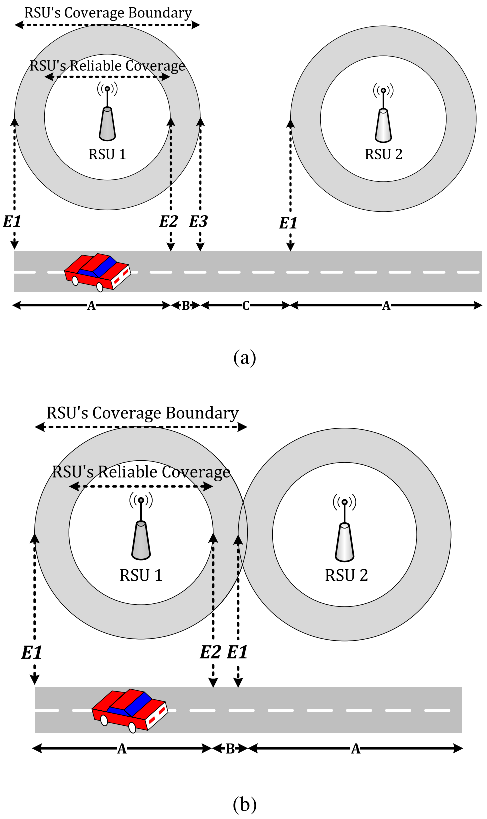


FIGURE 3. **RSU deployment. (a) Disjointed coverage. (b) Overlapped coverage.**

the sending RSU as the serving RSU. The vehicle begins communication with a peer in the Internet. The AR then relays the data packets between the CN and the vehicle via RSU 1.

Event 2 [Handover Preparation (Section B)]: RSU 1 detects the vehicle from the vehicle's safety beacon and checks the vehicle's current position and direction in order to determine whether or not the vehicle is located in its handover zone, along with whether or not it will be outside of the range of coverage; if so, it sends the HP to the AR in order to indicate that the handover may need to occur soon. After receiving the HP, the AR starts the packet buffering until it receives the AI from another RSU or until the predefined timer expires. It still forwards the data packets to the vehicle via RSU 1, as the connection between the vehicle and RSU 1 remains alive. The AR and RSU 1 start to interact via an ARQ mechanism to remove the delivered packets in the AR's buffer and also to prevent duplicated packet deliveries to the vehicle. Whenever a packet is not delivered to the vehicle, RSU 1 sends the NACK-ARQ message with part of the undelivered packet to the AR. The AR attempts to find the buffered packet that matches the packet information contained in the received NACK-ARQ, then flushes the buffer from the beginning to the matching packet. RSU 1 can alternatively send the ACK-ARQ message for successfully delivered packets in order to release the buffered packets in the AR.

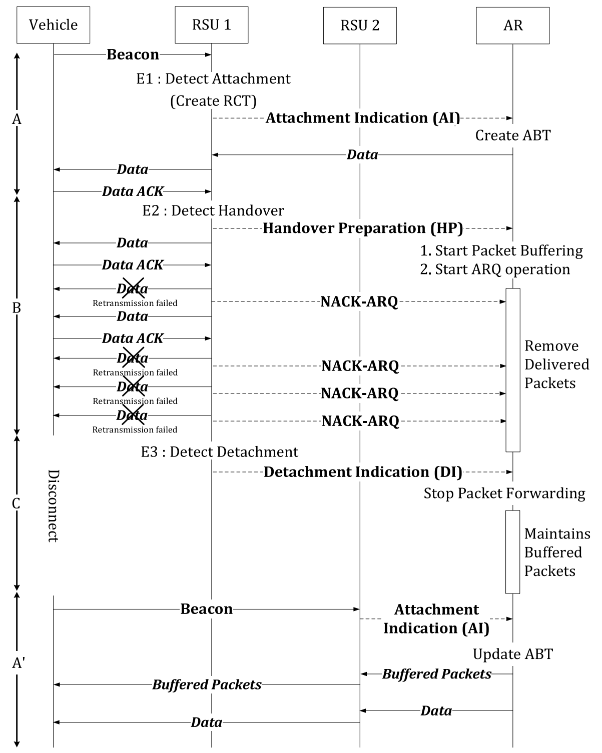


FIGURE 4. **Intra Handover Procedure.**

Event 3 [Disconnection (Section C. The Disjointed Coverage Case Only)]: In the case that RSU 1 no longer receives the vehicle's safety beacon and/or it fails to deliver consecutive packets to the vehicle, RSU 1 sends a DI to the AR. The AR then stops packet forwarding to the vehicle,it but maintains the buffering until it receives the AI from another RSU, or until the predefined timer expires. A disconnection only occurs when the coverage areas of the two RSUs are disjointed.

Event 1 [Detection (Section A′)]: When RSU 2 receives a safety beacon from the vehicle, RSU 2 detects that a new vehicle has entered its area based on the fact that the RCT has no matching entry. If the vehicle is moving into RSU 2's area, RSU 2 creates a new RCT entry for the vehicle and sends an AI to the AR. When the AR receives the AI, it see that it has a matching entry in the ABT, and detects that the vehicle is moving toward RSU 2. The AR then updates the serving RSU MAC address and the VID field of the matched entry. If the buffer of the vehicle has buffered packets, the AR forwards the buffered packets to the vehicle via RSU 2.

2) INTER AR L3 HANDOVER

Inter AR handover occurs when the vehicle is outside of the coverage area of 1 MAG. Fig. 5 describes the overall inter AR handover procedure. The processing of the detachment event is the same as that of the intra AR handover. When the MAG 2 (AR 2) detects the vehicle from the RSU 2's attachment indication, it registers the vehicle in its Binding Update List (BUL) and sends the Proxy Binding Update (PBU) message

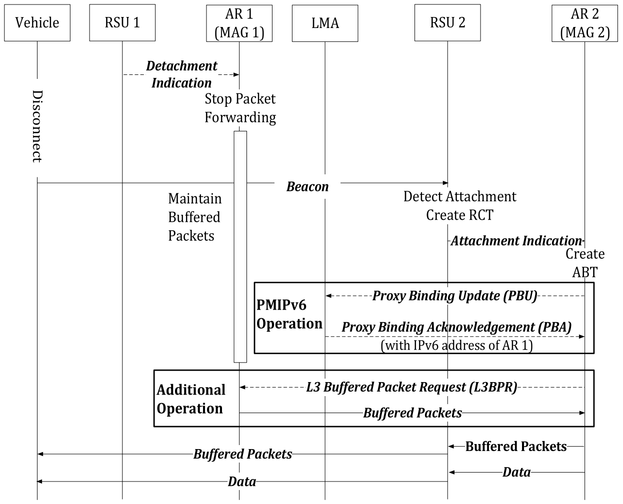


FIGURE 5. Inter AR Handover Procedure.

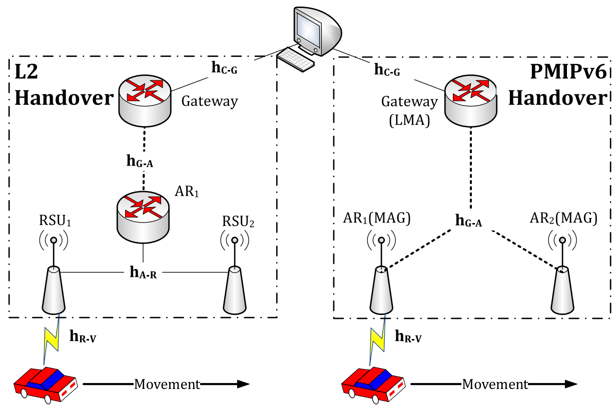


FIGURE 6. Division of communication area.

to the LMA according to the existing PMIPv6 operation. The LMA that received the PBU sends the Proxy Binding Acknowledgement (PBA) to MAG 2. Since the existing PBA does not have a mobility option to contain the information of MAG 1 that serves the vehicle, a new mobility option is added into the PBA so as to include the IPv6 address of MAG 1. MAG 2 then sends the newly added L3 Buffered Packet Request (L3BPR) control message to MAG 1 through the IPv6 address of MAG 1 in the PBA. If buffered packets for the vehicle already exist in the MAG 1 buffer, it transmits the buffered packet to MAG 2, then MAG 2 forwards the buffered packet to the vehicle via RSU 2.

3) APPLYING PMIPV6 TO C-ITS

ETSI C-ITS introduces the GeoNetworking (GN) [21] protocol in order to forward packets through geo-routing based on geographical location rather than IPv6 address. The GeoNetworking to IPv6 Adaptation Sub-Layer (GN6ASL), which is the adaptation sub-layer, is introduced in order to transmit IPv6 packets over the GN. The vehicle with GN6ASL creates a Static Geographical Virtual Link (SGVL) when it receives the RA from an RSU. The IPv6 multicast domain is extended to a specific geographical area by the SGVL. However, the use of the unicast RA is prohibited in C-ITS [22]. This is due to the fact that unicast packets can not carry a specific geographical area, so that the GN6ASL receiving unicast RA may not be able to generate SGVL. Therefore, PMIPv6, which requires the use of unicast RA, is also restricted in C-ITS.

In order to address this problem, UDP encapsulation is used. We have confirmed that unicast RA can be used in C-ITS through experiments in the following environments. The MAG encapsulates the unicast RA with the UDP header. A vehicle operates an application level daemon for the processing of an encapsulated unicast RA. When the daemon receives a packet, it parses the packet in order to confirm whether or not it is an Internet Control Message Protocol (ICMPv6) packet. It then generates an IPv6 address with the prefix information contained in the RA and allocates the IPv6 address to a default interface using the input and output control functions.

IV. PERFORMANCE EVALUATION

In this section, we compare PMIPv6 [30] with the proposed L2 Handover Scheme (L2HS) in terms of the signaling cost and handover latency. Figure 6 shows the network topology for performance comparison and network entities used for PMIPV6 and L2HS, respectively. In PMIPv6, the RSU simultaneously performs the roles of AR and MAG. In contrast, L2HS expands the coverage of AR by separating the roles of the RSU and the AR. Since both protocols comprise the local mobility management scheme, only the performance evaluation for the single domain (intra-domain mobility) is covered.

A. MOBILITY MODEL

The mobility model is first considered in order to evaluate the mobility management protocols. The mobility model represents the movement of the vehicle within a single domain. All RSUs have a circular coverage with a radius of R, and the average velocity of vehicles is represented by v. Then, let μ_a be the RSU crossing rate of the vehicle. Therefore, the signaling cost to which the mobility model is applied can be represented as $\mu_a \cdot C_S^{\cdot}$.

B. COST MODELING

An analytical cost model for performance evaluation is based on [31], and the notations used in the cost model are based on [32]. α refers to the weighting factor of a wired link and β represents the weighting factor of a wireless link; they express the characteristics of links. N(p) refers to the number of packets per session.

The signaling cost $C_S^{(\cdot)}$ is calculated by accumulating the size of the mobility signaling messages multiplied by the hop distance traversed by these packets.

TABLE 3. Definition of parameters required for performance evaluation.

Parameter	Comments
T_{L2}	The link-layer handover latency
T_{RD}	Random delay before sending an RS
T_{RS}	Arrival delay of an RS from vehicle to RSUs
T_{BU}	Binding update delay
T_P	Arrival delay of the first packet sent
B_{WD}/B_{WL}	Bandwidth of the wired and wireless link
PT_{WD}/PT_{WL}	Propagation time over the wired and wireless link
L_{RS}	Router Solicitation Message
L_{PBU}/L_{PBA}	Proxy Binding Update & Proxy Binding Acknowledgment
L_{AI}/L_{DI}	Attachment Indication & Detachment Indication message
L_{ACK}	Acknowledgment message for L_{AI}/L_{DI}
L_{DATA}	Data Packet

1) PROXY MOBILE IPV6

$C_S^{(PMIPv6)}$ represents the signaling cost of PMIPv6 and is expressed as

$$C_S^{(PMIPv6)} = \mu_a\{2L_{PBU}\alpha h_{G-A} + 2L_{PBA}\alpha h_{G-A}\} \qquad (1)$$

The LMA and MAG perform the mobility signaling over a wired link on behalf of the vehicle. The mobility signaling occurs twice, because the previous MAG that supported the vehicle sends a de-registration message to the LMA.

2) L2 HANDOVER SCHEME

In L2HS, the mobility signaling also occurs twice, similar to PMIPv6, because the new RSU registers the vehicle's attachment to the AR while the previous RSU informs the AR of the detachment of the vehicle. However, in L2HS, the signaling packets are transmitted within the AR's coverage. As a result, the number of hops the signaling packet goes through is reduced in comparison to that of PMIPv6. The signaling cost of L2HS is represented as

$$C_S^{(L2)} = \mu_a\{(L_{DI} + L_{AI})\alpha h_{A-R} + 2L_{ACK}\alpha h_{A-R}\} \qquad (2)$$

While the vehicle exits the old RSU and enters the new RSU, two notification signals are generated, along with responses to these.

C. HANDOVER LATENCY

The handover latency is defined by the difference between the time the vehicle received the last packet before leaving the previous RSU and the time the vehicle receives the first packet after approaching the new RSU. Table 3 summarizes the definitions of the parameters required to calculate the handover latency. We refer to the handover latency definition in [33], which is expressed as

$$T_{HO}^{(\cdot)} = T_{L2} + T_{RD} + T_{RS} + T_{BU}^{(\cdot)} + T_P^{(\cdot)} \qquad (3)$$

1) PROXY MOBILE IPV6

In PMIPv6, the handover delays of L2 and L3 must be considered in order to obtain the total handover delay. Upon completion of the L2 handover, the vehicle should send an RS to the network entity in order to request the start of the handover process. $T_{RD}^{(PMIPv6)}$, the time that the vehicle should wait before sending the RS, is selected between 0 and MAX_RTR_SOLICITATION_DELAY (1000ms) [16]. $T_{RS}^{(PMIPv6)}$, the time taken for the RS to arrive from the vehicle to the RSU, is expressed as

$$T_{RS}^{(PMIPv6)} = \frac{L_{RS}}{B_{WL}} \qquad (4)$$

The delay of the binding update process in PMIPv6 is expressed as

$$T_{BU}^{(PMIPv6)} = h_{G-A}\left(\frac{L_{PBU} + L_{PBA}}{B_{WD}} + 2PT_{WD}\right) \qquad (5)$$

The arrival time when the vehicle receives the first packet following the handover procedure of PMIPv6 is expressed as

$$\begin{aligned} T_P^{(PMIPv6)} = h_{G-A}\left(\frac{L_{DATA} + \omega}{B_{WD}} + PT_{WD}\right) \\ + h_{R-V}\left(\frac{L_{DATA}}{B_{WL}} + PT_{WL}\right) \end{aligned} \qquad (6)$$

The 40 byte IPv6 tunnel header ω is added when the data packet passes through the LMA and the MAG.

2) L2 HANDOVER SCHEME

In L2HS, only the L2 level handover is performed, unlike in PMIPv6. We modified the handover-latency definition in [33] in order to adapt it to the VANET-environment. The modified handover latency is expressed as

$$T_{HO}^{(L2)} = T_{Detect} + T_{BU}^{(L2)} + T_P^{(L2)} \qquad (7)$$

In VANET, the RSU detects the vehicle with a beacon sent by the vehicle. Therefore, the delay of the vehicle detected by the RSU depends on the vehicle's beacon interval. The delay of the binding update for H2LS is expressed as

$$T_{BU}^{(L2)} = h_{A-R}\left(\frac{L_{AI} + L_{ACK}}{B_{WD}} + 2PT_{WD}\right) \qquad (8)$$

The arrival time of when the vehicle receives the first packet following the handover process of L2HS is expressed as

$$\begin{aligned} T_P^{(L2)} = h_{G-A}\left(\frac{L_{DATA}}{B_{WD}} + PT_{WD}\right) \\ + h_{A-R}\left(\frac{L_{DATA} + \gamma}{B_{WD}} + PT_{WD}\right) \\ + h_{R-V}\left(\frac{L_{DATA}}{B_{WL}} + PT_{WL}\right) \end{aligned} \qquad (9)$$

The 4 byte VLAN tagging γ is added when the data packet passes through the AR and the RSUs.

D. SIGNALING COST ANALYSIS RESULTS

This section presents the cost analysis results for PMIPv6 and L2HS. The default system parameters for the analysis are set at $h_{C-G} = 5$, $h_{G-A} = 3$, $h_{A-R} = 1$, $h_{R-V} = 1$, $\alpha = 1$, $\beta = 1.5$, $L_P = 64$, R = 400 m, $L_{PBU} = L_{PBA} =$ 84bytes, $L_{RS} =$ 52bytes, and N(p) = 20 based on [34]. We set the

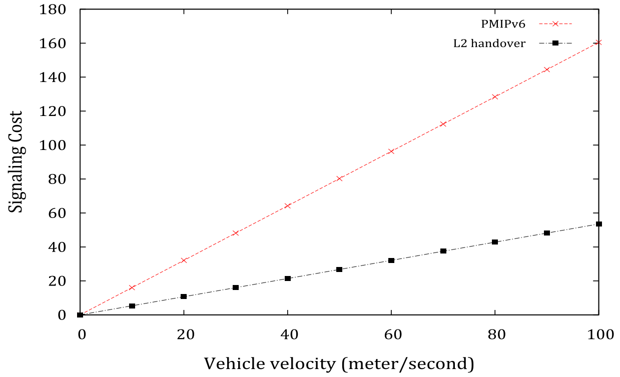


FIGURE 7. Signaling cost versus velocity.

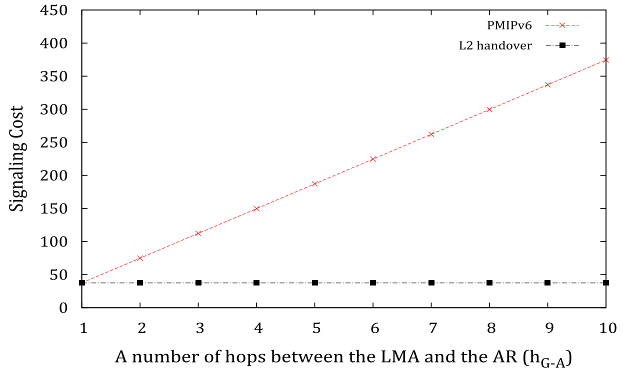


FIGURE 8. Signaling cost versus h_{G-A}.

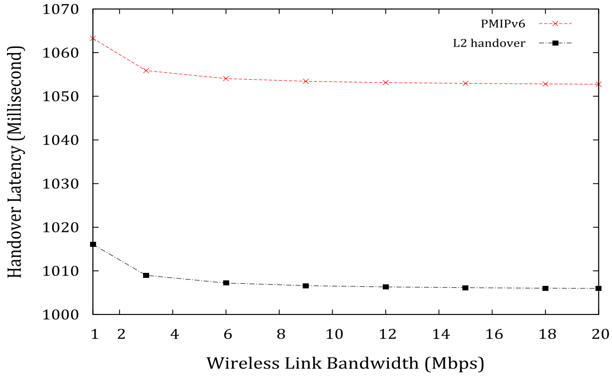


FIGURE 9. Handover latency versus B_{WL}.

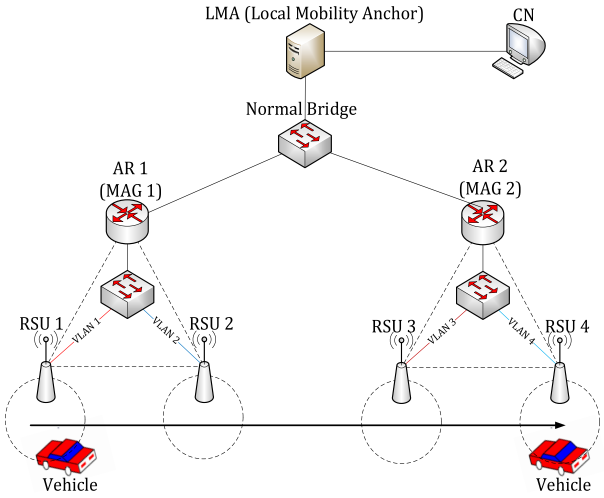


FIGURE 10. Simulation topology.

size of the control message used in L2HS to be equal to that of PMIPv6. This is to confirm the difference due to factors beyond the control packet size.

Fig. 7 represents the signaling cost versus velocity (v). In PMIPv6 and L2HS, the signaling cost increases in direct proportion to increases in the vehicle speed, but the signaling cost of PMIPv6 is higher than that of L2HS. This is because the number of hops transmitted by the signaling packet is limited to 1 hop in the intra AR handover. This difference is even more pronounced in Fig. 8. The longer the distance between the gateway and the AR, the lager the signaling cost of the inter AR handover of PMIPv6, but that of the intra AR handover of L2HS is unaffected.

E. HANDOVER LATENCY ANALYSIS

This section explains the handover latency results for PMIPv6 and L2HS. The system parameter values are set at T_{L2} = 45.35ms, B_{WL} = 11Mbps, B_{WD} = 100Mbps, T_{RD} = 1000ms, L_{DATA} = 1328bytes, PT_{WL} = 2 and PT_{WD} = 0.5ms, based on [35] and [36].

Fig. 9 depicts the handover latencies versus the wireless bandwidth. In PMIPv6, the vehicle must transmit an RS in order to initiate the handover. On the other hand, L2HS uses beacons periodically transmitted by the vehicle. Consequently, L2HS shows better performance in terms of handover latency because the vehicle does not need to wait to send the RS.

V. SIMULATION

We use the ns-3 network simulator (version 3.23) and its WAVE model library to simulate the proposed VANET handover scheme. Figure 10 shows the network topology used in the simulation.

The vehicle has a WAVE interface and moves sequentially from RSU 1 to RSU 4 at a constant velocity (25m/s). The vehicle broadcasts a safety beacon every 100 ms. The RSUs are deployed on the side of a highway and they broadcasts a WAVE Service Advertisement (WSA) at a rate of 100 times per 5 sec. The RSUs are set at 760 m intervals for the overlapped coverage case and 920 m for the disjoint coverage case. The normal zone is defined as being within 370 m of the RSU. This is because the experimental result of [37] shows that the maximum reliable communication distance of the WAVE interface is approximately 370 meters. Based on these experimental results, we assigned the maximum communication coverage of each RSU to 410 m in this simulation.

The L2 switch connects the RSUs with the AR and has VLAN functions. The normal L2 bridge is used to connect the ARs (MAGs) with the LMA. The CN is connected to the LMA and it sends the UDP packets to the vehicle at a rate of 500 Kbps. Unlike TCP, UDP is advantageous in measuring the amount of packet loss because there is no additional packet exchange procedure for congestion control or packet retransmission. We set the speed of all wired links to 100 Mbps and the speed of all wireless links to 6 Mbps. The link delay of the wired section is set to 10 ms, and the link delay between the CN and the LMA is set to 60 ms.

In order to show the effectiveness of the proposed L2 extension mechanism and intra AR handover scheme, simulations are performed under four different scenarios. In Scenario 1 (S1), the simulation is performed without the VLAN configuration and the buffering scheme. In Scenario 2 (S2), the simulation is performed only with the VLAN configuration. In Scenario 3 (S3) and Scenario 4 (S4), the simulations are performed with the buffering scheme and the VLAN configuration. S3 is performed under disjointed coverage, while S4 is performed under overlapped coverage.

Fig. 11 shows the sequence of packets at the vehicle as it moves from RSU 1 to RSU 2. In all scenarios, the vehicle receives packets without any loss before handover occurs. The S1 result in Fig. 11(a) highlights the necessity of the VLAN configuration. Even if the AR detects that the vehicle enters an area of RSU 2, the vehicle cannot receive the packets. As the frame carrying a UDP packet does not contain the RSU 2 MAC address, the L2 switch with the self-learning mechanism forwards the frame to RSU 1 until the vehicle at RSU 2 generates an up-link packet to the AR. The S2 result shown in Fig. 11(b) shows that the vehicle receives the packets again after the vehicle enters the coverage of RSU 2. However, some packet loss still occurs due to the absence of buffer at the AR. The results of S3 and S4 present the effectiveness of the packet buffering at the AR. Fig. 11(c) shows that the vehicle rapidly receives the buffered packets from RSU 2 after the handover process is completed. In the result of S4, presented in Fig. 11(d), the vehicle receives the packets continuously without any loss. This is because the coverages of RSU 1 and RSU 2 overlap and the WAVE interface can receive the packets without any specific association procedure [1]. Therefore, similar to the concept of soft handover, a vehicle can simultaneously receive the packets from both RSU 1 and RSU 2 within the overlapped coverage.

Fig. 12 shows that the ARQ operation between the AR and the RSUs is effective. When the vehicle enters the handover zone, the AR begins to buffer the packets and the RSU continues to transmit the packets to the vehicle. However, as shown in Fig. 12(a) and Fig. 12(b), some packet loss occurs because the communication link is unreliable. The simulation result in Fig. 12(a) shows that the vehicle does not receive duplicated packets that it has already received following the handover. According to the ARQ operation, the AR can remove the successfully transferred packets in collaboration with the RSU. On the other hand, the simulation result in Fig. 12(b) shows that the vehicle receives duplicate packets due to the absence of an ARQ operation between the AR and the RSUs.

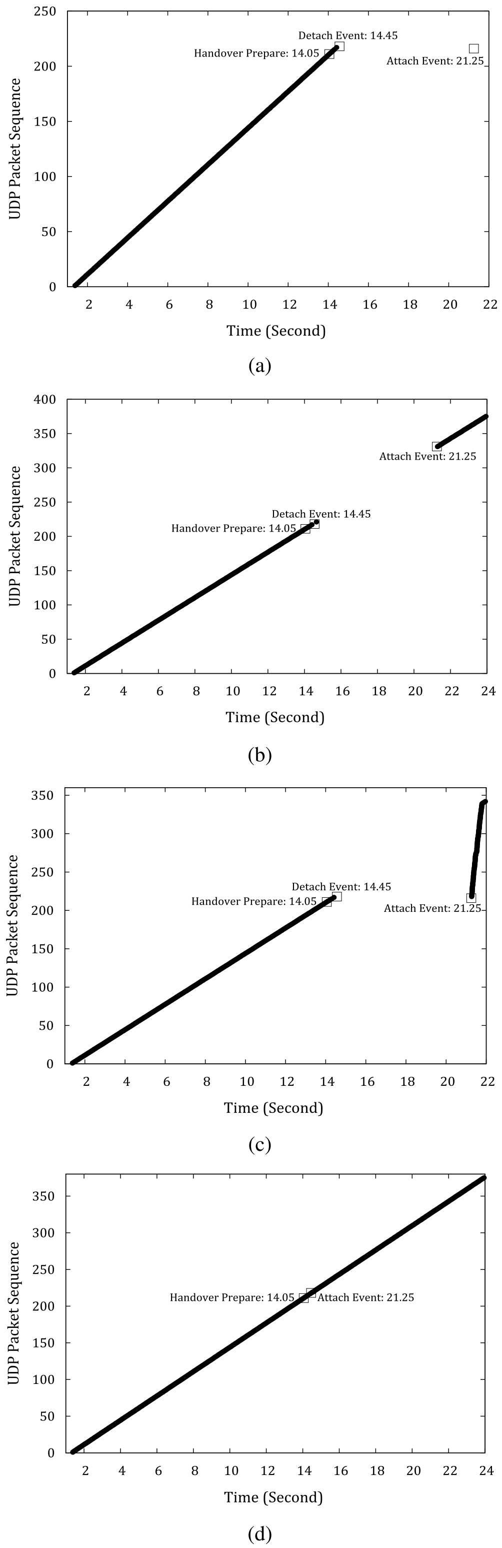
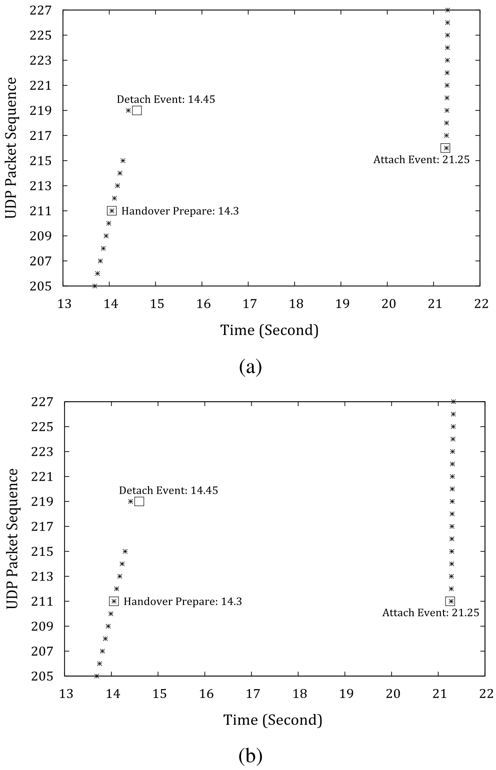


FIGURE 11. **Received packet sequences in the vehicle (Intra AR handover). (a) Packet sequence without VLAN configuration. (b) Packet sequence with VLAN configuration / without buffering. (c) Packet sequence with buffering. (d) Packet sequence within overlapped coverage.**



(a)

(b)

FIGURE 12. **Received packet sequences in the vehicle (Intra AR handover). (a) Packet sequence with ARQ operation. (b) Packet sequence without ARQ operation.**

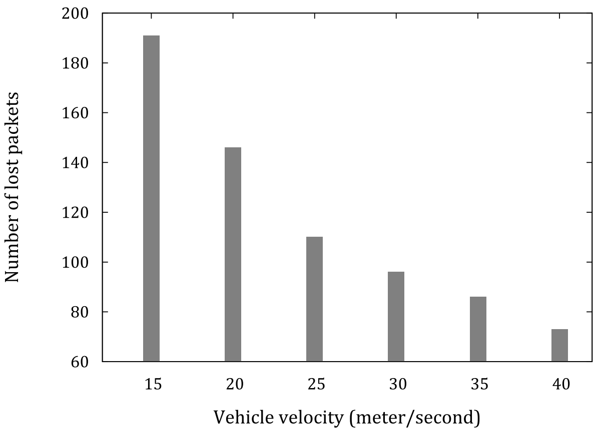
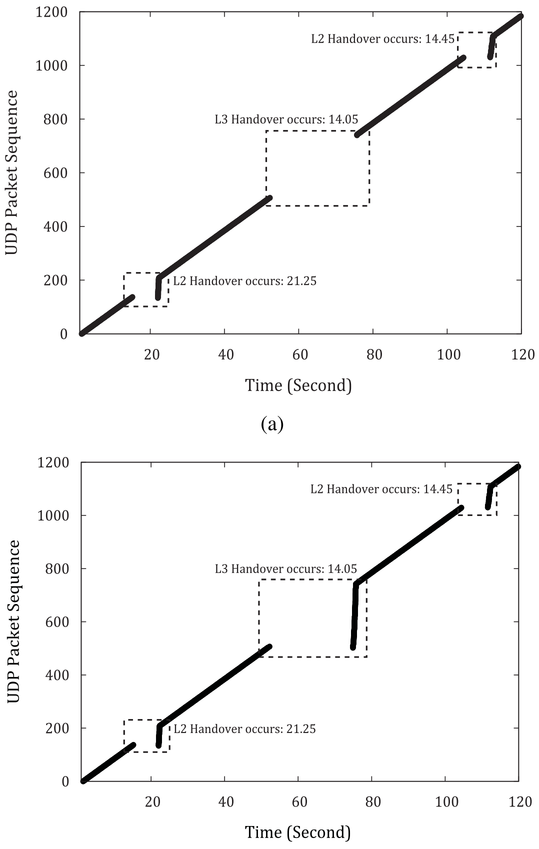


FIGURE 13. **Number of lost packets versus velocity.**

Fig. 13 represents the number of packets lost in the handover process depending on the vehicle's velocity when there is no packet buffer in the AR. Packet loss occurs when the vehicle does not belong to any RSU coverage. The faster the vehicle speed, the less time the vehicle stays in the shadow area, thus reducing the amount of packet loss. In other words, as the interruption time is increased due to the slowness of the vehicle, the number of packets that the vehicle does not receive increases. Based on these experimental results, it is possible to estimate the approximate buffer size that the AR should have in the proposed scheme.



(a)

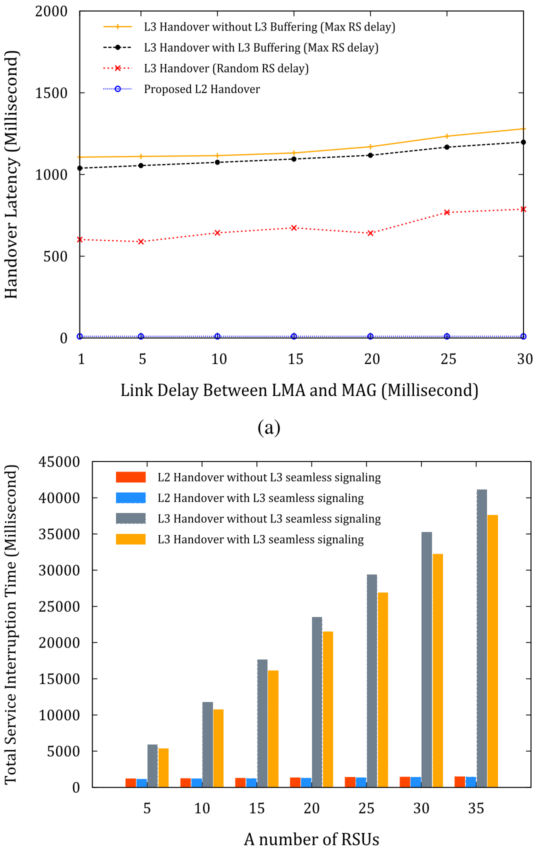
(b)

FIGURE 14. **Received packet sequences in the vehicle (Inter AR handover). (a) Packet sequence without L3 buffering. (b) Packet sequence with L3 buffering.**

In order to handle the inter AR handover, the PMIPv6 is applied in our proposed scheme. Fig. 14(a) shows the received packet sequence with PMIPv6. The vehicle receives the packets upon completion of the inter AR handover. However, some packet loss occurs when the vehicle does not belong to the coverage of any RSU's.

A modification of PMIPv6 is required in order to reduce such packet loss. We modified the PMIPv6 operation to include the previous MAG's information when the LMA sends the Proxy Binding Acknowledgment to AR 2 (MAG 2). Then, AR 2 requests that AR 1 sends buffered packets. Consequently, in Fig. 14(a), the vehicle receives the packet without loss, even if the L3 handover occurs.

Fig. 15 represents the performance comparison between the PMIPv6 L3 handover and the proposed L2 handover. In this experiment, the handover latency is defined as the time to when the vehicle received the first packet after entering the RSU's coverage. The simulation result in Fig. 15(a) shows the handover latency depending on the link delay between LMA and MAG. Since the proposed L2 handover only occurs within the expanded coverage of the AR, the handover latency is not affected, even in the case that the link delay between the LMA and the MAG increases.



(a)

(b)

FIGURE 15. **Handover performance comparison. (a) Handover latency comparison. (b) Service interruption time comparison.**

The other graphs in Fig. 15(a) show the results of applying PMIPv6 as a handover scheme in a situation where all RSUs are operated as ARs. PMIPv6 requires the vehicle to send a Router Solicitation (RS) message to the AR for movement detection. However, the vehicle should wait for a certain period of time prior to sending the RS [16]. The yellow and black graphs show the results of setting the delay to MAX_RTR_SOLICITATION_DELAY (1000ms) before sending RS. As the link delay between LMA and MAG increases, the handover latency increases as well. The difference between the two graphs is caused by the addition of the buffer function in PMIPv6. The handover latency is slightly reduced by adding buffers at MAG and receiving buffered packets from the nearest MAG. The red graph shows the result when the delay is set to a random value between 0 ms and 1000 ms prior to sending the RS. We experimented 30 times for each link delay, and this graph shows the average value for these attempts. Since the most time consuming part of PMIPv6 handover latency is the IPv6 configuration, it can clearly be seen that the waiting time before sending RS is more influential than the link delay between LMA and MAG. Consequently, it can be confirmed that the proposed L2 handover is improved by tens of times in handover latency, in comparison to the PMIPv6 L3 handover.

Fig. 15(b) represents the total service interruption time that occurs every time a vehicle crosses an RSU. It can be seen that the proposed L2 handover scheme, in which the RSU operates as an access point, has significantly less service interruption time than the PMIPv6 L3 handover. Adding buffering capability to PMIPv6 reduces the service interruption time, but it still has a much longer service interruption time than the proposed L2 handover scheme.

VI. CONCLUSION

In this paper, we propose an L2-extension mechanism with a network-based seamless handover scheme for VANETs. The proposed scheme decouples the AR and RSU, and the coverage of the AR has increased by the coverage of several RSUs. This not only simplifies the function of the RSU, but also makes the deployment of VANET more flexible. As a result, most inter AR L3 handovers can be replaced by intra AR L2 handovers. Since the L3 handover latency is longer than the L2 handover latency, the proposed scheme, by reducing the frequency of the L3 handover, also significantly mitigates the total handover latency. As the L3 handover eventually occurs when the vehicle is outside of the range of the AR, the scheme proposes a handover scheme for VANET that covers both inter AR and intra AR handovers by applying PMIPv6. The scheme supports seamlessness packet delivery for all L2 and L3 handovers. Consequently, a vehicle could be supported for seamless IP mobility over a wide area without any modification.

The upcoming vehicles that can be expected in future will be complex smart machines that operate various applications; traffic monitoring for driver safety and infotainment applications such as video streaming are typical applications that will be provided to the driver. Since handover of the vehicle occurs frequently in the VANET environment, it is important to support seamless communication for the vehicle in order to improve driver safety. We expect that the proposed handover scheme will be helpful for addressing the mobility problem in VANET.

As for future work, we plan to compare our proposed VANET mobility scheme with other recently proposed VANET mobility schemes.

REFERENCES

[1] J. B. Kenney, "Dedicated short-range communications (DSRC) standards in the United States," *Proc. IEEE*, vol. 99, no. 7, pp. 1162–1182, Jul. 2011.

[2] A. Festag, "Cooperative intelligent transport systems standards in Europe," *IEEE Commun. Mag.*, vol. 52, no. 12, pp. 166–172, Dec. 2014.

[3] M. Gerla and L. Kleinrock, "Vehicular networks and the future of the mobile Internet," *Comput. Netw. J.*, vol. 55, no. 2, pp. 457–469, 2011.

[4] J.-T. Park and S.-M. Chun, "Fast mobility management for delay-sensitive applications in vehicular networks," *IEEE Commun. Lett.*, vol. 15, no. 1, pp. 31–33, Jan. 2011.

[5] *IEEE Guide for Wireless Access in Vehicular Environments (WAVE)—Architecture*, IEEE Standard 1609.0-2013, Mar. 2014.

[6] A. K. Tripathi, R. Radhakrishanan, and J. S. Lather, "Impact of wireless link delay on handover latency in Mobile IPv6 environment," in *Proc. Int. Conf. Issues Challenges Intell. Comput. Techn. (ICICT)*, Feb. 2014, pp. 424–428.

[7] L. Banda, M. Mzyece, and G. Nóel, "Fast handover management in IP-based vehicular networks," in *Proc. IEEE Int. Conf. Ind. Technol.*, Feb. 2013, pp. 1279–1284.
[8] S. Debnath and A. Majumder, "Enhanced MMIP6 for vehicular ad-hoc networks," in *Proc. Int. Symp. Adv. Comput. Commun.*, Sep. 2015, pp. 303–309.
[9] Q. B. Mussabbir, W. Yao, Z. Niu, and X. Fu, "Optimized FMIPv6 using IEEE 802.21 MIH services in vehicular networks," *IEEE Trans. Veh. Technol.*, vol. 56, no. 6, pp. 3397–3407, Nov. 2007.
[10] K. Taniuchi *et al.*, "IEEE 802.21: Media independent handover: Features, applicability, and realization," *IEEE Commun. Mag.*, vol. 47, no. 1, pp. 112–120, Jan. 2009.
[11] S. Cespedes, N. Lu, and X. Shen, "VIP-WAVE: On the feasibility of IP communications in 802.11p vehicular networks," *IEEE Trans. Intell. Transp. Syst.*, vol. 14, no. 1, pp. 82–97, Mar. 2013.
[12] V. Sandonis, M. Calderon, I. Soto, and C. J. Bernardos, "Design and performance evaluation of a PMIPv6 solution for geonetworking-based VANETs," *Ad Hoc Netw.*, vol. 11, no. 7, pp. 2069–2082, Sep. 2013.
[13] M.-S. Kim, S. Lee, and N. Golmie, "Enhanced fast handover for proxy mobile IPv6 in vehicular networks," *Wireless Netw.*, vol. 18, no. 4, pp. 401–411, May 2012.
[14] S. Tsourdos, A. Michalas, A. Sgora, and D. D. Vergados, "Enhanced fast handovers for PMIPv6 in vehicular environments," in *Proc. Inf., Intell., Syst. Appl.*, Jul. 2014, pp. 420–425.
[15] H. N. Al-Hashimi and W. N. Hussein, "PMIPv6 assistive cross-layer design to reduce handover latency in VANET mobility for next generation wireless networks," *Netw. Protocols Algorithms*, vol. 7, no. 3, pp. 1–17, Nov. 2015.
[16] T. Narten, E. Nordmark, W. Simpson, and H. Soliman, *Neighbor Discovery for IP Version 6 (IPv6)*, document RFC 4861, IETF, Fremont, CA, USA, 2007.
[17] E. Nordmark and I. Gashinsky, *Neighbor Unreachability Detection is too Impatient*, document RFC 7048, IETF, Fremont, CA, USA, 2014.
[18] CAMP Vehicle Safety Communication Consortium, "Vehicle safety communications project task 3 final report—Identify intelligent vehicle safety applications enabled by DSRC," Nat. Highway Traffic Safety Admin., U.S. Dept. Transp., Washington, DC, USA, Tech. Rep. DOT HS 809-859, 2005.
[19] R. Hinden and S. Deering, *Internet Protocol, Version 6 (IPv6) Specification*, document RFC 2460, IETF, Fremont, CA, USA, 1998.
[20] E. Baccelli, T. Clausen, and R. Wakikawa, "IPv6 operation for WAVE—Wireless access in vehicular environments," in *Proc. IEEE Veh. Netw. Conf.*, Dec. 2010, pp. 160–165.
[21] *Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 4: Geographical Addressing and Forwarding for Point-to-Point and Point-to-Multipoint Communications*, document ETSI EN 302 636-4-1, ETSI, Sophia Antipolis, France, Oct. 2013.
[22] *Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 6: Internet Integration*, document ETSI EN 302 636-6-1, ETSI, Sophia Antipolis, France, Oct. 2013.
[23] H. Yokota *et al.*, *Fast Handovers for Proxy Mobile IPv6*, document RFC 5949, IETF, Fremont, CA, USA, 2010.
[24] F. Teraoka *et al.*, *Unified Layer 2 (L2) Abstractions for Layer 3 (L3)-Driven Fast Handover*, document RFC 5184, IETF, Fremont, CA, USA, 2008.
[25] S. Thomson, T. Narten, and T. Jinmei, *IPv6 Stateless Address Autoconfiguration*, document RFC 2462, IETF, Fremont, CA, USA, 1998.
[26] *IEEE Standard for Information Technology—Local and Metropolitan Area Networks—Specific Requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments*, IEEE Standard 802.11p-2010. Jul. 2010.
[27] *Intelligent Transport Systems (ITS); Access Layer Specification for Intelligent Transport Systems Operating in the 5 GHz Frequency Band*, document ETSI EN 302 663 V1.2.0, ETSI, Sophia Antipolis, France, Nov. 2012.
[28] *IEEE Standard for Information Technology—Telecommunications and Information Exchange Between Systems Local and Metropolitan Area Networks—Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, IEEE Standard 802.11-2012, Mar. 2012.
[29] J.-M. Lee, M.-S. Woo, and S.-G. Min, "Performance analysis of WAVE control channels for public safety services in VANETs," *Int. J. Comput. Commun. Eng.*, vol. 2, no. 5, pp. 563–570, 2013.
[30] S. Gundavelli *et al.*, *Proxy Mobile IPv6*, document RFC 5213, IETF, Fremont, CA, USA, 2008.
[31] J. H. Lee, T. Ernst, and T. M. Chung, "Cost analysis of IP mobility management protocols for consumer mobile devices," *IEEE Trans. Consum. Electron.*, vol. 56, no. 2, pp. 1010–1017, May 2010.
[32] J.-H. Lee, T.-M. Chung, and S. Gundavelli, "A comparative signaling cost analysis of hierarchical mobile IPv6 and proxy mobile IPv6," in *Proc. IEEE 19th Int. Symp. Personal, Indoor Mobile Radio Commun. (PIMRC)*, Sep. 2008, pp. 1–6.
[33] J.-H. Lee, Y.-D. Kim, and D. Lee, "Enhanced handover process for proxy mobile IPv6," in *Proc. Multimedia Ubiquitous Eng. (MUE)*, Aug. 2010, pp. 1–5.
[34] S.-M. Kim, H.-Y. Choi, Y.-H. Han, and S.-G. Min, "An adaptation of proxy mobile IPv6 to openflow architecture over software defined networking," *IEICE Trans. Commun.*, vol. E98.B, no. 4, pp. 596–606, Apr. 2015.
[35] S. Pack, J. Choi, T. Kwon, and Y. Choi, "Fast-handoff support in IEEE 802.11 wireless networks," *IEEE Commun. Surveys Tuts.*, vol. 9, no. 1, pp. 2–12, 1st Quart., 2007.
[36] S. Pack, X. Shen, J. W. Mark, and J. Pan, "Adaptive route optimization in hierarchical mobile IPv6 networks," *IEEE Trans. Mobile Comput.*, vol. 6, no. 8, pp. 903–914, Aug. 2007.
[37] R. Meireles, M. Boban, P. Steenkiste, O. Tonguz, and J. Barros, "Experimental study on the impact of vehicular obstructions in VANETs," in *Proc. IEEE Veh. Netw. Conf. (VNC)*, Dec. 2010, pp. 338–345.

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