Fast Mobility Management for Delay-Sensitive Applications in Vehicular Networks

Jong-Tae Park, *Senior Member, IEEE,* and Seung-Man Chun, *Student Member, IEEE*

***Abstract*—This letter presents a fast IP mobility management scheme in vehicular networks where multiple wireless network interfaces are used to perform the fast handover without packet loss. In order to do that, the IETF standard HMIPv6 has been extended, where multiple simultaneous tunnels between the HMIPv6 MAP and the mobile gateway are dynamically constructed. The architecture for supporting multiple tunnels has been designed, and both mathematical analysis and simulation have been done for performance evaluation.**

***Index Terms*—HMIPv6, mobility management, handover with dual interfaces.**

I. INTRODUCTION

OVER the past few years, there has been significant progress in the development of vehicular ad-hoc networks (VANETs). The IEEE 802.11p standard has been developed for the link and network layer of VANET [1]. The new emerging infotainment applications or safety-related mobile applications call for the vehicular networks to support seamless wireless Internet services in the fast moving vehicle [2]. Unfortunately, as the fast moving vehicles pass through different IP domains of VANETs, a large handover delay might occur. This delay is mainly caused by the short coverage of IEEE 802.11p, the layer 3 handover delay of MIPv6, and coarse unreliable radio environment [2]. The IEEE 802.11p standard has relatively short radio coverage, for example, its maximum is up to 1km, through usually only 300m. This large handover delay is not suitable for delay-sensitive vehicular applications including safety applications as well as non-safety applications such as VoIP and infotainment applications.

Since the VANET architecture supports IPv6 for the Internet access protocol [1], most layer 3 mobility management schemes for V2I communication are based on IETF MIPv6 and its extensions such as FMIPv6, HMIPv6, Network Mobility (NEMO) [2]. Most of these IETF MIPv6 and its extensions are not suitable to support delay-sensitive vehicular applications in vehicular networks, especially for fast moving vehicles [2]. This is because large packet loss and delay might occur for fast moving vehicles which frequently change their points of attachment. Recently, in order to remedy these shortcomings, there appeared research efforts utilizing multiple channels for mobility management in vehicular networks [3]. In [3], the authors propose construction of multiple IP tunnels for handover between home agent (HA) and mobile gateway (MG) in vehicular network to improve the handover performance. However, for the case in which the HA and MG are located far apart, the large handover delay may occur.

HMIPv6 was developed to reduce the signaling overhead and handover latency for local mobility management. HMIPv6 employs a mobility anchor point (MAP) to reduce the amount of signaling between the mobile node and the correspondent node (CN) or its HA, so that comparing with MIPv6, it can reduce both the handover latency and signaling overhead. The MG is a router attached inside vehicles, usually being equipped with multiple wireless interfaces, and is responsible for mobility and Internet connectivity.

In this letter, we propose a new IP mobility management scheme for V2I communication in which the multiple channels of the MG are utilized for efficient handover operation in vehicular environment. The main difference between our approach and those of the MIPv6, its extensions and other related work [3], is that multiple IP tunnels are locally constructed between the HMIPv6 MAP and the MG. The packets are distributed in parallel over these tunnels during handover operation, which results in negligible performance degradation in both handover latency and packet loss.

Within the knowledge of the authors of this letter, there have been no previous attempts to support multiple tunnels between the MAP and the MG. The architecture and mobility model for supporting multiple tunnels are presented, mathematical analysis and simulation are done for performance evaluation, including handover latency and packet loss, as the MG rapidly passes over the overlapping areas of different IP domains. The analysis results show that in comparing MIPv6 and HMIPv6, the proposed mechanism demonstrates a high efficiency in performance with regard to handover latency and packet loss.

II. ARCHITECTURE AND MOBILITY MODEL FOR MULTIPLE TUNNEL SUPPORT

Fig. 1 shows the architecture and mobility model using multiple tunnels between the MG and MAP of HMIPv6. Here, the operation of the proposed extension of HMIPv6, i.e., E-HMIPv6 is described in detail. First, an MG is connected through local care-of-address 1 (LCoA1) to a previous access router (PAR) through interface 1 (IF1). The MG constructs an IP tunnel with end-points of LCoA1 and regional care-of-address (RCoA) to the E-MAP to exchange packets with HA/CN. Interface 1 and interface 2 (IF2) represent two wireless network interfaces of the MG which are chosen to be activated for data transmission from multiple wireless network interfaces. It is assumed that the MG selects two wireless network interfaces from multiple wireless network interfaces which have the best radio signal strengths from the AR.

As the MG moves away from PAR and enters into the overlapping area between network domain of the PAR and network domain of a next access router (NAR), the radio

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The authors are with the School of Electrical Engineering and Computer Science, Kyungpook National University, Daegu, Korea (e-mail: {jtpark, smchun}@ee.knu.ac.kr).

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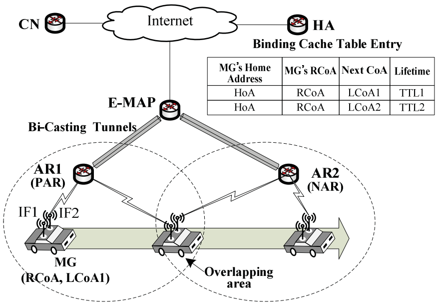

Fig. 1. Architecture of extension of HMIPv6 and mobility model using multiple tunnels.

signal strength from the PAR decreases and it starts to get LCoA2 and connects to NAR by activating the IF2. As the MG successfully connects to the NAR, it requests the E-MAP for binding the LCoA2 with RCoA. In this case, the E-MAP simultaneously binds both LCoA1 and LCoA2 with RCoA. In simultaneous binding, the packets from HA/CN can be transmitted through multiple tunnels of the E-MAP.

In the MG, the packets from multiple tunnels can be directed to the home IP address (HoA) using IPv6 home address option. In this way, the fast IP handover in E-HMIPv6 can be achieved without performance degradation in both packet loss and delay. The activity of handover usually takes place in the overlapping area, with distance of d meters, between PAR and NAR as the MG moves across the region. In evaluating the performance, the performance in the following mobility model is looked into: Case A, in which the handover can be completed within the overlapping area, Case B, in which the handover may not be sometimes accomplished due to the small overlapping area between PAR and NAR, and Case C where there is almost no overlapping area between cells. It is assumed that the MG moves with the speed of v m/sec from the PAR to NAR.

III. Mathematical Analysis of Handover Delay and Packet Loss of E-HMIPv6

For the mobility model in Fig. 1, the handover delay and packet loss are derived by mathematical analysis. The handoff latency at an MG side is the time interval during which an MG cannot send or receive any packets during handoff and it is composed of layer 2 (L2) and layer (L3) handoff latencies [4]. The total handover latency consists of the link switching time (t_{L2}) which is caused by L2 handover, IP connectivity latency (t_{IP}), and location update latency (t_{BU}). t_{IP} is sum of t_{MD} and t_{AC}, and t_{BU} is sum of t_{BU} and t_{NR}. Here, t_{MD} represents the movement detection delay, t_{AC} the addresses configuration and duplicate address detection delay, and t_{BU} is the binding update delay between MG and MAP, CN/HA or E-MAP. t_{NR} is the delay from completion of binding update to reception of first packet at the new IP address. In order to analyze the delay more precisely, the delay caused by the signaling message between the MG and the router is more specifically described below. Let $t_{X,Y}$ be defined as one-way signaling message transfer delay between nodes X and Y. If one of the endpoints is an MG, $t_{X,Y}$ is computed as follows [4]:

$$t_{X,Y}(s) = (\frac{s}{B_{wl}} + L_{wl}) + ((d_{x,y} - 1)(\frac{s}{B_w} + L_w + \varpi)) \quad (1)$$

TABLE I
Handover Latency

Protocol	Total handover latency
D_{MIPv6}	t_{L2}+t_{MD}+t_{AC}+4($t_{MG,\ HA}$+ $t_{MG,\ CN}$)+2$t_{HA,\ CN}$
D_{HMIPv6}	t_{L2}+t_{MD}+t_{AC}+2($t_{MG,\ MAP}$)
$D_{E-HMIPv6}$	t_{L2}+t_{MD}+t_{AC}+2($t_{MG,\ E-MAP}$)-t_{RT}

Here, s is the size of the signaling message, and B_{wl} and B_w are the bandwidths of the wireless link and wired links, respectively. L_{wl} and Lw are link delays of wireless and wired link, respectively. is the average queuing delay at each router in the Internet [4], and dx,y is the average number of hops between nodes X and Y. In Equation (1), the first term indicates one-way signaling message transfer delay in the wireless link, and the second term indicates one-way signaling message transfer delay in the wired link between the nodes X and Y. Let t_{RT}, called residence time, be defined as the duration of the MG to reside within the overlapping area while moving. Let $D_{HOprotocol}$ be defined as the total delay time of handover using handover protocol of $HOprotocol$. Then, three cases can be represented as follows. Case A is the case with $t_{RT} \geq D_{HOprotocol}$. The Case B with $t_{RT} < D_{HOprotocol}$ and the Case C with t_{RT}=0. The formula for handover latency was derived for each mobility management protocol for analytic performance evaluation. As described in [4], the handover latency in MIPv6 is composed of t_{L2}, t_{MD}, t_{AC}, t_{BU} and t_{RR}. Here, t_{BU}, t_{RR} are the delays, which the MG performs binding update to the HA and the return routability procedure, respectively. For MIPv6, t_{BU} is equal to 2($t_{MG,HA}$+$t_{MG,CN}$) and t_{RR} is equal to 2($t_{MG,CN}$+$t_{MG,HA}$+$t_{HA,CN}$).

In the HMIPv6, since it is only used for local mobility management, the binding update for either HA or CN is not necessary. However, instead of HA/CN, it requires a binding update for MAP, so the binding update delays (t_{BU}) to send back and forth the signaling message between the MG and the MAP are required. This incurs the delay of $2t_{MG,MAP}$.

Since both MIPv6 and HMIPv6 rely on the single wireless network interface, the handover delay is independent of the size of the overlapping area. However, in the case of E-HMIPv6, the handover delay is dependent on the size of the overlapping area. This is because for the case of MIPv6/HMIPv6, the MG should disconnect the current connection to the PAR in order to reconnect to the NAR. However, in case of the E-HMIPv6, the establishment of MG's new connection to the NAR can be completed while the MG's current connection to the PAR is still active, as long as the overlapping area between domains of the PAR and the NAR is large enough to sustain MG's connection to the PAR. As a result, t_{RT} in MIPv6/HMIPv6 does not change in Case A, Case B and Case C. On the contrary, in E-HMIPv6, t_{RT} gets different values for Case A, Case B and Case C.

The derivation of the handover latency for E-HMIPv6 is described below. For Case A, since the overlapping area is large enough to complete the handover operation while continuously receiving the packets, there will be no packet transfer delay due to handover operation. Therefore, the delay for the Case A is zero. For Case B, the handover delay depends on how long the current connection to the PAR is maintained during a handover operation in the overlapping area. For Case C, the MG cannot receive any data from the PAR during

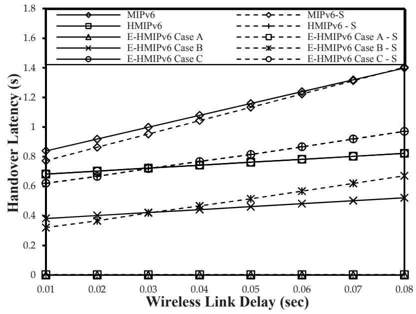

Fig 2. Impact of Wireless link delay on handover latency.

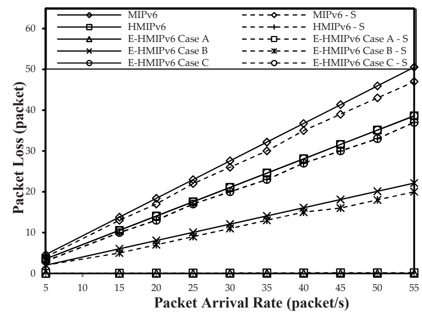

Fig 3. Packet loss as a function of packet arrival rate.

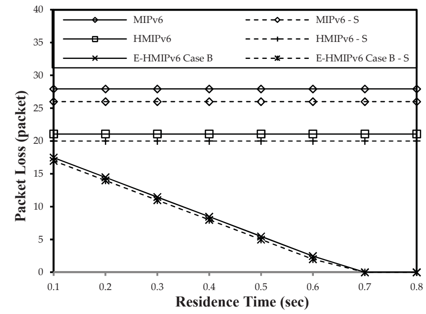

Fig 4. Packet loss as a function of residence time.

TABLE II
SYSTEM PARAMETER

Parameter	Value	Parameter	Value	Parameter	Value
t_{AC}	500ms	B_{wl}	11Mbps	s	96bytes
t_{MD}	100ms	ϖ	0.001s	λ_p	10pkts/s
t_{L2}	50ms	L_{wl}	20ms	v	20m/sec
B_w	100Mbps	L_w	2ms	$Pkt.Size$	100bytes

handover operation, since the current connection to the PAR is disrupted. A summary of the total handover delay for the MIPv6, HMIPv6 and E-HMIPv6 is in Table I. The packet loss is the amount packets dropped, lost or corrupted during transfer. Since the packet loss is proportional to the handover delay,the packet loss $P_{HOprotocol}$ of handover protocol of $HOprotocol$ can be calculated as follows [4]:

$$P_{HOprotocol} = \lambda_p \; D_{HOprotocol}$$

Here, λ_p is the packet arrival rate in unit of packet per time, and $D_{HOprotocol}$ is the handover latency of the handover protocol of $HOprotocol$.

IV. NUMERICAL RESULTS AND SIMULATION RESULTS

We have done the simulation and analysis using NS-2. Table II shows the basic system parameters for evaluating the performance of mobility management protocols. Most parameters used in this analysis are set to typical values found in [4]. It is assumed that the number of hops between an MG and an AR, CN and HA, E-MAP and PAR/NAR, and HA/CN and E-MAP are set to 1, 2, 2 and 2, respectively. It is also assumed that the MG is equipped with two wireless network interfaces, i.e., the IEEE 802.11a and g interfaces for layer 2 access networks. Since 802.11a and 802.11g are using difference frequencies, the interference between these two wireless network interfaces is negligible.

In the performance evaluation, the UDP-based audio application traffic with data rates of below 64 kbps, the packet size of 100 bytes, and the packet arrival rate of below 55 packets/second is used. In addition, the residence time is set to be varied between 0.1 and 0.8 ms, taking into account the vehicle speed. Both mathematical analysis and simulation results are shown in Fig. 2, Fig. 3 and Fig. 4. In the figures, the dotted line indicates the simulation results and continuous line indicates the analysis results. Fig. 2 shows a change of handover latency of the mobility protocol based on the changes of the wireless link delay. Handover latency of the proposed E-HMIPv6 is smaller than MIPv6 or HMIPv6 handover latency. As shown in Fig. 2, since the overlapping area is large enough to execute the handover operation in case of E-HMIPv6, the handover latency is negligible. However, for the Case B in which the overlapping area is relatively small to execute the handover operation, the handover latency may be occurred. For the Case C of E-HMIPv6, because there is no overlapping area the handover latency is the same as that of HMIPv6.

Fig. 3 shows the change of packet loss in terms of packet arrival rate. As shown in Fig. 3, the packet loss of the proposed E-HMIPv6 is less than those of the MIPv6 and HMIPv6. Furthermore, the packet loss of either MIPv6 or HMIPv6 increases sharply as the packet arrival rate increases. In contrast, for Case A of the E-HMIPv6, almost no packet loss occurs. For the Case B of E-HMIPv6, relatively small amount of packet loss occurs, where the value of t_{RT} was set to 0.3 sec. For the Case C, since there is almost no overlapping area, the packet loss is identical to that of HMIPv6.

In Fig. 4, the change of packet loss with regard to t_{RT} for the Case B of the E-HMIPv6 is shown. In order to measure the packet loss, the value p was set to 30 packets/second with the value of t_{RT} varying between 0.1 sec and 0.8 sec. As shown in Fig. 4, the packet loss for either MIPv6 or HMIPv6 is almost constant, without being impacted by t_{RT}. However, for the case of E-HMIPv6, the packet loss is drastically reduced as t_{RT} increases. This is because the handover can be more effectively completed within the overlapping area as t_{RT} increases. This result shows an interesting point that the packet loss can be decreased by reducing the moving speed of MG, since t_{RT} is inversely proportional to the moving speed. The results from the mathematical analysis and simulation are almost the same.

V. CONCLUSION

In this letter, we have presented a new fast IP mobility management scheme in which bi-casting multiple tunnels tunnels between mobile gateway and MAP of HMIPv6 using multiple wireless network interfaces are dynamically constructed during handover operation. The analysis results show that the proposed scheme, comparing with the HMIPv6 and MIPv6, demonstrates a high efficiency in performance with regard to handover latency and packet loss.

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