A Scheme Improving Fast PMIPv6-based Network Mobility by Eliminating Tunneling Overload for ITS

Seonggeun Ryu[1], Ji-Woong Choi[1], and Kyung-Joon Park[1]

***Abstract*— NEtwork MObility Basic Support (NEMO BS) protocol has been investigated to provide Internet connectivity of a group of nodes, which is suitable for Intelligent Transportation Systems (ITS) applications. Since NEMO BS is based on Mobile IPv6 (MIPv6), it often increases traffic load and handover latency due to the handover procedure. Thus, schemes combining Proxy MIPv6 (PMIPv6) with NEMO (P-NEMO) have emerged to solve these problems. However, they still suffer from packet loss and long handover latency during the handover. To prevent packet loss and reduce the handover latency, Fast P-NEMO (FP-NEMO) has emerged. Although FP-NEMO accelerates the handover procedure through tunneling, it may cause a serious burden of the tunnel between Mobile Access Gateways (MAGs). This is because all packets destined for Mobile Network Nodes (MNNs) are forwarded to a New MAG (NMAG) through the tunnel between MAGs. This problem becomes more critical, as the number of MNNs is large and there exists heavy traffic between MAGs. Therefore, we propose a scheme Improving FP-NEMO (IFP-NEMO) to eliminate that tunneling burden. IFP-NEMO performs the registration prior to the layer 2 handover. When the registration is completed, packets are forwarded to the NMAG directly, so that the tunnel between MAGs is not used during the handover. IFP-NEMO is analyzed and compared with FP-NEMO through performance evaluations. We show that IFP-NEMO outperforms FP-NEMO in numerical results.**

I. INTRODUCTION

Intelligent Transportation Systems (ITS) have attracted considerable interest in recent years. Although ITS applications were initially designed for safety-oriented communications, the role of infotainment has rapidly taken an important place [1]. In other words, Internet access service for ITS applications is required. To maintain vehicle's Internet connectivity for a group of nodes that moving together, NEMO BS [2] has been developed by the Internet Engineering Task Force (IETF). NEMO BS is considered in ITS standards, because it is a protocol which is able to provide network mobility [3], [4]. The International Organization for Standardization (ISO) TC204 WG16 has developed Communications Access for Land Mobiles (CALM) which adopts NEMO basic support referred to as the ITS station reference architecture [5]. The European Telecommunications Standards Institute (ETSI) has standardized Geographic addressing and routing (GeoNetworking) initially specified by the GeoNet European project and NEMO BS has been combined with GeoNetworking [4], [6], [7].

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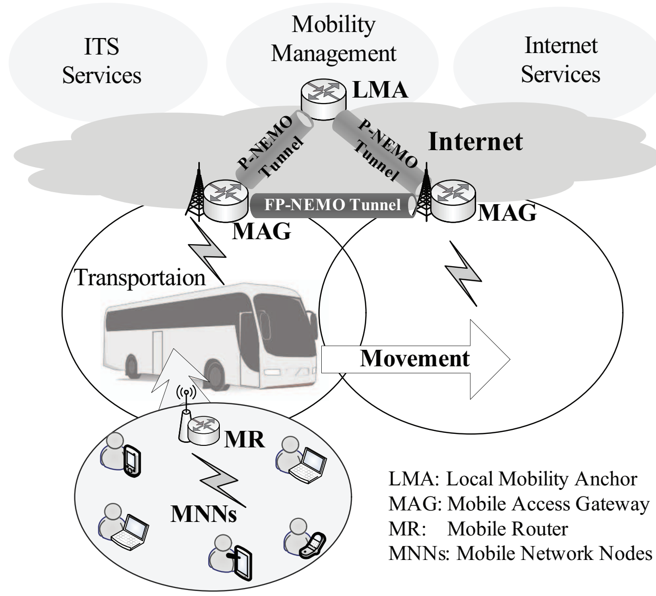

Fig. 1. Architecture overview of PMIPv6-based NEMO.

NEMO BS ensures session continuity for all nodes in the mobile network, which is a mobility support protocol specially designed to manage mobility of a moving network. In NEMO, a special device, called Mobile Router (MR) is defined to extend the Mobile Node (MN) of Mobile IPv6 (MIPv6) [8], by adding capability routing between its point of attachment and a subnet that moves with the MR. For instance, the MR handles the communication with the fixed infrastructure and provides access to passengers' devices using a convenient short-range radio technology in transportation systems. That is, the MR supports mobility for Mobile Network Nodes (MNNs) attached to it, so that it enables MNNs not to recognize movement.

Although NEMO BS seems to fit well in the context of ITS, it introduces packet loss and long handover latency during the handover. To solve these problems, Proxy MIPv6 (PMIPv6) [9] is adopted in NEMO [10], [11], [12]. PMIPv6 has been developed to provide the network-based mobility management concept. This approach does not require the MN to be involved in the exchange of signaling messages between itself and the Home Agent (HA). A proxy mobility agent such as a Mobile Access Gateway (MAG) in the network performs the signaling with the HA and performs the mobility management on behalf of the MN attached to the network [9]. Thus, PMIPv6-based NEMO (P-NEMO) can enhance the handover performance of NEMO. Fig. 1 shows

ISBN: 978-84-695-3472-4

architecture overview of P-NEMO. When the MR moves between MAGs, the MAG in the new network performs Proxy Binding Update (PBU) on behalf of the MR to maintain the connectivity to Internet. The PBU message is sent to a Local Mobility Anchor (LMA) which is the HA for the MR in PMIPv6 domain. However, P-NEMO still suffers from packet loss during the handover. To prevent packet loss and reduce the handover latency, Fast P-NEMO (FP-NEMO) is introduced by Lee et al. [4]. FP-NEMO utilizes wireless layer 2 events to anticipate the impending handover. The tunnel is established between a Previous MAG (PMAG) and an NMAG to prevent packet loss during the handover. Packets destined for MNNs are forwarded to the NMAG during the handover.

Even though FP-NEMO accelerates the handover procedure through tunneling, it may cause a serious burden of the tunnel between MAGs. This is because all packets destined for MNNs are forwarded to the NMAG through the tunnel between the PMAG and the NMAG. This problem becomes more critical, as the number of MNNs is large and there exists heavy traffic between MAGs. For example, when many MNNs are communicating with CNs and a link between the PMAG and the NMAG is in congestion, the tunnel which is established during the handover is overloaded. Hence, packets traversing the tunnel may be lost.

In this paper, we propose a scheme Improving FP-NEMO (IFP-NEMO) to eliminate the tunneling burden. IFP-NEMO makes use of TBU scheme [13], [14] which performs the registration to the HA prior to the layer 2 handover. When the registration is completed, packets are forwarded to the NMAG directly, so that the tunnel between the PMAG and the NMAG is not used during the handover. Detailed handover operation of IFP-NEMO is presented, and IFP-NEMO is compared with FP-NEMO using comprehensive performance evaluations. The main contributions of this paper are given as follows: First, we point out the significant tunneling burden of FP-NEMO through investigating fast handover schemes in NEMO. Second, we propose IFP-NEMO to eliminate the tunneling burden of FP-NEMO by performing the registration in advance. Third, we evaluate IFP-NEMO compared with FP-NEMO using analysis of the overall cost in detail. Fourth, IFP-NEMO requires only minor modifications to FP-NEMO. If the NMAG or the LMA is not aware of IFP-NEMO, FP-NEMO will be operated without further process.

The rest of this paper is organized as follows. Section II introduces description of NEMO, P-NEMO, and FP-NEMO as preliminary. In Section III, we describe the proposed scheme improving fast PMIPv6-based NEMO. In Sections IV and V, performance analysis and numerical results are presented, respectively. Finally, Section VI concludes this paper and suggests future works.

II. PRELIMINARY

In the vehicles, Internet access is required to support various ITS applications. Although MIPv6 can support mobility of a vehicle, it causes a lot of signaling messages when the large number of MNNs in the vehicle moves at once. To reduce the signaling burden of each node in the vehicle, NEMO BS has been introduced, which supports network mobility. NEMO BS is an efficient and scalable scheme, since the mobility management is transparent to each node in the vehicle. That is, MNNs do not send and receive signaling messages during the handover, because a special device, an MR, provides mobility of each MNN connected to it. When the MR moves to a new network, it creates a Care-of Address (CoA) and sends a Binding Update (BU) message to inform its new location to the HA. The HA then sends a Binding Acknowledgement (BA) message back to the MR. After that, a bidirectional tunnel between the MR and the HA is established, and all packets destined for the MNNs attached to the MR are delivered through this tunnel.

NEMO BS may be suitable for ITS applications. It, however, introduces packet loss and long handover latency during the handover. This is because the handover procedure of NEMO BS is based on that of MIPv6. To solve these problems, studies combining NEMO with PMIPv6 (P-NEMO) have been presented in [10], [11], [12]. PMIPv6 is intended for providing network-based IP mobility management support to the MN, without requiring the participation of the MN in any IP mobility related signaling. The mobility entities in the network will track the MN's movements and will initiate the mobility signaling and set up the required routing state. The core mobility entities are the LMA which is responsible for maintaining the MN's reachability state like the HA, and the MAG which is the entity that performs the mobility management on behalf of the MN. In P-NEMO, the MAG manages the mobility of the MR. Thus, the handover signaling induced by the MR is mitigated and the handover latency is reduced.

However, P-NEMO still causes packet loss, since all pack-

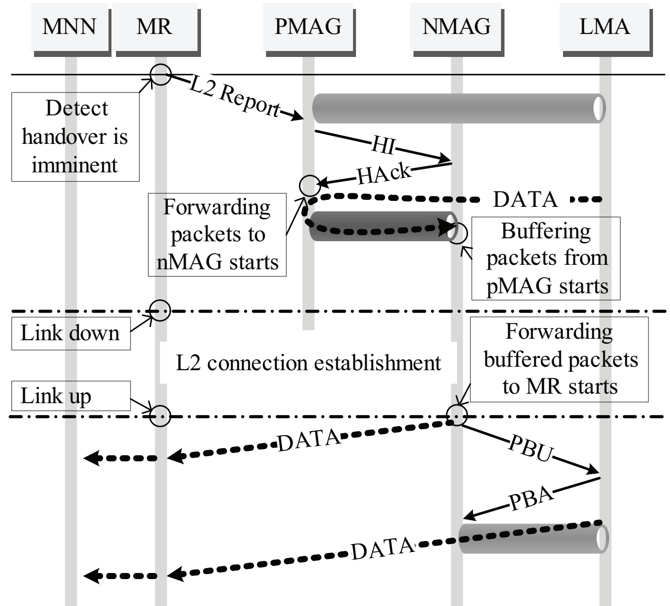

Fig. 2. The handover operation of FP-NEMO.

ISBN: 978-84-695-3472-4

ets destined for the MR are lost during the handover. To solve these problems, FP-NEMO has emerged as an extension to P-NEMO [4]. FP-NEMO can reduce packet loss and the handover latency of P-NEMO by adopting Fast Handovers for PMIPv6 (FPMIPv6) [15]. FP-NEMO uses wireless layer 2 events to anticipate the impending handover of the vehicle's MR. Then, the tunnel is established between MAGs prior to the attachment of the MR to the NMAG. Thus, packets are forwarded to the NMAG without loss during the handover.

Fig. 2 illustrates the detailed handover operation of FP-NEMO. When the MR detects that the handover is imminent, it reports its movement to the PMAG. On receiving the report, the PMAG then sends the Handover Initiate (HI) message to the NMAG. The HI message includes the MN ID, Home Network Prefix (HNP), and the address of the LMA that is currently serving the MR. The NMAG sends the Handover Acknowledge (HAck) message back to the PMAG. When the PMAG receives the HAck message, the tunnel is established between the PMAG and the NMAG, and packets destined for MNNs are forwarded from the PMAG to the NMAG over this tunnel. Those packets may be buffered at the NMAG. Buffered packets are forwarded to the MR, after the MR attaches the NMAG. Then, the NMAG updates BCE in the LMA for the MR by sending the PBU message. When the NMAG receives the PBA message, the handover is completed.

III. THE PROPOSED SCHEME (IFP-NEMO)

FP-NEMO reduces packet loss and the handover latency through tunneling between the PMAG and the NMAG. In FP-NEMO, however, the tunneling burden is not significantly considered during the handover. Tunneling increases traffic burden of the link between the PMAG and the NMAG during the handover when the number of MNNs is large and MNNs communicate with heavy traffic. Especially, when that link is in congestion, tunneling may heavily overload that link. For example, packets destined for MNNs are delivered through various paths from the LMA to the PMAG before the handover. Then, they are forwarded from the PMAG to the NMAG during the handover. At that time, if there is high data traffic over the link between the PMAG and the NMAG, tunneling poses a heavy burden in that link. As a result, packets destined for MNNs may be lost during the handover.

Therefore, we propose IFP-NEMO to eliminate the tunneling burden. IFP-NEMO adopts TBU scheme [13], [14] which performs the registration to the HA prior to the layer 2 handover. Before the layer 2 handover is begun, the Tentative PBU message (TPBU) is sent to the LMA to register in advance. Then, the LMA delivers packets destined for MMNs to the NMAG directly. As a result, the tunnel between MAGs is not used during the handover, and packets destined for MNNs are delivered through various paths from the LMA and the NMAG. IFP-NEMO is designed to be backwards compatible with FP-NEMO, as well as it requires only minor modifications to FP-NEMO. These are possible because the handover operation of IFP-NEMO is similar to

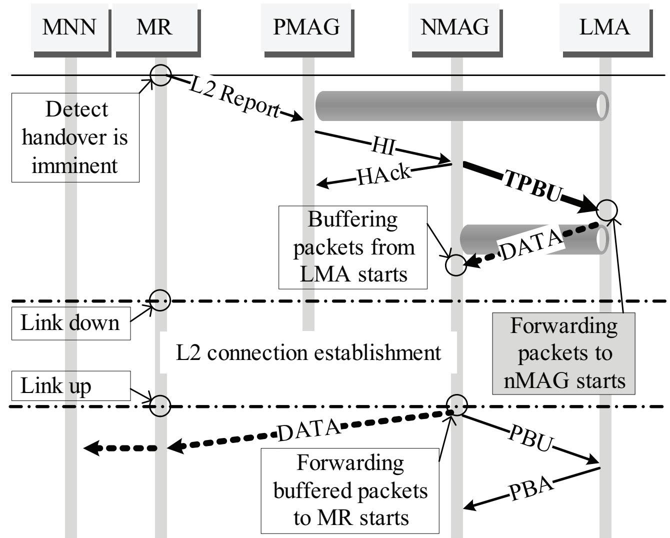

Fig. 3. The handover operation of IFP-NEMO.

that of FP-NEMO except delivering the TPBU message. If the NMAG or the LMA are not aware of IFP-NEMO, FP-NEMO will be operated without further process. Fig. 3 shows the detailed handover operation of IFP-NEMO.

IFP-NEMO utilizes wireless layer 2 events to anticipate impending handover. As illustrated in Fig. 3, IFP-NEMO is initiated with the MR's the layer 2 handover report. The PMAG sends the HI message to the NMAG. The HI message includes the MR ID, HNP and the address of the LMA. On receiving the HI message, the NMAG creates the TPBU message using received information. The TPBU message is the same as the PBU message except that the binding lifetime is short. Then, the NMAG sends the TPBU message to the LMA, and it sends the HAck message to the PMAG. When the LMA receives the TPBU message, it creates an additional entry in Binding Cache Entry (BCE), tentatively. The previous binding is preserved in BCE during the handover, since it should be used to prevent the ping-pong movements. For example, if the MR moves back to the PMAG during the handover, the tentative binding expires so that packets destined for MNNs are forwarded to the PMAG using the previous binding in the LMA. As soon as the new binding is created, packets destined for MNNs are forwarded to the NMAG directly. The NMAG receives and buffers packets from the LMA during the handover. When the PMAG receives the HAck message, a tunnel between the PMAG and the NMAG is established. However, the tunnel between MAGs is not used during the handover, since packets destined for MNNs are forwarded to the NMAG directly. In IFP-NEMO, the tunnel remains for the further use when the HA cannot process the TBU message or the TBU message does not delivered. After the layer 2 handover is completed, the NMAG sends the PBU message to the LMA to update BCE in the LMA. When the MAG receives the PBA message from the LMA, the handover is finished.

TABLE I
NOTATIONS

Notation	Description
L_{PBU}	The length of the PBU message
L_{PBA}	The length of the PBA message
L_{TBU}	The length of the TBU message
L_{HI}	The length of the HI message
L_{HAck}	The length of the HAck message
L_{HD}	The length of a tunnel header
$H_{LMA-MAG}$	The number of hops between LMA and MAG
H_{MAGs}	The number of hops between MAGs
τ	The weight factor for tunneling
N_{MNN}	The number of MNNs
ρ	Session to Mobility Ratio (SMR)
ω	Ratio of using indirect path
$E(S)$	The session length

IV. PERFORMANCE ANALYSIS

In this section, we develop analytical models to investigate the handover performance of IFP-NEMO compared with FP-NEMO. The performances of IFP-NEMO and FP-NEMO are compared in terms of the overall cost. We define that the overall cost is a sum of handover overhead incurred during a session. Notations used in the performance analysis are listed in Table I.

A. System Model

In this section, we assume that the intersession arrival time follows an exponential distribution with rate λ_S. The residence time of an MR in the MAG follows a general distribution with $1/\mu_L$, and its probability density function is $f_L(t)$. $f_L^*(s)$ denote the Laplace transform of $f_s(t)$ and is given by

$$f_L^*(s) = \int_{t=0}^{\infty} e^{-st} f_L(t) dt.$$

Then, the Laplace-Stieltjes transform for an exponentially distributed random variable is obtained as follows [4]

$$f_L^*(s) = \int_{t=0}^{\infty} e^{-st} \mu_L e^{-\mu_L t} dt.$$

Let N_L be the number of subnet crossings during intersession arrival time. Then $Pr(N_L = i) = \alpha(i)$ is derived as follows [16]

$$\alpha(i) = \begin{cases} 1 - \frac{1 - f_L{}^*(\lambda_S)}{\rho}, & i = 0 \\ \frac{1}{\rho} \cdot [1 - f_L^*(\lambda_S)]^2 \cdot [f_L^*(\lambda_S)]^{i-1}, & i > 0, \end{cases}$$

where ρ is Session to Mobility Ratio (SMR) and $\rho = \lambda_S/\mu_L$ [4], [16].

B. Cost Analysis

In this section, we derive cost functions of the signaling overhead and the packet tunneling to investigate FP-NEMO and IFP-NEMO, respectively. The signaling overhead is defined as the handover signaling cost incurred during a session, and it is calculated by the product of message's length and the number of hops [17]. The packet tunneling cost is defined as additional tunneling overhead incurred during a session. Therefore, the overall costs of FP-NEMO, $C^{(FP-NEMO)}$, and IFP-NEMO, $C^{(IFP-NEMO)}$, are expressed as follows, respectively

$$C^{(FP-NEMO)} = C_{SG}^{(FPN)} + C_{PT}^{(FPN)},$$
$$C^{(IFP-NEMO)} = C_{SG}^{(IFPN)} + C_{PT}^{(IFPN)},$$

where $C_{SG}^{(FPN)}$, $C_{PT}^{(FPN)}$, $C_{SG}^{(IFPN)}$, and $C_{PT}^{(IFPN)}$ are the signaling overheads and the packet tunneling costs of FP-NEMO and IFP-NEMO, respectively.

Referring to Fig. 2, the signaling overhead of FP-NEMO is obtained as follows

$$C_{SG}^{(FPN)} = \sum_{i=0}^{\infty} i \cdot \alpha(i) \cdot \left(S_{MAGs} + S_{LMA-MAG}^{FPN}\right),$$

where S_{MAGs} and $S_{LMA-MAG}^{FPN}$ are sums of signaling costs incurred between MAGs, and between the LMA and the MAG, respectively, and they are expressed as $S_{MAGs} = H_{MAGs} \cdot (L_{HI} + L_{HAck})$ and $S_{LMA-MAG}^{FPN} = H_{LMA-MAG} \cdot (L_{PBU} + L_{PBA})$. $\sum_{i=0}^{\infty} i \cdot \alpha(i)$ denotes the average number of handovers during a session.

In FP-NEMO, packets destined for MNNs are generally forwarded to the PMAG or NMAG directly, while they are tunneled between MAGs during the handover. Therefore, the packet tunneling cost of FP-NEMO, $C_{PT}^{(FPN)}$, is given by

$$C_{PT}^{(FPN)} = N_{MNN} \cdot E(S) \cdot \{\omega \cdot (P_{LMA-MAG} + \tau \cdot P_{MAGs}) + (1-\omega) \cdot P_{LMA-MAG}\}, \quad (1)$$

where N_{MNN} is the number of MNNs, $E(S)$ is the session length which is determined by the number of fixed-size packets, τ is the weight factor of tunneling, and ω is the ratio of data packets forwarded through the tunnel between MAGs during a session. In this paper, τ is used to investigate a burden of the tunnel between MAGs. P_{MAGs} and $P_{LMA-MAG}$ are unit costs of packet tunnel overhead between MAGs and between the LMA and the MAG, respectively, and they are given as $P_{MAGs} = H_{MAGs} \cdot (L_{HD} + L_{HD})$ and $P_{LMA-MAG} = H_{LMA-MAG} \cdot L_{HD}$.

The signaling overhead of IFP-NEMO is obtained as follows, referring to Fig. 3

$$C_{SG}^{(IFPN)} = \sum_{i=0}^{\infty} i \cdot \alpha(i) \cdot \left(S_{MAGs} + S_{LMA-MAG}^{IFPN}\right),$$

where $S_{LMA-MAG}^{IFPN}$ is a sum of signaling costs incurred between the LMA and the MAG, and it is calculated as $S_{LMA-MAG}^{IFPN} = H_{LMA-MAG} \cdot (L_{TBU} + L_{PBU} + L_{PBA})$.

In IFP-NEMO, packets destined for MNNs are forwarded to the PMAG or NMAG directly, regardless of performing the handover. Thus, the packet tunneling cost of IFP-NEMO, $C_{PT}^{(IFPN)}$, is expressed as follows

$$C_{PT}^{(IFPN)} = N_{MNN} \cdot E(S) \cdot P_{LMA-MAG}.$$

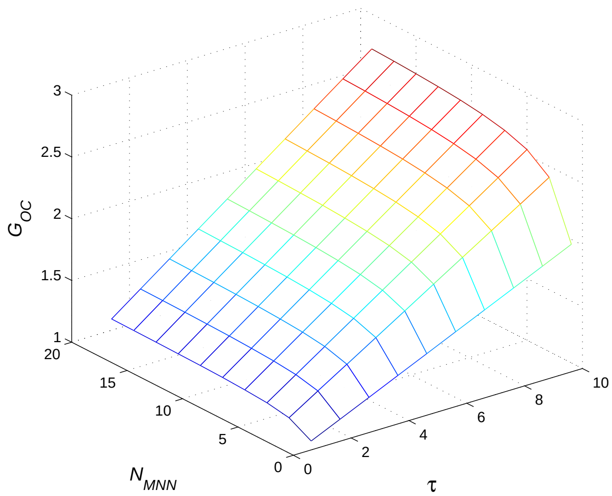

Fig. 4. The relative overall cost gain ($\rho = 1$ and $\omega = 0.2$): G_{OC} vs. the weight factor of tunneling, τ, and the number of MNNs, N_{MNN}.

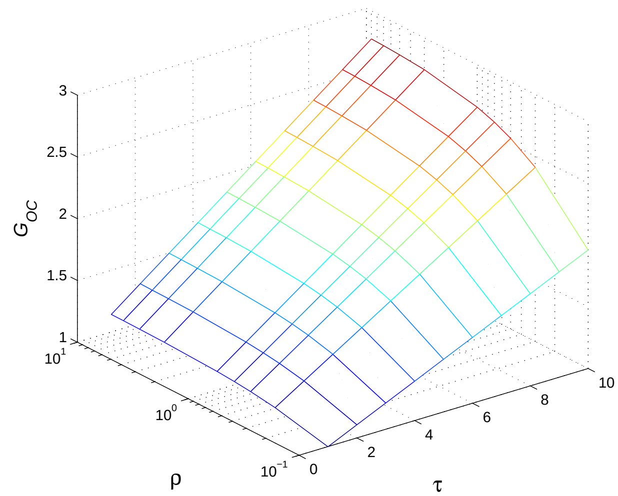

Fig. 5. The relative overall cost gain ($N_{MNN} = 10$ and $\omega = 0.2$): G_{OC} vs. the weight factor of tunneling, τ, and the session to mobility ratio, ρ.

V. NUMERICAL RESULTS

In this section, we show comparative numerical results on FP-NEMO and IFP-NEMO. Parameters used in this analysis are defined as follows: $L_{PBU} = L_{PBU} = L_{TBU} = 76bytes$, $L_{HI} = S_{HAck} = 52bytes$, $L_{HD} = 40bytes$, $H_{LMA-MAG} = 5$, $H_{MAGs} = \sqrt{H_{LMA-MAG}}$, and $E(S) = 10$ [4], [17].

For the purpose of comparison, we define the relative overall cost gain as follows

$$G_{OC} = \frac{C^{(FP-NEMO)}}{C^{(IFP-NEMO)}}.$$

When $G_{OC} > 1$, IFP-NEMO outperforms FP-NEMO.

Fig. 4 shows the relative overall cost gain as a function of the weight factor of tunneling, τ, and the number of MNNs, N_{MNN}. τ indicates degree of traffic density in the link between the PMAG and the NMAG. When traffic on that link increases, τ becomes high. We define that $\tau = 1$ when that link is in the good condition. In general, the relative overall cost gain increases as τ increases, since IFP-NEMO does not make use of the tunnel between the PMAG and the NMAG. Even when τ is low, IFP-NEMO outperforms FP-NEMO. When N_{MNN} is large, the relative overall cost gain becomes high. Hence, IFP-NEMO can be more efficient than FP-NEMO, when lots of users use Internet services at the same time in the case of public transportation, such as a bus and a train. Especially, when τ is high as well as N_{MNN} is large, IFP-NEMO greatly outperforms FP-NEMO.

The relative overall cost gain depending on τ and the SMR, ρ, is plotted in Fig. 5. When ρ is high, session rate is higher than handover rate and then mobility is low. On the other hand, session rate is lower than handover rate and then mobility is high, when ρ is low. As shown in Fig. 5, the relative overall cost gain increases as ρ increases. This is because that IFP-NEMO can reduce the packet tunneling cost than FP-NEMO. The packet tunneling cost is more affected by high ρ. Additionally, the handover performance of IFP-NEMO is not lower than that of FP-NEMO, even when ρ is low.

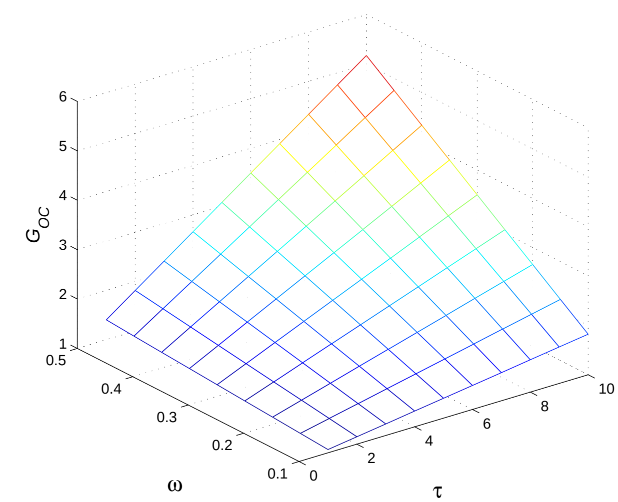

Fig. 6. The relative overall cost gain ($N_{MNN} = 10$ and $\rho = 1$): G_{OC} vs. the weight factor of tunneling, τ and the ratio of using indirect path, ω.

Fig. 6 shows the relative overall cost gain against τ and ω. ω indicates the ratio of data packets forwarded through the tunnel between the PMAG and the NMAG during a session. When ω is high, the handover rate is high or the handover latency is long, and then ratio of using the tunnel between MAGs becomes high in FP-NEMO. However, IFP-NEMO is not affected by ω, since packets destined for MNNs are always forwarded to the PMAG or the NMAG directly. Thus, the relative overall cost gain increases as ω increases. IFP-NEMO significantly outperforms FP-NEMO when ω and τ are high.

ISBN: 978-84-695-3472-4

VI. CONCLUSIONS AND FUTURE WORKS

FP-NEMO has emerged to accelerate the handover for PMIPv6-based NEMO by anticipating impending handover. Even though FP-NEMO enhances the handover performance, it may incur tunneling overload between the PMAG and the NMAG. In this paper, we propose IFP-NEMO eliminating the tunneling overload. The handover operation of IFP-NEMO is analyzed through performance evaluations. The handover performance of IFP-NEMO compared with FP-NEMO is shown through numerical results. We show that IFP-NEMO may outperform FP-NEMO in any environment.

For future works, we will consider the followings: First, the predictive and reactive modes of IFP-NEMO will be investigated altogether like in [18]. In IFP-NEMO and FP-NEMO, the predictive mode is only considered. Second, the handover latency of IFP-NEMO will be analyzed to compare with FP-NEMO. IFP-NEMO can reduce the handover latency of FP-NEMO, since the registration is performed in advance.

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