STATISTICAL PERFORMANCE ANALYSIS OF THE PREDICTIVE FAST AND SEAMLESS HANDOFF SCHEME FOR THE NESTED MOBILE NETWORK

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ABSTRACT

In the past, our proposed HCoP-B has achieved route optimization and resolved the RO-storm problem for handoffs of the nested mobile network. However, because HCoP-B was a pure layer three, i.e., network layer, approach which handoff operations were performed after the layer two, i.e., data link layer, link breaks, it still suffered from a long handoff latency and serious packet losses. In this paper, by adopting the handoff prediction concept of the fast mobile IPv6 on HCoP-B, we proposed a cross-layer architecture, which was called the fast HCoP-B (FHCoP-B), to trigger layer three HCoP-B route optimization flow by 802.11 and 802.16 link events before the actual Layer 2 handoff occurs. In this way, FHCoP-B further shortened both the handoff latency and packet losses of HCoP-B. We further adopted the analytical model to investigate handoff latencies and total buffer sizes of HCoP-B, FHCoP-B and two well-known NEMO schemes with the radio link protocol, which could detect packet losses and performs retransmissions over the error-prone wireless link. Hence, FHCoP-B outperformed the other three schemes by achieving shortest handoff latencies, the smallest numbers of packet losses and the least total handoff costs during handoff with little extra buffers. Consequently, it exhibited significant benefits on supporting fast and seamless handoff in the nested mobile network even over error-prone wireless links.

KEY WORDS

HCoP-B; FHCoP-B; Fast Handoff; Nested Mobile Network; radio link protocol.

INTRODUCTION

NEtwork MObility (NEMO) has been identified as an important concept of collective mobility of a set of mobile nodes as in the vehicular network (Lach et al., 2003). The IETF NEMO working group extends MIPv6 (Johnson et al., 2003) as NEMO Basic Support (NBS) (Devarapalli and Wakikawa, 2005) by creating a bi-directional tunnel between the mobile router (MR) and its home agent (MR-HA) to achieve performance improvements over MIPv6 for network mobility. As the levels of nesting of the nested NEMO increase, packets destined to a mobile network node (MNN) should pass through MR-HAs at each level. This kind of pinball routing (Thubert and Molteni, 2002) introduces large transmission delays and tunneling overheads. Hence, there have been lots of researches working on how to support route optimization (RO) for NEMO (Thubert and Molteni, 2007; Calderón et al., 2006; Chang and Chou, 2009). In (Chang

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and Chou, 2009), we have proposed the hierarchical care-of prefix (HCoP) with a novel binding update tree (BUT) scheme, i.e., HCoP-B, at the mobility anchor point (MAP) to achieve an optimal route between the correspondent node (CN) and MNN, reduce the handoff latency and avoid duplicate global binding update (GBU) messages for RO.

For alleviating the quality of service (QoS) degradation during the handoff of the mobile node (MN), IETF has proposed the Fast Handovers for Mobile IPv6 (FMIPv6) protocol (Koodli et al. 2008) to reduce the handoff latency of MIPv6 and thereby achieve seamless handoff of an MN. As the received wireless link signal strength falls below a predefined threshold, the link layer, i.e., layer two (L2), of the mobile node will notify its network layer, i.e., layer three (L3), to start its L3 handoff operations proactively with its current and forthcoming access routers, which are called the previous access router (PAR) and next access router (NAR) in FMIPv6 respectively. Hence, the mobile node immediately resumes its connections with the CN as soon as it has re-attached to the NAR through the new wireless link. As the mobile network is more and more popular in recent years, it is important to support seamless handoff of the nested mobile network and thereby maintain the QoS of each ongoing real-time application. Hence, we will propose the cross-layer FHCoP-B here for efficient mobility management of the nested mobile network. FHCoP-B achieves the following merits. First, it defines a cross-layer architecture and corresponding message flows which integrate the L2 fast handoff event notification of FMIPv6 into the L3 route optimization flow of HCoP-B. Second, the FHCoP-B works over heterogeneous wireless networks, which consist of two kinds of prevalent wireless links, i.e., the short-range 802.11 one between each mobile router (MR) and MNN inside the mobile network and the long-range 802.16 one between the top-level MR of the mobile network and the access router. Third, it classifies the mobile network handoff into two major categories and eight handoff scenarios. In this way, FHCoP-B proactively starts its message flow before the handoff occurs such that it can significantly reduce the handoff latency and packet loss of the real-time application. The MIPv6 return routability (RR) procedure, which refers to the method for establishing the mobile node is able to receive packets delivered to the IPv6 addresses that it claims to own (Koodli and Perkins, 2007), is also included in the proposed FHCoP-B for NEMO to avoid vulnerabilities to denial-of-service attacks and traffic stealing at the CN and MNN.

In this paper, we further adopt the analytical model proposed in (Mohanty and Akyildiz, 2007) to investigate performances of HCoP-B, FHCoP-B and two well-known schemes by considering the frame error rate over error-prone wireless links, which is rare in the NEMO literature. Based on the radio link protocol (RLP) (Bao, 1996), which is an automatic repeat request (ARQ) fragmentation one, to detect packet losses and performs retransmissions on the wireless link, we first mathematically analyze handoff latencies, total buffer sizes and total handoff costs of FHCoP-B and then utilize numerical data to exhibit significant benefits of FHCoP-B on supporting fast and seamless handoffs in the nested mobile network.

The remainder of this paper is organized as follows. Section 2 describes related work on using FMIPv6 for mobile nodes and for mobile networks. Section 3 presents the proposed FHCoP-B architecture and its signaling flows for handoff. Section 4 exhibits performance evaluations for three metrics of FHCoP-B with RLP and Section 5 shows
numerical results of HCoP-B, FHCoP-B and the other two well-known NEMO schemes, respectively. Section 6 concludes this paper.

RELATED WORKS

Reverse Routing Header (RRH) (Thubert and Molteni, 2007) uses a type 4 routing header to record the care-of address (CoA) of each intermediate MR in the nested NEMO when the MNN first sends a packet to the CN. Whenever the CN sends a packet destined to the MNN, this packet is routed to the HA of the MNN’s serving MR first and forwards to the MNN via an optimal route, according to CoAs of all intermediate MRs recorded in a type 2 routing header. In this way, RRH resolves the pinball routing problem. However, RRH introduces extra packet and processing overhead for the routing header. The CN and MR-HA also need spaces to record routing information for each MNN. Mobile IPv6 route optimization for NEMO (MIRON) (Calderón et al., 2006) uses DHCPv6 in each MR to provide topologically meaningful IPv6 addresses to every child MR of the next lower layer and the visited mobile node (VMN) in the nested NEMO. The VMN sends a binding update (BU) message to its HA and every CN to optimize the path between them for RO. In HCoP-B (Chang and Chou, 2009), the MAP inherits the concept of HMIPv6 (Soliman et al., 2005) to manage care-of prefix (CoP) allocation and maintain the binding cache for all MNNs. HCoP-B also builds a BUT on the MAP to record the NEMO topology and information about all CNs of MNNs and all MR-HAs in the nested NEMO. HCoP-B first achieves an optimal route between the CN and MNN by coping with the pinball routing for the nested NEMO. Second, it reduces the handoff latency by overlapping the duration of the prefix delegation and the local binding update (LBU) to the MAP, and the global binding update from the MAP to MR-HAs and CNs for RO. Finally, it avoids duplicate GBU messages for RO from an MNN to all connecting CNs and thereby reduces GBU bandwidth consumption. However, these NEMO schemes introduce many extra L3 operations to optimize the route between the CN and MNN after the L2 handoff has been completed, which in turn significantly raises the handoff latency and deteriorates QoS of active real-time applications.

FMIPv6 was proposed to reduce the significant MIPv6 handoff latency that was introduced by operations like link-layer procedures, movement detection, IP address configuration and location update. It enables the MN to issue the Router Solicitation for Proxy Advertisement (RtSolPr) message to its PAR and wait for the Proxy Router Advertisement (PrRtAdv) message from the PAR for quickly detecting that it will move to a new subnet of an NAR and configuring a prospective new CoA (NCoA) on the NAR when the MN is still connected to its PAR. In (Dimopoulou et al., 2005), the authors adopt three types of 802.11 L2 events, i.e., Link going down, Link down and Link up to notify L3 of the current wireless link status. Oppositely, as the IEEE 802.16e suite of specifications has been proposed in recent years, the work in (Jang et al., 2008) describes how the MIPv6 fast handover can be implemented on 802.16e link layers. In essential, these schemes only support the fast handoff of a single MN. They cannot be adopted as fast handoff schemes of a NEMO.

In (Li et al., 2008), an enhanced fast handover scheme for MIPv6 was proposed to achieve low handover latency and packet delay by reducing latencies of the duplicate address detection (DAD) for verifying uniqueness of the new CoA at the NAR and
MIPv6 binding update procedures before handoff. However, it cannot be easily integrated with those non-MIPv6-based route optimized NEMO schemes like MIRON and HCOP-B. There are few researches mentioned about supporting fast handover in NEMO. In (Zhong et al., 2007), a fast NEMO (FNEMO) scheme was proposed. When the handover of an MR is triggered, the MR sends an FBU to its HA for setting up a tunnel with the NAR by exchanging the handover initiate (HI) and handover acknowledge (HACK) messages. Hence, FNEMO eliminates the round trip and extra encapsulation of the PAR by directly tunneling the packet via the NAR to the MR. However, it has not mentioned how to forward packets received by the PAR to the NAR during the handover for avoiding packet losses.

**FAST HCOP-B ARCHITECTURE AND HANDOFF FLOWS**

As shown in Figure 1(a), the HCoP-B handoff procedure begins with layer 2 channel scanning, authentication and association, and follows with layer 3 prefix delegation, binding update and media stream resumption. Hence, all MNNs in the moving mobile network will stop receiving ongoing media streams between time $t_2$, i.e., the time when the L2 link down event of the old link occurs, and $t_6$, i.e., the time to resume receiving packets that are forwarded from the NAR, which will thereby significantly degrade QoS of real-time services. Hence, as shown in Figure 1(b), our FHCoP-B will overlap the L3 prefix delegation, L2 authentication and association procedures with the modified L3 binding update, i.e., the predictive binding update (PBU), by the L2 link going down event of the old link at time $t_1$, which is notification of the imminent handoff. Hence, the MNN can resume its media stream as early as possible after $t_4$. In this way, the handoff latency of FHCoP-B will be reduced to the value of $(t_4-t_2)$, instead of that of $(t_6-t_2)$ in original HCoP-B.

![Fig. 1: Timing diagrams of HCoP-B and FHCoP-B handoffs](image)

Figure 2 shows the network architecture where FHCoP-B works. Because IEEE 802.16 supports long-distance transmission, it is adopted as the wireless link to provide connectivity between the top-level MR of the NEMO and its associated AR on Internet. Oppositely, short-range IEEE 802.11 wireless links are used to connect internal MRs and underlying MNNs. Notations used are listed in Table 1.
Table 1: Notations and Their Descriptions

<table>
<thead>
<tr>
<th>Notations</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$MR_i$</td>
<td>The $i$th MR at the $i$th layer of the nested NEMO</td>
</tr>
<tr>
<td>$HA_i^l$, $HR_i^l$</td>
<td>Home agent and home registrar of $MR_i$</td>
</tr>
<tr>
<td>$H_D^l$</td>
<td>Internet distance in hop count from the source node S to the destination one D in the nested NEMO</td>
</tr>
<tr>
<td>$t_{bc}$</td>
<td>The processing time, which value is 5ms, for the node to update the binding cache when receiving the BU.</td>
</tr>
<tr>
<td>$t_{sc}$</td>
<td>The processing time, which value is 5ms, for the MR to configure its new CoA.</td>
</tr>
<tr>
<td>$t_{in}$</td>
<td>The propagation delay, which value is 10ms/hop, between any two adjacent nodes in the nested NEMO.</td>
</tr>
<tr>
<td>$t_{out}$</td>
<td>The propagation delay, which value is 10ms/hop, between any two adjacent nodes in Internet.</td>
</tr>
<tr>
<td>$t_{RS}, t_{RA}, t_{HMRA}, t_{URI - Allocation}$</td>
<td>The propagation delay, which value is 10ms/hop, to transmit the RS, RA, HMRA or SIP URI allocation message between two adjacent MRs in the nested NEMO.</td>
</tr>
<tr>
<td>$t_{L2}$</td>
<td>Layer 2 handoff latency, which value is 20ms (Mohanty and Akyildiz, 2007)</td>
</tr>
<tr>
<td>$t_{DAD}$</td>
<td>Latencies of the duplicate address detection (DAD), which value is 1000ms (Lai and Chiu, 2005)</td>
</tr>
<tr>
<td>$T_f$</td>
<td>The one-way frame transportation delay through a wireless link with RLP (Mohanty and Akyildiz, 2007)</td>
</tr>
<tr>
<td>$B$</td>
<td>The end-to-end packet transportation delay between two nodes with RLP</td>
</tr>
<tr>
<td>$D_p$</td>
<td>The average one-way signaling packet transportation delay using UDP between two nodes with RLP</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>The initial value of the retransmission timer using UDP, which value is 150ms (Mohanty and Akyildiz, 2007)</td>
</tr>
<tr>
<td>$r$</td>
<td>The factor by which the retransmission timer timeout duration is increased after each failed retransmission, which value is 2 (Mohanty and Akyildiz, 2007)</td>
</tr>
<tr>
<td>$m$</td>
<td>The maximal number of failed retransmissions to freeze the timeout value of the retransmission timer, which value is 10 (Mohanty and Akyildiz, 2007)</td>
</tr>
<tr>
<td>$A$</td>
<td>$\Delta / (r - 1)$</td>
</tr>
<tr>
<td>$K$</td>
<td>The number of link layer frames per packet; the frame size is 19 bytes (Mohanty and Akyildiz, 2007).</td>
</tr>
<tr>
<td>Notations</td>
<td>Descriptions</td>
</tr>
<tr>
<td>-----------</td>
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</tr>
<tr>
<td>( n )</td>
<td>The maximum number of RLP trials to transmit a frame over the link layer before aborting transmission, which is 3 for RLP (Mohanty and Akyildiz, 2007).</td>
</tr>
<tr>
<td>( \tau )</td>
<td>The link layer interframe interval, which is 20ms (Mohanty and Akyildiz, 2007).</td>
</tr>
<tr>
<td>( P(\epsilon_{i,j}) )</td>
<td>The probability that the first frame transmitted by the MNN is received correctly by the BS, being the ( i )th retransmitted frame at the ( j )th retransmission trial (Bao, 1996).</td>
</tr>
<tr>
<td>( P_c )</td>
<td>Packet loss probabilities of the wired link, which value is equal to ( 1e^{-5} ) (Mohanty and Akyildiz, 2007).</td>
</tr>
<tr>
<td>( P_w )</td>
<td>Packet loss probability in the wireless link,</td>
</tr>
<tr>
<td>( P_f )</td>
<td>Frame error rate of the link layer.</td>
</tr>
<tr>
<td>( q )</td>
<td>End-to-end packet loss probability between two nodes with RLP</td>
</tr>
</tbody>
</table>

Depending on whether the moving mobile subnet leaves its original MAP, there are two types of handoffs in FHCoP-B. First is the *intra-MAP* handoff and the other the *inter-MAP* one. Because the flow of the inter-MAP handoff is more complex than that of the intra-MAP one, we describe it below. The inter-MAP handoff occurs when the mobile subnet leaves its old NEMO, which is managed by the previous MAP (PMAP), and arrives at the new NEMO under the new MAP (NMAP). Based on the L2 type of the egress link used by the HLMR before and after handoff, the Inter-MAP handoff can be further classified into four L2 handoff scenarios.

1. The whole NEMO, which connects directly to the PAR under the PMAP, performs its handoff as a new NEMO to the NAR that is managed by the NMAP. Because both the old and new L2 links are 802.16 ones, we call this kind of handoff as the 802.16 to 802.16 one.
2. The whole NEMO, which connects directly to the PAR, performs its handoff to a new previous MR (PMR) inside the new NEMO under the NAR managed by the NMAP. Because the old and new L2 links are 802.16 and 802.11 ones respectively, we call this kind of handoff as the 802.16 to 802.11 one.
3. The mobile subnet inside the old NEMO under the PAR hands over to the NAR, which is managed by the NMAP, as a new NEMO. Because the old and new L2 links are 802.11 and 802.16 ones respectively, we call this kind of handoff as the 802.11 to 802.16 one.
4. The mobile subnet inside the old NEMO under the PAR hands over to a new PMR inside the new NEMO under the NAR managed by the NMAP. Because both the old and new L2 links are 802.11 ones, this handoff is called as the 802.11 to 802.11 one.

Figure 2 shows a general example of the 802.11 to 802.11 inter-MAP handoff. The HLMR, i.e., \( MR_{\text{HLMR}}^j \), of the mobile subnet, which is the \( j \)th MR at the \( j_{\text{HLMR}} \)th layer of the old nested NEMO under the PAR before the handoff, will connect to an MR under
the NAR as $MR_{HLMR}^l$ at the $l_{HLMR}$th layer of the new nested NEMO under the NAR managed by the NMAP after the handoff. In the following, we will describe the inter-MAP handoff flow of FHCoP-B. Due to space limitation, please refer to (Lu, 2009) for those of RRH, MIRON and HCoP-B.

- **FHCoP-B inter-MAP Handoff**
  
  The proposed flow of FHCoP-B 802.11 to 802.11 inter-MAP handoff is shown in Figure 3. In this section, the time spent for each FHCoP-B stage is calculated for the ideal case that assumes no error occurs when the packet passes through the wireless and wired links, which is far from reality. Hence, performance evaluations of all FHCoP-B stages with RLP will be presented in next section.

  (a) Whenever the L2 of HLMR, i.e., $MR_{HLMR}^l$ at the $l_{HLMR}$ layer in the old NEMO, receives a new 802.16 MOB_NBR-ADV message from the PMR’s L2 (S-BS) and observes an imminent L2 handoff according to its handoff decision algorithm, it will issue the 802.16 NEW_LINK_DETECTED (NLD) message, which needs the time of $t_{c2}$, to trigger the FHCoP-B L3 handoff procedure. Then the L3 of
$MR_{i}^{l_{\text{last}}} \text{ performs the RtSolPr/PrRtAdv procedure with the PMAP to acquire AP-IDs and MR-Infos of the nearby NMAP with the ideal time of } 2 \left[ t_{in} \times \left( j_{HLMR} + 1 \right) + t_{out} \right]. \text{ After that, } MR_{i}^{l_{\text{last}}} \text{ follows the prefix delegation process for configuring prospective CoAs of underlying MRs and MNNs layer by layer with the maximal time of } (t_{in} \times \left( j_{HLMR} + 1 \right)) \times \left( L - j_{HLMR} + 1 \right) \text{ for } MR_{i}^{l_{L}} \text{ at layer } L. \text{ Then each MR and MNN executes the LBU/LBA procedure to create the temporary LBC and VBC at } MR_{i}^{l_{\text{last}}} \text{ with the maximal time of } t_{in} \times \left( L - j_{HLMR} + 1 \right) + t_{bc}.\text{

Fig. 3: The flow of FHCoP-B 802.11 to 802.11 inter-MAP handoff

(b) For modifying prospective BUT of the NMAP at the same time of delegating prefix in the mobile subnet, $MR_{i}^{l_{\text{last}}} \text{ simultaneously issues an LBU message to the PMAP for retrieving BUT information of the mobile subnet such that the PMAP}
can then forward this LBU with those BUT information embedded to the NMAP. Hence, the NMAP can perform the time-wasting DAD process with the time of $t_{DAD}$ by detecting uniqueness of prospective CoAs at the NMAP before the inter-MAP handoff actually occurs. Consequently, these overlapped procedures spend the ideal time formulated as Equation 1 for the FHCoP-B inter-MAP handoff.

$$\text{MAX} \left\{ \left[ (t_{\text{HMRA}} + t_{bc}) \times (L - j_{\text{HLMR}} + 1) \right] + \left[ t_{\text{in}} \times (L - j_{\text{HLMR}} + 1) + t_{bc} \right], \right\}$$

(1)

After that, $MR_{i}^{HLMR}$ performs the FBU/FBAck process to the PMAP. The PMAP further starts buffering all packets, which are denoted as the first, intermediate and last forwarded ones in Figure 3, sent to MNNs in the mobile subnet to avoid packet losses during handoff as it receives the FBU. It converts the FBU into the HI message and forwards it to the NMAP for creating a tunnel to redirect packets between them and modifying the binding cache of the NMAP with new entries of the mobile subnet. After that, the HAck message is first sent back to the PMAP and finally reached $MR_{i}^{HLMR}$ with the format of the FBAck. At the time when the PMAP receives the HAck, which means the tunnel is ready, it will forward its buffered packets to the NMAP for buffering them again. Hence, the $PMAP_{i}^{buffering\ \text{time}}$, i.e., the duration that each forwarded packet has been buffered in the PMAP, is equal to $t_{hc} + 2 \times t_{out} \times H_{NMAP}^{PMAP}$. The round trip time of FBU/BI/HAck/FBAck in this case is equal to $2 \times \left[ t_{\text{in}} \times (j_{\text{HLMR}} + 1) + t_{\text{out}} \times (H_{NMAP}^{PMAP} + 1) \right] + t_{bc}$.

On the other hand, after the NMAP finishes the DAD process, it will first send GBU messages and then wait for global binding acknowledgement (GBAck) with all HAs of MRs in the mobile subnet for modifying mappings of corresponding binding entries into the NMAP’s address, according to the hierarchical management concept of HMIPv6. As proposed in HCoP-B, the NMAP is responsible to securely update location information with the CN on behalf of the MNN in the mobile subnet. Therefore, it performs the RR mechanism to verify the CN by completing the HoTi/HoT process through its HA and the CoTi/CoT one with the CN before it sends non-duplicated GBUs to update binding information of the CN for optimizing routes of subsequent packets from the CN to the NMAP, instead of to the PMAP for forwarded packets before the CN receives the GBU. Hence, the maximal time of the RR process and the round-trip time of the GBU/GBAck process for route optimization are formulated as the value of

$$2 \times t_{\text{out}} \times \text{MAX} \left[ H_{NMAP}^{NMAP} + H_{\text{CN}}^{HLMR}, H_{\text{CN}}^{HLMR} \right] \text{ and } 2 \times t_{\text{out}} \times H_{\text{CN}}^{NMAP} \text{ respectively.}$$

Subsequent packets have to be cached in the NMAP for maintaining correct packet ordering until all preceding forwarded ones have been redirected from the PMAP to the NMAP, which starts when the PMAP receives the HAck as described above. We denote the time to buffer subsequent packets in the NMAP as the $NMAP_{i}^{buffering\ \text{time\ for\ subsequent\ packets}}$, which is equal to the difference of the following two periods and formulated as Equation 2. The first one consists of four
epochs for the last forwarded packet to travel from the CN to the PMAP \((t_{in} \times H_{PMAP}^{CN})\), buffer in the PMAP \((t_{in} + 2 \times t_{out} \times H_{SNMAP}^{PMAP})\), redirect to the NMAP \((t_{in} \times H_{SNMAP}^{PMAP})\) and buffer again in the NMAP until all preceding forwarded packets have been forwarded to the MNN, i.e., the NMAP buffering time for forwarded packets, which will be described later. The second period is the time for the first subsequent packet to travel from the CN to the NMAP, which is equal to \(t_{out} \times H_{SNMAP}^{CN}\). Hence, with this kind of predictive binding update procedure, i.e., part b in Figure 3, executed before or during the imminent L2 handoff actually occurs, FHCoP-B can update binding entries, reattach BUT information, and perform DAD, GBU and RR processes in the NMAP such that the handoff latency of FHCoP-B inter-MAP handoff is significantly reduced. Further, with aforementioned packet buffering and forwarding mechanisms, packet disordering and losses during handoff are avoided altogether.

\[
t_{in} + 2 \times t_{e} + t_{l2} + t_{in} \times (j_{HLMR} + l_{HLMR} + 2) + t_{out} \times (2 \times H_{SNMAP}^{PMAP} + H_{SNMAP}^{CN} - H_{SNMAP}^{CN} + 2) \quad (2)
\]

(c) Whenever the handoff decision algorithm of \(MR_{i}^{l_{HLMR}}\) decides to start the handoff, L2 of \(MR_{i}^{l_{HLMR}}\) will notify its L3 of the 802.16 LINK_SWITCH (LSW) message with the time of \(t_{e}\) to begin the 802.16 network entry procedure with the NAR’s L2, i.e., T-BS, which also needs the time of \(t_{l2}\) . As a result, the L2 handoff procedure introduces latency of \(t_{e} + t_{l2}\).

(d) As soon as the L2 handoff procedure of the HLMR, i.e., \(MR_{i}^{l_{HLMR}}\) at the \(l_{HLMR}\) layer of the new NEMO after handoff, has completed, the L2 will issue the 802.16 LINK_UP message to its L3, which spends the time of \(t_{e}\) and in turn lets the L3 send the unsolicited neighbor advertisement (UNA) message through the NAR to the NMAP to finish the L3 handoff process with the time of \(t_{e} + t_{l2} + t_{out}\) . Hence, packets buffered in the NMAP will be forwarded to each MNN to continue the media stream via NAR, all upper MRs of the MNN in the new NEMO, which will introduce the latency of \(t_{in} \times (L - j_{HLMR} + l_{HLMR} + 2) + t_{out}\) for the MNN under the deepest \(MR_{i}^{l_{HLMR} + l_{HLMR} + l_{HLMR}}\) in the mobile subnet after handoff. As a result, the total time for continuing the media stream is equal to \(t_{in} \times (L - j_{HLMR} + 2 \times l_{HLMR} + 3) + t_{l2} + 2 \times t_{out}\) . With this approach, each forwarded packet has to be buffered in the NMAP with the NMAP buffering time for forwarded packets, which is calculated as follows. First, the period from when the PMAP receives the HAck until when the NMAP receives the UNA is equal to \(t_{in} \times (j_{HLMR} + l_{HLMR} + 2) + 2 \times t_{e} + t_{l2} + 2 \times t_{out}\) . Second, the period for packets to be forwarded from the PMAP to NMAP is \(t_{out} \times H_{SNMAP}^{PMAP}\) . Hence, the NMAP buffering time for forwarded packets is equal to the difference of these two periods, as shown with Equation 3.

\[
t_{in} \times (j_{HLMR} + l_{HLMR} + 2) + 2 \times t_{e} + t_{l2} - t_{out} \times (H_{SNMAP}^{PMAP} - 2) \quad (3)
\]
Ideal Handoff Latency: At the worst case, the deepest MNN under $MR_{i}^{l}$ under HLMR stops receiving packets during the period from the time when the last packet following the original path is received to that when the first forwarded packet has arrived at this MNN. Hence, the ideal inter-MAP handoff latency of FHCoP-B can be formulated as Equation 4, which is the difference of the following two periods. One is the period from the time when the PMAP receives the last original packet and the FBU before handoff to that when the first forwarded packet arrives at the MNN; the other is the period to convey the last original packet from the PMAP to the MNN.

$$2 \times t_{e2} + t_{L2} + t_{nc} + \left(2 \times t_{H_{PMAP}} + 3\right) + t_{in} \times \left(j_{H_{LMR}} + 2 \times t_{H_{LMR}} + 4\right)$$  \hspace{1cm} (4)$$

Ideal Total Buffering Time: The ideal total buffering time for this handoff scenario is the sum of these three buffering times, i.e., that of PMAP, that of NMAP for forwarded packets and that of NMAP for subsequent packets, which is formulated as Equation 5.

$$2 \times t_{nc} + 4 \times t_{e2} + 2 \times t_{L2} + t_{in} \times \left(j_{H_{LMR}} + t_{H_{LMR}} + 2\right) + t_{out} \times \left(2 \times t_{H_{PMAP}} + t_{H_{PMAP}^CN} - H_{SNMAP}^CN + 4\right)$$  \hspace{1cm} (5)$$

Ideal Packet Loss Time: because all packets during handoff are buffered by the PMAP and NMAP, there is no packet loss for the inter-MAP handoff of FHCoP-B.

Ideal Total Handoff Cost: Though FHCoP-B spends the handoff latency formulated by Equation 4 to resume receiving packets from the CN, it has no packet losses during the handoff due to its packet buffering and forwarding mechanisms in the PMAP and NMAP with the cost of total buffering times formulated by Equation 5, as mentioned above. Conversely, without any buffering mechanism, RRH, MIRON and HCoP-B all suffer packet losses for the duration equal to their handoff latencies. Hence, we define the total handoff cost (in the unit of time) for each scheme as the sum of its packet loss time and total buffering time in this paper to express the cost to handle the inter-MAP handoff, which is equal to the value calculated by Equation 5 for FHCoP-B.

PERFORMANCE EVALUATIONS WITH RLP

In the following, we analyze real handoff latencies and total buffer sizes for storing real-time VOIP messages issued by the CN during handoff for FHCoP-B with RLP. Due to the space limitation of this paper, please also refer to (Lu, 2009) for mathematical analyses of RRH, MIRON and HCoP-B. The handoff latency is defined as the time required for the deepest MNN to resume packet transmissions of VOIP sessions when the handoff occurs. In this paper, we extend the analytical model, which contains only one wireless link connecting the MN and the BS, for MIP in (Mohanty and Akyildiz, 2007) to that for FHCoP-B, whose communication path between the CN in the Internet and the MNN attached to the deepest $MR_{i}^{l}$ in the nested mobile network consists of $(L+2)$ wireless links between this MNN and PAR in Figure 2, and $W$ wired links between PAR and the CN. Then the end-to-end packet loss probability $P$ between the CN and this MNN before handoff is formulated by Equation 6, where $P_{w}$ and $P_{e}$ denote packet loss probabilities of a wireless link and a wired link, respectively.
Consider RLP is used for error recovery in the link layer. The packet loss probability in a single wireless link, \( P_w \), is given in (Mohanty and Akyildiz, 2007) and is formulated as Equation 7, where \( P_f \) is the frame error rate of the link layer, \( K \) is the number of link layer frames per packet and \( n \) is the maximum number of RLP trials to transmit a frame over the link layer before aborting transmission. Hence, the end-to-end packet loss probability \( q \) with RLP between two nodes, which consists of \( W_f \) wireless links and \( W \) wired links, in NEMO is formulated by Equation 8.

\[
P_w = 1 - \left[ 1 - P_f \left( 2 - P_f \right) P_f^{\frac{1}{2}} \right]^K
\]

\[
q = 1 - \left[ 1 - P_f \left( 2 - P_f \right) P_f^{\frac{1}{2}} \right]^{K+n} (1 - P_f)^W
\]

According to (Mohanty and Akyildiz, 2007), the one-way frame transportation delay, \( T_f \), through a wireless link with RLP is formulated by Equation 9, where \( t_m \) is the propagation delay through a wireless link and \( \tau \) is the link layer interframe interval. Further, \( p(c_{i,j}) \), which is given by (Bao, 1996) and formulated by Equation 10, denotes the probability that the first frame transmitted by the sending node is received correctly by the receiving node, being the \( i \)th retransmitted frame at the \( j \)th retransmission trial for \( i = 1, 2, \ldots, n \) and \( j = 1, 2, \ldots, i \).

\[
T_f = t_m (1 - P_f) + \sum_{i=1}^{w} \sum_{j=i}^{w} p(c_{i,j}) \left( 2i \times t_m + 2(j - 1) \tau \right)
\]

\[
p(c_{i,j}) = P_f \left( 1 - P_f \right)^{\frac{i}{2}} \left( 2 - P_f \right) P_f \left( \frac{i}{2} \right)^{\frac{i}{2}} \tau^{-i} f^{-j}
\]

Thus, passing through \( W_f \) wireless links and \( W \) wired links between two nodes in NEMO with RLP, the end-to-end packet transportation delay, \( B \), is formulated by Equation 11, where \((K - 1)\tau\) is the total interframe interval over a wireless link.

\[
B = W_f \times T_f + (K - 1) \tau + W \times t_m
\]

Because FHCoP-B signaling messages are transported by UDP, the average one-way signaling packet transportation delay, \( D_p \), using UDP between two nodes through \( W_f \) wireless links and \( W \) wired links is formulated by Equation 12 (Mohanty and Akyildiz, 2007), where \( \Delta \) is the factor by which the retransmission timer timeout duration is increased after each failed retransmission, \( \Delta \) is the initial value of the retransmission timer, \( m \) denotes the maximal number of failed retransmissions to freeze the timeout.
value of the retransmission timer, and $A$ is $\Delta/(r-1)$, respectively. Values of these parameters are listed in Table 1.

$$D_p = (1-q) \times \left[ B + A \sum_{i=1}^{\infty} q^{i-1} \left( r^{i-1} - 1 \right) + \sum_{i=m+1}^{\infty} q^{i-1} \left[ A \left( r^{m-1} - 1 \right) + (i-m) r^{m-2} \Delta \right] \right]$$  (12)

### 4.1 Handoff Latency of FHCoP-B with RLP

As described in Section 3, the inter-MAP handoff latency of FHCoP-B is the difference of the following two periods. One is the period from the time when the PMAP receives the last original packet and the FBU before handoff, and the other is the period to convey the last original packet from the PMAP to the MNN before handoff. The first period can be further divided into four stages. First, as the PMAP receives the FBU, it converts the FBU into the HI message and forwards it to the NMAP through $H_{\text{PMAP}}^\text{Hi}$ wired links on Internet for creating a tunnel to redirect packets between them and modifying the binding cache of the NMAP with new entries of the mobile subnet. After that, the HAck message is sent back to the PMAP along the same $H_{\text{NMAP}}^\text{Hi}$ wired links but in reverse direction of HI. The message lengths of HI and HAck, which contains CoAs of all $2^{l-j_{\text{HLMR}}+1}$ MRs in the mobile subnet, are equal to $(56+16\times 2^{l-j_{\text{HLMR}}+1})$ bytes. Hence, the one-way duration for the HI/HAck stage can be formulated by Equation 13. Second, the PMAP converts the HAck to the FBAck, which is 88 bytes, and forwards it to $MR_{\text{HLMR}}^{j}$ through $(l_{\text{HLMR}} + 1)$ wireless links with the duration calculated by Equation 17. Third, after the L2 handoff procedure of $MR_{\text{HLMR}}^{j}$ at the $l_{\text{HLMR}}$ layer of the new NEMO after handoff has completed, the L2 issues the 802.16 LINK_UP message to its L3, which then sends the 40-byte UNA message through $l_{\text{HLMR}}$ wireless links and one wired link to finish the L3 handoff process, which duration is calculated by Equation 18. Finally, as the NMAP receives the UNA, packets buffered in the NMAP will be forwarded to each MNN to continue the VoIP media stream via NAR, all upper MRs of the MNN in the new NEMO. Hence, the latency for the MNN under the deepest $MR_{\text{HLMR}}^{j}$ in the mobile subnet after handoff to receive the first forwarded VoIP packet, which is 93 bytes (i.e., the sum of 40 bytes of IPv6 header, 8 bytes of UDP header and 45 bytes of RTP message), through $(L-l_{\text{HLMR}} + l_{\text{HLMR}} + 2)$ wireless links and one wired link is formulated by Equation 19. On the other hand, the second period spends the time to convey the last original 93-byte VoIP packet from the PMAP to the MNN through $(L+2)$ wireless links and one wired link before handoff so that the duration of the second period is expressed by Equation 16. Consequently, the handoff latency of FHCoP-B with RLP is equal to $2 \times t_{1} + t_{2} + t_{3} + 2 \times (13) - (16) + (17) + (18) + (19)$ and formulated as Equation 20.

$$\left(1-q_{13}\right) \left[ B_{13} + A \sum_{i=2}^{\infty} q_{13}^{i-1} \left( r_{13}^{i-1} - 1 \right) + \sum_{i=m+1}^{\infty} q_{13}^{i-1} \left[ A \left( r_{13}^{m-1} - 1 \right) + (i-m) r_{13}^{m-2} \Delta \right] \right]$$  (13)

where $q_{13} = 1 - \left(1-p_{r}\right)^{H_{\text{PMAP}}^\text{Hi}}$, $B_{13} = H_{\text{NMAP}}^\text{Hi} \times T_{\text{out}}$.
\( (1-q_{14}) \{ B_{14} + A \sum_{i=2}^{\infty} q_{i4}^{-1} (r^{i-1} - 1) + \sum_{i=m+1}^{\infty} q_{i4}^{-1} \left[ A \left(r^{m+1} - 1\right) + (i-m)r^{m-2}\Delta \right] \} \) \hspace{2cm} (14) 

where \( q_{i4} = 1 - (1-p_i) \gamma_{i4}\), \( B_{14} = H_{PMAP}^{CN} \times T_{out} \)

\( (1-q_{15}) \{ B_{15} + A \sum_{i=2}^{\infty} q_{i5}^{-1} (r^{i-1} - 1) + \sum_{i=m+1}^{\infty} q_{i5}^{-1} \left[ A \left(r^{m+1} - 1\right) + (i-m)r^{m-2}\Delta \right] \} \) \hspace{2cm} (15) 

where \( q_{i5} = 1 - (1-p_i) \gamma_{i5}\), \( B_{15} = H_{NMAP}^{CN} \times T_{out} \)

\( (1-q_{16}) \{ B_{16} + A \sum_{i=2}^{\infty} q_{i6}^{-1} (r^{i-1} - 1) + \sum_{i=m+1}^{\infty} q_{i6}^{-1} \left[ A \left(r^{m+1} - 1\right) + (i-m)r^{m-2}\Delta \right] \} \) \hspace{2cm} (16) 

where

\[ q_{16} = 1 \left[ 1 - p_f \left( \left( \frac{1}{2} - p_f \right) p_f \right) \right]^{K(L+2)} \times (1-p_e) \]

\[ B_{16} = (L+2) \times T_f + (K-1) \tau + t_{out} \]

\( (1-q_{17}) \{ B_{17} + A \sum_{i=2}^{\infty} q_{i7}^{-1} (r^{i-1} - 1) + \sum_{i=m+1}^{\infty} q_{i7}^{-1} \left[ A \left(r^{m+1} - 1\right) + (i-m)r^{m-2}\Delta \right] \} \) \hspace{2cm} (17) 

where

\[ q_{17} = 1 \left[ 1 - p_f \left( \left( \frac{1}{2} - p_f \right) p_f \right) \right]^{K(L_{\text{lHLMR}}+1)} \times (1-p_e) \]

\[ B_{17} = (j_{\text{lHLMR}}+1) \times T_f + (K-1) \tau + t_{out} \]

\( (1-q_{18}) \{ B_{18} + A \sum_{i=2}^{\infty} q_{i8}^{-1} (r^{i-1} - 1) + \sum_{i=m+1}^{\infty} q_{i8}^{-1} \left[ A \left(r^{m+1} - 1\right) + (i-m)r^{m-2}\Delta \right] \} \) \hspace{2cm} (18) 

where

\[ q_{18} = 1 \left[ 1 - p_f \left( \left( \frac{1}{2} - p_f \right) p_f \right) \right]^{K(L_{\text{lHLMR}}+1)} \times (1-p_e) \]

\[ B_{18} = (j_{\text{lHLMR}}+1) \times T_f + (K-1) \tau + t_{out} \]

\( (1-q_{19}) \{ B_{19} + A \sum_{i=2}^{\infty} q_{i9}^{-1} (r^{i-1} - 1) + \sum_{i=m+1}^{\infty} q_{i9}^{-1} \left[ A \left(r^{m+1} - 1\right) + (i-m)r^{m-2}\Delta \right] \} \) \hspace{2cm} (19) 

where
4.2 Buffering Times of FHCoP-B with RLP

- **PMAP buffering time:**
  As mentioned in Section 3, the PMAP buffering time, i.e., the duration that each forwarded packet has to be buffered in the PMAP, is equal to the time to update the binding cache, i.e., $t_{bc}$, added by the round trip time of HI/HAck between the PMAP and NMAP, which is equal to $2 \times (13)$. Hence, the PMAP buffering time of FHCoP-B with RLP is expressed by Equation 21.

$$t_{bc} + 2 \times (13)$$

$$= t_{bc} + 2 \times (1-q_{13}) \left\{ B_3 + A \sum_{i=2}^{m} q_3^{-1} (r^{i-1} - 1) + \sum_{i=m+1}^{\infty} q_3^{-1} \left[ A\left(r^{i-1} - 1\right) + (i-m)r^{i-\Delta} \right] \right\}$$

(21)

- **NMAP buffering time for forwarded packets:**
  The NMAP buffering time for forwarded packets is equal to the difference of the following two periods. The first period is from the time when the PMAP receives the HAck until when the NMAP receives the UNA, which is equal to the sum of $2 \times t_{s2} + t_{l2}$, the duration for transmitting the FBAck, which is calculated by Equation 17, and that for conveying the UNA message, which is calculated by Equation 18. The second period is spent for packets to be forwarded from the PMAP to NMAP, which is expressed by Equation 13. Hence, the NMAP buffering time for forwarded packets of FHCoP-B with RLP is expressed by Equation 22.
\begin{align*}
2 \times t_{i,2} + t_{e,2} + (17) + (18) - (13) \\
= 2 \times t_{i,2} + t_{e,2} \\
-(1 - \mu_{i}) \times \left\{ B_{i} + A \sum_{i=1}^{m} q_{i}^{-1} \left( r_{i}^{-1} - 1 \right) + \sum_{i=1}^{m} q_{i}^{-1} \left[ A(r_{i-1} - 1) + (i - m) r_{i}^{-2} \Delta \right] \right\} \\
+ \sum_{x \in \{17,18\}} \left\{ (1 - \mu_{i}) \times \left\{ B_{i} + A \sum_{i=1}^{m} q_{i}^{-1} \left( r_{i}^{-1} - 1 \right) + \sum_{i=1}^{m} q_{i}^{-1} \left[ A(r_{i-1} - 1) + (i - m) r_{i}^{-2} \Delta \right] \right\} \right\} \\
\end{align*}

- **NMAP buffering time for subsequent packets:**

The NMAP buffering time for subsequent packets is equal to the difference of the following two periods, as mentioned above. The first one consists of four epochs for the last forwarded packet to travel from the CN to the PMAP with the time formulated by Equation 14, to be buffered in the PMAP with the PMAP buffering time, to redirect from the PMAP to the NMAP with the time formulated by Equation 13 and to be buffered again in the NMAP with the NMAP buffering time for forwarded packets. The second period is the time for the first subsequent packet to travel from the CN to the NMAP, which is formulated by Equation 15. Consequently, the NMAP buffering time for subsequent packets is equal to Equation 23.

\begin{align*}
(13) + (14) + \text{PMAP buffering time} + \text{NMAP buffering time for forwarded packets} - (15) \\
\end{align*}

- **Total buffering time:**

As mentioned above, the total buffering time for the inter-MAP handoff scenario is the sum of three buffering times, i.e., that of PMAP, that of NMAP for forwarded packets and that of NMAP for subsequent packets, which is expressed as Equation 24.

\begin{align*}
\text{PMAP buffering time} + \text{NMAP buffering time for forwarded packets} \\
+ \text{NMAP buffering time for subsequent packets} \\
= \text{PMAP buffering time} + \text{NMAP buffering time for forwarded packets} \\
+ (13) + (14) + \text{PMAP buffering time} \\
+ \text{NMAP buffering time for forwarded packets} - (15) \\
= 2 \times (\text{PMAP buffering time} + \text{NMAP buffering time for forwarded packets}) \\
+ (13) + (14) - (15) \\
\end{align*}
Because the total handoff cost (in the unit of time) for each scheme is defined as the sum of its packet loss time and total buffering time, it can be calculated by Equation 24 for FHCoP-B with RLP:

\[
4.3 \text{ Total Handoff Cost of FHCoP-B with RLP}
\]

In the following, we present average handoff latencies, total buffering times and total handoff costs for four NEMO schemes, i.e., RRH, MIRON, HCoP-B and FHCoP-B by applying aforementioned equations for numerical results with RLP two hundred times. As shown in Figure 2 for the topology of the nested NEMO, hop counts between any two nodes, except the PMAP and NMAP, in Internet are assumed to be uniformly distributed among 1 to 30 hops but that between the PMAP and NMAP is among 1 to 10 hops. HLMR \( j \) at the \( HLMR \ l \)th layer and its underlying mobile subnet in the old NEMO will perform an inter-MAP handoff to the \( HLMR \ l \)th layer of the new NEMO. Default values of \( L \), \( HLMR \ j \) and \( f_P \) are set as 6, 3 and 0.1, respectively. We use three different values, i.e., 0, 3 and 6, of \( HLMR \ l \), to observe influences of different inter-MAP handoff destinations on these three performance metrics.

5.1 Handoff Latencies with RLP

We illustrate average values of the handoff latency for these four schemes in Figure 4. First, inter-MAP handoff latencies of MIRON, RRH and HCoP-B with RLP decrease as the value of \( HLMR \ j \) raises, which is because the number of layers, i.e., \((L - HLMR \ j + 1)\), for control packets and VoIP messages to pass in the new NEMO decreases accordingly, as shown in Figure 4. RRH with RLP suffers higher handoff latencies than MIRON with RLP because it appends the extra routing header with \((16 \times (L - HLMR \ j + 1))\) bytes into each GBU and VoIP packet to the deepest MNN.
for recording CoAs of all parent \((L - j_{HLMR} + l_{HLMR} + 1)\) MRs in the new NEMO, which therefore enlarges its GBU and VoIP packet length and their corresponding numbers, i.e., \(K\), of wireless frames. However, GBU and VoIP packet length of MIRON are 88 bytes and 93 bytes respectively, which are fixed no matter the value of \(j_{HLMR}\). Please note that the decreasing rate of HCoP-B handoff latency is significant when applying RLP. The reason of this is due to the packet size, i.e., \((122 + 16 * 2^{L - j_{HLMR} + 1})\) bytes, of its LBU, which contains CoAs of all \(2^{L - j_{HLMR}}\) MRs in the mobile subnet and is conveyed from the \(MR_{HLMR}^{l_{HLMR}}\) to the NMAP, is decreased exponentially. Hence, no matter the value of \(l_{HLMR}\) is, HCoP-B with RLP achieves smaller handoff latencies than MIRON and RRH with RLP do as \(j_{HLMR} \geq 3\). Conversely, because HCoP-B has to perform its L3 prefix delegation, DAD and binding update processes after its L2 handoff, handoff latencies of it with RLP are much larger than those of FHCoP-B with RLP that executes its L3 and DAD processes triggered by L2 events before the old link breaks, which behaves the same as they are in the ideal case. On the other hand, as the value of \(P_f\) grows from 0 to 0.2, the end-to-end packet loss probability \(q\), the end-to-end packet transportation delay \(B\), the average one-way signaling packet transportation delay, \(D_p\), using UDP grow slightly. Hence, handoff latencies of all four schemes with RLP raise accordingly.

![Fig. 4: Comparisons of inter-MAP handoff latency \(l_{HLMR} = 0, 3 \text{ and } 6\)](image)

### 5.2 Total Buffering Times with RLP

As shown in Figure 5, because no packet buffering mechanisms are proposed for MIRON, RRH and HCoP-B, all their total buffering times are equal to zero. Conversely, the total buffering time of FHCoP-B with RLP for the inter-MAP handoff is the sum of
buffering times of the PMAP, the NMAP for forwarded packets and the NMAP for subsequent packets. Therefore, its value grows as values of $l_{HLMR}$ or $j_{HLMR}$ raise, according to Equation 17 or 18, which is a component of Equation 24 respectively. Similar to the trend of handoff latencies mentioned above, as the value of $P_j$ grows from 0 to 0.2, total buffering times of all four schemes with RLP grow slightly.

![Graphs showing total buffering times for different $l_{HLMR}$](image)

**Fig. 5: Comparisons of inter-MAP total buffering time ($l_{HLMR} = 0, 3$ and $6$)**

### 5.3 Packet Loss Times and Total Handoff Costs with RLP

As mentioned above, because all forwarded and subsequent packets during handoff are buffered by the PMAP and NMAP, the packet loss time for the inter-MAP handoff of FHCoP-B with RLP is zero. Oppositely, with MIRON, RRH and HCoP-B, those packets issued from the CN during inter-MAP handoff are completely lost because these three schemes have no packet buffering and forwarding mechanisms at all. Hence, values of their packet loss times are equal to those of their handoff latencies, which decrease as the value of $j_{HLMR}$ raises, as shown in Figure 6. Furthermore, FHCoP-B with RLP achieves the lowest total handoff cost (in the unit of time) among all four schemes because it executes the proposed predictive binding update process to avoid packet losses with little extra total buffers.
Statistical performance analysis of the predictive fast and seamless…

Fig. 6: Comparisons of inter-MAP packet loss time \( l_{HLMR} = 0, 3 \) and 6

Fig. 7: Comparisons of inter-MAP total handoff cost \( l_{HLMR} = 0, 3 \) and 6
CONCLUSION

In this paper, we have proposed an efficient FHCoP-B scheme to support fast and seamless handoff for the nested NEMO. We have also derived mathematical equations to denote performance metrics of FHCoP-B with RLP over error-prone wireless links. As compared to HCoP-B and two traditional NEMO schemes, i.e., RRH and MIRON, FHCoP-B achieves the lowest handoff latencies, the smallest numbers of packet losses and the least total handoff costs with little extra buffers when a mobile subnet hands over to a new NEMO. In the future, we will further propose the reactive FHCoP-B process to handle situations such as fast or erroneous movements for the inter-MAP handoff of the mobile subnet.

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