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Fast MIP Handover Amelioration in Wireless Networks by Cross-layer Solution

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Abstract—Mobile IP allows a mobile node to maintain a continuous connectivity to the Internet when moving from one access point to another. However, due to the link switching operations packets designated to mobile nodes can be delayed or lost during the handover period. This paper presents a two-layer solution to improve the handover performance both at the Link Layer and the Network Layer in the context of Mobile IP over wireless networks. At the Network Layer, we use a new function named Extended Handover Control Function (EHCF) which allows us to delete the DAD operation. At the Link Layer, a neighbor graphical prediction approach (NGP) reduces the probe latency. Moreover, the EHCF can buffer the packets during the handover process in order to decrease the packet loss. With an analytical model and some OPNET simulations, we show in this paper that our solution allows to provide low latency, low packet loss to the standard handover of Mobile IPv6.

Index Terms—Cross layer, Fast Handover and Mobile IPv6

I. INTRODUCTION

The need to keep an "everywhere and at any time" connection with Internet has been more and more demanded in recent years with the success of IEEE 802.11 and of IEEE 802.16 wireless networks standards. A growing number of 802.16/802.11 based wireless networks has been deployed as access networks to the Internet. With those access networks, the mobility support has thus become possible. However, the continuous Internet connectivity and the correct routing of packets were not guaranteed when users change their access points to Internet with classical protocols. To resolve these problems, the Mobile IPv4 (MIPv4) and Mobile IPv6 (MIPv6) protocols [1], [2] were respectively published by the Internet Engineering Task Force (IETF). MIPv6 works well when Nomad users connects spontaneously at Internet without a continuous move. If an user continuously change its access points, the high handover latency and the high packet loss provide some troubles to support the continuous connection with MIPv6.

As described in MIPv6, the handover latency consists of the link latency and the network latency caused both at the Link Layer and Network Layer. According to some studies [7], [19], it is found that the handover latency normally takes hundreds of milliseconds due to the probe at the Link Layer and more one second due to the DAD (Detection Address Duplication) operation at the Network Layer.

Since 2003 [20], the main proposals by the IETF and the IEEE are the Hierarchical Mobile IPv6 (HMIPv6) and the Fast Handover for MIPv6 (FHMIPv6). HMIPv6 introduces a Mobility Anchor Point (MAP) which acts somehow like a local Home Agent (HA) for the visiting Mobile Node (MN). The concept of MAP can limit the amount of signaling required outside the MAP's domain at the Link Layer [5], [7]. While FHMIPv6 used location-based fast handover with the Inter-Access Point Protocol (IAPP) at the Link Layer [8], [14], [22]. The network uses a Link Layer trigger to launch either Pre-Registration or Post-Registration handover operations. Besides of these main proposals, there has been also some approaches for providing the lossless handover and minimizing the handover delay [9]–[12]. In [9], a Pre-Handover Signaling (PHS) protocol is proposed in order to support the triggering of a predictive handover and to allow the network to achieve accurate handover decisions by considering different constraints such as Quality-of-Service (QoS), user profile and mobile node service requirements. In [10], a Hierarchical Network-layer Mobility Management (HNMM) framework is described in which an integrated IP-layer handover solution provides an optimized network connectivity. Also, a Competition based Soft Handover Management (CSHM) protocol [11] and a Multi-path Transmission Algorithm (MTA) [12] have been presented to decrease packet loss during a handover.

The goal of this paper is to optimize the Mobile IPv6 handover procedure both at the Link Layer and the Network Layer. At the Network Layer, we use a new function named Extended Handover Control Function (EHCF) which allow us to delete the DAD operation. At the Link Layer, a neighbor graphical prediction approach reduces the probe latency. Moreover, the EHCF can buffer the packets during the handover process in order to decrease the packet loss.

The remainder of the paper is thus organized as follows: Section II presents both the Neighbor Graphical Prediction (NGP) and the Extended Handover Control Function (EHCF) approaches with the associated operations. Then we describe the cross-layer solution with the NGP and EHCF approaches. Section III deals with the handover performance in terms of handover latency and packet loss. Regarding the standard handover of MIPv6, our numerical results show that our cross-layer solution NGP-EHCF reduces significantly both the
latency and the packet loss. Finally, some conclusions are drawn in Section IV.

II. CROSS-LAYER SOLUTION WITH THE NGP AND THE EHCF

A. Handover latency overview

Generally speaking, a handover consists of a Link Layer handover and a Network Layer handover. The Link Layer handover includes a Discovery phase (scanning the channels to discover an available Access Point), an Authentication phase, and a Re-association phase, whereas the Network Layer handover concerns a Router Discovery phase, a Detection Address Duplication (DAD) phase, a Binding Update phase and a Binding Acknowledgement phase respectively. As displayed on Figure 1, the standard MIPv6 handover latency has been estimated to a maximum value of 1620 ms [7], [19]. This high latency is not acceptable for real time applications such as video and audio. If we analyze each phase during the handover process, we can note that the probe provides a 240-360 ms latency at the Link Layer and the DAD latency costs almost 1000 ms at the Network Layer.

B. Neighbor Graphical Prediction-NGP at the Link Layer

To reduce the number of channels scanned, two approaches (active and passive) have been used. With the active approach, a MN decides which is the channel for the next connection. In this case, the MN chooses the first scanned channel with enough energy without scanning any further channels. On the contrary, with the passive approach, an external server indicates the channels that the MN can scan [21].

We present a Neighbor Graphical Prediction approach (NGP) being based on a hierarchical network architecture which is illustrated on Figure 2. Directly linked with its ARs/APs/MNs, each EHCF router can collect all transit data coming from each entity.

Assuming that an EHCF router charges 30 APs as shown on Figure 3, the NGP approach allows an EHCF router to predict the next access point for the moving MN if the next access point is found (see Figure 4).

The NGP method works as the following: when a MN moves from an AP_i (for example, AP_i = 21) to another AP_j (for example, AP_j = 25), it indicates its EHCF router that triggers a handover. According to the graphical map, the EHCF router then launches the NGP-A algorithm to decide which is the next access point for the moving MN (the procedure of the EHCF router is illustrated on Figure 5).

B. Neighbor Graphical Prediction-NGP at the Link Layer

During a handover, the Probe phase allows a MN to scan all nearby APs (Access Point) and then to choice it self the best channel for its new connection. The probe latency depends on the number of channels (in the IEEE 802.11 case; the number of channels scanned is about 11). The idea to reduce the number of channels scanned or to predict a good channel is studied in [20]–[22] indicated in the Section I.

C. Extended Handover Control Function-EHCF at the Network Layer

At the Network Layer, we introduce a local intelligent entity called Extended Handover Control Function (EHCF) which should be capable of controlling its attached Access...
Routers (ARs), Access Points (APs) and Mobile Nodes (MNs). As shown on Figure 2, linked directly with its ARs, each EHCF router reserves a list of all available IP local addresses. An EHCF router also generates and updates periodically a second list which records the used ARs/APs/IP addresses. By comparing these two lists, the EHCF router can find a potential duplicate IP address (collision) in its domain. Then, this EHCF router can withdraw this potential duplicate IP address or can ask a concerned sub-node to change its IP address. In this way, the EHCF router enables to insure an unique IP address to a MN without DAD.

Furthermore, an EHCF router could exchange both some local information with its ARs/APs/MNs and some external information with other EHCF routers. To realize our EHCF proposal, we propose six new messages: MN Request (MN-Req), MN Reply (MNRep), HCF Request (HCFReq), HCF Reply (HCFRep), Connection Established Information (CEInf) and Handover Finished Confirmation (HFCon) messages (for the detailed information about the formats of these messages see [15]). In order to minimize the packet loss during a handover, an EHCF router stores packets into a buffer until the MN is really attached to the new IP address. The entire handover procedure is displayed on Figure 6.

1) EHCF Procedure: We first recall that HCFReq/HCFRep messages are used between EHCF routers for extra-domain handovers. Each EHCF router must record and update its database periodically. This database helps to decide an unique new IP configuration in order to adapt for MN movements without the DAD phase during a handover.

As illustrated on Figure 6, the EHCF procedure is composed of the following steps:

- Moving in the network, if the threshold of the received signal strength is overstepped, the MN begins to probe the neighbor AR/AP’s information, including the signal strength, some IP addresses, AP’s BSSID, AR interface addresses and the sub-network prefix. Then the MN sends a MNReq message to its E-HCF original router (via its AR/AP) to report this information.
- Receiving the MNReq message, the AR stops to forward all the packets sent to the MN and forwards them to its E-HCF original router in order to avoid the packet loss during the handover procedure.
- Receiving the MNReq message, the E-HCF original router decides to which AR/AP the MN will be associated. The choice of the AR/AP is mostly based on database obtained with periodic exchange messages from an E-HCF router to another (HCFReq and HCFRep messages) or with periodic exchange messages from ARs/APs/MNs. For example, if the number of registered MNS in one AR or AP has reached a limit, the EHCF original router will not attach the MN to this saturated AR or AP. After making the previous decision, the EHCF original router sends to the MN a MNRep message which consists of a new AP’s BSSID, an AR interface address, a sub-network prefix and a new IP address.
- With the MNRep message, the MN can obtain its new CoA and configure it automatically.
- The MN sends a CEInf message to its EHCF original router to confirm its new attachment.
- After receiving the CEInf message, the EHCF original

Fig. 4. 30 APs Graphical Map correspond to one of Paris’s Districts

Fig. 5. Procedure of the NGP prediction

![Fig. 5. Procedure of the NGP prediction](image)

Fig. 6. EHCF Procedure (EHCF original router is an attached router with an EHCF function; the EHCF distant/ remove router is a router with whom an EHCF original router can communicate)

![Fig. 6. EHCF Procedure](image)
router transfers the buffered packets to the MN’s new CoA. Then, the EHCF original router sends an HFC
message to end the handover procedure.
• The MN can then exchange Binding Update (BU) and 
  Binding Acknowledgement (BA) messages with its home 
  agent and its correspondent node.

As shown in the E-HCF procedure, a MN can obtain its 
new CoA before it really attaches to its next AR/AP. Moreover, 
any DAD latency (about 1000 ms) is avoided. Thus, the EHCF 
approach allows the reduction of both the traditional handover 
latency and the packet loss. The handover performance is thus 
optimized compared to a traditional approach.

III. NGP-EHCF PERFORMANCE ESTIMATION

The NGP-EHCF performance estimation has been evaluated 
in terms of the total handover latency and of the packet loss 
with an analytical model. This model allows us to compare our 
NGP-EHCF handover performance with the standard handover 
of the MIPv6 protocol.

A. NGP-EHCF Latency Analysis

According to the handover procedure on Figure 3, we 
cite the following latency notations to estimate the handover latency:
• \( L_{EHCF} \): Total handover latency with the EHCF approach.
• \( L_{NGP} \): Latency due to the MN’s handover at the Link Layer.
• \( L_{MNReq} \): Latency for a MN to send a MNReq message to 
  its E-HCF original router.
• \( L_{dec} \): Latency necessary to an EHCF router to decide 
  which AR/AP the MN should be attached (including the 
  short delays to send an HCFReq message and to receive an HCFRep message).
• \( L_{MNRep} \): Latency for an E-HCF router to send a MNRep message to the MN.
• \( L_{CNinf} \): Latency necessary for a MN to auto-configure its new CoA.
• \( L_{conf} \): Latency due to the fact that an EHCF router sends buffered packets and a HFCOn message.
• \( L_{BU/BA} \): Binding Update/Binding Acknowledgement latency.

The average overall EHCF handover latency \( L_{EHCF} \) can 
be summed as following:

\[
L_{EHCF} = L_{NGP} + L_{MNReq} + L_{dec} + L_{MNRep} + L_{CNinf} + L_{conf} + L_{BU/BA}
\]

As this \( L_{EHCF} \) depends upon the mobile link bandwidth 
and the computation capacity of each entity in the wireless 
network, we summarize the parameter values used in our 
numerical analysis in Table I.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel scan time</td>
<td>50 ms</td>
<td>MIPv6 standard</td>
</tr>
<tr>
<td>BU/BA latency</td>
<td>140 ms</td>
<td>MIPv6 standard</td>
</tr>
<tr>
<td>Wireless link bandwidth</td>
<td>3.5 Mb/s</td>
<td>IEEE 802.11b</td>
</tr>
<tr>
<td>AR computation capacity</td>
<td>20 Mb/s</td>
<td>general router</td>
</tr>
<tr>
<td>MN computation capacity</td>
<td>10 Mb/s</td>
<td>PC computation capacity</td>
</tr>
<tr>
<td>MNReq message size</td>
<td>72 byte</td>
<td>NGP-EHCF approach</td>
</tr>
<tr>
<td>MNRep message size</td>
<td>45 byte</td>
<td>NGP-EHCF approach</td>
</tr>
<tr>
<td>HCFReq message size</td>
<td>45 byte</td>
<td>NGP-EHCF approach</td>
</tr>
<tr>
<td>CEinf message size</td>
<td>45 byte</td>
<td>NGP-EHCF approach</td>
</tr>
<tr>
<td>HFCon message size</td>
<td>24 byte</td>
<td>NGP-EHCF approach</td>
</tr>
</tbody>
</table>

B. Numerical Results of the Total Handover Latency

With the parameters of Table I, we give a latency 
comparison between the standard handover latency and the NGP-EHCF latency according to equation (1). These latencies are 
functions of the wireless link bandwidth and of the computation capacity. For example, the \( L_{MNReq} \) latency can be 
numerically estimated as following: with a 10 Mb/s computation capacity, a MN needs 57.6 \( \mu \)s to generate a 72-byte
\( MNReq \) message, whereas, 28.8 \( \mu \)s are required for an Access Router. Putting this 72-byte message on a 9kb/s GSM network, 
requires about 64 ms, so that the global of \( L_{MNReq} \) is about 64 ms.

On Figure 7, the standard MIPv6 handover latencies (upper curve) and the NGP-EHCF handover latencies as function of the number of handovers are displayed. With an IEEE 80.211b wireless network, the average of the NGP-EHCF handover latency is about 200 ms. This average NGP-EHCF handover latency is validated by our simulation results on OPNET illustrated on Figure 8.

![Fig. 7. NGP-EHCF handover latencies and the standard MIPv6 handover latencies with IEEE802.11b](image_url)

Using the NGP-EHCF cross-layer solution, the latency 
reduction from 1620 ms to less 200 ms comes from avoiding the probe process at the Link Layer and the DAD phase at the 
Network Layer.

C. NGP-EHCF Loss

In terms of packet loss with the NGP-EHCF approach, 
packets can be stored into a buffer during the handover (see
subsection II-C.1). Figure 9 illustrates the comparison of packet loss rates between the NGP-EHCF approach and the MIPv6 standard. The upper curve represents the number of lost packets with the MIPv6 standard (38 packets received out of 100 emitted packets), where the bottom curve with NGP-EHCF approach (68 packets received out of 100 emitted packets). This gives a typical 30% gain with the NGP-EHCF approach.

IV. CONCLUSION

In order to improve the handover performance for the Mobile IPv6, this paper proposes a cross-layer solution-NGP-EHCF based on a location graph at the Link Layer (NGP) and on a control function at the Network Layer (EHCF). The NGP-EHCF approach allows to collect and store some link and network data in order to anticipate some handover operations. Regarding the classical Mobile IPv6 handover performance, our numerical results validated by simulations show that the NGP-EHCF approach enables to decrease significantly both the total handover latency and the packet loss.

REFERENCES