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 allow 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 MIP.

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*) who 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

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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.

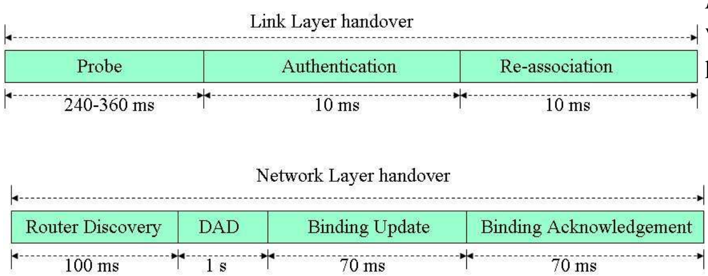

Fig. 1. Standard MIPv6 Latency both at the Link Layer and at the Network Layer

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.

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

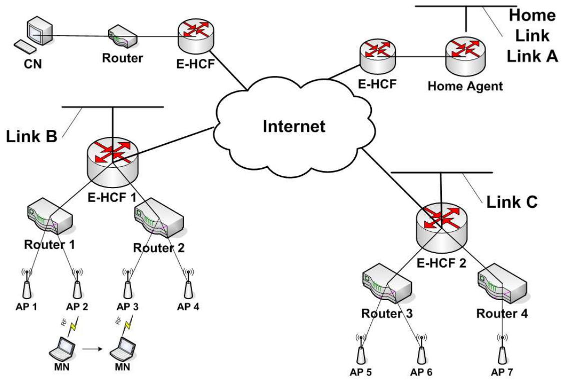

Fig. 2. Architecture of Fast Handover in IEEE 802.11 Wireless Networks(Router is an Access Router; EHCF is an EHCF router)

predict the next access point for the moving MN if the next access point is found (see Figue4).

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).

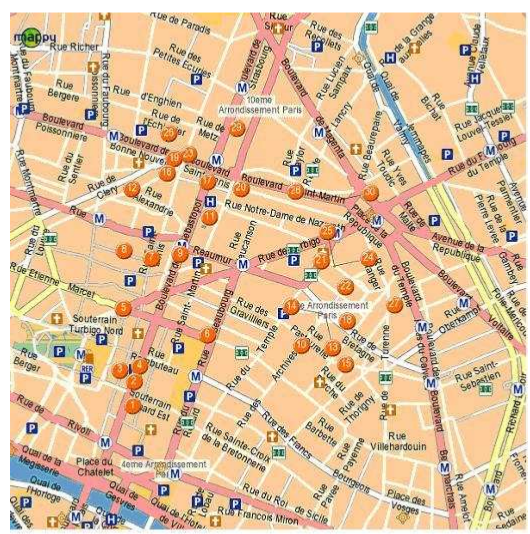

Fig. 3. 30 APs at one of Paris's Districts

The NGP-A algorithm chooses the MN's next access point according to the MN's localization and nearby signal powers. The *Reply* message (on Figure 5) thus consists of the next SSID, the next channel and the IP temporary address. (for the detailed information about the formats of these messages see [15]). As a result, the *probe* latency at the Link Layer can be reduced from 400 ms to 40 ms.

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

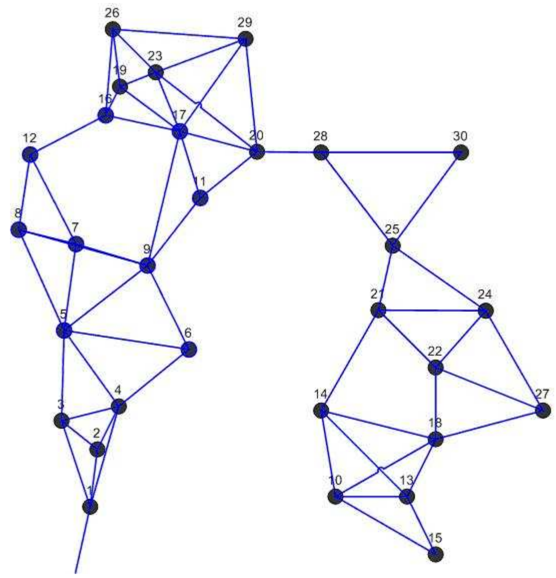

Fig. 4. 30 APs Graphical Map correspond to one of Paris's Districts

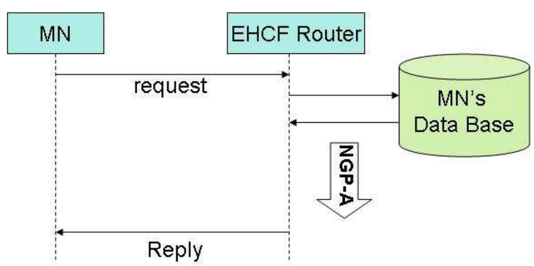

Fig. 5. Procedure of the NGP prediction

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

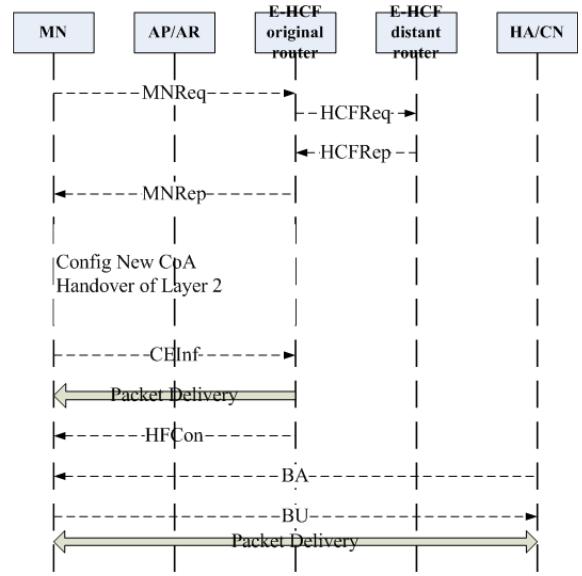

Fig. 6. EHCF Procedure (EHCF original router is an attached router with an EHCF function; the EHCF distant/remove router is a router with who an EHCF original router can communicate)

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/A*P's information, including the signal strength, some IP addresses, *AP*'s *BSSIDs*, *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 *MN*s 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

router transfers the buffered packets to the *MN*'s new *CoA*. Then, the *EHCF* original router sends an *HFCon* 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:

$$
\begin{aligned}
L_{EHCF} = & \\
& L_{NGP} + L_{MNReq} + L_{dec} + L_{MNRep} + \\
& L_{CNinf} + L_{conf} + L_{BU/BA} \qquad (1)
\end{aligned}
$$

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 I
PARAMETER SETTING

Parameter	Value	Comment
Channel scan time	50 ms	MIPv6 standard
BU/BA latency	140 ms	MIPv6 standard
Wireless link bandwidth	5.5 Mb/s	IEEE 802.11b
AR computation capacity	20 Mb/s	general router
MN computation capacity	10 Mb/s	PC computation capacity
MNReq message size	72 byte	NGP-EHCF approach
MNRep message size	45 byte	NGP-EHCF approach
HCFReq message size	45 byte	NGP-EHCF approach
HCFReq message size	45 byte	NGP-EHCF approach
CEInf message size	45 byte	NGP-EHCF approach
HFCon message size	24 byte	NGP-EHCF approach

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 μs to generate a 72-byte *MNReq* message, whereas, 28.8 μs 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.

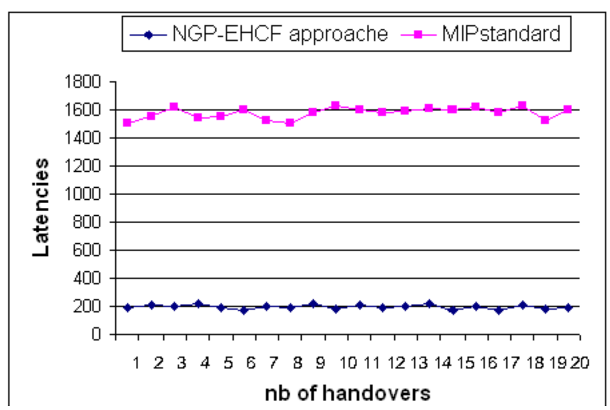

Fig. 7. NGP-EHCF handover latencies and the standare MIPv6 handover latencies with IEEE802.11b

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

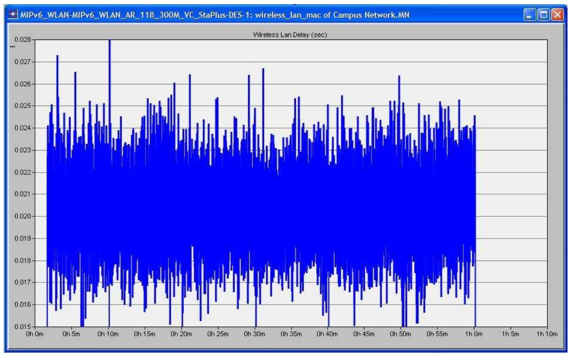

Fig. 8. NGP-EHCF handover latency by simulation

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.

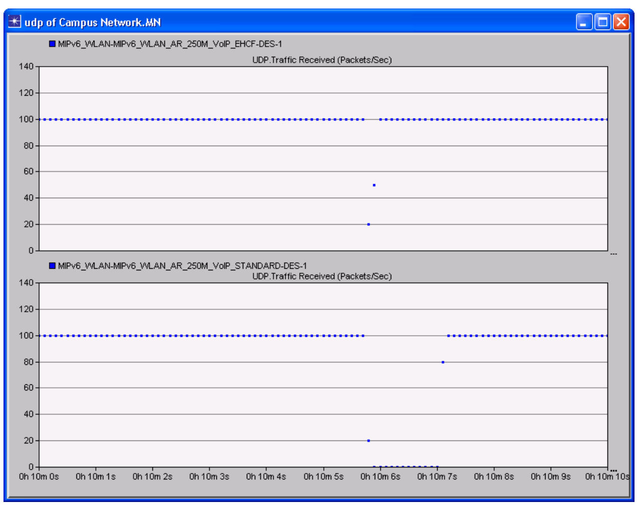

Fig. 9. Comparison of loss rates between the NGP-EHCF approach and the MIPv6 standard by simulation

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.

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