Enhanced Fast Handovers Using a Multihomed Mobile IPv6 Node

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Abstract. Wireless technologies have rapidly evolved in recent years. IEEE 802.11 jointly with Mobile IP provides mobility to the internet. The most critical part of this technology (IEEE 802.11 and Mobile IP) is the handover. During this time the connection may be interrupted and packets can be lost or delayed. These issues makes difficult to run VoIP applications in a mobile environment. In this paper we propose an extension to the Mobile IPv6 protocol using a multihomed mobile node and a cross-layer design. We compare our proposal with Fast Handovers for Mobile IPv6 and Hierarchical Mobile IPv6.

1 Introduction

Wireless technologies have evolved in recent years. IEEE 802.11 [1] is one of the most used wireless technologies. In current Internet status, a user can be connected through a wireless link but he cannot move without breaking the IP communications. That's why IETF designed Mobile IP which jointly with IEEE 802.11 provides mobility to the Internet. The most critical part of this technology (IEEE 802.11 and Mobile IP) is the handover. The handover is the time spent when changing from one point of attachment (i.e. an access router) to another. During this time the mobile node is not able to send or receive data and thus, the connection may be interrupted, packets may be lost or delayed due to intermediate buffers. This issue makes difficult to run VoIP applications in such environment.

The IETF has designed two versions of Mobile IP, one for IPv4 and another one for IPv6. Mobile IPv6 [2] is very similar to Mobile IPv4 [3]. Although Mobile IPv6 is more efficient than Mobile IPv4 it still suffers of some problems, slow handover latency and signaling overhead. To address these issues the IETF has designed two protocols that extend Mobile IPv6 and improve its performance: Fast Handovers for Mobile IPv6 [4] and Hierarchical Mobile IPv6 [5]. Both solutions effectively reduce the handover latency and the signaling overhead but they are complex solutions.

* This work was partially funded by the Spanish Ministry under contract TSI2005-07250-C03-02 and the Generalitat de Catalunya under contract 2005-SGR-00481.

Y. Koucheryavy, J. Harju, and V.B. Iversen (Eds.): NEW2AN 2006, LNCS 4003, pp. 152–163, 2006.

This paper presents a novel Mobile IPv6 extension to improve the handover latency using a multihomed-host and a cross-layer design. Our solution reduces the handover latency to zero, packets are not lost or delayed, and does not require complex network support. Even more, it is able to run VoIP applications in mobile environments. Our solution is intended for mobile vehicles such as cars or trains where movement is restricted to a well-known predefined area.

2 Mobility Protocols Evaluation

This section presents an overview of the IEEE 802.11, Mobile IPv6, Fast Handovers for Mobile IPv6 and Hierarchical Mobile IPv6 protocols. A performance evaluation focused on the handover latency is also presented. We define the handover latency as the amount of time spent while packets sent or received by the MN are being lost or delayed (buffered) due to the handover operations.

2.1 IEEE 802.11

The Wireless LAN protocol [1] is based on a cellular architecture managed by an Access Point or AP. If a mobile node (MN) desires to join a cell, it can use passive scanning, where it waits to receive AP's Beacon Frames messages or active scanning, where it sends Probe Request frames and receives a Probe Response frame from all available APs. Scanning is followed by the Authentication Process, and if that is successful, the Association Process. Only after this phase the MN is capable of sending and receiving data frames.

Several studies have measured the wireless handover ([6] and [7]). In average, the MN spends 257ms to change from one AP to another, the most time consuming phase is the Scan Phase which takes 95% of the total handover latency time.

2.2 Mobile IPv6

The main goal of the Mobile IPv6 (MIPv6) protocol is to allow mobile nodes to change its point of attachment to the Internet while maintaining its network connections. This is accomplished by keeping a fixed IP address on the mobile node (Home Address or HAd). This address is unique and when the mobile node is connected to a foreign network (not its usual network) it uses a temporal address (Care-of Address or CoA) to communicate however, it is still reachable through its Had (using tunnels or with special options in the IPv6 header). MIPv6 has three functional entities, the Mobile Node (MN), a mobile device with a wireless interface, the Home Agent (HA), a router of the home network that manages localization of the MN and finally, the Correspondent Node (CN), a fixed or mobile node that communicates with the MN.

The handover latency for Mobile IPv6 has several components. When a MN is changing from one point of attachment to another it first needs to associate to the new AP, which involves Scanning, Authentication and Association (D_{L2}), this is the wireless part of the handover. Then, in the Agent Discovery phase the MN needs to check that the old AR is unreachable using the Neighbor Unreachability Detection (D_{NUD}) [24] algorithm and obtain a new temporal IP address (Care-of-Address). It also needs to ensure that the recently obtained CoA is unique on the new link using the Duplicate Address Detection algorithm (D_{DAD}) [25]. Finally, the MN must send three Binding Updates in the Registration phase, one to its Home Agent and two to the Correspondent Node (we suppose that the MN is only communicating with one CN, this parameter does not affect our solution). One of the CN's BU messages must be sent through the HA and the other one directly. The equation (1) models the handover latency for the Mobile IPv6 protocol.

$$\begin{aligned} HL_{MIPv6} = D_{L2} + D_{DAD} + D_{NUD} + RTT(MN, HA) \\ +max[(RTT(MN, HA) + RTT(HA, CN)), RTT(MN, CN)] \end{aligned} \quad (1)$$

Experimental measurements show that the handover latency for the Mobile IPv6 protocol takes in average 2107ms [7], during this time packets are lost making difficult to run VoIP applications. Most of the time (87%) is spent by the D_{DAD} and the D_{NUD} algorithms. Those algorithms are required for IPv6 auto-configuration. Note that several improvements can be done to reduce D_{L2}, D_{DAD} or D_{NUD}. However the time spent by the Binding Update and Binding Acknowledgment messages depend exclusively on the Round Trip Time between the MN and the HA or the CN.

2.3 Fast Handovers for Mobile IPv6

FMIPv6 is a Mobile IPv6 extension that reduces the handover latency and, during the handover it buffers packets delaying them instead of losing them. This is accomplished by allowing the MN to send packets as soon as it detects a new subnet link (IEEE 802.11 in our case) and delivering packets to the MN as soon as its attachment is detected by the new access router. In FMIPv6 the MN discovers nearby APs and then requests all the important information related to the corresponding new access router. When attachment to an AP takes place, the MN knows the corresponding new router's coordinates. Through special Fast Binding Update and Fast Binding Acknowledgment messages the MN is able to formulate a prospective new CoA. As soon as it is attached, the MN sends a Fast Neighbor Advertisement message announcing its presence. Moreover, the previous access router will tunnel and forward packets to the new CoA until the MN sends a Binding Update registering its new CoA to the HA and to the CNs hence, any packet is lost.

FMIPv6 reduces the handover latency almost to the layer 2 handover latency. Once the MN has received the Fast Binding Acknowledgement message the communications between the MN and the CN will be interrupted. Packets destined to the MN will be buffered at the new access router (and thus delayed) until the MN regains connectivity. When the layer 2 handover is finished, and the MN is connected on the new link it will announce its presence through a Fast Neighbor Advertisement (FNA) message and the new access router will forward the buffered packets. We define D_{FNA} as the time between the MN regains connectivity and the FNA message has been received by the new access router. Equation (2) models the handover latency for the FMIPv6 protocol operating in Predictive mode, which is the fastest one.

$$HL_{FMIPv6} = D_{L2} + D_{FNA} \quad (2)$$

Experimental measurements show that the handover delay for FMIPv6 using the Predictive mode is 319ms in average [8]. Note that the handover latency is very close to the layer 2 handover latency because the D_{FNA} is very small, moreover it does not depend on the distance to the HA or to the CN. During this time, packets are being buffered at the new access router making difficult to run VoIP applications.

2.4 Hierarchical Mobile IPv6

Hierarchical Mobile IPv6 (HMIPv6) is another extension of Mobile IPv6. Its main goal is to reduce the signaling overhead and to improve the handover latency. HMIPv6 introduces a new entity called Mobile Anchor Point (MAP) placed at any point of the hierarchy of a network. The MAP is essentially a Home Agent which will limit the amount of Mobile IPv6 signaling outside the local domain. The HMIPv6 handover latency is very similar to the Mobile IPv6 handover latency. If a HMIPv6-aware MN moves from one access router to another one outside the MAP boundaries it will have the same handover latency than Mobile IPv6. However, when the MN moves to another AR which is inside the MAP domain it will not need to send Binding Updates. The MN will just send one Binding Update to the MAP. Equation (3) models this handover latency.

$$HL_{HMIPv6} = D_{L2} + D_{NUD} + D_{DAD} + RTT(MN, MAP) \quad (3)$$

3 Proposed Solution

The proposed solution is an enhancement of Mobile IPv6 and it uses two IEEE 802.11 interfaces with a cross-layer design in the MN, figure 1 presents how it operates.

On the first phase, the MN is connected to the first AR using the first wireless interface. This interface has a configured CoA1 and it is communicating with the CN. The second interface is scanning for better connectivity. When the MN moves, the first wireless interface using layer 2 triggers will inform to the upper layers that the signal quality is becoming low. Meanwhile the second interface has detected a new access point with better signal quality. The IPv6 layer will start to obtain a new CoA for the second interface (CoA2) in the new access router. Next, in the third phase it will start to send the corresponding Binding Update messages to the CN and HA announcing that it has a new CoA while the first interface is still sending and receiving packets. Finally, in the fourth

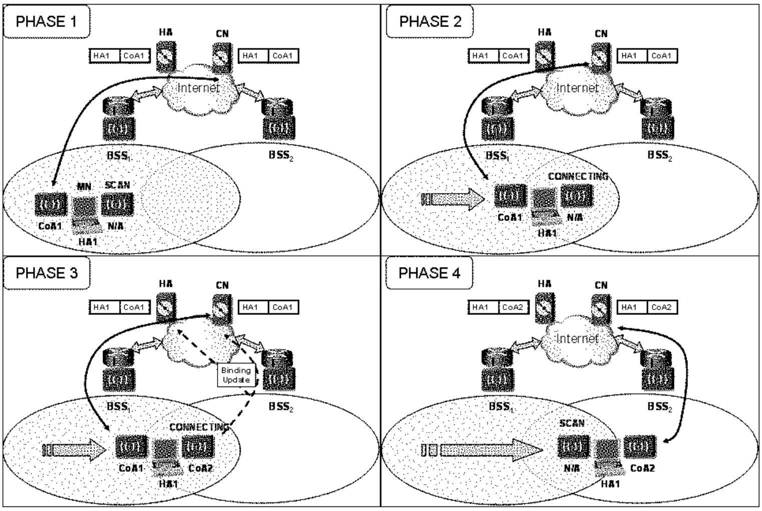

Fig. 1. An overview of the proposed solution

phase, when the Binding Update messages have arrived to the CN and to the HA they will stop sending packets to the CoA1 and start to send them to the CoA2. The handover is now complete and the first wireless interface will enter the scan mode, looking for better signal quality.

3.1 System Architecture

This section presents the different modifications required to run our proposed solution, note that all the modifications need to be done on the MN. Our solution does not require any modification on the network, the CN or the HA.

3.2 The IEEE 802.11 Layer

To provide seamless handovers our solution needs link-layer triggering i.e., events will be fired at the link layer module and communicated to the network layer module. Moreover, the network layer module will be able to force the layer 2 to connect or disconnect to a given Access Point. Different organizations, such as IETF and IEEE are defining a generic interface to provide link-layer triggering [9],[10] and [11].

The link-layer triggers used by our solution are based on [9] and they are divided into three categories. First, the *Events* are fired at layer 2 providing important information for the network layer. The *LinkUp* event indicates that the network layer can start sending packets because the layer 2 link has established a link whereas the *LinkDown* event indicates that the link-layer is down. Finally the *Link Quality Crosses Threshold* indicates that the signaly quality has remained low for a certain period of time and that the network may start preparing for a handover. Secondly, the *Information* is provided by the link-layer and accessible by the network layer. The *Link Quality* information is used by the network layer to check the signal quality received on a given wireless interface. Finally, the *Services* are actions that can be requested by the network layer to the link-layer. The network can request to the link-layer to *Connect* or *Disconnect* from a given AP. Moreover it can *Scan* for available APs.

The required link-layer triggers are divided into three different types. The Events are fired from the layer 2 to inform about different aspects of the link-layer connectivity. The Information can be accessed by the network layer to obtain connectivity information. Finally, the Services are actions that can be requested by the network layer to change different aspects of the link-layer. Our solution is intended for IEEE 802.11, however this list is a generic framework that can fit on almost any link-layer technology based on radio access such as GPRS or UMTS.

3.3 IPv6 and the Mobile IPv6 Layer

The network layer, IPv6 in our case, is responsible of maintaining at least one interface connected to an access router while the other one is scanning for better signal quality. While one interface is connected to an access router, the IPv6 layer using the Scan service defined in the previous section will scan looking for available APs. When an AP is found the network layer will connect the second interface to the new AP. If more than one AP is detected, the wireless interface will connect to the best one in terms of signal quality. Once the second wireless interface is connected to a new AP it will start to perform all the operations related with auto-configuration in order to obtain a new CoA. This CoA will not be used and any packet will be sent or received using it.

The second interface will wait until the first one raises the Link Quality Crosses Threshold event. This event indicates that the handover is imminent and that the second wireless interface needs to register its new CoA with the HA and with the CNs. In order to prevent that the second interface losses connectivity with the AP before the handover, the interface will monitor the signal quality received using the Link Quality information. If the Link Quality Crosses Thresholds is raised on the second interface it will start to Scan for other available APs with better connectivity and the whole process will start again.

If the signal quality on the second interface is high and the first one fires the Link Quality Crosses Thresholds event, the MIPv6 layer will send Binding Update messages to its HA and CN using the new CoA (CoA2). Once the corresponding Binding Acknowledgment messages have been received, and the HA and CN have changed its bindings with the new CoA the network layer will disconnect the first wireless interface. Next, the communication with the CN will continue without interruption, and the first wireless interface will start to Scan to look for better signal quality.

Figure 2 presents a schema of the proposed solution and shows that the handover latency is zero and that packets are not lost. The handover latency, as shown in figure 4 is zero. While the first wireless interface is receiving and sending

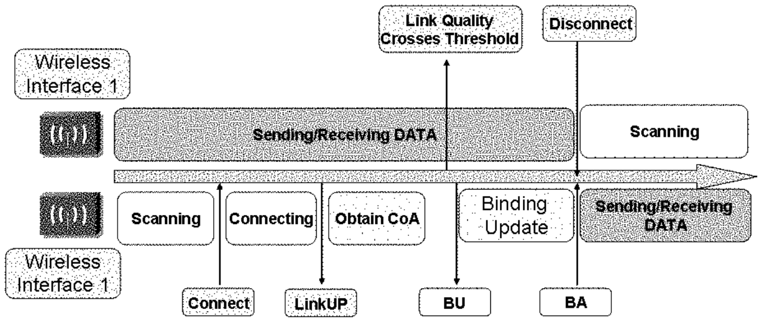

Fig. 2. Schema of the proposed solution

packets, the second interface will be performing all the related operations with the handover. When the Binding Acknowledgment message is received, the HA and all the CN have switched from the old CoA to the new one. All the packets in transit have been received and thus, the network layer can disconnect the first interface and start sending and receiving packets through the second one.

The time spent by the link layer to connect to the new AP is D_{L2}. The time spent by the IPv6 layer to obtain a new CoA is improved in comparison with Mobile IPv6. In the Mobile IPv6 case this time was modeled as $D_{NUD} + D_{DAD}$. Our solution does not require executing the Neighbor Unreachability Detection algorithm. This algorithm is required because the IPv6 layer must switch from the old access router (considered as primary) to the new one (considered as secondary) [24]. In our proposal the IPv6 layer of the second wireless interface does not have any default router configured and thus, does not need to check that the primary one is no longer reachable. Moreover, our solution incorporates Optimistic Duplicate Address Detection [12]. This new algorithm, which has not been standardized yet, aims to minimize address configuration delays in the successful case and interoperates with unmodified hosts and routers.

The handover latency for our proposal is zero. However the second wireless interface spends a certain amount of time performing the handover related operations. Due to the improvements of our solution, avoiding the D_{NUD} term and reducing the D_{DAD} term, this time is always lower than the Mobile IPv6 handover latency (HL_{MIPv6}).

3.4 Applicability of the Solution

The proposed solution uses two IEEE 802.11 wireless interfaces to achieve zero handover latency and no losses. It requires that within the domain where the MN will move the different APs coverage areas have an overlapped region. In other words, our system requires of this overlapped region to connect to the new access router while it is sending and receiving packets through the old one. In this section we will focus on these requirements.

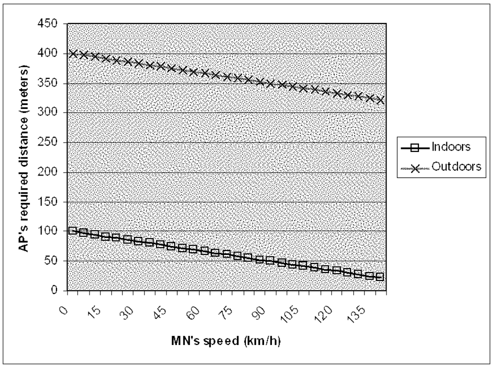

Fig. 3. Inter-APs required distance

According to [13] and other tech specs, APs usually have an outdoor range of 400 meters and an indoor range of 100 meters. Our system requires that during at least HL_{MIPv6} (1) seconds, which is the maximum amount of time spent by one of the interface to perform all the handover related operations, the MN is able to communicate with two APs at the same time. Depending of the MN's speed we will need that the APs are close enough to provide this overlapped region. For example, if the MN is moving at 50km/h and the HL_{MIPv6} is 2 seconds [7] (worst case) our system requires an overlapped region of 28 meters and thus, in an outdoors environment, two consecutives APs must be set 372 meters away one from the other.

Figure 3 shows the distance required between two consecutives AP to provide the necessary overlapped region depending on the MN's speed. If the system is deployed indoors the MN's speed will be up to 10km/h (a person walking), the required overlapped region is about 5 meters and the APs must be set around 95 meters away. If the system is deployed outdoors the MN's speed can be up to 120km/h (a MN traveling in a car) and the APs must be set 333 meters away. These results demonstrate the applicability of our proposal. Note that our solution is intended for mobile vehicles where movement is within a well known area. For instance the proposed solution can be deployed along a railway where MNs are inside the train.

3.5 Proposed Solution Evaluation and Comparison

In this section we evaluate different important parameters of our proposal and compare it with Fast Handovers for Mobile IPv6 and Hierarchical Mobile IPv6.

Handover Latency: Our proposal has zero handover latency because one of the wireless interfaces sends and receives the data packets while the other one is performing the handover operations. FMIPv6 has very low handover latency, close to the layer 2 handover latency and HMIPv6 has higher handover latency due to the IPv6 auto-configuration delays.

Packet Loss: Our proposal does not lose any packet. FMIPv6 does not lose any packet neither, however packets are stored in a buffer and delayed. This delay makes difficult to use FMIPv6 with real-time traffic such as VoIP. HMIPv6 suffers of great packet losses during the handover latency.

Inter Packet Delay Variation: During the handover, HMIPv6 losses packets. FMIPv6 does not lose packets, but packets received during the handover are buffered introducing IPDV. This also makes difficult to use it with VoIP applications. Our proposal does not introduce any kind of delay during the handover.

Network Support: FMIPv6 requires that access routers and MNs are FMIPv6-aware, even more it needs that each access router knows the prefix announced by its neighbors. Probably this information will be obtained through a discovery protocol, but it has not been yet defined. HMIPv6 does not require any kind of support by the access routers but it introduces a new entity called Mobility Anchor Point. The MAP must be deployed in each domain to support hierarchical handovers. Even more, all the packets destined to MNs inside the domain will be routed through the MAP becoming a Single Failure Point. The network support required by both protocols makes them more expensive to deploy and to maintain. Our solution does not require any kind of network support, just modifications on the MN. Our proposal is also interoperable with MNs and CNs that do not implement it.

Buffering: FMIPv6 requires that each access router incorporates a buffer where packets will be stored during the MN's handover. It requires a buffer for each MN that it is changing its point of attachment. This buffer may introduce some security issues and increments the deployment cost. HMIPv6 and our solution do not use buffers.

State-based Protocol: Both FMIPv6 and HMIPv6 are state-based protocols. FMIPv6 needs to track MN's localization information. When a MN changes its point of attachment, the new access router must know it in advance, store its IP address and the packets destined to it. The HMIPv6's MAP is essentially a Home Agent and it needs to store the bindings between Regional CoA and oCoAs. State-based protocols introduce security issues and have a greater cost to deploy and to maintain. Our proposal is a stateless protocol.

Signaling Overhead: HMIPv6's main goal is to reduce the signaling outside the MAP boundaries and it has the lower signaling one. Our solution and FMIPv6 have the same signaling overhead than MIPv6.

Overlapping Requirements: Our solution has hard overlapping requirements compared with the other MIPv6 extensions. FMIPv6 and HMIPv6 can run in non-overlapped networks but their performance will be severely affected because the wireless handover will increase (D_{L2}) producing a greater handover latency. Our proposal will perform at the same level than Mobile IPv6 in non-overlapped networks.

Table 1 summarizes the comparison and demonstrates that our proposal performs better than the other extensions to Mobile IPv6. It has better handover latency, packet losses and IPDV. This makes our proposal suitable to use it with real-time traffic applications such as VoIP. Moreover, FMIPv6 and HMIPv6 have a high deployment and maintenance cost due to the network support requirements while our proposal does not require modifying access routers and does not introduce any new entity. Finally, HMIPv6 and FMIPv6 are state-based protocols introducing security issues and Single Failure Points (the MAP) whereas our solution is a stateless protocol and pushes the complexity to the MNs, keeping the network simple.

The main issues with our proposal are that requires a hard overlapped network and two wireless interfaces for each MN. Both wireless cards can increase the energy drain, which can be a problem in battery operated devices. Regarding the wireless interfaces, nowadays the cost of an IEEE 802.11 card is very low and decreases rapidly, even more in [14] authors present a smart device driver for a Prism-based WLAN card that operates as two wireless cards. Regarding the overlapping requirements all the mobility extensions (including ours) require an overlapped network to provide seamless handovers. Our proposal allows VoIP applications to run in a mobile environment and keeps the network simple, cheap to maintain and to manage, pushing the complexity to the MN.

Table 1. Summary of the comparison

	FMIPv6	HMIPv6	Proposed Solution
Handover Latency	Low	High	0
Packet Loss	0	High	0
IPDV	Yes	No	No
Network Support	Yes	Yes	No
Buffering	Yes	No	No
State-Protocol	Yes	Yes	No
Wireless Interfaces	1	1	2
Signaling Overhead	High	Low	High
Overlapping-Requirements	Low	Low	Hard

4 Related Work

New wireless standards are rapidly appearing and at the same time terminals which have radio and protocol support for two, three or even more standards are appearing. The idea of having a multihomed node to improve Mobile IPv6's performance is not new. The IETF has recently created the MONAMI6 [15] working group which will take advantage of this and will standardize how the Mobile IPv6 RFC must be modified to support multiple interfaces and thus, multiple Care-of-Addresses registrations. Finally, in [16],[20] the authors discuss the benefits of having multihomed MNs and how Mobile IPv6 can take advantage. Those proposals require modifications on the CNs, MNs and HAs and their main goal is not to improve the handover but to allow using more than one Care-of-Addresses trough multiple bindings at the same time. Our proposal does not require multiple CoA registrations.

The IETF has also recently created the Detect Network Attachment [21] working group. Its main goal is to reduce the Mobile IPv6 handover latency, specifically the IPv6 part of the handover (modeled as D_{NUD} in our paper) by using link-layer triggers. They have yet published an RFC [17] discussing the goals of the working group and an internet draft [18]. We also avoid such delay in our proposal, not by using link-layer triggering but because our MN does not need to perform this operation. Our proposal use an extended version of link-layer triggers, we use a cross-layer design.

Several papers aim to enhance the handover, [22] improves the wireless handover by using neighbor graphs, a data structure which dynamically captures the mobile topology of a wireless networks. [14] also improves the IEEE 802.11 handover by virtualizing a single wireless card that is able to be connected to multiple networks simultaneously. Our proposal improves the whole Mobile IPv6 handover, not just the wireless part. Finally [19] and [23] enhances the whole Mobile IP handover by using multicast while our proposal does not require of complex network support.

5 Conclusions

This paper presents a novel extension to the Mobile IPv6 protocol that improves the handover performance. The handover is the most critical part of the mobile technologies because packets can be lost or delayed making difficult to run VoIP. Our solution uses a multihomed mobile node with two IEEE 802.11 cards and a cross-layer design allowing interaction between the link-layer and the network layer. While one interface is sending and receiving data packets from CNs the other is performing all the operations related with the handover.

The IETF has designed two extensions to Mobile IPv6: FMIPv6 and HMIPv6. These solutions add complexity to the network, they require of special network support and they introduce new functional entities. We claim that we must keep the network simple, cheap to maintain and to manage pushing the complexity to the edges, the MN in our case. Our solution, intended for mobile vehicles, takes advantage of this philosophy providing a simple protocol. Moreover our solution performs better than FMIPv6 and HMIPv6 and it has zero handover latency and no losses. We have not validated our proposal through simulations because this would not provide any kind of significant information. Our solution can be considered a generic framework to provide seamless handovers between any different link layer radio technologies such as GPRS or UMTS. In other words, we can apply our proposal to provide seamless handovers between IEEE 802.11 and GPRS, or UMTS using Mobile IPv6.

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