Optimized FMIPv6 Using IEEE 802.21 MIH Services in Vehicular Networks

Qazi Bouland Mussabbir, *Student Member, IEEE*, Wenbing Yao, *Member, IEEE*, Zeyun Niu, *Student Member, IEEE*, and Xiaoming Fu, *Member, IEEE*

***Abstract*—In this paper, we optimize the handover procedure in the Fast Handover for Mobile IPv6 (FMIPv6) protocol by using the IEEE 802.21 Media Independent Handover (MIH) services. FMIPv6 is used to enhance the performance of handovers in Mobile IPv6 and its basic extension for network mobility (NEMO), i.e., the fundamental mobility management protocols used in vehicular networks. With the aid of the lower three layers' information of the mobile node/router (MN/MR) and the neighboring access networks, we tackle the radio access discovery and candidate access router (AR) discovery issues of FMIPv6. We introduce an "Information Element Container" to store static and dynamic Layer 2 (L2) and Layer 3 (L3) information of neighboring access networks and propose to use a special cache maintained by the MN/MR to reduce the anticipation time in FMIPv6, thus increasing the probability of the predictive mode of FMIPv6 operation. Furthermore, we propose a cross-layer mechanism for making intelligent handover decisions in FMIPv6. The lower layer information of the available links obtained by MIH services and the higher layer information such as quality-of-service (QoS) parameter requirements of the applications are used by a Policy Engine to make intelligent handover decision. We will show through analysis and simulations of the signaling procedure that the overall expected handover (both L2 and L3) latency in FMIPv6 can be significantly reduced in the proposed mechanism.**

***Index Terms*—Cross-layer design, Fast Handover for Mobile IPv6 (FMIPv6), IEEE 802.21, mobility management, network mobility (NEMO).**

I. Introduction

THE provisioning of seamless mobility to vehicles across heterogeneous access networks is essential for the next generation's vehicular communication networks. A variety of access network technologies (e.g., 802.11a/b/g WIreless-FIdelity (WiFi), 802.11p Wireless Access in Vehicular Environments (WAVE), 802.16 World Interoperability for Microwave Access (WiMAX), General Packet Radio Service, and Universal Mobile Telecommunications Systems networks) are converging their core network infrastructure to the Internet Protocol (IPv4/6) [1], [2] suite. While IPv6 is being chosen as an underlying convergence protocol for vehicle networking, the introduction of high-speed WAVE necessitates the support of "breakthrough" safety and commercial applications in Intelligent Transportation Systems (ITS). In particular, the new emerging "infotainment" applications call for the vehicular networks to support multimedia and real-time services.

To enable mobile nodes (MNs) and networked vehicles to seamlessly roam across heterogeneous networks while enjoying the plethora of "all-IP-based" services, there are many challenges arising from intertechnology "vertical" handovers. A number of network layer mobility solutions have been proposed or discussed in the Internet Engineering Task Force (IETF). Among them, Mobile IPv6 (MIPv6) [3] is one of the few solutions that has been widely accepted in the academic world and the industry. Since MIPv6 is designed for supporting the mobility of single mobile hosts, the IETF Network Mobility (NEMO) [4] Working Group (WG) has extended it to support the mobility of moving networks.

As an extension to the MIPv6 protocol, the NEMO Basic Support [5] is concerned with the mobility of an entire network that dynamically changes its Point-of-Attachment (PoA) (i.e., Access Points and Base Stations) and, thus, its reachability in the Internet. Its main objective is to maintain session continuity between the Mobile Network Nodes (MNNs) and the Corresponding Nodes (CNs) while the mobile router (MR) changes its PoA. The MNNs behind the MR are IPv6 nodes and do not need to individually register or bind their home addresses with the Home Agent (HA). The MR, while acting as a gateway between the intervehicle network and the network infrastructure, updates its change in IP subnets at the HA by sending a prefix-scope Binding Update (BU) message that associates its Care-of-Address (CoA) with the Mobile Network Prefix (MNP) used by MNNs.

Continuous Air interface for Long and Medium range (CALM) is a family of umbrella protocols being developed in ISO/TC204/WG16 ("Wide Area ITS Communications") "to provide a uniform environment for vehicle data communications that allows vehicles to stay connected using the best communications technology available both in the vehicle and in the infrastructure wherever the vehicle is located" [6]. In fact, under CALM, MIPv6 and NEMO are selected as two options for supporting host mobility and NEMO in vehicular communications.

Handover performance plays a crucial role in the quality-of-service (QoS) provisioning for real-time services in heterogeneous networks. The period during which the MN/MR loses connectivity with its current link until the time it receives the

Manuscript received February 22, 2007; revised June 1, 2007; accepted July 16, 2007. The review of this paper was coordinated by Dr. L. Cai.

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Digital Object Identifier 10.1109/TVT.2007.906987

first IP packet after connecting to the new link is known as the *handover latency*. The overall handover latency in NEMO and MIPv6 consists of Layer 2 (L2) latency and Layer 3 (L3) latency. The L2 handover latency is the period when the MN/MR is disconnected from the air link of the current access router (AR) until the time it successfully accesses the air link of the new AR (nAR). The L3 handover latency comprises the latencies incurred during IP layer movement detection, network reauthentication, CoA configuration, and BU. With the help of L2 triggers, the Fast Handover for MIPv6 (FMIPv6) protocol [7] developed within the IETF Mobility for IP: Performance, Signaling and Handoff Optimization (MIPSHOP) WG can reduce handover delays in MIPv6.

FMIPv6 reduces the handover delay by exploiting various L2 triggers to prepare a New CoA (NCoA) at the nAR while being connected to the link of the old AR (oAR). It relies on the oAR to resolve the network prefix of the nAR based on the L2 identifier reported by the link layer triggers in the MN. Note that, although FMIPv6 is originally designed for improving the handover delay in MIPv6, it can also be used to support NEMO after minor extensions. The idea is very simple: the traffic addressed to MNNs in a mobile network would need to be tunneled to the MR's CoA; the MR here will be treated like an MN by FMIPv6 for traffic redirection between oAR and nAR using the binding of the previous CoA and the NCoA maintained at the oAR. The overall handover process (i.e., handover message signaling) would be identical to the procedure described in the original FMIPv6 request for comments (RFC) [7] with minor extensions. We will discuss the details about the extensions later in Section III-A.

The IEEE 802.21, namely the Media Independent Handover (MIH) Standard WG [8] officially formed in 2004, is developing a standard that provides generic link-layer intelligence and other network-related information to upper layers to optimize handovers between different heterogeneous media such as 3GPP/3GPP2, and both wired and wireless media of the IEEE 802.21 family. Considering the overlap of work in IEEE 802.21 and CALM in the handover area, a liaison between these two is being discussed. The IETF MIPSHOP WG has liaised with IEEE 802.21 WG to investigate the delivery and security issues of transporting MIH services over IP [9]–[12], [24].

In this paper, we investigate the potential of applying FMIPv6 in vehicular environments and optimize the handover procedure of the FMIPv6 protocol in vehicular environments by using IEEE 802.21 MIH services. With the aid of the lower three layers' information of the MN/MR and the neighboring access networks we tackle the radio access discovery and candidate AR discovery issues of FMIPv6. We design an "Information Element Container" to store static and dynamic L2 and L3 information of neighboring access networks, and propose to use a special cache maintained by the MN/MR to reduce the anticipation time in FMIPv6, thus increasing the probability of the predictive mode of operation. Furthermore, we propose a cross-layer mechanism for making intelligent handover decisions in FMIPv6. The lower layer information of the available links obtained by MIH services and the higher layer information such as QoS parameter requirements of the applications are used by a Policy Engine (PE) to make intelligent handover decisions. We will show through analysis and simulations of the signaling process that the overall expected handover (both L2 and L3) latency in FMIPv6 can be reduced in the proposed mechanism.

The rest of this paper is organized as follows: Section II introduces the related works, where the issues of FMIPv6 in vehicular environments, IEEE 802.21 MIH Function (MIHF), and its related services will be introduced. Section III provides an overview of the proposed mechanism and the extension of FMIPv6 for NEMO. Section IV introduces the detailed handover procedure in the proposed mechanism. Mathematical and numerical evaluations of the handover performance of the proposed mechanism are given in Sections V and VI concludes this paper and discusses future work.

II. Related Works

A. FMIPv6: Overview and Problem Statement

FMIPv6 concentrates on the protocol operation and does not consider issues such as radio access network discovery and candidate AR discovery (i.e., how the ARs could map the network prefix with the corresponding L2 identifier). Although the anticipation mechanism specified by FMIPv6 is useful, it also introduces additional problems.

1) Neighboring Access Network Discovery: The FMIPv6 does not address any radio access network discovery mechanism. Discovering the available PoAs by actively scanning all the channels provided by the neighboring networks takes a considerable amount of time, which has significant contribution to the overall handover latency. For example, in 802.11b, the L2 scanning can take 400–800 ms [18].

2) Information Exchange With Neighboring ARs: How neighboring ARs exchange information to construct Proxy Router Advertisement (PrRtAdv) messages is not specified in the RFC of FMIPv6. The IETF SEAMOBY WG has developed the Candidate Access Router Discovery protocol [19], [23] to address this issue. However, it does not support the sharing of L2 information between ARs.

3) Cost of Anticipation: There are three FMIPv6 signaling messages involved in the anticipation phase, i.e., *Router Solicitation for Proxy Advertisement* (RtSolPr), PrRtAdv, and *Fast BU* (FBU). These messages are used for assisting IP movement detection and NCoA configuration. In FMIPv6, the L2 handover is triggered by the degraded link condition. It is likely that the MN will not be connected to the oAR long enough to send and receive all FMIPv6 messages. When anticipation is used, the MN may not have sufficient time to update the oAR with the FBU. As a result, if the MN has already lost connection with the oAR, the MN will then be forced to operate in the reactive mode, and the handover latency will consequently increase.

B. IEEE 802.21 MIHF

In the mobility management protocol stack of both the MN and the network element, the IEEE 802.21 MIHF is logically defined as a shim layer between the L2 data link layer and the

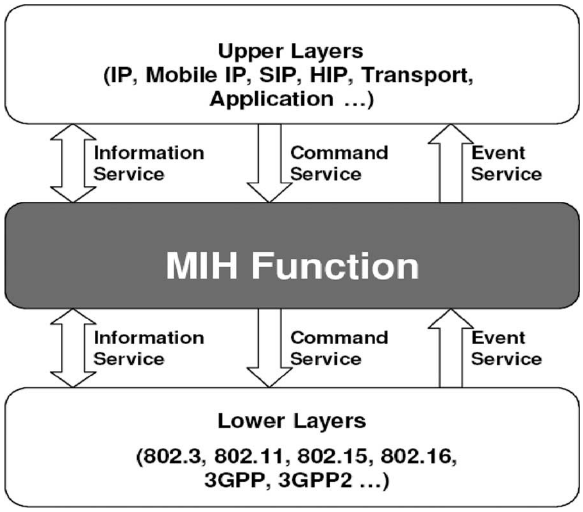

Fig. 1. IEEE 802.21 MIH framework [8].

L3 network layer [8]. The upper layers are the provided services by the MIHF through a unified interface. The services exposed by the unified interface are independent of access technologies. This unified interface is known as MIH_SAP. The lower layer protocols communicate with the MIHF via media-dependent service access points (SAPs) (i.e., Link_SAP).

MIHF defines three main services that facilitate handovers between heterogeneous networks, i.e., MIH Event Services [Media Independent Event Service (MIES)], MIH Command Services [Media Independent Command Service (MICS)], and MIH Information Services [Media Independent Information Service (MIIS)]. Fig. 1 shows the MIH framework. Detailed discussions of each of the services are given below.

MIES provides event reporting, event filtering, and event classification service corresponding to the dynamic changes in link characteristics, link quality, and link status. The MIES reports both local and remote events to the upper layers. Some of the events that have been specified by IEEE 802.21 are "Link Up," "Link Down," "Link Detect," "Link Parameter Reports," and "Link Going Down." Mobility management protocols can use some of these events, for example, Link Down or Link Going Down as handover triggers. Together with the QoS requirements from the application layer, the reported link status, quality, and characteristics will also be very useful for the Mobility Management Entity (MME) to make handover decisions, i.e., to decide to which network and PoA within several available networks and PoAs the MN should switch and when the MN should make the handover.

MICS uses the MIHF primitives to send commands from higher layers (e.g., PEs and Mobility protocols) to lower layers. The MICS commands are utilized to determine the status of the connected links and to execute mobility and connectivity decisions of the higher layers to the lower layers. For example, the mobility management protocol can use MICS to inform the link layer to get ready before the actual handover happens and to give the command to the link layer to switch from one network interface to another. It also allows the mobility management protocols to inquire about the link layer's status before the handover decision making.

MIIS provides a framework and mechanism for an MIHF entity to discover available neighboring network information within a geographical area to facilitate the handover process. The primary idea is that to represent the information across different access technologies, the MIIS specifies a common way of representing this information by using a standard format such as Extensible Markup Language (XML), Abstract Syntax Notation One (ASN.1), or Type Length Value (TLV), and this information can be obtained through a certain query/response mechanism. Both static and dynamic information are provided by the MIIS. Examples of static information include the names of service providers, medium access control (MAC) addresses, and channel information of the MN's current network neighborhood. Dynamic information includes link-layer parameters such as data rate, throughput, and other higher layer service information to make intelligent handover decision.

In the current 802.21 MIIS specification, an MN gets the heterogeneous neighborhood information by requesting information elements (IEs) from the information server (IS). It also allows the neighborhood information to be delivered to the MN by using predefined Information Reports/IE Containers to effectively represent the heterogeneous neighborhood information in TLV format. In the IEEE 802.21 draft, the defined IEs provide mostly static L2 information.

In [9], a problem statement is defined in transporting the MIH services over IP. Some usage scenarios and models for MIH Event, Command, and Information services are outlined in [10] and [11]. The security considerations of MIH services are also discussed in these papers. In [12], a user datagram protocol-based mechanism for the transport of MIH services between network nodes is defined.

The network requirements of IPv6-based vehicular communication systems are investigated in [13]. The use of the IEEE 802.21 reference model for appropriate network selection in vehicle-to-infrastructure systems is discussed in [14] and [15], respectively. An optimized solution for reducing the handover latency in Nested NEMO is provided in [16]. Works have also been done on using MIH services as a way to reduce the handover latencies in [17] and [18]; however, they did not address the vehicular networking environment.

III. Improving FMIPv6 With IEEE 802.21 Services in Vehicular Networks

Fig. 2 illustrates the network architecture considered in this paper. The MN/MR could be an MIH-enabled multimode mobile device. The MIH-enabled PoA that the MN is currently attached to is the *Point of Service to serving* (PoS), while the other MIH-enabled PoAs are *candidate PoSs*. The IS also serves as an MIH PoS that could be located in either the access network or the core network. The IS could be considered as a data reservoir for storing and managing the knowledge of neighboring networks.

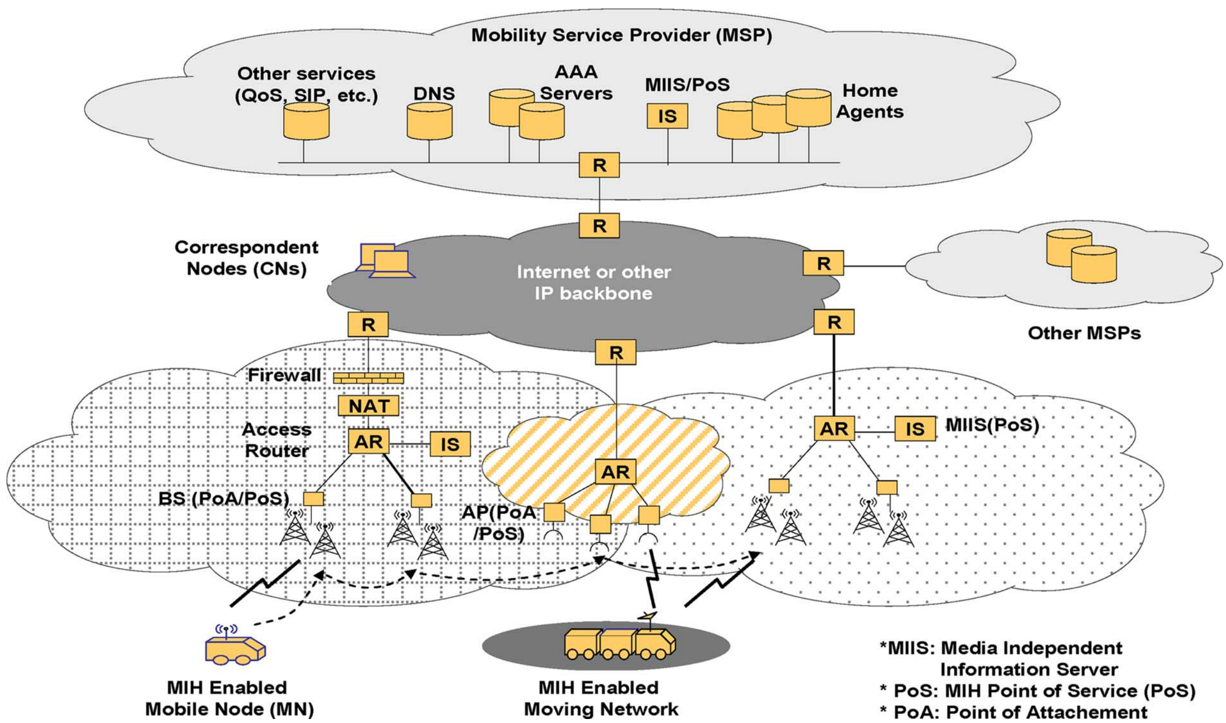

Fig. 2. Overview of the considered network architecture.

A. Extending FMIPv6 to Support NEMO Solution

As mentioned in Section I, FMIPv6 could be used to support NEMO but needs minor extensions. The necessary extensions will include extending the FBU, Handover Initiation (HI), HAck, and Fast Binding Acknowledgement (FBack) messages specified in the NEMO Basic Support [5].

1) FBU Message: A new Flag Option(R) will be needed in the original FBU message to distinguish the message sender—whether it is a single MN or an MR of a mobile network. We set R to be 0 for the MN and 1 for the MR. A new Mobility Header Option will be needed for carrying MNP. Upon receiving an FBU message, the oAR will first check the R flag. If R is 0, i.e., the FBU is sent from the MN, the FMIPv6 will operate as it is originally defined. If R is 1, the oAR will understand that the FBU is sent from the MR of a mobile network, and it needs to forward incoming packets that are destined to the mobile network to the MR. The oAR will then find out the MNP from the Mobile Header option and tunnel the packets with this MNP (destined to the MNNs in the mobile network) to the nAR during handovers. Note that the MNP only needs to be carried as mobility options in the *explicit mode* [5] of NEMO operation. In the NEMO *implicit mode* [5], the MR does not include any MNP, the oAR can then use any mechanism to determine the route to the MNNs.

2) FBack Message: A new Flag Option(R) will be needed in the original FBack message to distinguish the FBack message receiver—whether it is a single MN or an MR of a mobile network.

3) HI Message: The MNPs can be transmitted between the oAR and the nAR using one of the "Options" fields of the HI message. Both the oAR and the nAR could maintain a Prefix Table [5] for preventing the clash between a newly claimed MNP and an MNP that is being used. The mechanism for tackling duplicate MNPs is out of the scope of this paper.

4) HAck Message: The HAck message should contain new status results that indicate the success or failure in accepting the MNPs maintained by the MR.

B. Overview of the 802.21-Assisted FMIPv6 Mechanism

In this section, we use IEEE 802.21 MIH services to assist FMIPv6 in enhancing the overall handover performance in vehicular environments by addressing the issues discussed in Section II.

1) We define a Heterogeneous Network Information (HNI) Container to facilitate the storing and retrieval of the L2 and L3 static information of neighboring networks obtained through the IEEE 802.21 MIIS. The IE known as "Subnet Prefix" is used to provide subnet prefixes of neighboring ARs. Alongside with the L2 information, they form the proposed predefined HNI container/report. The draft has defined a PoA container and an Access Network Container [8], which include many IEs such as MAC address, channel range, network type, cost, roaming agreements, and network security. Instead of including all of the IEs from these two containers, we select the ones that can further optimize our proposal and put them in a single IE container, which is our HNI container. Having a single predefined HNI container will be ideal in vehicular environments and help in reducing the message overheads, processing, and lookup/indexing times.

The handover latency caused by the radio access discovery in FMIPv6 will be eliminated by using the L2 link information retrieved from the MIIS. Furthermore, with the L3 information of the corresponding PoAs, the MN will learn the subnet prefixes of the nAR and form the NCoA prior to handover. This eliminates the router discovery time and optimizes the L3 handover latency in FMIPv6. Note that the HNI report maintained by an IS will be similar to the mapping table maintained by the ARs for resolving L2 identifiers of corresponding subnet prefixes. This could eliminate the need for ARs to exchange neighboring information to maintain the mapping table, thereby tackling the candidate AR discovery issue in FMIPv6.

2) To reduce the adverse impacts of the long anticipation time in FMIPv6, we propose to create the Neighboring Network Report (NNR) cache in the MN for storing and maintaining the HNI report. This would help to reduce the number of signaling messages during the anticipation phase and thereby the overall anticipation time. The HNI report will be delivered to the MN through the "MIH_Get_Information" service primitives. By reducing the anticipation time, the probability of operations in predictive mode is increased. Also, the CoA configuration time can be reduced, and thereby, the L3 handover latency is reduced.
3) We use MICS to collect/obtain dynamic QoS link-layer parameters directly from MIH-enabled candidate PoAs. Dynamic neighboring network information includes packet loss rate, average packet transfer delay, signal-to-noise ratio (SNR), available data rates, etc.
4) We define a new MICS service primitive for requesting application QoS requirements and a new MIES for delivering the application QoS parameters to the PE. A cross-layer mechanism is proposed for intelligent handover decision making by using the static and dynamic information of neighboring networks, the local link condition, and the application QoS requirements.

C. IEEE 802.21 MIH Services to be Used

We utilize a subset of existing IEEE 802.21 MIH services to enhance the handover process in FMIPv6. Their corresponding primitives and parameters are listed in Table I. In Table II, the new MIH service primitives that we defined for the handover decision making are presented.

D. Structure of HNI Report

The MIIS "HNI" report will be delivered through a request/response mechanism and will be represented in a standard format such as XML, ASN.1, or TLV. Table III shows the HNI request message in TLV format by which the MN/MR can obtain the HNI_report by specifying the Link Type and Operator Identifiers as parameters. Table IV shows the HNI response message. The HNI report containing the IEs will be produced and stored in an IS.

TABLE I
EXISTING MIH SERVICES USED AND EXTENDED

Primitives	*Service*	*Parameter*
MIH_Link_Going _Down	MIES	MN MAC Addr, MAC Addr of Curent PoA
MIH_Link_Up	MIES	MN MAC Addr, MAC addr of new PoA, Link ID
MIH_Link_Down	MIES	MN MAC Addr, MAC addr of new PoA, Reason Code
MIH_MN_HO_ Commit	MICS	Old Link ID, New Link ID
MIH_MN_HO_ Candidate_Query (extended)	MICS	SNR, Available Data Rate, number of associated user, Throughput , Packet Error Rate, CoS Minimum Packet Transfer Delay, CoS Average Packet Transfer Delay, CoS Maximum Packet Transfer Delay, CoS Packet Loss
MIH_N2N_HO_ Candidate_Query	MICS	SNR, Available Data Rate, number of associated user, Throughput , Packet Error Rate, CoS Minimum Packet Transfer Delay, CoS Average Packet Transfer Delay, CoS Maximum Packet Transfer Delay, CoS Packet Loss

TABLE II
NEWLY DEFINED MIH SERVICE PRIMITIVES

Primitives	*Service*	*Parameters*
MIH_App_Par	MIES	Required data rate, delay, jitter, priority of applications
MIH_App_req	MICS	SNR, Required data rate, throughput , jitter, delay

TABLE III
HNI REQUEST

Type = TYPE_ IE_HNI_REPORT	Length = Variable
Type_IE_Container_HNI Report	

TABLE IV
HNI RESPONSE

Type = TYPE_IE_HNI_REPORT	Length = Variable
HNI Container #1	
PoA MAC Address IE	
POA Channel Range IE	
POA MAC Type IE	
POA PHY Type IE	
PoA Subnet Prefix IE	
PoA Subnet Prefix IE	
Network Type IE	
Roaming Partners IE	
Cost IE	
Network Security IE	
HNI Container #2	
… … …	

IV. DETAILED HANDOVER PROCEDURE OF THE 802.21-ASSISTED FMIPV6

A. Events Subscription

At the very beginning, when an MN is switched on, the FMIPv6 protocol in the MN will register for MIES notifications (i.e., L2 triggers) within its local stack. This will be done via the MIH Event Subscription service primitives [8] that are listed in Table I.

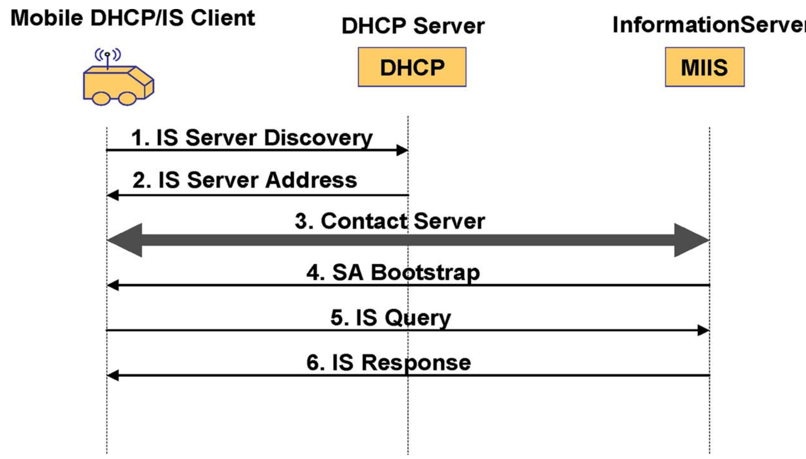

Fig. 3. IS discovery and message exchange.

B. IS Discovery and Usage

Valid ISs can be discovered through either L2 or L3 mechanisms. At the time of this writing, the Dynamic Host Control Protocol is one of the candidate solutions for discovering the IS [11], [22]. Fig. 3 shows the three phases related to our MIIS usage scenario, i.e., IS Discovery, Security Association (SA) bootstrap, and IS Query/Response. The MIIS serves the upper-layer entity that implements network selection and handover algorithms, i.e., the MME.

C. SA Bootstrap

Before the MME can exchange any messages with the IS server, a set of SA has to be established. Authentication and encryption must be provided by each SA for keeping the mobile device anonymity to prevent eavesdroppers. The SA negotiation mechanism depends on the used transport layer and the required security services [11]. For instance, the Transport Layer Security will be advised for use if the upper layer protocols use TCP, while the Encapsulation Security Payload using IPSec/IKE will work in most situations without the need to worry about the upper layer protocols as long as the IS protocol identifiers are handled by IKE [11].

D. Retrieval of Neighboring Network Information From the IS

It must be noted that the communications between the MN and the IS will be handled by the MIH protocol as specified in the IEEE 802.21 draft. The MIH protocol defines the frame structure for exchanging messages between MIH functional entities. The payload of the MIH message contains service-specific TLVs. Details on the MIH protocol message structure are provided in [8].

After the IS discovery and SA association phase, the MN will send an MIH message that carries the "MIH_Get_Information" request TLV as its payload to request the HNI Report from the IS. The HNI report will then be delivered in a returned MIH message from the IS to the MN in the format shown in Table III. The contents of the report will be processed by the MN and stored in its NNR cache.

We suggest a time stamp to be maintained by the MN for periodical access to the IS. This would help the MN renew its contents and check whether it is in the same or different IS domain.

E. Handover Operations

In the proposed 802.21-assisted FMIP6, we replace the RtSolPr/PrRtAdv messages with "MIH_Get_Information" request/reply messages, which are exchanged far before the L2 trigger occurs. This is different from the original FMIPv6 in which the RtSolPr/PrRtAdv only occurs after L2 triggers (i.e., when the MN senses that the signal strength of existing link is becoming too weak). Later, when the signal strength of the current PoA becomes weak, the MIES will be informed by the MAC layer of the MN. The MIES will scope and filter this link-layer information against the rules set by the MIH user (FMIPv6 in this case) and then produce an "MIH_Link_Going_Down" event indication message and send it to the network layer where the FMIPv6 protocol resides.

Upon receiving this event notification, the MN checks its NNR cache and selects an appropriate PoA to which to hand over. Since the MN knows the radio link information (i.e., MAC address and channel range of PoAs, etc) of the candidate access networks, the time to discover them is eliminated. In IEEE 802.11 networks, for example, there will be no need to use the "scanning" mechanism to find the neighboring access points (APs). In this paper, we propose to select the appropriate PoA with a cross-layer mechanism.

F. Intelligent Handover Decision Making Using Cross-Layer Mechanisms

The decision to select the appropriate (i.e., optimal) network is based on a PE, which takes into account the QoS parameter requirements from the application and matches them with the dynamic QoS link parameters from the lower layers (L2 and below) of the available networks. As mentioned before, it is clearly specified in [8] that the dynamic link-layer parameters (e.g., QoS parameters such as throughput, average packet

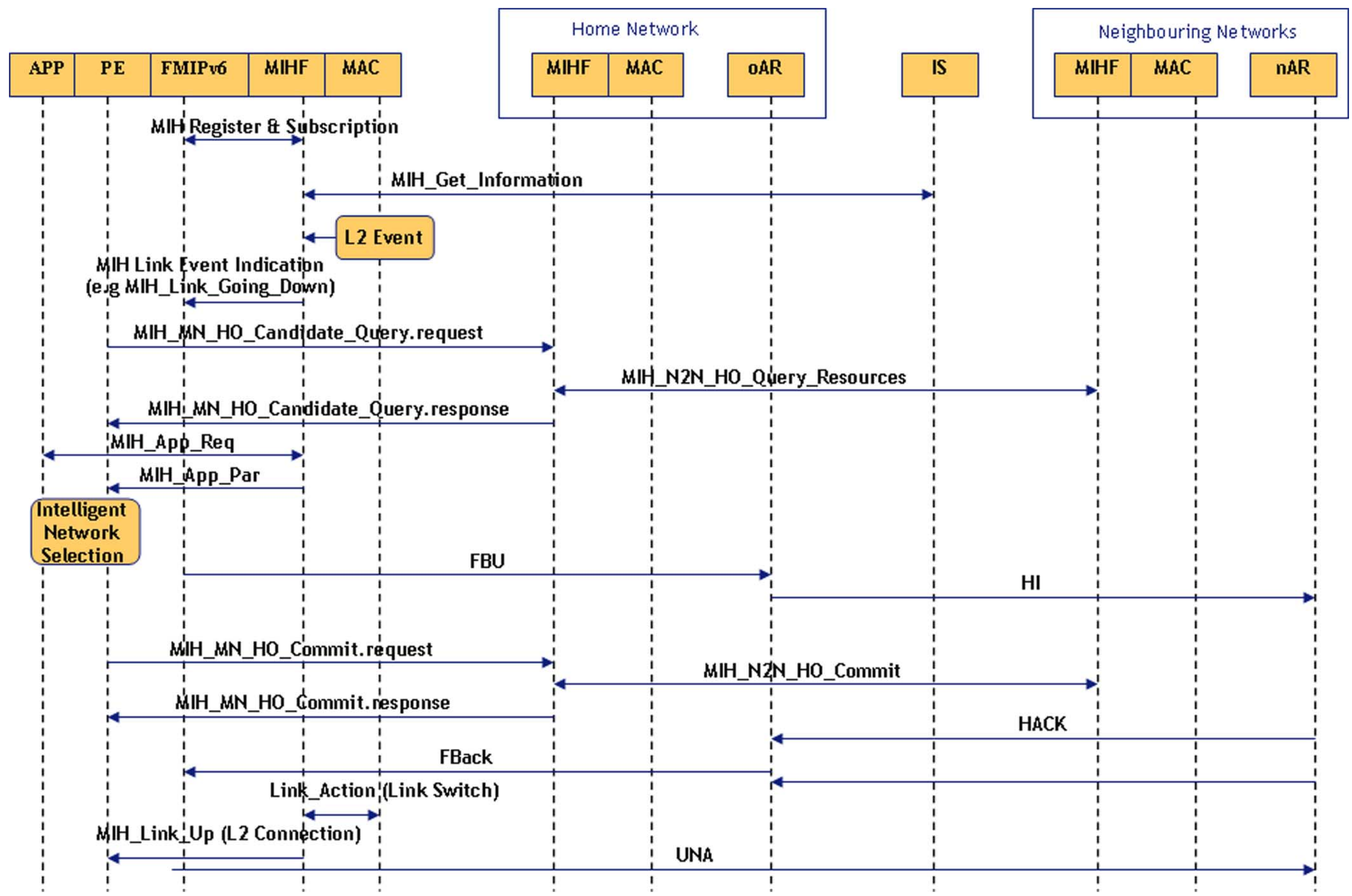

Fig. 4. Message flow in the IEEE-802.21-assisted FMIPv6 handover operations (predictive mode).

transfer delay, packet loss rate, SNR, etc.) have to be obtained based on direct interaction with the access networks, and the MIIS may not to be able to help much in this regard. Such dynamic QoS link parameters will have to be delivered to the MN through the MICS. For this purpose, we extend the service primitive "MIH_MN_HO_Candidate_Query" defined in [8] to include the list of resources shown in Table I as the "Query Resource List."

The MIH_MN_HO_Candidate_Query service primitive works in a request/reply fashion and is carried as payloads of an MIH message as service-specific TLVs [8].

Upon choosing a PoA from the HNI container/report in the NNR solely on the grounds of the static L2 and L3 information (e.g., MAC address, channel range, and subnet prefix), the PE in the MN will use the extended "MIH_MN_HO_Candidate_Query" service primitive via the MIHF to send a request to the serving PoA.

The Serving PoA will use the MIH_N2N_HO_Query_Resources to prepare and query the available resources in the candidate networks.

After receiving the MIH_MN_HO_Candidate_response, the PE receives the QoS requirements of the applications. Using the newly defined MICS service primitive "MIH_App_Req," the QoS requirement parameters are delivered from the application layer to the MIH Layer. The newly defined MIES service primitive "MIH_App_Parameter" is triggered to deliver

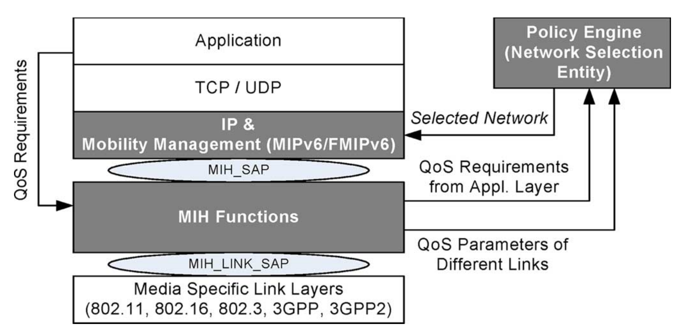

Fig. 5. Cross-layer mechanism for intelligent handover decision making (MN side).

the application QoS parameter requirements to the PE. Fig. 4 illustrates how MIH service primitives help the PE in the MN/MR acquire the dynamic QoS parameters of neighbor networks.

The PE takes the application QoS parameter requirements and compares them with the dynamic QoS parameter from the lower layers of the candidate access networks. The "best" PoA to which to attach can be selected according to the rules or policies input by the users. Details of such policies are out of the scope of this paper. Note that sophisticated and complicated algorithms can be implemented in the PE to make an intelligent decision. The overall cross-layer mechanism is depicted in Fig. 5.

G. Handover Operations—Switching Link

After selecting an appropriate radio access network, the MME in the MN/MR utilizes MIHF MICS and generates a link switch command using "MIH_MN_HO_Commit" and MIH_N2N_HO_Commit primitives, as described in [8]. The parameters are shown in Table I. Prior to sending the "MIH_MN_HO_Commit" command, the MN uses the L3 information, i.e., the PoA subnet prefix, to form an NCoA and sends an FBU to its default AR (oAR). There is no longer any need to send the RtSolPr/PrRtAdv messages for router discovery as the candidate AR information (i.e., "Subnet Prefix" IE) is already in the NNR cache. The CoA address configuration procedure that is related to the candidate AR discovery or RtSolPr/PrRtAdv messages is eliminated. During the anticipation phase, only the FBU message will be sent to the oAR. As opposed to the original FMIPv6 operation, in our proposed mechanism, only a single signaling overhead will be incurred during the anticipation phase. The probability of a predictive mode of operation in FMIP6 will be increased, and the L3 handover latency in FMIPv6 will be optimized. After receiving the FBack message on the oAR's link and the necessary L2 authentication and association procedure, an MIH_Link_Up event notification will be sent to inform the FMIP6 that the L2 connection with the target PoA is established. After the "MIH_Link_Up" notification, the Unsolicited Neighbor Advertisement message is immediately sent, and the traffic starts to flow from the new link. Fig. 5 shows the procedure of the cross-layer mechanism in selecting the optimal network with the assistance of the newly defined MIH services.

V. Handover Performance Evaluation

As explained in Section I, FMIPv6 can improve the handover performance of MIPv6 as well as NEMO. Our proposed 802.21-assisted FMIPv6 mechanism should also be applicable to optimize NEMO handover procedures. In this section, we analyze the handover delay of the original NEMO, the original FMIPv6, and the 802.21-assisted FMIPv6. The overall handover latency (both L2 and L3), i.e., the time interval between the moment the MN/MR loses connectivity with its current PoA until the moment it receives the first IP packets in the new subnet, is analyzed. For this reason, we include both the L2 and L3 handover.

A. Handover Latency in NEMO

The handover procedure for both FMIPv6 and NEMO can be expressed by

$$d_t = D_{\mathrm{L2}} + D_{\mathrm{L3}} \tag{1}$$

where d_t is the overall handover latency time, including both L2 and L3 latencies. Here, D_{L3} is the time period when MN/MR is unable to send or receive any IP packets due to handover action. D_{L2} is the time period the MN/MR loses connectivity with its current air link (i.e., PoA) until the time it connects to a new PoA. The overall handover procedure in both NEMO and FMIPv6 is started when the L2 handover is initiated.

The L2 handover latency in the IEEE 802.11 wireless local area network (WLAN), for example, could take place in two distinct phases, i.e., the *discovery* phase and the *reauthentication* phase. During the "discovery" phase, when the MN detects that the signal strength from the current AP is degraded to an unacceptable level, the MR/MN will start to scan available neighboring APs and generate a list of the APs prioritized by the corresponding signal strength. The "reauthentication" phase involves exchanging authentication and association messages between the MN and the AP. More details of the L2 handover in IEEE 802.11 can be found in [26]. The 802.11 L2 handover delay can be expressed as

$$D_{\mathrm{L2}} = D_{\mathrm{Discovery}} + D_{\mathrm{Reauthentication}}. \tag{2}$$

For an MR in NEMO, its first step in the L3 handover is to perform movement detection, during which, the MR sends Router Solicitation (RS) to nAR. Upon reception of the RS, the nAR sends a Router Advertisement (RA) to the MN. After receiving the RA, the MN will know that it has moved. The delays caused by movement detection can be expressed as

$$D_{\mathrm{MV}} = D_{\mathrm{RD}} + D_{\mathrm{CoA}} + D_{\mathrm{DAD}} \tag{3}$$

where

$$D_{\mathrm{RD}} = D_{\mathrm{RS}} + D_{\mathrm{RA}}. \tag{4}$$

Here, D_{MV} is the time required for a MR to detect its movement and to form NCoA. D_{RD} is the router discovery time and includes the delays caused by sending RS (i.e., D_{RS}) and RA (i.e., D_{RA}). It also includes the time the MN takes to form NCoA (i.e., D_{CoA}) and to perform Duplicate Address Detection (DAD), i.e., D_{DAD}.

After movement detection, the MR must send BU to inform the HA and the CN of its new location, i.e., NCoA. The total handover latency can be expressed as the sum of L2 and L3 handover latency as

$$\begin{aligned} d_t &= D_{\text{HO-NEMO}} \\ &= D_{\mathrm{L2}} + D_{\mathrm{RD}} + D_{\mathrm{CoA}} + D_{\mathrm{DAD}} + D_{\text{BU(MN-HA)}}. \end{aligned} \tag{5}$$

B. FMIPv6 Handover Latency in FMIPv6

The handover latency in FMIPv6 also comprised the L2 and L3 parts. However, the delays associated with movement detection, NCoA configuration, and DAD are eliminated in FMIPv6. The FMIPv6 has the HI time to perform the CoA configuration prior to the L2 handover. After the L2 handover, the MN sends a Fast Neighbor Advertisement (FNA) message to nAR to inform its presence and then perform the BU operations, i.e.,

$$D_{\text{HO-FMIPv6}} = D_{\mathrm{L2}} + D_{\text{MN-nAR}}. \tag{6}$$

In (6), $D_{\text{MN-nAR}}$ is the delay to send the FNA message from the MN to the nAR. In the reactive mode, this will take a single round trip time since the MN will have to wait for the FNA acknowledgement message after sending the FNA. The HI/anticipation time is equal to the time required to send

TABLE V
COMPARISON OF HANDOVER LATENCIES OF NEMO, FMIPv6, AND THE 802.21-ASSISTED FMIPv6

Handover Mechanism	*Handover Latency*	*Handover Initiation Time*
NEMO	$D_{Discovery} + D_{Re\text{-}authentication} + D_{RD} + D_{CoA} + D_{DAD} + D_{BU}$	
FMIPv6 (Predictive)	$D_{Discovery} + D_{Re\text{-}authentication} + D_{MN\text{-}nAR}$	$D_{PrRD} + D_{FMIPv6}$
FMIPv6 (Reactive)	$D_{Discovery} + D_{Re\text{-}authentication} + 2D_{MN\text{-}nAR}$	$D_{PrRD} + D_{FMIPv6}$
802.21 assisted FMIPv6	$D_{Re\text{-}authentication} + D_{MN\text{-}nAR}$	D_{FMIPv6}

the RtSolPr and PrRtAdv and FBU and FBack messages. Note that it is not necessary to include FBack in the HI time as it is not required to be received on the current link. However, for operations in the predictive mode, it is mandatory for the FBack message to be received while being connected to the oAR's link. The HI time is given below in the following equation:

$$T_{\mathrm{HI}} = D_{\mathrm{PrRD}} + D_{\mathrm{FMIPv6}} = D_{\mathrm{RtSolPr}} + D_{\mathrm{PrRtAdv}} + D_{\mathrm{FBU}} + D_{\mathrm{FBack}}. \quad (7)$$

Here, D_{PrRD} is the time to send the RtSolPr and PrRtAdv messages. D_{FMIPv6} is the time it takes to send the FBU and to receive the FBack message.

C. Handover Latency of the 802.21-Assisted FMIPv6

In our proposed mechanism, the L2 handover latency is significantly reduced by removing the radio access network discovery delay (i.e., scanning time). The HI/anticipation time is reduced by removing the RtSolPr and PrRtAdv delay from D_{PrRD}, i.e.,

$$T_{\mathrm{HI}} = D_{\mathrm{FBU}} + D_{\mathrm{FBack}} = D_{\mathrm{FMIPv6}}. \quad (8)$$

The "discovery" phase will be eliminated from the L2 handover time in the proposed mechanism. Therefore, the overall handover delay is

$$D_{\mathrm{HO\text{-}FMIPv6}} = D_{\mathrm{Reauthentication}} + D_{\mathrm{MN\text{-}nAR}}. \quad (9)$$

Table V shows the comparison of the handover latencies of the original NEMO, FMIPv6, and 802.21-assisted FMIPv6.

D. Simulation Results

To evaluate our proposed mechanism, we simulate a network scenario in an area of 2000 m × 2000 m, where one WiMAX (IEEE 802.16) cell and one IEEE 802.11b WLAN Basic Service Set (BSS) are located. The WiMAX cell has a radius of 1000 m, while the coverage area of the WLAN has a radius of 50 m. The WLAN BSS is inside the WiMAX cell. We assume that they are managed by one mobility service provider. The WiMAX network is the home domain where the HA is located. Each domain has one PoA that is connected to the core network through 100-Mb/s connection. A correspondent node (CN) is connected to the core network through the 100-Mb/s Ethernet. A WiMAX/WLAN dual-mode MN/MR is communicating with a CN while it is moving in the above area at a random speed between 5 and 25 m/s. Each time it enters and leaves the WLAN area, handover procedures will be initiated.

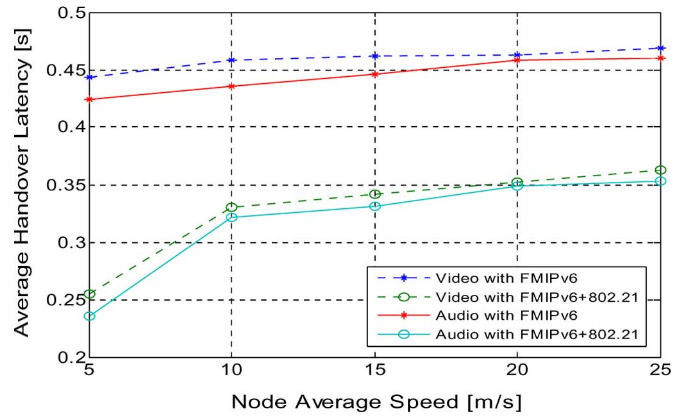

Fig. 6. Average handover latency versus node average speed.

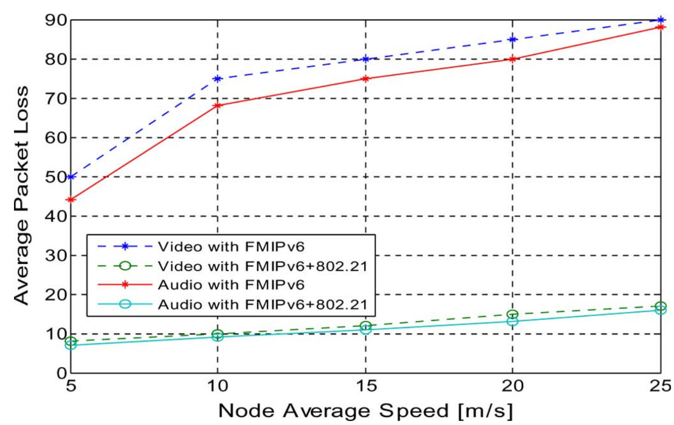

Fig. 7. Average packet loss versus node average speed.

Based on the FMIPv6 package we developed and the 802.21 and 802.16 NS2 extension developed by the National Institute of Standards and Technology [25], we carry out the simulations in NS2. We focus on evaluating the handover performance in terms of handover latency, packet loss, and handover signaling.

Two types of traffic flows are transmitted between the MN and the CN. One is a video stream with a packet size of 4960 B and a packet rate of 100 packets/s. Another is an audio flow with a packet size of 320 B and a packet rate of 200 packets/s. The simulation time is set up as 200 s. For each mean speed, we take the average of the results of ten simulations.

From the simulation results presented in Figs. 6–8, we can obviously see that the handover process of FMIPv6 can be significantly improved by using the IEEE 802.21 MIH services. Unsurprisingly, the handover latency increases in both the original FMIPv6 and the 802.21-assisted FMIPv6 as the moving speed of the MN/MR increases (Fig. 6). This may be due to the signaling packet loss over the deteriorated physical link or the

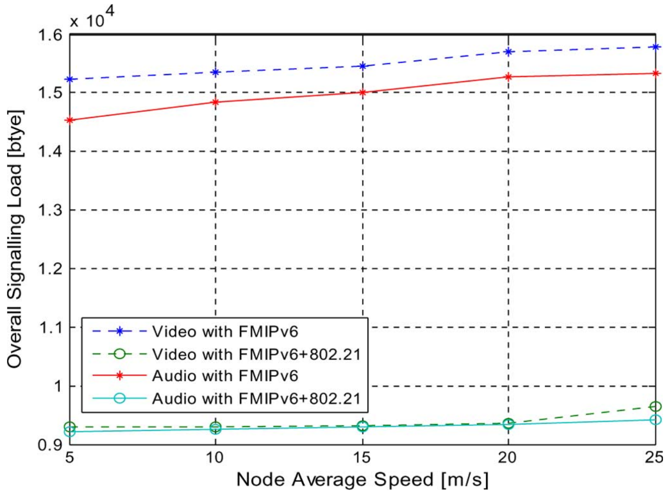

Fig. 8. Overall signaling loads versus node average speed.

fact that MN/MR might not have sufficient time to complete all FMIPv6 signaling at the oAR's link. The 802.21-assisted FMIPv6 can reduce almost half of the handover latency of the original FMIPv6.

Fig. 7 shows that the 802.21-assisted FMIPv6 loses fewer packets than the FMIPv6 does when the speed increases. When MN/MR moves at high speed, the FMIPv6 handover process might not be completed at the oAR's link; hence, the packets received by the oAR would be dropped. The overall signaling overhead here is the average signaling overhead (in bits) at the network and above layers during each handover interval. Fig. 8 shows that the 802.21-assisted FMIPv6 has about 50% less signaling overhead than the original FMIPv6 does. This is aligned with our analysis on the proposed mechanism given in the previous sections.

VI. Conclusion

In this paper, we have proposed a mechanism that optimizes the FMIPv6 handover procedure with the assistance of IEEE 802.21 MIH services for vehicular networking. To do so, we have exploited the MIH services. Most notably, we utilize the 802.21 MIIS and include the L3 information of neighboring access networks in the MIIS service. We define a new Information Report, i.e., the "HNI container/report," to contain the L2 and L3 information of neighboring access networks, which can help the FMIPv6 protocol to tackle issues such as radio access discovery and candidate AR discovery. Moreover, we propose to store the contents of the HNI container/report in the NNR cache, which can be maintained in the volatile memory of the MN. This eliminates the need for sending RtSolPr/PrRtAdv messages that in turn reduce signaling overheads and the long anticipation time imposed by FMIPv6. Therefore, we show through analytical and simulation results that when our proposed mechanism is applied to FMIPv6, it increases the probability predictive mode of operation and reduces the overall (both L2 and L3) handover latency. The proposed mechanism outperforms the original FMIPv6 protocol and NEMO Basic Support.

Moreover, the handover decision is made by a PE where a cross-layer mechanism is adopted. New MIH service primitives are defined to support the intelligent handover decision making. The cross-layer mechanism takes into account QoS parameter requirements from the applications and compares it with the dynamic parameters of the available access networks. The parameters are then matched with predefined policies to optimize the handover decision.

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