Optimized FMIPv6 using IEEE 802.21 MIH Services in Vehicular Networks

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

***Abstract*— In this paper, we optimize the handover procedure in Fast Handover for Mobile IPv6 (FMIPv6) protocol by using IEEE 802.21 Media Independent Handover (MIH) services. FMIPv6 is used to enhance the performance of handovers in Mobile IPv6 (MIPv6) and its basic extension for Network Mobility (NEMO), 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 the FMIPv6 operation. Furthermore, we propose a cross-layer mechanism for making intelligent handover decisions in FMIPv6. Lower layer information of the available links obtained by MIH services as well as the higher layer information such as quality of service parameter requirements of the applications are used by a Policy Engine (PE) 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*— IEEE802.21, FMIPv6, NEMO, Cross-layer design, Mobility Management**

Manuscript received Feb 15, 2007. This work was supported in part by the EU FP6 ENABLE – *Enable efficient and operational mobility in large scale heterogeneous IPv6 networks* (IST No. 027002). Q. B. Mussabbir, W. Yao and Z. Niu are with the Research Center for Networks and Multimedia Communications, School of Engineering and Design, Brunel University, Uxbridge, London, UB8 3PH UK (Tel: +44-1895-266746; fax: +44-1895-258728;e-mail:qazi.mussabbir@brunel.ac.uk; wenbing.yao@brunel.ac.uk; zeyun.niu@brunel.ac.uk). X. Fu is with the Institute for Informatics, University of Goettingen, Germany (Tel: +49-551-3914411, email: fu@cs.uni-goettingen.de)

I. INTRODUCTION

The provisioning of seamless mobility to vehicles across heterogeneous access networks is essential for the next generation's vehicular communication networks. Luckily, a variety of access network technologies (e.g. 802.11a/b/g WiFi, 802.11p WAVE, 802.16 WiMAX, GPRS and UMTS 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 Wireless Access in Vehicular Environments (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.

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

The NEMO Basic Support [5], as an extension to the Mobile IPv6 protocol, is concerned with the mobility of an entire network which dynamically changes its Point-of-Attachment (PoA) (i.e. Access Points, Base Stations) and thus its reachability in the Internet. Its main objective is to maintain session continuity between the Mobile Network Nodes (MNNs) and Corresponding Nodes (CNs) while the Mobile Router (MR) changes its PoA. The MNNs behind the MR are IPv6 nodes and do not need to register or bind their home addresses with the Home Agent (HA) individually. The MR, acting as a Gateway between the inter-vehicle network and the 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.

CALM (Continuous Air interface for Long and Medium range) is a family of umbrella protocols being developed in ISO/TC204/WG16 ("Wide Area ITS Communications") in order "*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 network mobility in vehicular communications.

Handover performance plays a crucial role in the Quality of Service (QoS) provisioning of real-time services in heterogeneous networks. The period during which the MN/MR looses connectivity with its current link till the time it receives the first IP packet after connecting to the new link is known as the handover latency. The overall handover delay in NEMO and MIPv6 consists of Layer 2 (L2) and Layer 3 (L3) handover latency. The L2 handover latency is the period when the MN/MR is disconnected from the air-link of the current Access Router (AR) till the time it successfully access the air-link of the new AR. The L3 handover latency comprises the latencies incurred due to the processes of IP layer movement detection, network re-authentication, Care-of-Address (CoA) configuration and BU. Such latencies would be unacceptable for the time/delay stringent real-time applications like Voice over IP (VoIP), streaming multimedia or video conferencing which have very high quality of service (QoS) requirements (e.g. high throughput, low delay, etc). With the help of L2 triggers, the Fast Handover for Mobile IPv6 (FMIPv6) protocol [7] developed within the IETF MIPSHOP (Mobility for IP: Performance, Signalling and Handoff Optimization) WG can help to reduce such handover delays in MIPv6.

FMIPv6 reduces the handover delay by exploiting various L2 triggers to prepare a New CoA (NCoA) at the new AR (nAR) in advance 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 tunnelled to the MR's CoA; the MR here will be treated like a MN by FMIPv6 for redirection of traffic between oAR and nAR using the binding of the Previous CoA (PCoA) and NCoA maintained at the oAR. The overall handover process (i.e. handover message signalling) would be identical to procedure described in the original FMIPv6 RFC [7] with minor extensions. We will discuss the details about the extensions later in Section III-B.

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:

- The additional anticipation time imposed by FMIPv6 causes the handover to start earlier than planned, hence reducing the certainty about the MN's movement.
- Also, due to sudden degradation of the wireless link during the handover initiation phase, the MN may lose connectivity with the oAR. In this case, if the anticipation time is long, then there might not be sufficient time for the MN to configure its NCoA while being attached to the oAR's link. This will result in a long handover latency.

The IEEE802.21, namely the Media Independent Handover (MIH) Standard WG [8] officially formed in 2004, is developing a standardized specification to enable optimized handover and interoperability between heterogeneous networks including both 802 and non-802 (i.e. cellular) networks. Considering the overlap of work in IEEE802.21 and CALM in the handover area, a liaison between these two is being discussed. The IETF MIPSHOP WG has liaised with IEEE802.21 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 IEEE802.21 Media Independent Handover (MIH) services. With the aid of the lower three layers' information of the MN and the neighboring access networks, we tackle the radio access discovery and candidate AR discovery issues of FMIPv6. We design 'Information Element Conatainer' to store static and dynamic L2 and L3 information of neighboring access networks, and propose to use a special cache maintained by the MN 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. Lower layer information of the available links obtained by MIH services as well as the higher layer information such as Quality of Service (QoS) parameter requirements of the applications are used by a Policy Engine (PE) to make intelligent handover decision. 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 the paper is organized as follows. Section II introduces the related works, where the issues of FMIPv6 in vehicular environments, IEEE802.21 MIH Function and its related services will be introduced. Section III provides an overview of the proposed mechanism and the extension of FMIPv6 for NEMO. Section VI introduces the detailed handover procedure in the proposed mechanism. Mathematical and numerical evaluations of the handover performance of the proposed mechanism are given in Section V, and Section VI concludes the paper and discuss the future work.

II. RELATED WORKS

A. FMIPv6 : Overview and Problem Statement

FMIPv6 is designed to address issues related to IP layer movement detection, CoA configuration and BU in MIPv6. It exploits various L2 triggers to prepare a NCoA at the nAR in advance while being connected to oAR's link. Upon receiving a L2 trigger, FMIPv6 starts to 'anticipate' or prepare for the forthcoming handover before-hand. It assumes that the oAR is configured with a table containing the MAC addresses of its own and the neighbouring Point-Of-Attachments (PoA) and the corresponding subnet prefixes of the neighbouring ARs. During the anticipation phase, the oAR assists in the NCoA formation by resolving subnet prefixes based on the table and the L2 identifier reported by the MN. There are three FMIPv6 signaling messages involved in the anticipation phase: *Router Solicitation for Proxy Advertisement* (RtSolPr), *Proxy Router Advertisement* (PrRtAdv) and *Fast Binding Update* (FBU). These messages are used for aiding IP movement detection and NCoA configuration. Through the RtsolPr and PrRtAdv messages, the MN formulates the NCoA when it is still present on oAR's link. Hence the latency due to new prefix discovery suffered by FMIPv6 is eliminated. The MN could immediately use the prospective address after attaching to the nAR's link when the MN has received a *Fast Binding Acknowledgement* (FBack) message prior to it's mobility to the new link (i.e. Predictive Mode of operation). This reduces long binding update latency suffered by FMIPv6. In the event, the MN moves upon receiving the FBack, and the NCoA would be usable only after it sends the *Unsolicated Neighbour Advertisement* (UNA) message and the FBU to the oAR from the nAR's link (i.e. Reactive Mode). In any case, the oAR stars tunnelling packets arriving for PCoA to NCoA. Such a tunnel is established by the *Handover Initiate* (HI) and *Handover Acknowledgement* (HAck) messages. Apart from that these message could also be used for the ARs to transfer resident contexts, such as access control, QoS, header compressions etc.

When using the FMIPv6 based mobility management, there are still rooms for improvement in reducing the handover latency and handover packet loss:

- **Neighbouring access network discovery**: The FMIPv6 doesn't address any radio access network discovery mechanism. Discovering the available PoAs by actively searching/scanning all the channels provided by the neighbouring networks takes a considerable amount of time, which has a significant contribution to the overall handover latency. For example, in 802.11b, the L2 scan time takes about 400ms to 800ms [18].
- **Information exchange with neighbouring ARs**: The method by which neighbouring ARs exchange the information that enables the construction of PrRtAdv messages is not specified in the original FMIPv6. The IETF SEAMOBY WG produced the Candidate Access Router Discovery (CARD) protocol [19] to address this issue. The CARD protocol allows MNs to dynamically construct and populate their own CAR (Candidate Access Router) tables, which contain the mapping between the L2 PoA ID and corresponding IP addresses of the Candidate ARs. However, the use of CARD protocol so far is very limited for the reason that it will need additional support and upgrade to routers. Also, CARD enables a MN to gather attributes associated with target subnets so that a suitable AR could be selected for handover. But it does not provide the MN with appropriate L2 information in order to tackle the issue of radio access discovery that FMIPv6 faces. In [23], a mechanism to build (AP-ID, AR-Info) between ARs in hierarchical structure is described. However such mechanism is still very pre-mature and would require the ARs to be upgraded.
- **The Cost of Anticipation**: In FMIPv6, the L2 handover is triggered by degrading link conditions. There is no guarantee that the MN will 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 oAR, then the MN is forced to operate in the reactive mode and the handover latency will increase consequently.
- **The Ping Pong Movement**: Time taken by the signalling exchange of the three FMIPv6 anticipation messages (RtSolPr, PrRtAdv and FBU) is long enough to increase the uncertainty of a MN's movements. For example, the handover may take place earlier than originally anticipated by the link layer. The border between overlapping cells may change dynamically due to the objects (e.g. buildings, trees etc) blocking the signals between the APs and MN. Due to the intrinsic dynamic nature of wireless channels, the MN may not move to the originally anticipated PoA. It may not move after all, or it may move somewhere else. That is to say that the MN would *ping-pong* between cells. Hence premature forwarding of data by the oAR (upon

reception of an FBU) could be harmful because the MN may not move to the anticipated PoA. As a result there will be packet losses and long handover latencies.

B.IEEE 802.21 Media Independent Handover Function

The scope of the IEEE802.21 MIH standard is to develop a standard that would provide 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 IEEE802.21 family. In the mobility management protocol stack of both the MN and network element the Media Independent Handover Function (MIHF) is logically defined as a shim layer between the L2 data link layer and L3 network layer [8]. The upper layers are provided services by the MIH function 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 SAPs (i.e. Link_SAP).

MIHF defines three main services that facilitate handovers between heterogeneous networks: MIH Event Services (MIES), MIH Command Services (MICS) and MIH Information Services (MIIS). Figure 1 shows the MIH Framework. Detailed discussions of each of the services are given below.

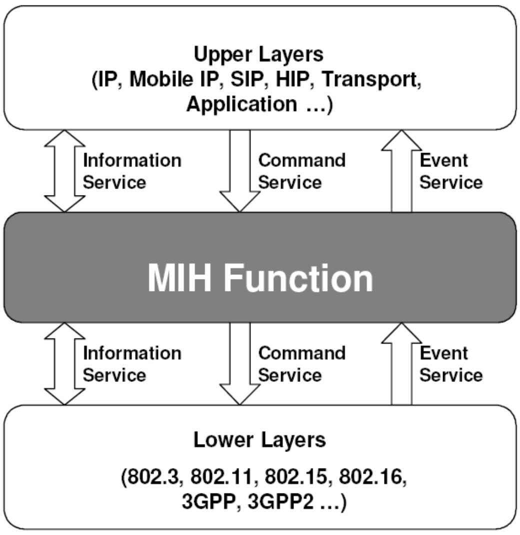


Figure 1: Media Independent Handover Framework [8]

- ***Media Independent Event Service (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 report 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 protocol can use some these events as handover trigger, for example, Link Down or Link Going Down. 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 to make handover decision, i.e. to decide which network and PoA within several available networks and PoAs the MN should switch to, and when the MN should make the handover.

- ***Media Independent Command Service (MICS)*** uses the MIHF primitives to send commands from higher layers (e.g. Policy Engines, Mobility protocols) to lower layers. The MICS commands are utilized to determine the status of the connected links and also 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 happen, and to give the command to the link layer to switch from one network interface to another. It also allows the mobility management protocol to enquire the link layer’s status before the handover decision making.
- ***Media Independent Information Service (MIIS)*** provides a framework and mechanism for an MIHF entity to discover available neighbouring network information within a geographical area to facilitate the handover process. The primary idea is that, in order 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 XML (Extensible Markup Language), ASN.1 (Abstract Syntax Notation One), TLV (Type Length Value), and this information can be obtained through a certain query/response mechanism. Both static and dynamic information is provided by the MIIS. Examples of static information include the names of service providers, MAC addresses, channel information of the MN’s current network neighbourhood. 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, a MN gets the heterogeneous neighbourhood information by requesting Information Elements (IEs) from the IS. It also allows the neighbourhood information to be delivered to the MN by using pre-defined Information Reports IE

Containers to effectively represent the heterogeneous neighbourhood information in TLV format. In IEEE 802.21 draft, the defined IEs provide mostly static L2 information.

The MIIS empowers 802.21 to be a truly media independent mechanism, since the MNs or PoAs, i.e. the handover decision maker, will be able to discover information about their nearby networks to make intelligent handover decision no matter what access technology these networks use. For example, with the help of MIIS, a duo mode WiMAX/WLAN MN will be able to find out the nearby WLAN hotspots while it is still in the WiMAX coverage area and decide whether it wants to switch to a particular WLAN hotspot based on the QoS requirements of the applications currently running on the MN and the status of the WLAN hotspots, e.g. whether this hotspot is already very busy, etc.

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 UDP-based mechanism for the transport of MIH services between network nodes is defined.

The network requirement of IPv6 based vehicular communication systems are investigated in [13]. The use of IEEE802.21 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, handover issues in vehicular environments are not addressed in [17] and [18].

Type = TYPE_TLV_REPORT_TEMPLATE	Length =Variable
Type_IE_Container_HNI Report	

Figure 2. HNI request

Type =TYPE_IE_HNI_REPORT	Value
HNI Container # 1	
PoA MAC Address IE	
PoA Channel Range IE	
PoA MAC Type IE	
PoA PHY Type IE	
PoA Subnet Prefix IE	
Network Type IE	
Roaming Partners IE	
Costs IE	
Network Security IE	
HNI Container # 2	
....	

Figure 3. HNI Response

III. IMPROVING FMIPV6 WITH IEEE 802.21 MIH SERVICES IN VEHICULAR ENVIRONMENTS

A. An Architectural Overview

In general, handover involves co-operative use of both the network infrastructure and MN in order to meet the satisfaction levels of network operators and end-users. As it is illustrated in our architectural model in Figure 4, the MIHF instances on different network entities communicate with each other for various purposes. The different network entities along with their functional components are defined below:-

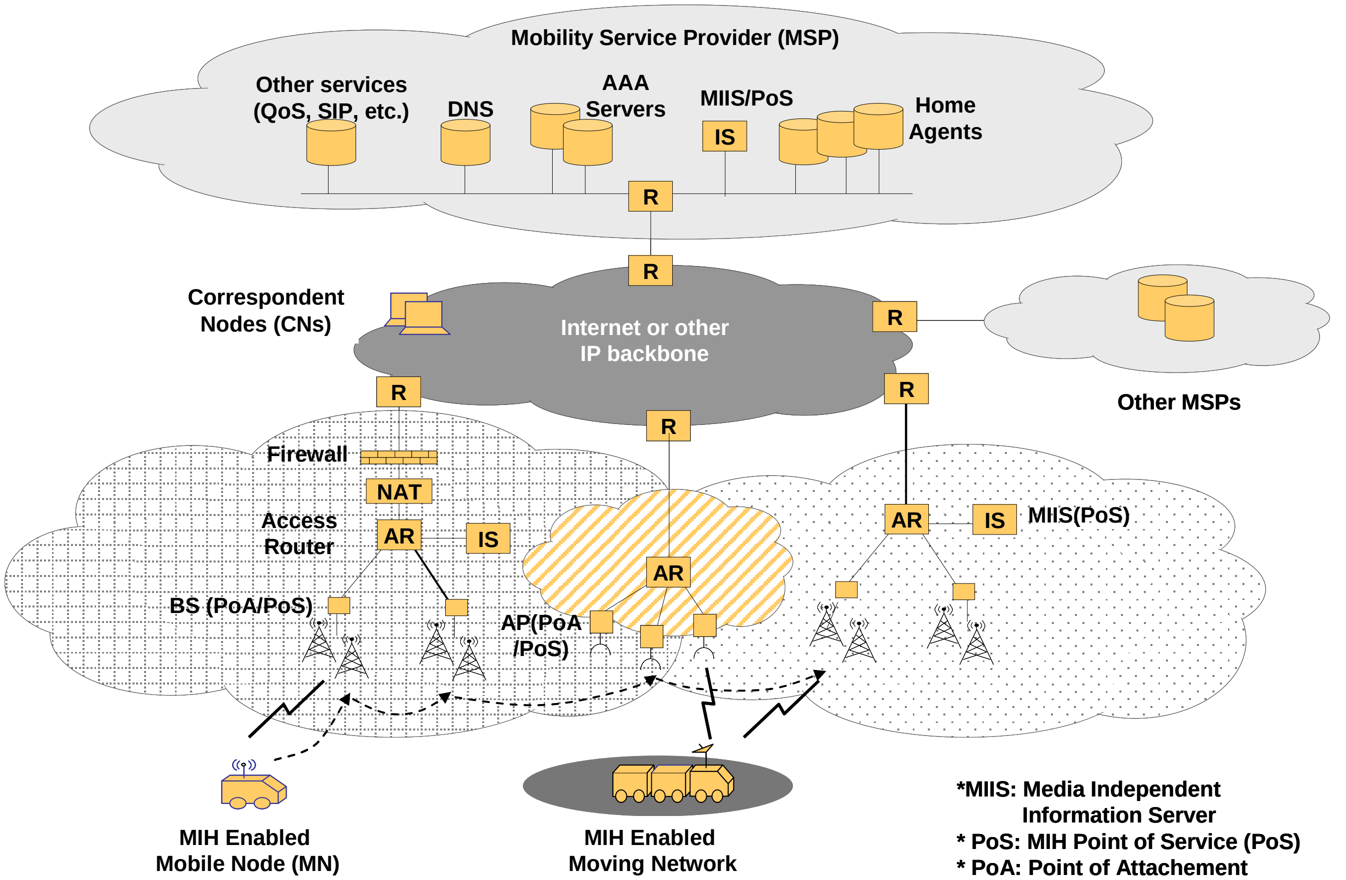


Figure 4: An Overview of the Considered Network Architecture

- ***The MN:*** An MIH capable multi-modal device with a protocol stack described in [8].
- ***Serving PoA/PoS:*** The current serving PoA (i.e. AP or BS) which is also a MIH PoS. The MIH PoS is a network side MIHF instance that is capable of directly exchanging MIH messages with an MIH-enabled MN.
- ***Candidate PoA/PoS:*** A candidate PoA (i.e. AP or BS) is a PoA that the MN is aware of but not currently attached to. Once the handover occurs, it may become the target PoA. Similar as the current serving PoA, the candidate PoA is also a MIH PoS.
- ***Information Server:*** The IS server serves as a MIH PoS which could be located in access network or core network. The IS could be thought of as data reservoir for storing and managing the neighbouring network knowledge. It can be used to provide essential network related information, e.g. list of network providers, PoA MAC address, channel information, higher layer services etc, which may allow for optimized network selection.
- ***ARs:*** The ARs (oAR and nAR) are MIHF enabled and is assumed to have all protocol of a normal IP router.

B. Extending FMIPv6 to support Network Mobility Solution - NEMO

As mentioned above in Section 1, FMIPv6 could be used to support network mobility, but needs minor extensions. The necessary extensions will include extending the FBU, HI, HAck and FBack messages specified in the NEMO Basic Support [5]:

- ***The FBU message -*** 1) 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 a MR of a mobile network. We set R to be 0 for a MN, and 1 for a MR. 2) A new Mobility Header Option will be needed for carrying Mobile Network Prefix (MNP). Upon receiving a FBU message, the oAR will first check the R flag. If R is 0, i.e. the FBU is sent from a MN, the FMIPv6 will operate as it is originally defined. If R is 1, the oAR will understand that, the FBU is send from a 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 mbile network) to the nAR during handovers. Note that, the MNP only need to be carried as a 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. For example, the oAR can maintain a route to the Mobile Network Prefix with the next hop set to the Mobile Router's PCoA. When the oAR tries to forward the packet to the next hop, it finds a binding cache entry for the PCoA which is the NCoA.
- ***The 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 a MR of a mobile network.
- ***The HI message -*** The MNPs can be transmitted between the oAR and nAR using the one of the "Options" fields of the HI message. Both the oAR and nAR could maintain a Prefix Table [5] for preventing the clash between a newly claimed MNP and a MNP that is being used. The mechanism for tackling duplicate MNPs is out scope of this paper.
- **The HAck message -** should contain new status results indicating the success or failure in accepting the MNPs maintained by the MR.

C. Introduction to the Proposed Mechanism

In this section, we propose to use IEEE802.21 MIH services to assist FMIPv6 to enhance the overall handover performance in vehicular environments by addressing the issues discussed in Section 2. The overview of the proposed mechanism is shown in Figure 5.

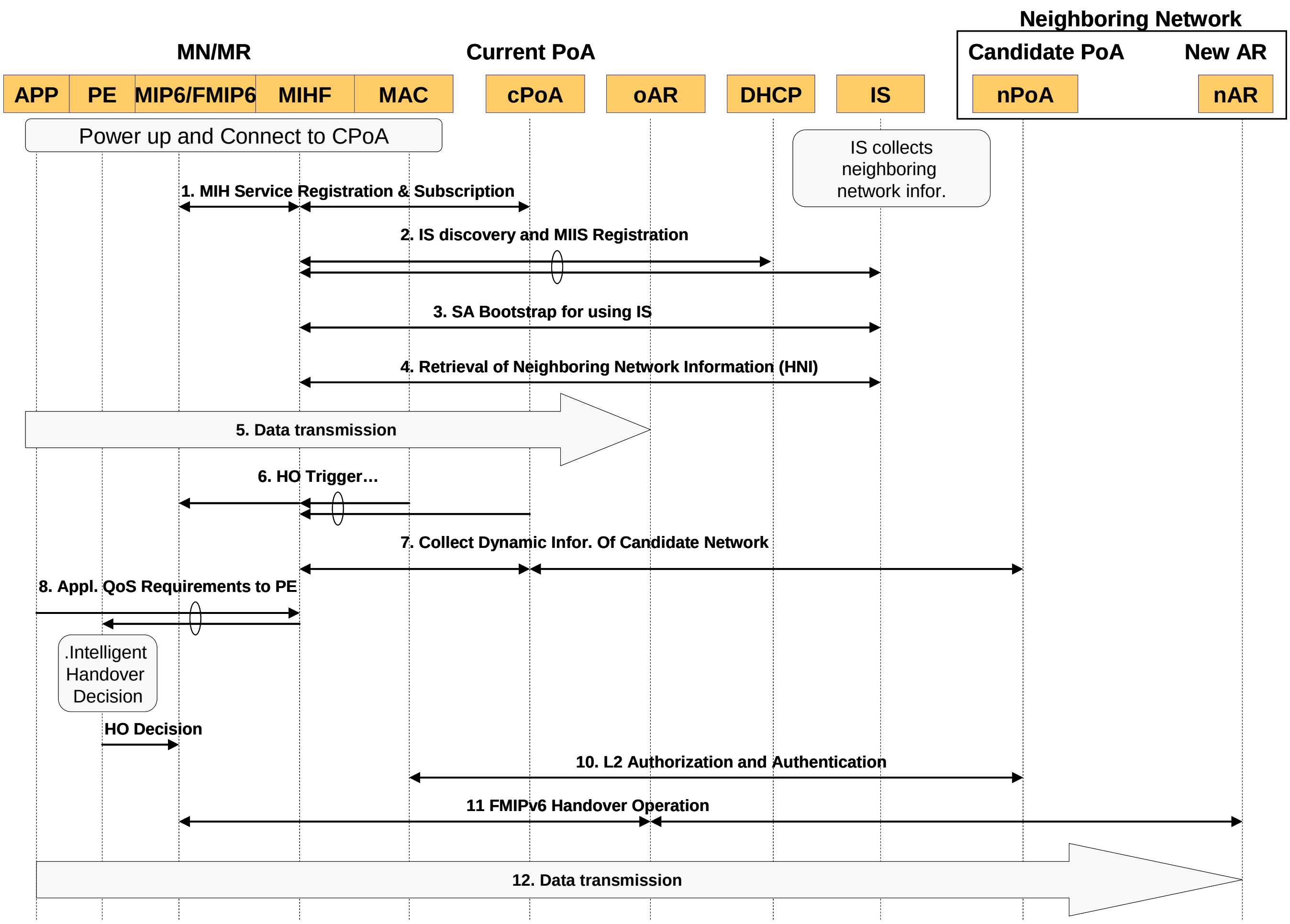


Figure 5 An Overview of the Proposed Mechanism

Our main contributions are:

1. We define a Heterogeneous Network Information (HNI) Container for facilitating in the store and retrieval of the L2 & L3 static information of neighbouring networks obtained through the IEEE 802.21 MIIS. A new IE known as 'Subnet Prefix' is defined to provide subnet prefixes of neighbouring ARs. Alongside with the L2 information, they form the proposed pre-defined Heterogeneous Network Information (HNI) container/report.

   The draft has defined a PoA container and an Access Network Container (ANE) [8], which include many IEs such as MAC address, channel range, Network Type, Cost, Roaming Agreements, Network Security. Instead of including all of IEs from these two containers, we select the ones which can further optimize our proposal and put them in a single IE container, which is our HNI container. Having a single predefined HNI contrainer 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 having the L2 link information from the MIIS. Furthermore, with the L3 information of corresponding PoAs, the MN will learn of 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 neighbouring information for maintaining the mapping table and thereby tackling the candidate AR discovery issue in FMIPv6.

2. In order to reduce the adverse impacts of the long anticipation time in FMIPv6, we propose to create a Neighbouring Network Report (NNR) Cache in the MN for storing and maintaining the HNI report. This would help to reduce the number of signalling messages during the anticipation phase and thereby reducing the overall anticipation time. The HNI report will be delivered to the MN through the 'MIH_Get_Information' request/reply service primitives. By reducing the anticipation time, the probability of operations in predictive mode is increased. Also the CoA configuration procedure time can be decreased 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 access networks (i.e. MIH PoS – Candidate PoAs). Dynamic neighbouring network information include 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 policy engine. A cross-layer mechanism is proposed for intelligent handover decision making by using the static and dynamic information of neighboring network, the local link condition and application QoS requirements.

D. The IEEE802.21 MIH Services to be used

The FMIPv6 can use the 802.21 MIES to get the L2 trigger and therefore quickly detect any L3 movement and perform handover initiation for NCoA configuration before a L2 handover. The upper layer, including the Mobility Management Entity (MME) that implements network selection and handover decision algorithms and utilizes mobility signalling protocols at the MN or network side, could use the MICS to control the behavior of the underlying link layer. In this section, we list the MIH service primitives that will be used in our proposed mechanism. Also we present the MIH service primitives that we defined for the handover decision making in Table 2.

We utilize a subset of existing IEEE802.21 MIH services to enhance the handover process in FMIPv6. Table 1 lists the chosen MIH services, their corresponding primitives and parameters.

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_Link_Switch	MICS	Handover Mode, Old 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 1: Existing MIH Services Used and Extended

Table 2 show the MIH service primitives we defined for obtaining application QoS requirements..

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 2: Newly defined MIH Service Primitives

E. The Structure of HNI Container/Report

The MIIS 'HNI' report will be delivered through a request/response type mechanism and will be represented in a standard format such as XML, ASN.1 or TLV. Figure 2 illustrates 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. Figure 3 shows the HNI response message in which our defined IE containing the L3 information is the 'PoA Subnet Prefix' IE.

The HNI container/report containing the IEs will be produced and stored in an IS. Amongst the MIH services, the MIIS is deployed over IP [10]. The IS could be an independent node in the network, or could be co-located in an AR [10]. Such a scenario is partly addressed by experimental information services in CARD and FMIPv6. However, this brings us back to the issue of upgrading the ARs to adapt MIIS capabilities which may only happen in the future. In particular, security association establishment in these environments is warranted [7] [19].

F. IS Deployment

In our proposed mechanism, the IS is deployed outside the MN's subnet. This has the advantage of not requiring explicit upgrade of the ARs and other related network elements. Also, in this way, the server can serve many access subnets simultaneously which can reduce administrative overheads. Various IS deployment scenarios is provided in [10]. Figure 1 shows a topological view of how the IS could be deployed. It will be seen that neighboring access networks are divided into domains. Each domain is served by an IS. Replicate servers could also be deployed to prevent single point of failure. A L2 or L3 based mechanism is required to identify or discover a valid IS. Such a mechanism will be discussed in details in the next section.

IV. Detailed Handover Procedure Of The Proposed 802.21 Assisted FMIPv6

In this section, we will describe the detailed procedure of the IEEE802.21 assisted FMIPv6 handover as we proposed in Section IV.

A. Events Subscription

At the very beginning, when a MN is switched on (refer to figure 8), the FMIPv6 protocol in the MN will register for Media Independent Event Service (MIES) notifications (i.e. L2 triggers) within its local stack. This will be done via MIH Event Subscription service primitives which work in a request/response mode [8]. The events services that will be registered by the FMIPv6 protocol are shown in Table 1.

B. IS Discovery and Usage

The system would need to provide discovery mechanisms, security association (SA) bootstrap, and transport of information services over IP. A valid information server will need to be identified or discovered through either layer 2 or layer 3 mechanisms. At the time of writing, DHCP (Dynamic Host Control Protocol) [22] was selected as a candidate solution for discovering the IS in IEEE802.21 MIIS specification [11]. Figure 6 shows the three phases related to our MIIS usage scenario: Discovery, SA bootstrap, request/response. The MIIS will be used by the MME, an upper layer entity which implements network selection and handover algorithms. The MME in our scenario initially uses DHCP [22] to acquire the location of IS; specifically, the IS server's IP address, the IS server's FDQN (Fully Qualified Domain Name) and URI (Uniform Resource Identifier).

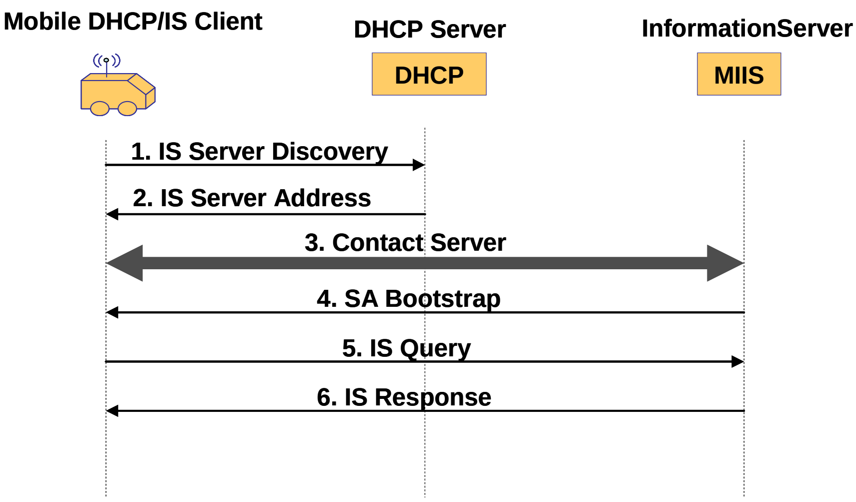


Figure 6: Information Server Discovery & Message Exchange

C. SA Bootstrap

Before the MME can exchange any messages with the IS server, a set of Security Associations (SA) have to be established. Authentication and encryption must be provided by each SA for keeping the mobile device anonymity so as to prevent eavesdroppers. The SA negotiation mechanism depends on the used transport layer and required security services [11]. For Instance, TLS (Transport Layer Security) will be advised for use if upper layer protocols use TCP, whilst ESP (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].

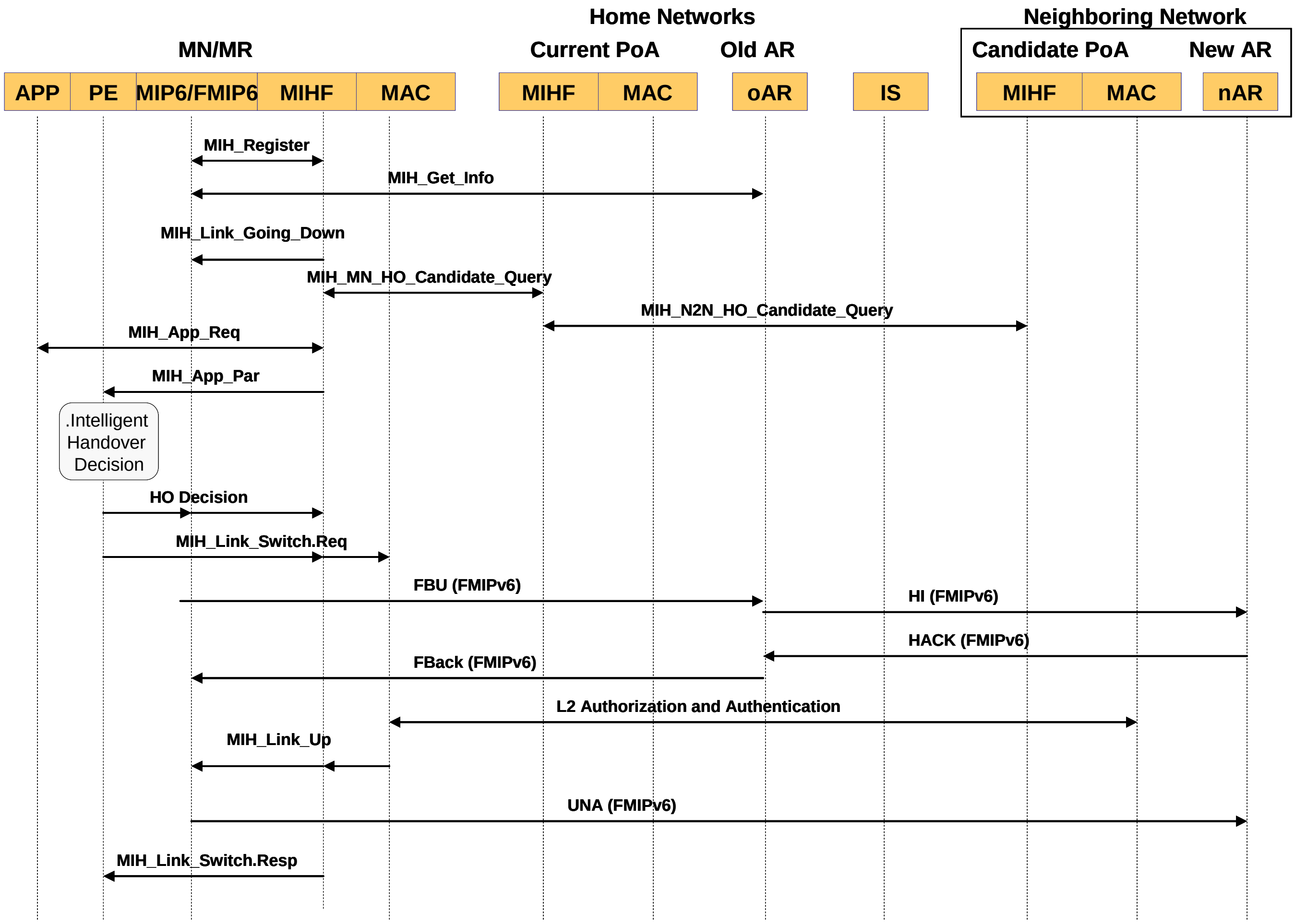


Figure 7. Message Flow in Handover Operations (Predictive Mode)

D. Retrieval of Neighbouring Network Information (HNI Container/Report) from the IS

After the IS discovery and SA association phase, MME uses the 'MIH_Get_Information' service primitive to retrieve the HNI Container/Report from the IS. The 'MIH_Get_Information' primitive works in a request/reply mode. The 'MIH_Get_Information' request primitive will contain the encoded HNI request in TLV format as shown in Figure 2. The MIHF in the IS will respond with a 'MIH_Get_Information' response primitive and encodes the HNI Response in TLV format as its parameter, as shown in Figure 3.

Upon receiving the response to the 'MIH_Get_Informantion' request, the MN will process the received HNI Container/Report and store its contents as a list in the 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 also check whether it is in the same or different IS domain. It must be noted here that the communications between the MN and the IS will be handled by the MIH protocol defined by the IEEE802.21 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. In our case, the MIH message will carry the 'MIH_Get_Information' request/response TLV as the payload. Further details on the MIH protocol message structure is provided in [8].

The MIH message in our proposal is carried over an IP based transport protocol. However such a transport protocol should be generic (i.e. not specific to any link type) in nature and considers both security and signaling requirements. Requirement for such MIH transport design and security requirements are discussed in [10].

E. Handover Operations

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

Upon receiving this event notification, the MN checks its NNR Cache and selects an appropriate PoA to handover to. Since the MN knows the radio link information (i.e. MAC address and channel range of PoAs, etc) of the candidate access network, the time to discover them is eliminated. In IEEE802.11 networks, for example, there will be no need to use the 'scanning' mechanism to find the neighbouring APs. As discussed in the previous sections (see section I and IV), the criteria for selecting the appropriate PoA is based on a cross layer mechanism. Explanation of such mechanism will be explained in the next section.

F. Intelligent Handover Decision Making using Cross Layer Mechanisms

The decision to select the appropriate (i.e. optimal) network is based on the policy engine which takes into account the QoS parameter requirements from the application and maps/matches them with the dynamic QoS link parameters from the lower layers (L2 and below) of the available mediums/networks. As mentioned before, it is clearly specified in the [8] that dynamic link layer parameters (e.g. QoS Parameters such as Throughput, Average Packet Transfer delay, Packet Loss Rate, SNR etc) have to be obtained or selected based on direct interaction with the access networks and MIIS may not to be able to help much in this regard. Such dynamic QoS link parameters will be delivered to the MN through the use of MICS. The service primitive used for this purpose is defined as the MIH_MN_HO_Candidate_Query in [8].

Since the link status is very dynamic in nature and varies with time, information provided by MICS (i.e. MIH_MN_HO_Candidate_Query in our case), such as available data rate, Packet Transfer delay, Throughput etc (refer to Table 2) is very dynamic, whereas MIIS information is more static in nature. MICS and MIIS information could be used in combination by the MN/MR and network to facilitate the handover. 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, subnet prefix), the PE in the MN will use the newly defined/extended 'MIH_MN_HO_Candidate_Query' service primitive via the MIHF to send the 'MIH_MN_HO_Candidate_Query.request' to the current MIH_PoS (i.e. serving PoA). The MIH_MN_HO_Candidate_Query service primitive works in a request/resply fashion and are carried as payloads of a MIH message as service specific TLVs [8].

As it is seen in Table 2, the request message would contain 'Query Resource List' parameter along with all the other parameters (i.e. Destination Identifier, Current Link Identifier, Candidate Link List and Candidate PoA List) as TLVs [8]. However, in the current IEEE802.21 working draft [8] the definition of the contents of this parameter is not specified. In this context, we have extended/modified the 'MIH_MN_HO_Candidate_Query.request/response' messages to include the list of resources shown in Table 2 as the 'Query Resource List'. After

MIH_MN_HO_Candidate_Query.request' is received being received by the current PoA, the 'MIH_MN_HO_candidate_Query.indication' is sent as an event to all registered MIH user entities in the local stack of the candidate MIH PoS - PoA. This would serve as an acknowledgement to the MIH users which subscribe to such events/services [8] to indicate the successful reception of a MIH_MN_HO_candidate.resquest from a peer MIHF.

Upon receiving the MIH_MN_HO_Candidate_Query.request, message, the serving MIH PoS (i.e. current PoA) exchanges an MIH_N2N_HO_Query_Resources messages with the MIH Function in the candidate networks utilizing the information from the received MIH_MN_HO_Candidate_Query.request message. The MIH_N2N_HO_Candidate_Query message is meant as a notification sent on behalf of the MN/MR from the serving MIHF entity (the current MIH PoS – PoA) to the target MIH PoS - PoA in the candidate access network for resource query (i.e. dynamic QoS link parameters in our case), context transfer (if applicable) and handover preparation. The MIH_N2N_HO_Query_Resources message exchanges in our proposed mechanism works in a request/response manner as specified in [8]. An indication message, MIH_N2N_HO_Candidate.indication may be sent as an event to all registered MIH users in the candidate MIH PoS – PoAs to assert a successful reception of the MIH_N2N_HO_Candidate.request from a remote MIHF. Upon receiving the MIH_N2N_HO_Candidate.response, the current MIH PoS replies back to the MN/MR with MIH_MN_candidate_Query.response . The response would contain the parameters listed in Table 2 (i.e. Available Resource Set) as TLVs along with other parameters specified in [8]. Most notably, the response message would contain the 'Available Resource Set' TLV which includes the dynamic QoS paprameters the MN is interested in from the candidate networks.. Once the MIH_MN_HO_Candidate.respose is received by the MN, the MIHF sends a MIH_MN_HO_Candidate_query.confirmation with the result of any dynamic QoS link parameters the MIH users may have requested.

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 'MIH_App_Req' works in request/reply mode. After receiving the 'MIH_App_Req' request, the MIH Function executes the command which in turn exploits the newly defined MIES service primitive 'MIH_App_Parameter' to trigger an event which delivers the application QoS parameter requirements to the PE. Figure 7 illustrates how the proposed MIH service primitives help the PE in the

MN acquire the lower layer dynamic QoS link parameters from the network as well as the QoS requirements from the applications

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 attach to can be selected according to the rules or policies input by the users. To consider a very simple example, the PE could formulate a table containing a list of all the neighboring PoAs. The table would contain only two parameters for each PoA, which are the Received Signal strength (RSS) and available data rate. A set of candidate PoAs is selected if their RSS is stronger than a pre-configured threshold. Then we choose the candidate PoA with the best available bandwidth. The policies can also be changed so that, the available bandwidth has higher priority than the RSS, therefore, the group of candidate PoAs will be selected if their available bandwidth is higher than the threshold. The final candidate PoA is the one in this group that has the strongest RSS. Note that more complicated algorithms can be implemented in the PE to make intelligent decision. The overall cross-layer mechanism is depicted in Figure 8.

G. Handover Operations – Switching Link

After selecting an appropriate radio access network, the MME in the MN utilizes MIHF MICS, and generates a link switch command using ‘MIH_Link_switch’ primitive. As it can be seen from Table 1, the parameters, such as the ‘handover mode’, may be used to perform a ‘make-before-make’ mechanism along with the target link information (new link ID). Following the link switch command, the MN uses the L3 information, the PoA Subnet Prefix, to form a NCoA, and sends a 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 oppose to the original FMIPv6 operation, in our proposed mechanism only a single signalling 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 (Fast Binding Acknowledgement) message on the oAR’s link and necessary L2 authentication and association procedure, a MIH_Link_Up event notification will be sent to inform the FMIP6 that the L2 connection with the target PoA is established.

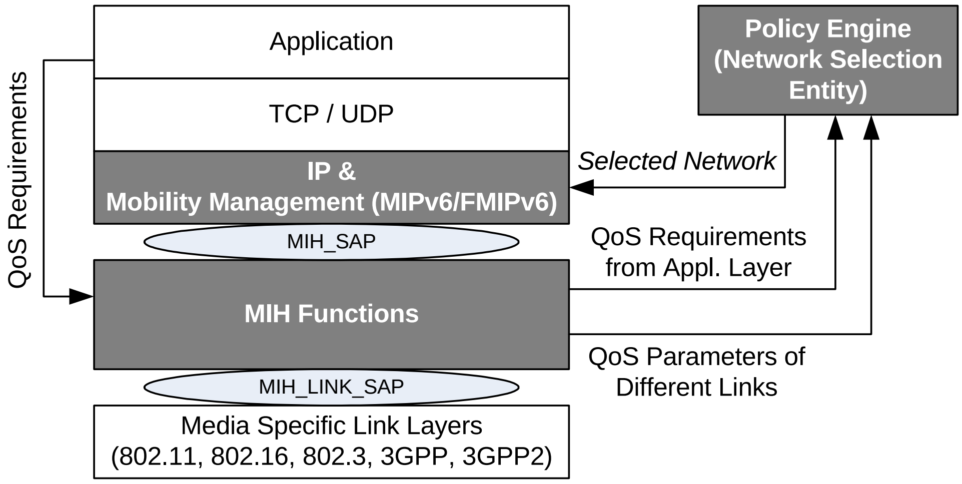


Figure 8: A Cross Layer Mechanism for Intelligent Handover Decision Making (MN side)

After the 'MIH_Link_Up' notification, the UNA (Unsolicited Neighbour Advertisement) message is immediate sent. Once the traffic starts to flow from the new link, the MIHF in the MN sends a MIH_Link_switch response. Figure 8 shows the procedure of the cross layer mechanism in selecting the optimal network with the assistance of the newly defined the 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 analyse the handover delay of the original NEMO, original FMIPv6 and our proposed 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 till the moment it receive the first IP packets in the new subnet, is analysed. 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 illustrated by the following equation

$$d_t = D_{L2} + D_{L3} \qquad (1)$$

where d_t is the overall handover latency time, including both L2 and L3. Here D_{L3} is the time period when the 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) till the time it connects to a new PoA. The overall handover procedure in both NEMO and FMIPv6 is started when L2 handover is initiated.

The L2 handover latency in IEEE802.11 WLAN, for example, could take place in two distinct phases: (i) The discovery and (ii) the re-authentication phase. During the 'discovery' phase, the MN detects the signal strength from the current AP to be reduced to an unacceptable level. The MR/MN would then start to scan or search for available neighbouring APs and generate a list of APs prioritized by the corresponding signal strength. 'Re-authentication' phase involves authentication and association messages exchanged between the MN and the AP. Extensive details of the L2 handover in IEEE802.11 can be found in [26].

The L2 handover can be illustrated in the following equation.

$$D_{L2} = D_{Discovery} + D_{Re\text{-}authentication} \quad (2)$$

After the L2 handover, the L3 handover is initiated. The first step for the MR during the L3 handover in NEMO is to perform the movement detection. During movement detection, the MR sends Router Solicitation to nAR. Upon reception of the RS, the nAR sends a Router Advertisement RA. After receiving the RA, the MN will know that it has moved. The delays caused by movement detection can be expressed as follows:

$$D_{MV} = D_{RD} + D_{CoA} + D_{DAD} \quad (3)$$

where,

$$D_{RD} = D_{RS} + D_{RA} \quad (4)$$

Here D_{MV} is the time required for a MR to detect that it has moved and form a new CoA. D_{RD} is the router discovery time and includes the delays caused by RS (i.e. D_{RS}) and RA (D_{RA}). Also, it includes the time the MN takes to form a new CoA (i.e. D_{CoA}) and test it for address duplication (i.e. D_{DAD}).

After the movement detection phase, the MR must perform the BU operations to inform its HAs and CNs of its new location, i.e., its new CoA. The total handover latency can be expressed as the sum of L2 and L3 handover latency. The equation below shows the total handover latency in NEMO.

$$d_t = D_{HO\text{-}NEMO} = D_{L2} + D_{RD} + D_{CoA} + D_{DAD} + D_{BU\,(MN\text{-}HA)} \quad (5)$$

B. FMIPv6 Handover Latency

The FMIPv6 handover latency time is also the sum of both the L2 and L3 handover. However, the delays associated with movement detection and new CoA configuration and DAD is eliminated in FMIPv6. The FMIPv6 has the handover initiation time to perform the CoA configuration prior to the L2 handover. After the L2 handover, the MN sends a FNA message to nAR to inform its presence and then perform the BU operations.

$$D_{HO\text{-}FMIPv6} = D_{L2} + D_{MN\text{-}nAR} \quad (6)$$

Here, $D_{MN\text{-}nAR}$ is the delay to send the FNA (i.e. a single message) from the MN to the nAR. For the reactive mode a single Round Trip Time (RTT) would be incurred as the MN would have to wait for FNAAck (FNA Acknowledgement) message after sending the FNA message. The Handover Initiation (HI)/anticipation time is equal to the time required to send the RtSolPr and PrRtAdv, FBU and FBack messages. Note that it is not necessary to include the FBack in the HI time as it is not required to be received on the current/old link. However, for operations in predictive mode, it is mandatory for the FBack message to be received while being connected to the oAR's link. The Handover Initiation time is given below in the following equation.

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

Here, the D_{PrRD} in the above equation is the time for sending the RtSolPr and PrRtAdv messages. D_{FMIPv6} is the time it takes for sending the FBU and receive the FBack message.

C. Handover Latency of the 802.21 assisted FMIPv6

In our proposed mechanism, L2 handover latency is considerably reduced by removing the delays associated with the radio access network discovery (i.e. scanning time). Also, the handover initiation/anticipation time is reduced by removing the Proxy Router Solicitation and Discovery (RtSolPr and PrRtAdv) time from D_{PrRD}. The calculation below shows this:

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

The 'discovery' phase (i.e. scanning time) will also be eliminated from the L2 handover time in the proposed mechanism. Therefore, the overall handover delay is expressed as below:-

$$D_{HO\text{-}FMIPv6} = D_{Re\text{-}authentication} + D_{MN\text{-}nAR} \quad (9)$$

Table 3 show the comparison of the handover latencies of the original 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}

Table 3: Comparison of handover latencies of the original NEMO, FMIPv6 and the 802.21 assisted FMIPv6

D. Simulation Results

To evaluate our proposed mechanism, we simulate a network scenario in an area of 2000 meters by 2000 meters that 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 meters, whilst the coverage area of the WLAN has a radius of 50 meters. 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 which is connected to the core network through 100Mbps connection. A correspondent node (CN) is connected to the core network through the 100Mbps Ethernet. A WiMAX/WLAN dual mode MN/MR is communicating with the CN while it is moving in the above area at a random speed between 5 meter/s and 25 meter/s. Each time it enters and leaves the WLAN area, handover procedures will be initiated.

Based on the FMIPv6 package we developed and the 802.21 and 802.16 NS2 extension developed by NIST [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 byte and a packet rate of 100 packets/s. Another is an audio flow with a packet size of 320 byte and a packet rate of 200 packets/s. Simulation time is set up as 200s. For each mean speed, we take the average of the results of 10 simulations.

From the simulation results presented in Figure 9, 10, and 11, we can see that obviously 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 (Figure 9). This may be due to the signaling packet loss over the deteriorated physical link, or the fact that MN/MR might not have sufficient time to complete all FMIPv6 signaling at the oAR's link. 802.21 assisted FMIPv6 can reduce almost half of the handover latency of the original FMIPv6.

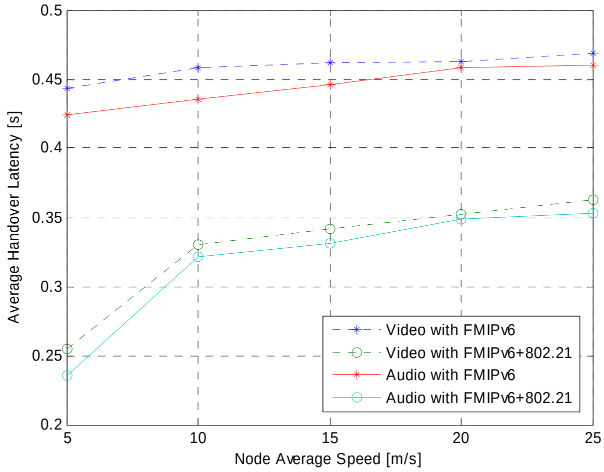


Figure 9. Average handover latency vs. node average speed

Figure 10 shows that 802.21 assisted FMIPv6 loses less packets than the FMIPv6 does when speed increases. When MN/MR moves at high speed, the FMIPv6 handover process might not be completed at the oAR's link hence packets received by the oAR would be dropped.

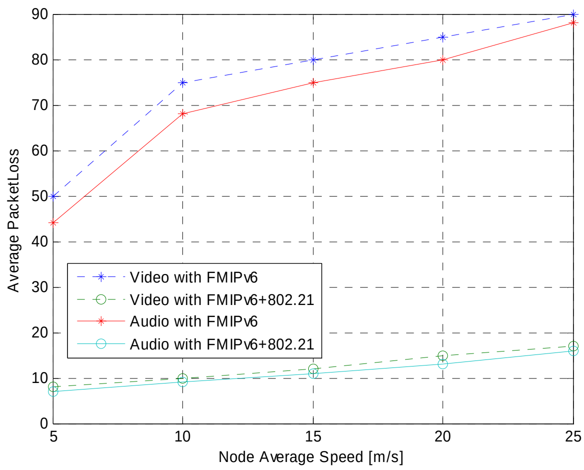


Figure 10. Average packet loss vs. node average speed

The overall signaling overhead here is the average signaling overhead (in bits) at the network and above layers during each handover interval. Figure 11 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 previous sections.

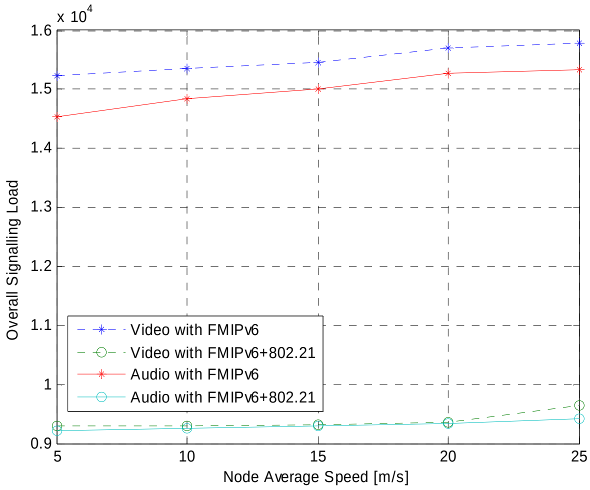


Figure 11. Overall signalling loads vs. node average speed

VI. CONCLUSION

In this paper, we propose a mechanism which optimizes the FMIPv6 handover procedure with the assistance of IEEE802.21 MIH services for vehicular networking. To do so, we have exploited the MIH services. Most notably, we utilize the 802.21 MIIS and include L3 information of neighbouring access networks in the MIIS service. We define a new Information Report, the ‘HNI Container/Report’ to contain L2 and L3 information of neighbouring access networks which can help the FMIPv6 protocol to tackle issues such as radio access discovery and candidate AR discover. 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 which in turn reduces signalling 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 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 policy engine 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 parameters requirements from the applications and compares it with the dynamic parameters of the available access networks. The parameters are then matched with pre-defined policies to optimize the handover decision.

REFERENCES

[1] S. Deering et al, “Internet Protocolv6 Specification”,RFC 791, IETF, December 1998

[2] Marina del Rey, “Internet Protocol Specification”,RFC 2460, IETF, September 1981

[3] D. Johnson et al., ”Mobility Support in IPv6”. RFC 3775, IETF, June 2004.

[4] Ernst, T., “Network Mobility Support Goals and Requirements”, Internet Draft (work in progress), IETF, November 2006

[5] Devarapali, V., Wakikawa, R., Petrescu, A., and P. Thubert, “Network Mobility (NEMO) Basic Support Protocol”, RFC 3963, IETF, January 2005.

[6] “CALM –Medium and Long Range, High Speed, Air Interfaces parameters and protocols for broadcast, point to point, vehicle to vehicle, and vehicle to point communication in the ITS sector – Networking Protocol – Complementary Element”, ISO draft ISO/WD 2121 (works in progress), ISO, Technical committee 204, WG16, December 2005

[7] Koodli, R., et al., “Fast Handovers for Mobile IPv6”, RFC 4608, IETF, April 2006

[8] Draft IEEE standards ,“IEEE802.21 Standard and Metropolitan Area Networks: Media Independent Handover Services”, Draft P802.21/D00.05, March 2006

[9] T. Melia, E. Hepworth S. Sreemanthula, S. Faccin, Y. Ohba, G. Vivek, J. Korhonen, S. Xia, “Mobility Services Transport: Problem Statement”, IETF Draft (work in progress), IETF, May 2007

[10] S. Sreemanthula, S. Faccin, G. Daley, E. Hepworth, S. Das, “ Requirement For Handover Information Services”, Internet Draft (work in progress), IETF, March 2006

[11] S. Sreemanthula, G. Daley, E. Hepworth, “Problem Statements and requirements for Event and Command Services in Media Independent Handovers”, Internet Draft (work in progress), IETF, March 2006

[12] A. Rahman, U. Olvera-Hernandez, J.C. Zuniga, M. Watfa,, H.W. Kim “Transport of Media Independent Handover Messages over IP”, Internet Draft (work in progress), IETF, February 2007

[13] T. Ernst, “The Information Era of the Vehicular Industry”, in *Proceedings of* ACM SIGCOMM Computer Communication Review, volume 36, number 2, April 2006

[14] E. Weiss, G. Gehlen, S. Lukas, C. Rokitansky and B. Walke , “MYCAREVENT- Vehicular Communication Gateway for car maintenance and Remote Diagnosis, in *Proceedings of* ISCC, 2006

[15] G. Gehlen, E. Weiss, S. Lukas, C. Rokitansky, B. Walke, “Architecture of Vehicle Communication Gateway for Media Independent Handover”, http://www.mycarevent.com, February 2007

[16] M. Sebeur, B. Jaoaber, D. Zeghlache, “Low Latency Handoff for Nested Mobile Networks”, in *Proceedings of* IEEE CCNC, 2006

[17] Y. Young An, B.H Yae, K.W Lee, Y.Z Cho and W.Y Jung, “Reduction of Handover Latency Using MIH Services in MIPv6”, in *Proceeding of* AINA’06

[18] Q. B. Mussabbir and W. Yao, “Optimized FMIPv6 Handover using IEEE802.21 MIH Services”, *in Proceedings* of the 1st ACM/IEEE International Workshop on Mobility in the Evolving Internet Architecture (MobiArch 2006).

[19] M. Liebsch, et.al, “Candidate Access Router Discovery (CARD)”, RFC 4066, IETF, 2005.

[20] H. Fathi, S. Chakraborty, “Optimizations of Mobile IPv6 based Handovers to support VoIP services in Heterogeneous Networks”, *IEEE Transactions on vehicular Technology*, vol 56, pp 260-269, January 2007

[21] T.T. Kwon, M. Gerla, and S. Das, “Mobiltity Management for VoIP services : Mobile IP vs SIP” , IEEE Trans. Wireless Commun, vol 9, no 5, pp 66-75, October 2002

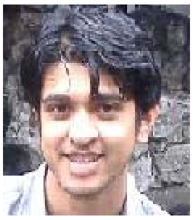
[22] Bound, J., Carney, M., Perkins, C., Lemon, T., Volz, B. and R. Droms (ed.), "Dynamic Host Configuration Protocol for IPv6 (DHCPv6)", RFC 3315, IETF, May 2003.

[23] J.Zhang, H.Chen, Z. Xia, X. Duan, Z. Zhou, “AR Information for FMIPv6”, IETF, June 2006

[24] Y Ohba, “IEEE 802.21 Basic Schema”, Internet Draft, IETF, Jan 2007

[25] NIST Project- Seamless and Secure Mobility tool suits: http://www.antd.nist.gov/seamlessandsecure/doc.html, May 30, 2007

[26] H. Soliman, ‘Mobile IPv6 : Mobility in Wireless Internet’,Addison-Wesley, 2004



Qazi Bouland Mussabbir (S'05) was born in Bangladesh, 2nd November 1982. He received his Degree in Computer Systems Engineering in June 2005 from Brunel University, London, UK. In August 2006, he joined the centre for Networks and Multimedia Communication at Brunel University *(Dept of Electronic and Computer Engineering*) as a research fellow. His current research includes mobility management in MIPv6 based wireless networks, bootstrapping and service authentication in heterogeneous networks, HA reliability and so forth. Currently he is also pursuing a Ph.D degree in Wireless Communications from the School of Engineering and Design at Brunel University, London, UK.

Wenbing Yao (M'01) received her Ph.D. degree in digital signal processing from Huazhong University of Science and Technology (HUST), China, in 2001. At HUST, She was a Member of the Signal Processing Research Group. From 2001 to 2002, she was a Research Scientist in the Wireless Technology Research Division at Hanwang High Technologies Inc., China. In 2002, she joined the Department of Electronic and Computer Engineering, Brunel University as a Research Fellow. Since 2003, she has been a Lecturer in wireless communications with the same department and a member of Research Centre of Networks and Multimedia Communications. Her current research includes mobility management in mobile networks, location technologies in wireless networks, MIMO channel analysis, signal processing for wireless communications and so forth. She was the referee of many international conferences and IEEE Transaction journals and has coauthored over 30 technical international journal and conference papers. She was a recipient of the Outstanding Graduate Fellowship and HUST Alumni Fellowship in 2001 and 2002, and a member of IET.

Zeyun Niu (S'04) received her B. Eng degree in Biomedical Engineering from Tsinghua University, Beijing China, 2003. She joined the Research Centre of Networks and Multimedia Communications as a PhD candidate in Brunel University, London, UK, 2003. Her current research includes routing algorithm design for vehicular ad hoc networks, QoS support with service differentiated for wireless ad hoc networks, mobility management, and cross-layer QoS model design.

Xiaoming Fu (M'02) is a professor of Computer Science and heading the Computer Networks Group at the University of Goettingen, Germany. He received his PhD in Computer Science from Tsinghua University, Beijing, China, in 2000. Prior to joining the University of Goettingen in September 2002, he was a postdoc research fellow at the Telecommunications Networks (TKN) group, Technical University Berlin. Between 2003 and 2005 he also served in the European Telecommunications Standards Institute (ETSI) as an Expert in Specialist Task Forces in Internet Protocol (Version 6) Testing. His research interests include network architectures and mobile computing, protocols and services, especially signaling and QoS, transport protocol performance, emerging mobility support and overlays in the evolving Internet architecture. He is a member of IEEE and ACM, and has served as a TPC member/session chair/program chair for INFOCOM, ICDCS, ICNP, GLOBECOM, ICC, MobiArch etc.