Enable Multimedia Mobility with IEEE 802.21

Guang Lu
InterDigital Communications
e-mail: Guang.Lu@InterDigital.com

***Abstract*—Mobile devices supporting multiple radio technologies are becoming mainstream in the market. These devices can experience vertical handovers between heterogeneous networks due to device mobility or multiple network coverage. Handover latency is critical to ensure session continuity and end user experience. This paper presents a solution using IEEE 802.21 to enable seamless mobility for data and video streaming sessions. The solution was implemented and evaluated using commercial wireless networks and mobile devices. Lab and field trial results show minimal handover delay and improved user experience.**

Keywords-IEEE 802.21; MIH; handover; mobility; streaming; load balancing

I. INTRODUCTION

There have been revolutionary changes in both mobile devices and mobile networks in recent years. Mobile devices supporting multiple radio technologies are proliferating and becoming the mainstream in the market. Such devices can be smartphones, netbooks, laptops, etc. Most devices support WiFi and cellular simultaneously. With the increasing processing power and the popularity of app stores, mobile devices are commonly used for multimedia applications.

The rapid advancement of mobile networks provides the infrastructure and bandwidth for multimedia applications. 3GPP LTE, mobile WiMAX, and WiFi all operate at comparable bit rate and within the all IP framework. In many regions, such as downtown, offices, homes, hot spots, there are usually multiple overlaid networks available.

The multi-mode mobile devices and overlaid network infrastructure enable the end users to be always connected. However, it imposes new challenges of mobility, i.e., when and how to always stay with the best connection. It is the interest of both end users and network operators to maintain session continuity and quality of service. In addition, network operators may also want to off load traffic to avoid network congestion.

In this paper, an IEEE 802.21 Media Independent Handover (MIH) based mobile client implementation is introduced. The 802.21 client enables fast handover of mobile devices between different radio access technologies. Specifically, streaming sessions with stringent handover delay requirements were used to evaluate the performance of the solution. The MIH client was ported to commercial mobile devices and tested with an MIH server over commercial networks. Results indicate that the MIH mechanisms can largely reduce handover delay and enhance media mobility.

The rest of the paper is organized as follows. Section II gives an overview of the IEEE 802.21 standard and related research work. Section III provides the system architecture design of the MIH system. Section IV describes the field tests and results of a data streaming application using the MIH framework. Section V presents a video streaming application using the same MIH implementation. Finally section VI concludes the work.

II. BACKGROUND AND RELATED WORK

A. IEEE 802.21 Media Independent Handover

IEEE 802.21[1] provides a framework and mechanisms to facilitate handover between heterogeneous networks. Such networks can include wired, wireless, 802 and cellular networks. The standard defines link-layer intelligence and other related network information to upper layers to optimize handovers.

The IEEE 802.21 standard provides three types of services to facilitate vertical handovers. They are Media Independent Event Service (MIES), Media Independent Command Service (MICS), and Media Independent Information Service (MIIS). The module that realizes the MIH services is called an MIH Function (MIHF). The MIHF can be in a mobile node, or it can be on the network side. Entities that receive the services provided by the MIHF are called MIH users.

The Event Service (ES) provides dynamic information in link characteristics, link status and link quality. It contains two categories: the Link Event and MIH Event. The Link Event originates from lower layers (L2 and below) and propagates to MIHF. The MIH Event is from the MIHF to higher layers (L3 and above). Examples of MIES are Link_Up, Link_Down, Link_Going_Down, Link_Detected, etc.

The Command Service (CS) enables MIH users to manage and control link behavior relevant to handovers and mobility. Commands propagate from higher layers to lower layers. Similar to the Event service, there are Link Command and MIH Command. Examples of MICS are Link_Action, HO_Commit, etc.

The Information Service (IS) enables network operators to facilitate better network selection with policies and network information. The MIIS provided by the MIH information server can be a list of neighboring networks, access network information, etc. In 3GPP [2][3], a similar network element called Access Network Discovery and Selection Function (ANDSF) is introduced. ANDSF contains data management and control functionality to provide network discovery and selection per operator's policy.

B. *Related Work*

In [4], an 802.21 based prototype was developed in BT's 21CN environment and Intel's mixed network (MxN) system. The prototype implemented a client-initiated network-assisted handover mechanism using Session Initiation Protocol (SIP) with an audio/video conferencing application. The handover is performed between WiFi and WiMAX networks. Performance evaluation in the test bed shows that by using predictive triggers the system can reduce handover delay from 10 seconds to 305ms.

Another joint research work from BT and Intel [5] is focused on network selection for optimal energy efficiency. The system utilizes frequency information from the MIH information server to reduce unnecessary scanning time. The network selection algorithm showed a power saving of up to 40% for WiMAX and 80% for WiFi.

III. MIH SYSTEM DESIGN

The MIH implementation is compliant to the published 802.21 standard [1]. The details of the MIH system design are illustrated in the following sections.

A. *Client-Server Architecture*

An MIH client-server architecture is implemented as shown in Figure 1. All the three MIH services (MIES, MICS, and MIIS) are supported on both the client side and server side. The transport between MIH client and server is via UDP or TCP over IP. MIH messages are encapsulated as payload in the TCP segment or UDP datagram. Typically, TCP is used for MIH Information Service (IS) messages and UDP is used for other MIH messages [6].

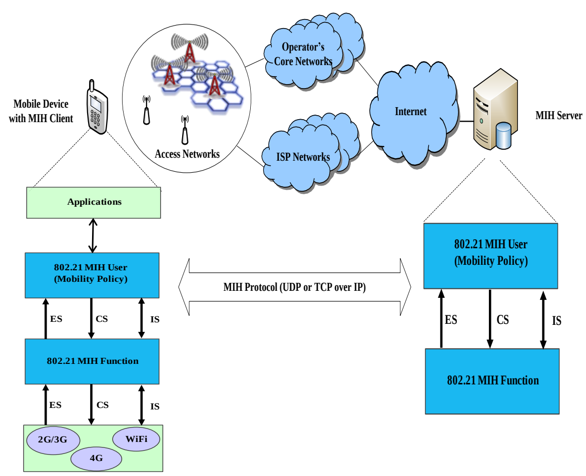

Figure 1 MIH Client-Server Architecture

B. *MIH Client*

Figure 2 shows the architecture of the MIH client on a netbook or laptop platform running Windows XP with USB dongle. The implementation was also ported to various smartphone platforms running different Operating Systems (OS), such as Windows Mobile and Android. For smartphones, the MIH client module runs in the Application Processor (AP) and uses OS abstraction layer to interface to different modems. The MIH client supports WCDMA, CDMA2000, WiMAX, and WiFi.

The MIH client module implements the three MIH service (MIES/MICS/MIIS) and MIH management services. It has various Application Programming Interfaces (APIs) to different layers, including the connection manager, SIP, Mobile IP (MIP), and device drivers for multiple radio technologies. The interface to the devices can be through C function calls, APIs defined in OS, or standard based AT commands for easy integration.

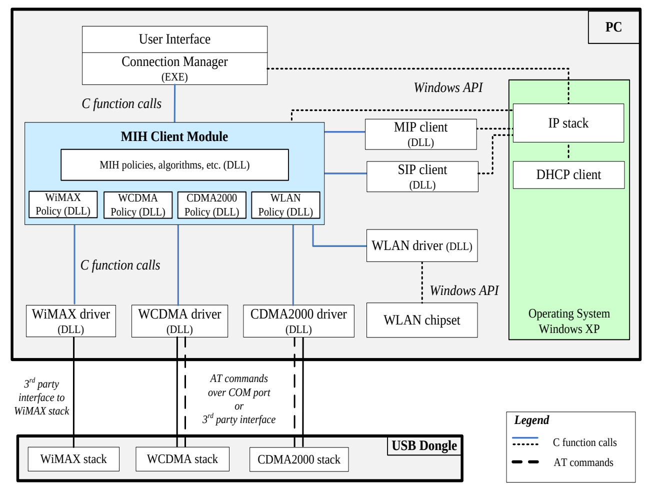

Figure 2 MIH Client Architecture

C. *Handover Modes*

The MIH system supports different handover modes, including:

- Mobile controlled handover: The mobile node has the primary control over the handover process [1]. Within this mode, there can be network assisted handover, in which the mobile utilizes the information service from the MIH server to facilitate handover decision. This mode also includes a special case of mobile autonomous handover, in which the handover decision is solely based on the local configuration and information at the mobile node.
- Network controlled handover: The MIH server has the primary control over the handover process [1]. Within this mode, there can be mobile assisted handover and mobile unassisted handover. In mobile assisted handover, the MIH server takes input, such as measurements from the mobile, as part of its handover decision. In mobile unassisted handover, the MIH sever initiates the handover command based on information from the network side only.

Handover can also be categorized in the following three types:

- Fallback Handover: Fallback handover is a mechanism to maintain network connectivity. It occurs when the current connection is jeopardized or is lost. Fallback handover is triggered by the MIH event indications, such as Link Going Down or Link Down. Since such situation is usually time critical, the handover target is usually the cellular network due to its coverage and availability.
- Optimization Handover: This type of handover, as the name indicates, is designed to optimize the connection. When the current connection is stable, if there is a more preferred network available, the mobile is handed over to the more desired network. The mobile maintains a database with a list of preferred networks and their information. The mobile takes input from the connection manager and the MIH information server for the configuration and updates of preferred networks.
- Load Balancing Handover: Operators may need to perform handover requests for purposes such as network load balancing, maintenance, etc. This is realized by MIH server initiated handovers, using MIH command services.

Both Make-Before-Break (MBB) and Break-Before-Make (BBM) handovers are supported. In the rest of this paper, MBB handover is discussed.

A Ping-pong situation is avoided by carefully monitoring the handover types and intervals between two consecutive handovers.

In addition to lab testing, the implementation was also validated via various Interoperability Testing (IOT), field trials, and Fixed-Mobile Convergence Alliance (FMCA) Plugfest. The following sessions describe the evaluation with two different multimedia applications.

IV. DATA STREAMING

A SIP-based data streaming application is used to evaluate the handover delay using the MIH implementation.

A. *Evaluation Setup*

Figure 3 shows the network setup using a SIP-based streaming data application. An IP Multimedia Subsystem (IMS) core is emulated with a SIP proxy server. The MIH server can be an IMS Application Server (AS), or beyond the IMS core. The data streaming server produces a real time continuous Sine wave. These servers can be co-located, or can be separated in different geographical regions. For example, they were located in two different cities of different countries in some tests performed.

The MIH client can run on a smartphone, a laptop, or a netbook. It connects to a commercial WCDMA network and WiFi hotspots. The device obtains its IP address via DHCP.

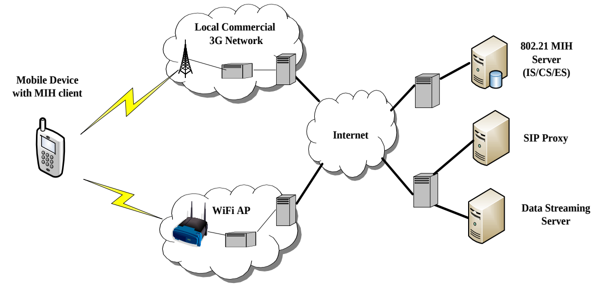

Figure 3 Data Streaming Network

Figure 4 is a screenshot of the Sine wave application running on a smartphone. It shows one occurrence of a handover, which caused one packet loss indicated as the interruption of the Sine wave.

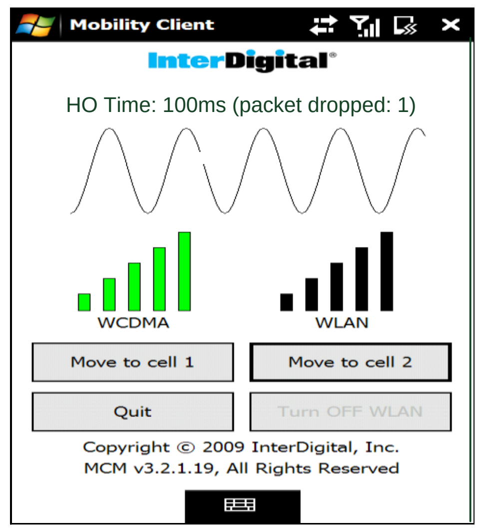

Figure 4 Sine wave Application Screenshot

B. *Handover Scenarios*

All the handover modes discussed in section III were implemented and evaluated. Handover can occur completely without user intervention when the handover conditions are met. The Graphical User Interface (GUI) of the MIH client also enables user intervention to turn on and off radios for purposes such as testing and demonstration.

Figure 5 illustrates the call flow of one of the handover scenarios from WiFi to WCDMA network due to the lack of WiFi coverage (fallback handover). The procedures are explained as follows:

1) The illustration starts when WiFi is the current active connection. The MIH client can start with any interface, and perform handover back and forth whenever the handover criteria are met.

2) When the MIH client connects to a new radio access, it performs MIH registration (MIH_Register) and obtains network information from the MIH information server (MIH_Get_Information). The MIH information server indicates available neighboring networks with the order of preference from the operator's perspectives. In this example, the MIH server indicates that WiFi is the most preferred network. Therefore no handover is triggered. The mobile device also performs SIP registration. When the MIH client discovers the MIH server for the first time, it exchanges MIH capabilities (MIH_Capability_Discover) with the MIH server. MIH discovery is not shown in the diagram.

3) The user can press a "Start Application" button from the GUI interface of the Sine wave application. This triggers the SIP INVITE and establishes the data session with the streaming server.

4) When the WiFi signal degrades, for example, by moving away from the Access Point (AP), or using an attenuator at the AP, it triggers an MIH event indication (Link_Going_Down) from the WiFi driver to the MIH client. The user can also trigger a fallback handover by turnning off WiFi, which generates a Link_Down event.

5) The MIH client decides a handover to WCDMA network is necessary, and performs the handover. This example shows a mobile controlled, network assisted handover.

6) Upon obtaining the new IP address from the WCDMA network, the MIH client triggers the SIP client to issue a SIP RE-INVITE and re-stablish the data streaming session.

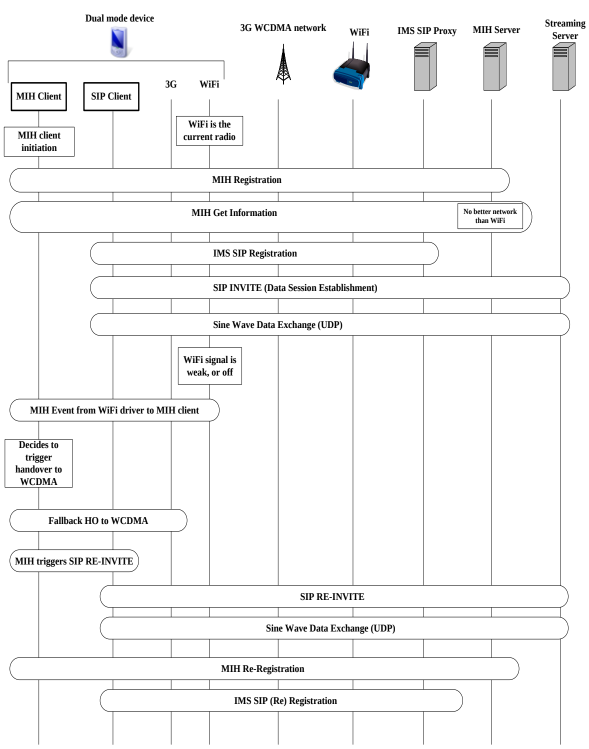

Figure 5 Handover from WiFi to WCDMA

C. *Field Trial Results*

In addition to lab testing, field trials were conducted in the city of Montreal, Canada, using the commercial WCDMA 3G network from Rogers™ and various hot spots such as cafés or stores. The MIH client implementation was ported to commercial platforms, such as the HTC Touch™ series of smartphones, and laptops or netbooks with USB dongles.

Results persistently show that the average handover delay is within the range of 150ms, causing the loss of 1-2 packets. Handover delay was measured as the interruption to the application. Note that the precision of the result is limited by the Sine wave application, which creates one packet per 100ms. Therefore the minimum measurable delay is 100ms. TABLE I. shows the results from laptop testing, using Sierra Wireless Compass™ 888 modem in USB dongle.

TABLE I. DATA STREAMING FIELD TRIAL RESULTS

Handover (HO) Scenarios	**Mean Handover Time (ms)**
Fallback HO from WiFi to WCDMA	150
Optimization HO from WCDMA to WiFi	147
Load Balancing HO from WiFi to WCDMA	133
Load Balancing HO from WCDMA to WiFi	100

V. VIDEO STREAMING

A Real Time Streaming Protocol (RTSP) based video streaming application is used to evaluate handover delay using the MIH implementation. Handover indications are sent to the video application module, triggering a new RTSP session.

A. *Evaluation Setup*

Similar to the Sine wave streaming application, the video streaming application also uses commercial networks with distributed client-server architecture. The MIH client was ported to a netbook computer. Figure 6 shows the setup for the video streaming application. Figure 7 is the screenshot from the video streaming client.

The handover scenarios supported by the video streaming application are the same as the Sine wave application.

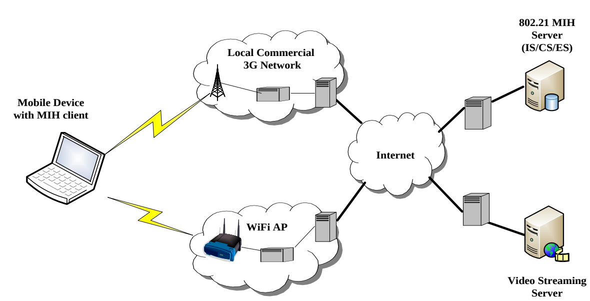

Figure 6 Video Streaming Network

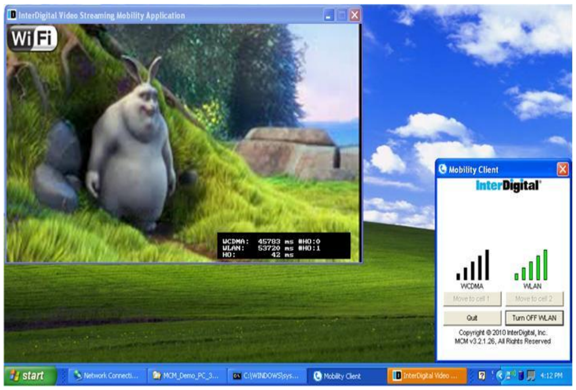

Figure 7 Video Streaming Application Screenshot

B. Evaluation Results

Lab testing was performed to evaluate the handover delay for video streaming. The handover delay being measured was the interruption time at the application level. TABLE II. shows the results for the RTSP streaming. During handover, the video playback might display some visible pixel artefacts and skip some frames. Note that since the duration of one video frame is 42ms, the minimum measurable delay is 42ms.

In the results below, the handover delay from WiFi to WCDMA is longer than the opposite direction because the WCDMA network causes longer delay for the RTSP messages. Therefore it takes longer to establish a new RTSP session. Comparing to the SIP based Sine wave data streaming, the results vary more due to the software delay variation introduced by the video player. All the above mentioned factors contribute to the longer delay at the application level.

TABLE II. VIDEO STREAMING LAB TESTING RESULTS

Handover Scenarios	**Mean Handover Time (ms)**
Fallback HO from WiFi to WCDMA	1100
Optimization HO from WCDMA to WiFi	42
Load Balancing HO from WiFi to WCDMA	605
Load Balancing HO from WCDMA to WiFi	130

VI. CONCLUSIONS

Converged mobile devices and networks create the challenge of connectivity and mobility between heterogeneous networks. To address this issue, a mobility solution using the IEEE 802.21 MIH framework was developed. The MIH Event Service, Command Service, and Information Service are utilized to facilitate handover decision and reduce handover delay. The solution was evaluated on commercial mobile devices, using commercial 3G and WiFi networks, with real-time streaming applications. Lab and field trial results constantly show that for the SIP based data streaming application, the handover delay is normally within 150ms (1-2 data packets). The delay for the RTSP based video application varies from 42ms to a few hundreds of milliseconds, due to network and software reasons. Future work includes precisely measuring and benchmarking the HO delay, eliminating the limitation of software and applications. More algorithms and features can be added to the MIH client and server to enhance the handover intelligence. It is expected that the handover delay can be further reduced with such enhancements.

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