5-2 Empirical Evaluation of Real-Time Vertical Handover for Beyond 3 G Wireless Network

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The Beyond 3 G Wireless Network, which is discussed at ITU-R, integrates various radio systems including 3 G, WLAN, and 4 G. It provides an all IP wireless solution to offer services taking advantage of each radio system. Current approach to integrate wireless systems is to localize wireless dependent functions and to integrate into all IP network using Mobile IP technologies. We proposed the Mobile Ethernet architecture, a Beyond 3 G, as all IP integrated wireless network using MAC layer technologies. There are some discussions to extend the Ethernet format to hold wireless frames efficiently caring about Mobility, QoS, and security along with the standardization activities in IEEE802 wireless technologies. In this paper we discuss mobility using common radio signaling scheme on the Mobile Ethernet and the vertical handover on the scheme. We design the Mobile Ethernet having W-CDMA and IEEE802.11b with the common radio signaling and evaluate the vertical handover performance in an outdoor test bed environment. We describe issues on packet loss in relation to link quality threshold for handover and speed of terminal movement. We also clarify remaining issues for the standardization.

Keywords
Mobility, Beyond 3 G, Vertical handover, Signaling, Ethernet

1 Introduction

The 3 G cellular system has been infiltrated into current market and the next generation wireless system called the Beyond 3 G is said to come up to the market. The Beyond 3 G integrates various radio systems including 3 G, 4 G and wireless LANs (WLANs) and provides an all IP wireless solution to offer IP services, taking advantage of each wireless communication. There are activities to integrate heterogeneous wireless networks into all IP network using IP technologies[1]-[3]. The main idea of that system is to localize wireless dependent functions as much as possible and to have a common IP layer to accommodate mobility management, network level authentication and signaling control. The IP network infrastructure is prevailing as metropolitan and wide area Ethernet using Provider Bridge[4] technology and is becoming available as commercial networks.

For wireless access technologies, on the other hand, the 3 G based systems are gradually extending as wireless networks, whereas IEEE802.11 is dramatically expanding its deployment because of the cost efficiency, though service is limited in small areas. The IEEE802.20 MBWA[5] Working Group is developing a specification optimized for high-speed IP data transport and vehicular mobility in a MAN environment. The IEEE802 LMSC[6] based high-speed wide range wireless system becomes a key component of the Beyond 3 G system, and many systems will converge on the IEEE802 MAC layer in addition to the IP layer.

There are many discussions of terminal mobility by enhancing Mobile IP[7] to manage the mobility in integrated wireless systems, but there are few talks about handovers at walking speed in metropolitan area. In the Mobile IP enhancements, efficient route optimization, fast handover[8] and control packet reduction using hierarchical network management[9] are raised. These enhancements are useful in a heterogeneous wireless system, but Mobile IP still needs capsulations and many message exchanges, such as Binding Update at terminal movements between access routers and Return Routability to check the validation of the binding update information. The capsulation increases process load and these messages exchanges increase signaling load for frequent handovers in metropolitan areas.

There are proposals to solve these Mobile IP related overheads by using MPLS. A Label, which is distributed along a terminal movement, hides the terminal IP address change and optimizes the route between the terminal and routers[10]. This mobility control has an advantage of using QoS control mechanism, but still there exist overheads to encapsulate packets same as Mobile IP.

The mobility management in the MAC layer is specified at the IEEE802.11 Task Force F. The Inter-Access Point Protocol (IAPP)[11] is designed to exchange security context of a mobile terminal between current access point (AP) and new AP and provides seamless data transfer to users during a handover. The IAPP, furthermore, does not require the mobility control feature provided by Mobile IP because the protocol includes micro mobility that updates entries about the MAC address of a terminal in Layer 2 switches and APs at high speed. All the Layer 2 switches can become an anchor point of traffic during handover so that a signaling of IP address change is not required. These mechanisms realize high-speed handover. The IAPP, however, sends the Layer 2 Update frame to the MAC broadcast address to provide an indication to an AP that may have an older association with a terminal. This feature increases control frames traffic, depending on the number of terminals and frequency of terminal movements, and affects the scalability of the Layer 2 network.

In this paper, we discuss the Mobile Ethernet architecture, a Beyond 3 G, and its common radio signaling scheme deploying the network initiated handover. We evaluate the handover performance on the practical Mobile Ethernet implementation equipped with W-CDMA and IEEE802.11b.

We describe the Mobile Ethernet architecture and its components in the section **2**. We show components and interfaces of the experimental system. We, then, explain the common radio signaling scheme and the network initiated handover in the section **3**. In the section **4**, we evaluate real-time vertical handover performance on the experimental system in an outdoor environment. We analyze the packet loss and discuss issues that come up by having real implementation. Lastly, we conclude with the summary and future perspective of the Mobile Ethernet.

2 Mobile Ethernet architecture

The Mobile Ethernet is a metropolitan area Layer 2 based network and can extend a support area using other technologies, such as Provider Bridge[4]. It also connects to the Internet via a router and provides transparent services over IP communication as shown in Fig. 1.

In the Mobile Ethernet, every message is virtually broadcasted on the core network shared with proper MAC addresses and allows to plug-in various kinds of radio systems, such as 3 G, 4 G, and WLANs, following a common MAC interface. To achieve scalability, Layer 2 switches with path-learning caches are deployed in an Ethernet. A path to a destination MAC address is learned at all switches on the path and unnecessary broadcast is suppressed once the path is learned[12][13].

Since mobile devices in a wireless network often change their attachment points to

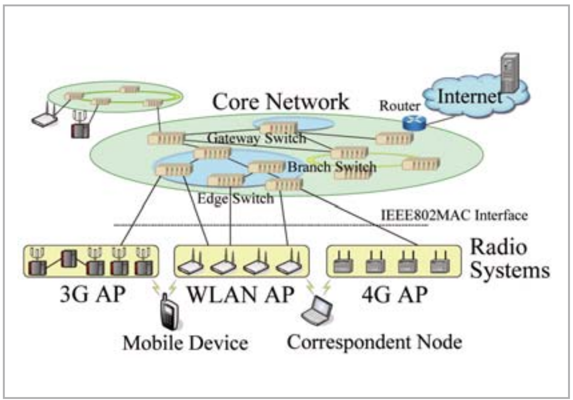

Fig.1 Mobile Ethernet

the network due to their movements, frequent updates of path-learning caches are needed. The Mobile Ethernet provides a real-time handover mechanism based on Layer 2 switch architecture and a prediction mechanism of seamless handover targeted for real-time communications. The Mobile Ethernet also provides a signaling mechanism to update path-learning caches on the switches dynamically, and needs suppressing broadcast signaling traffics. A broadcast message of the upper layer communication protocol, such as ICMPv6 neighbor solicitation message, is included in this mechanism.

The Mobile Ethernet consists of Layer 2 switches, the Common Signaling Server (CSS) and Buffering Server. There are three types of Layer 2 switches called the Gateway Switch (GSW), the Branch Switch (BSW), and the Edge Switch (ESW). The GSW has the basic mobility functions, such as MAC address learning with exchanging Layer 2 mobility management frames and IPv6 multicast traffic control without flooding, and interfaces for MAC address replacement and MAC address table setup to the Common Signaling Server. A BSW is the intermediate switch between a GSW and ESW and has the basic mobility functions in it. An ESW manages MAC frame transfers, such as relaying common radio signaling messages between an MD and the CSS, an AP and the CSS, besides the basic functions.

The Common Signaling Server manages messages to control mobile devices and various radio systems. The server informs to a mobile device adjacent APs list for the network access point detection and mobility management instruction such as a handover request. The mobile device, on the other hand, informs various common radio signaling messages, such as the Location Area Update message for mobility management in dormant mode and measured received-signal strength information used for triggering in network initiated handover. The Buffering Server keeps user data frames for paging mobile devices.

Our experimental system consists of the Mobile Ethernet and two radio systems, W-CDMA(3 G) and IEEE802.11b, that plugged into the Mobile Ethernet following the common MAC interface. The W-CDMA system is one type of the 3 G cellular system and attaches to the Mobile Ethernet emulating the IEEE802.11b AP at the GTP switch. The 3 G cellular system consists of the following components and an NTT DoCoMo FOMA (Freedom Of Mobile multimedia Access[14]) CF card is used to verify packet bearer service (UL 64 Kbps/DL 384 Kbps).

(1) W-CDMA Base Station
(2) Frequency Converter
(3) Radio Bearer Server
(4) GTP Switch
(5) Radio Control Server
(6) GTP Switch Control Server

Figure 2 shows the experimental equipment of the Mobile Ethernet. In the equipment, we use 3.35 GHz with a frequency converter to use a off-the-shelf W-CDMA Compact Flash (CF) card for a mobile device. The mobile device has a Linux based open platform which integrates the IEEE802.11b and a CF slot to plug in the W-CDMA CF card. The Mobile Ethernet switches use the freescale's C-5e™ network processor. The equipment works as two Edge Switches and one Gateway Switch. The hardware platform has an 866 MHz PowerPC™ 7455 with 2 MB L3 cache-memory, 512 MB of PC133 SDRAM main memory. The C-5e™ operates at 266 MHz and has 128 MB of SDRAM as a buffer memory.

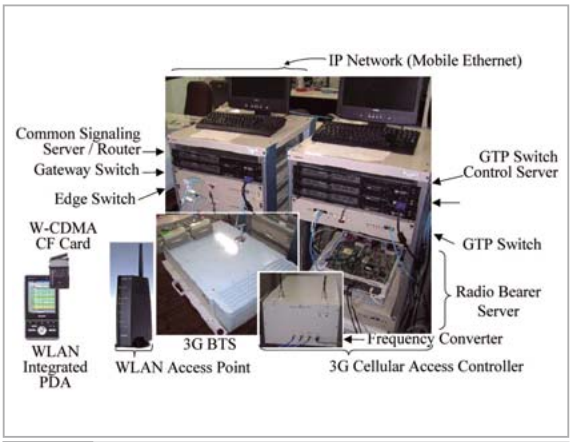

Fig.2 *W-CDMA/IEEE802.11b Equipment*

3 Common radio signaling scheme

The common radio signaling scheme provides efficient network initiated handover independent of radio systems utilizing all the wireless access information and mobile device movements, which realizes seamless and proactive handover between radio systems for real-time applications, such as Voice over IP (VoIP). The scheme has functions such as network initiated handover and paging with dormant mode.

Deploying the CSS, APs of respective radio systems are connected to an ESW. The CSS manages each MD database accompanied with a list of its neighbor APs. An MD updates the list periodically and when it acknowledges a change by scanning neighbor APs. The CSS gathers radio status information, such as Received Signal Strength Indicator (RSSI), and error correction rate by exchanging reports including format, timing (periodical, event-triggered) among MDs and APs in advance, cooperating with the Radio Resource Management (RRM) function. Since IEEE802.11 WLAN does not have an RRM mechanism like 3 G, the measurement interface discussed in the IEEE802.11 Task force K[15] is applied as the RRM.

There are two handover scenarios in the Mobile Ethernet; the network initiated handover which is triggered by an RRM and the station initiated handover which an MD requests. As the station initiated handover is an alternative to the network initiated handover for the situation that the network initiated handover can not handle, such as sudden RSSI drop, we focus on the network initiated handover and use the function for handover between 3 G and WLAN.

The paging works with the dormant mode in which an MD receives only a wakeup trigger to save its battery. The CSS manages the MD's mode and location to send the trigger. Before the MD enters the dormant mode, packets destined to the MD are stored in the Buffering Server. In this paper, we focus on only the network initiated handover and the paging is out of scope.

3.1 Signaling model

The Signaling Model separates the signaling domain into two areas, wireless and wired network. As shown in Fig. 3, the CSS manages an area between the MD and the ESW. The L2 Mobility Management Signaling and Common Mobility Control Signaling messages are used in the areas between the ESW and GSW and between the ESW and CSS, respectively. The reason for this separation is that suitable methods to send a L2 signaling message are dependent of radio systems. For example, users can not modify a 3 G signaling plane protocol so that the Point-to-Point Protocol (PPP) is one option to send a common radio control signaling message. WLAN, on the other hand, can send a common radio control signaling message. The L2 Mobility Management Signaling message, therefore, is dependent of a radio system and the Common Mobility Control Signaling message is independent of the radio system.

3.2 Network initiated handover

The network initiated handover is a function that the network asks an MD to switch the radio system from current radio system using a trigger according to the measurement report by scanning neighbor APs from the MD, and a handover is executed between the radio systems triggered by the Mobile Ethernet using the RRM. The procedure is shown in Fig. 4.

The CSS selects the best radio system or AP based on the measurement report from MDs and also on the usage ratio of channels/cells sent from radio systems that are connected to ESWs. The CSS directs an MD to execute a handover by a Handover Request message with the information.

The MD activates the radio system and links to the AP directed by the CSS. A Link Up message sent from the MD to the ESW is used as a trigger to configure a path by forwarding an Update Entry message to switches up to the GSW.

The MD, then, switches its interface to the radio and sends a MAC Address Replacement Request message to the CSS to update binding of its IP address and MAC address. By receiving the MAC Address Replacement Request, the CSS asks the GSW to replace the previous MAC address with the new address using frames destined to the previous MAC address.

Suppose network access cost is fixed, an MD switches its interfaces keeping previous connection. In this case, the MD does not need to link down the connection, but to send a Link UP trigger and switch from the previous interface to the new interface. To have this feature, we need to keep the communication protocol and link down only the radio system.

A handover is basically initiated by network, but station initiated handover is used when network initiated handover is unavailable, such as sudden degradation of link quality between an MD and the AP. The MD decides a handover, connects to a new AP, and sends a Link Up trigger to the ESW. The MAC Address Replacement Request message is also delivered to the CSS following the path to the GSW. The MD also sends a measurement report to notify the CSS of handover completion after the interface switch. This notification is not a trigger of a network initiated handover but a measurement report for location update.

In the case of the network initiated handover, the network can predict next AP for an MD and prepare a link beforehand. This is an advantage over the station initiated handover for real-time applications.

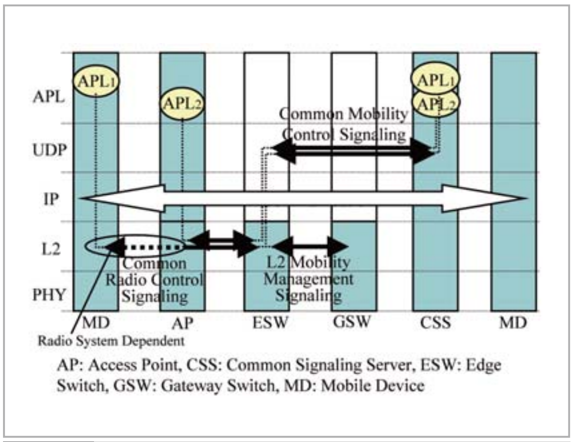

Fig.3 *Signaling Model*

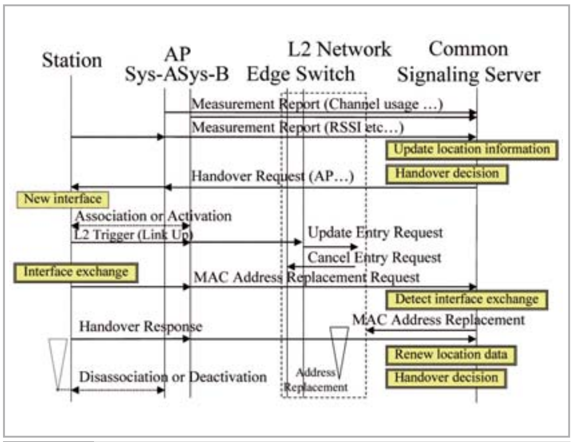

Fig.4 *Network Initiated Handover*

4 Evaluation

We evaluated the performance of real-time vertical handover and its latency between the W-CDMA (3 G) /IEEE802.11b (WLAN).

Figure 5 shows the experimental environment. There are one 3 G AP and one WLAN AP outside and the 3 G AP is placed on the roof of a building and its coverage area includes whole area where the MD moves. The MD has 802.11 WLAN and 3 G interfaces, and it can select an adequate interface according to a usage policy. In this experiment, the MD measures the link quality between the MD and a WLAN AP every 3 seconds for the handover indicator using wireless extension on Linux. The WLAN interface is used when the link quality is above a Han-

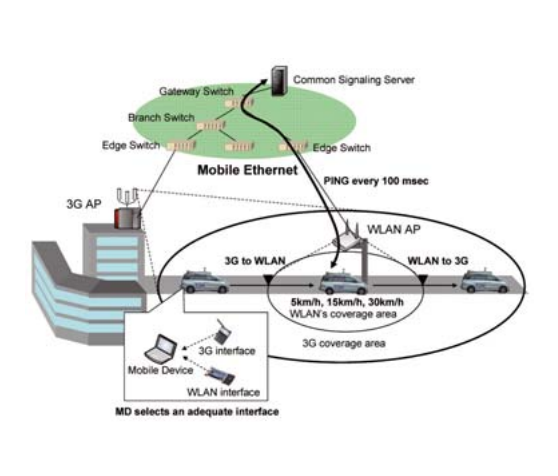

Fig.5 Overview of the experimental environment

Table 1 The number of packet loss in handover

(a) From 3G to WLAN

		Speed (km/h)		
		5	15	30
HIT	20	1	100	26
	40	1	5	-

(b) From WLAN to 3G

		Speed (km/h)		
		5	15	30
HIT	20	31	56	86
	40	1	19	-

dover Initiating Threshold (HIT), and the 3 G interface is used when the link quality is below the HIT.

We measured the number of packet loss during vertical handover. For packet loss measurement, we used ICMP echo messages with its sending interval 100 millisecond. To cause handovers, we moved from the 3 G only area, via just nearby the WLAN AP, to the other side of the 3 G only area. We used a car to make the moving speed kept constant in 3 patterns; 5 km/h, 15 km/h and 30 km/h. In this handover, we took a look at handover behaviors in two HIT parameters; 20 and 40.

Table 1 show the packet loss in handover from 3 G to WLAN and from WLAN to 3 G, respectively. The results are averaged by 10 measurements. The results revealed that the packet loss in HIT at 40 is relatively low. This is because the MD handover from WLAN to 3 G before the WLAN link quality goes worse. It takes about 8 to 9 seconds for 3 G network interface to establish network connection, so that there is possible that the WLAN link quality is changed to be worse not enough to communicate without packet loss during a 3 G connection establishment. Especially in the results of HIT at 20, we could find such kinds of cases.

(a) From 3 G to WLAN
(b) From WLAN to 3 G

For the purpose of only reducing packet loss, it is better to use a higher HIT. However it narrows the access area of WLAN, which loses user's chances to access high speed network. Therefore, in this issue, there is a trade-off to decide which we put weight on, stable quality with few packet loss or longer connection to wide bandwidth network.

No handover occurred in HIT at 40 and speed at 30 km/h because the MD could not detect higher link quality than the HIT within its scan interval of the link quality due to its fast speed. The less the scan interval is, the higher the preciseness of the link quality in MD becomes. However, frequent link scan consumes much electric power which causes shorter running time of mobile devices working with limited battery power. On the other hand, it might not be practical to use WLAN with narrow access area moving at a high speed because the time MDs can connect to WLAN is only about 10 to 20 seconds at 30 km/h.

5 Conclusions

We explained the Mobile Ethernet architecture and its common radio signaling scheme deploying the network initiated handover and evaluated the real-time vertical handover performance in the outdoor mobile environment on the practical Mobile Ethernet having 3 G and WLAN wireless systems. We achieved seamless handovers between the two radio systems in case of higher handover threshold and slow speed movement. However, while which to take wide WLAN access area or packet reduction is a trade-off issue, we need to find a way to configure the best threshold dynamically depending on applications and environments.

In near future, we will solve the issues and apply the Mobile Ethernet technology including paging feature to the next generation radio systems called 4 G. It is also necessary to find out other information candidates to trigger handover than the link quality.

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