Vertical Handovers in Multiple Heterogeneous Wireless Networks: A Measurement Study for the Future Internet

Youngbin Im
Seoul National University
ybim@mmlab.snu.ac.kr

Hakyung Jung
Seoul National University
hkjung@mmlab.snu.ac.kr

Ji Hoon Lee
Seoul National University
jhlee@mmlab.snu.ac.kr

Wonjun Yoon
Seoul National University
wjyoon@mmlab.snu.ac.kr

Ted “Taekyoung” Kwon
Seoul National University
tkkwon@snu.ac.kr

Yanghee Choi
Seoul National University
yhchoi@snu.ac.kr

ABSTRACT

As the access patterns of mobile users are diverse and their traffic demand is growing, multiple wireless access networks become dominant and their coexistence will be the norm in the future Internet infrastructure. To evaluate protocols and algorithms in these heterogeneous wireless networking environments, testbed-based experiments are of crucial importance since mathematical modeling and simulation cannot reflect the high complexity of systems and wireless link dynamics sufficiently. Leveraging femtocell technologies, we propose and build a testbed in which WiFi access points and WiMAX base stations are integrated. We also implement the vertical handover functionality through the SIP protocol, and carry out comprehensive measurements to analyze vertical handover delays. The testbed measurements of vertical handovers reveal that the DHCP mechanism, the authentication process in WiMAX, and the probing process in WiFi incur substantial delay.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless communication

General Terms

Experimentation, Measurement

Keywords

heterogeneous wireless network, wireless testbed, vertical handover, femtocell, WiMAX, WiFi

1. INTRODUCTION

Wireless access networks will be a key factor in the future Internet since no wiring for end user increases convenience and provides mobility and ubiquity. Various wireless networks - HSPA, WiFi, WiMAX, Bluetooth, etc - already have been widely deployed, and most devices are equipped with multiple interfaces, e.g., HSPA, WiFi, Bluetooth in iPhone. Furthermore, new wireless technologies are under standardization, e.g., LTE, LTE-Advanced, WiMAX-Evolution. A lot of new protocols and algorithms will appear in such heterogeneous network environments to improve the performance of the current technologies or to enable new technologies. However, due to the distinct characteristics of different wireless access networks, new kinds of problems will happen. For example, selecting which access network to use will be one of the main research issues. When multiple access networks are available, the interface selection is closely relevant to network performance as well as other metrics such as cost, energy efficiency. Another key issue is how to reduce the disruption when a mobile host moves across different networks since a handover between different networks takes longer than a handover in the same network.

Prior studies for the above problems in the heterogeneous networks have been carried out mainly through mathematical analysis, simulation, and commercial network measurement. Mathematical analysis and simulation cannot reflect the unpredictable dynamics of real wireless networks. Moreover, the environment where multiple wireless networks coexist makes the mathematical analysis difficult due to the high complexity. In the case of commercial network measurement, experimenters are often unable to access or control the network infrastructure directly. In addition, it has a limitation that the experimenter can control only his/her own traffic but not the traffic of real users which may have an effect on the result. On the other hand, experimenters of a testbed have an advantage that they can carry out tests with real wireless link dynamics, control the network infrastructure directly, and configure the other traffic easily.

The existing testbeds have their own limitations. PlanetLab [1], VINI [2], Emulab [3] focus on wired network experiments, and ORBIT [4], MIT Roofnet [5] testbeds are built by WiFi technologies only. In these testbeds, it is hard or impossible to conduct tests of complex scenarios that involve heterogeneous wireless networks. Therefore, we need a testbed where various wireless networks are integrated, so that validation of new algorithms and protocols by the actual measurements is possible.

In this paper, (1) we propose and build a testbed in which WiFi access points and WiMAX femtocell base stations can be integrated. (2) We implement the vertical handover functionality by making the SIP protocol undertake (application layer) mobility management. (3) We carry out comprehen-

CFI ’10 June 16–18, 2010, Seoul, Korea

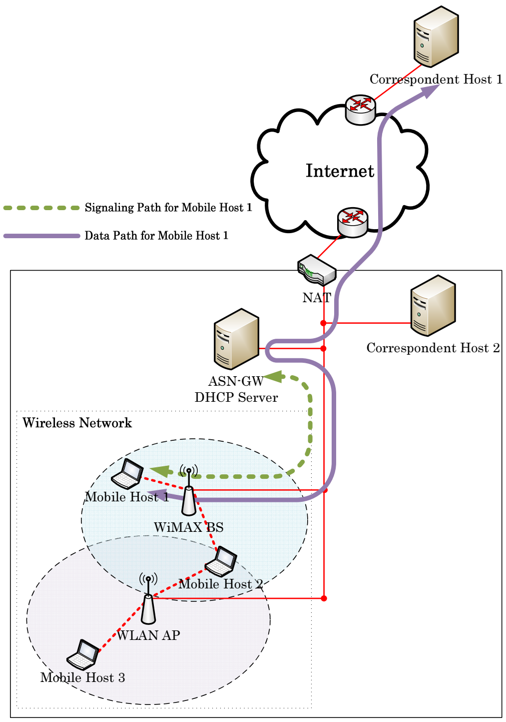

Figure 1: Testbed architecture

sive measurements to break down vertical handover delays. Even though heterogeneous networks using the SIP protocol have been studied in [6] [7], our work has a contribution in that this is the first measurement study of vertical handovers between WiMAX and WiFi using SIP in a real testbed.

The rest of this paper is organized as follows. Section 2 details how we build the testbed. The handover measurement results are analyzed in Section 3, and we conclude this paper in Section 4.

2. TESTBED ARCHITECTURE

As shown in Fig. 1, our testbed consists of mobile hosts, one WiFi access point (AP), one WiMAX base station (BS), one WiMAX ASN-GW (Access service network gateway), and correspondent hosts.

A mobile host is a laptop computer equipped with a WiFi and a WiMAX network interface cards (NICs). We use an IBM ThinkPad R40 2681 notebook for the mobile host, which has an Intel Pentium 4-M 1.9 GHz processor, 512MB memory, and Ubuntu 8.04 operating system. We use a Linksys WUSB600N Dual-Band Wireless-N USB Network Adapter [8] for the WLAN NIC and a Seowon Intech m-WiMAX USB Modem [9] for the WiMAX NIC. The mobile host is connected with the WLAN AP or WiMAX BS. We use a 3Com OfficeConnect Wireless 11g Cable/DSL Router [10] for the WiFi AP, and use a JFW-600 Indoor HotSpot MAX [11] for the WiMAX BS.

When a mobile host is connected to the WiMAX femtocell base station, it communicates with the correspondent host through the ASN-GW. In the case of commercial WiMAX networks, an ASN-GW is connected to a Connectivity Service Network (CSN) which provides management functions such as AAA, billing, policy and admission control. In our testbed, we use an Aricent WiMAX Integrated Gateway (WING) [12], which combines the ASN-GW and the CSN functionalities. In the case of mobile host 1 in Fig. 1, its data path consists of [mobile host 1, WiMAX BS, ASN-GW, and correspondent host]. The mobile host sends packets, which are encapsulated by the WiMAX BS. The encapsulated packets are forwarded to the ASN-GW, which decapsulates and forwards the packets to the correspondent host. In the reverse direction, the ASN-GW encapsulates packets from the correspondent host and the WiMAX BS decapsulates them. The tunneling between the WiMAX BS and the ASN-GW is needed to reroute packets to the mobile host even if it changes the currently communicating BS due to its mobility. The ASN-GW will participate in the network entry and connection establishment of mobile hosts. A DHCP server for assigning IP addresses to mobile hosts is co-located with the ASN-GW. So the signaling messages for the network entry and connection establishment and IP address acquisition are processed along the signaling path as shown in Fig. 1.

According to test scenarios, correspondent hosts can be positioned in the local network or across the Internet. We place two correspondent hosts: one host in the same testbed at Seoul National University (SNU) in Korea and the other host at the PlanetLab site at Princeton University in the US to evaluate the effect of geographical distances.

Data or signaling messages can be observed in many positions in the testbed. IP packets can be dumped at mobile hosts, ASN-GW, and correspondent hosts. To observe WiMAX signaling messages, we also modified the WiMAX NIC driver so that we can record the moments at which WiMAX layer2 signaling processes are done.

3. PERFORMANCE EVALUATION

3.1 Experimental Setup

In order to analyze the handover delay when a mobile host (MH) moves through heterogeneous wireless networks, we measured the delay in mid-call mobility using SIP. We consider two mobility scenarios: 1) when an MH moves to a WiMAX network and 2) when an MH moves to a WiFi network.

We used PJSIP [13] for implementation of SIP mid-call mobility, and tcpdump [14] for the delay measurement. The packet transmissions and receptions are visualized by WireShark [15]. We calculated the time duration for each step during a vertical handover by observing the message flow. Our experiments were conducted over the topology shown in Figure 1. An MH is configured to have both WLAN and WiMAX connectivities. The WLAN connectivity is tuned to channel 11 in 2.4 GHz band, and the center frequency of 10 MHz channel for the WiMAX connectivity is set to 2.518 GHz. We consider two locations of correspondent hosts (CHs) in LAN and WAN environments.

To measure the network entry, connection establishment, and IP address acquisition delay in WiMAX, we manually initiate the layer2, layer3 signaling part of the handoff procedure using a WiMAX connection management program. To measure the probing, authentication, association, IP address acquisition delay in WLAN, we use WLAN system commands.

To measure the SIP mobility management delay, we run a

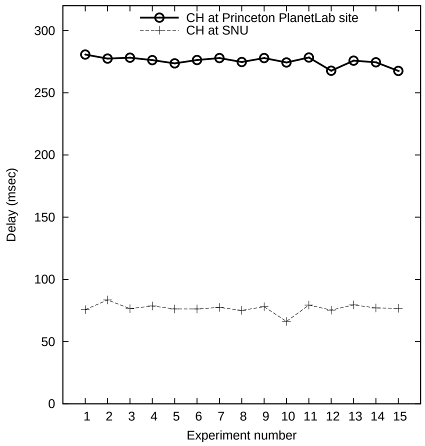

Figure 2: SIP re-establishment delay in WiMAX

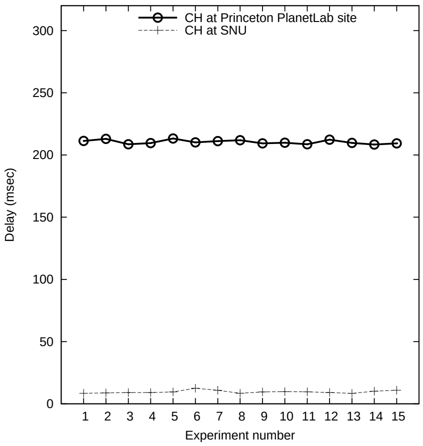

Figure 3: SIP re-establishment delay in WLAN

program (using PJSIP interfaces) by which the MH and the CH make a voice call using RTP/RTCP. After a connection is established, RTP packets of 214 bytes and RTCP packets of variable sizes are continuously transmitted in both directions between the MH and the CH. For each vertical handover, we intentionally initiate the SIP re-establishment process and measure the SIP message exchange delay. Note that the SIP messages experience different delays depending on the location of the CH.

3.2 Experimental Results

3.2.1 WiMAX handover delay

Table 1 is the measurement result of the delay when an MH enters the WiMAX network. We measured the handover delay 15 times. As shown in Table 1, WiMAX network entry and connection establishment take almost constant time around 750 and 150 msec, respectively. The reason why the WiMAX network entry and connection establishment take almost constant time can be explained like this. First, the channel condition of our experiments is good, and hence there is almost no retransmission. Second, due to the relatively long frame structure (5 msec WiMAX frame length is longer than the delay jitter between the BS and the ASN-GW), the delay variation in the wired part is diminished. In the case of WiMAX network entry delay, EAP process takes a large part. There is a huge delay in the IP address acquisition process. The reason is that the DHCP client should wait a random time ranging from one to ten seconds before sending the DHCP DISCOVER message according the DHCP RFC 2131 [16]. However, the implementation of the DHCP client software of Internet Systems Consortium in our testbed configures the MH to choose the waiting time between 0 and 5 seconds.

Fig. 2 is the delay measurement results when the MH and the CH exchange SIP messages in order to use a newly assigned IP address in the WiMAX network. If the CH is located at Princeton University, the SIP re-establishment delay is around 280 msec. The SIP re-establishment delay for the CH in the local network (at SNU) is around 80 msec.

3.2.2 WiFi handover delay

Table 2 is the delay measurement results when the MH enters the WiFi network. We measured the vertical handover delay to WiFi 15 times. As shown in Table 2, probing in IEEE 802.11 WiFi networks takes almost constant time around 1.65 seconds. During the probing process, the MH waits for Probe Response frames from APs for a predefined time for each channel. Due to the fixed number of channels, the probing time becomes constant. Authentication and association delays take almost negligible time. The reason is that authentication and association each require transmission of two messages. IP address acquisition of a WiFi handover takes the similar time to that of a WiMAX handover. Again, the random wait time between 0 and 5 seconds plays the dominant role in the handover delay.

Fig. 3 plots the SIP re-establishment delay when the MH and the CH exchange SIP messages over the WiFi network. Obviously, the SIP delay with the CH at Princeton University takes much longer time than the CH in the local network. However, note that the SIP signaling delays in the WiFi network are shorter than those of the WiMAX network from Figs. 2 and 3. The WiMAX network takes time to allocate the slot for the MH to send messages in uplink. Also, there are dedicated downlink and uplink portions in a TDD frame in the WiMAX network, which incur additional delay.

4. CONCLUSIONS

The existing network testbeds either focus on wired networking part or consider only a single wireless technology. However, the coexistence of multiple wireless access technologies will change the Internet access patterns and hence evaluation of new protocols and algorithms in a heterogeneous network testbed is crucial. In this paper, we propose and build a testbed in which WiFi access points and WiMAX femtocell base stations can be integrated. We also implement the vertical handover functionality through the SIP protocol, and conduct measurement experiments for the analysis of vertical handovers. We consider two vertical handover scenarios: (1) handover to a WiMAX network, and (2) handover to a WiFi network. The authentication process in WiMAX alone takes longer than 0.5 second and the probing process in WiFi takes longer than 1.5 second. Compared to these processes, IP address acquisition by DHCP incurs a huge delay (up to several seconds) due to random waiting

Table 1: WiMAX handover delay in layers 2 and 3 (Unit:msec)

	mean	stddev	max	min
WiMAX Network Entry (Before EAP)	140.70	3.22	146.97	134.22
WiMAX Network Entry (EAP)	613.44	5.51	631.90	606.16
WiMAX Network Entry (After EAP)	4.04	0.12	4.38	3.84
WiMAX Network Entry (Total)	758.18	6.64	778.35	751.01
WiMAX Connection Establishment	151.51	3.31	161.37	146.40
IP Address Acquisition	2167.87	1319.92	4523.00	529.00

Table 2: WiFi handover delay in layers 2 and 3 (Unit:msec)

	mean	stddev	max	min
Probing	1653.40	1.12	1655.00	1652.00
Layer-2 Signaling (Authentication)	0.33	0.27	0.95	0.19
Layer-2 Signaling (Association)	0.82	0.87	2.95	0.37
Layer-2 Signaling (Total)	1.15	1.14	3.75	0.55
IP Address Acquisition	2126.27	1248.86	3831.00	60.00

time. We leave reducing these delays as future work.

5. ACKNOWLEDGMENTS

This work was supported by NAP of Korea Research Council of Fundamental Science & Technology. The ICT at Seoul National University provides research facilities for this study.

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