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モバイルWiMAXにおけるIPv6とNEMOの性能評価

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近年，次世代無線技術として広範囲・高速通信サービスを提供できるWiMAXが注目を浴びている．慶應義塾大学ではその適合性を検証するためにモバイルWiMAX (IEEE 802.16e) のテストベットを構築し，実証実験を行っている．本論文では，モバイルWiMAX上でIPモビリティサービスを提供できるかどうかを検証するために，モバイルWiMAX上でのIPv4やIPv6，Network Mobilityの通信品質やモバイルWiMAXとWi-Fi間でのメディアハンドオーバ時の通信品質に関しての評価を行った．その結果，WiMAX上でNetwork Mobilityを動作させることに成功したが，将来WiMAX上でIPモビリティサービスを提供するにはIPv6ネイティブやシームレスハンドオーバといった技術が必要である．

Performance Evaluation of IPv6 and NEMO technologies over Mobile WiMAX testbed

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WiMAX provides broad coverage area and high bandwidth. It is one of the candidates for the next generation wireless technologies. A mobile WiMAX testbed is operated in Keio University and we have started demonstration experiment in order to investigate IP compatibility of this next generation wireless system. In this paper, we analyze the measured data of network performance of IPv4, IPv6 and Network Mobility over mobile WiMAX and that of media handover performance between mobile WiMAX and Wi-Fi on our real testbed. As a result, although we successfully operated the Network Mobility protocol over WiMAX, we need more efforts such as IPv6 native service over WiMAX and seamless handover IP technology support to achieve the future IP mobility service over WiMAX.

1. Introduction

Mobile computing becomes reality due to the progresses of wireless technologies and mobility technologies. In fact, many users have already obtained advantages of connecting to the Internet over wireless network and cellular networks. Wi-Fi is surely deployed everywhere, but its coverage area is limited to a few hundred meters and its communication quality is not stable due to collision and channel congestions. It is because Wi-Fi is operated with the ISM band (2.4 GHz) and installed easily without any licenses.

As new wireless services, the government has recently announced radio frequency assignment for the next generation wireless broadband technologies. WiMAX is one of the candidates and is currently tested by several companies and industries. WiMAX provides larger coverage than Wi-Fi and higher data transmit speed than current cellular systems. In addition, WiMAX is designed to use IP for the operation and has better compatibility with the IP networks. Moreover, IP mobility technologies have been aggressively considered as a core protocol by several Standards Development Organizations (SDO) such as 3GPP/3GPP2 and WiMAX Forum [1]. We finally face to the deployment stage of IP mobility technology after the decade development and discussion phase.

Keio University has been working on development of IP mobility technologies and tested them over many wireless systems such as DoPa, Wi-Fi, CDMA2000 1x EvDO, HSDPA and PHS systems [2]. We have experimented IP mobility over WiMAX (Mobile WiMAX, IEEE 802.16e) with eAccess Ltd. who acquired a WiMAX field test license from the government. In this paper, we report the performance of IPv4, IPv6 and Network Mobility protocol over WiMAX.

The remainder of this paper is organized as follows. Section 2 describes the technologies of WiMAX and Network Mobility. Section 3 illustrates our testbed topology. We analyze WiMAX network performance using IPv4, IPv6 and the Network Mobility protocol in Section 4. We also investigate media handover performance between WiMAX and Wi-Fi in Section 5. We make a conclusion in Section 6.

2. Overviews of WiMAX and Network Mobility

2.1 WiMAX

Mobile WiMAX is based on the IEEE 802.16e-2005 [3] (802.16e) standard that defines MAC and Physical (PHY) layer to cover wide area with mobile broadband wireless access services. IEEE 802.16 Working Group was established for the standardization of Wireless MAN (Metropolitan Area Network). The Working Group developed the IEEE 802.16-2004 for a fixed wireless access (FWA) system which delivers Point-to-Multipoint connectivity between a base station and subscriber stations. 802.16e is the expansion of IEEE 802.16-2004 mainly for the enhancement of mobility features such as handover. WiMAX Forum, which was launched by key equipment companies and operators, promotes the compatibility and interoperability of the products based on 802.16e. WiMAX Forum provides certification through testing process to ensure that different vendor equipment work seamlessly with one another. WiMAX Forum also defines the upper layer architecture of 802.16e for the operation of WiMAX system.

Mobile WiMAX is expected to operate at the speed of up to 120 km/h. A single base station can cover from several hundred meters to a few kilometers as large as cellular systems, having capability of the Internet access with high speed, more than 20 Mbps with 10 MHz channel bandwidth. 802.16e technology has a flexible and simplified architecture to achieve high compatibility with all-IP network.

As shown in Figure 1, Convergence Sublayer (CS) assists to fit the IP architecture system. Multiple CSs are provided for the interface with various protocols such as IPv4 CS and IPv6 CS. The format of the CS payload is unique to the CS, and the MAC Common Part Sublayer (MAC CPS) is not required to understand the format of any information from the CS. Thus, IPv4 and IPv6 network can be supported over same architecture of 802.16e.

In this evaluation, we utilized the 802.16e compliant prototype system based on the system requirement of Mobile WiMAX in Japan as shown in 1.

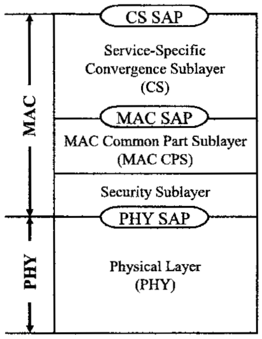

Figure 1 Protocol stack of 802.16e-2005

Table 1 System specification

Item	Spec.
Frequency	2.5 GHz
Bandwidth	10 MHz
Duplex	TDD
Multiplexing	OFDMA
FFT size	1024
Frame length	5 msec
Transmit power (Base Station)	43 dBm max
Transmit power (Mobile Station)	23 dBm max

2.2 Network Mobility

Network Mobility (NEMO) has been standardized as RFC3963 [4] by the Network Mobility (NEMO) Working Group in the Internet Engineer Task Force (IETF). The NEMO Basic Support protocol, an extension to Mobile IPv6 [5], allows a whole network to move and change its point of attachment to the Internet with movement transparency. A new entity, a mobile router, takes care of all the signaling and establishes a tunnel to its home agent. The goal of the NEMO Basic Support protocol is to hide mobility of the mobile router completely from the nodes in a mobile network. Any types of nodes can attach to the mobile network without awareness of the NEMO Basic Support protocol. Figure 2 shows movement of a mobile network.

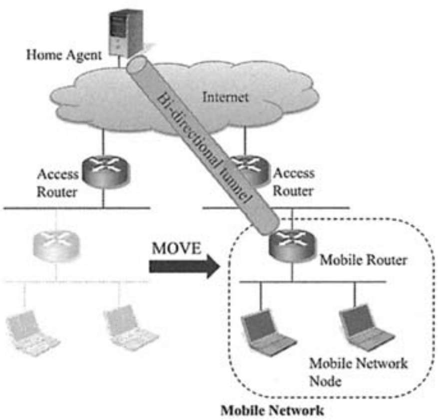

Figure 2 Network Mobility

As similar to Mobile IPv6, the mobile router has the permanent home address and its permanent mobile network prefix. The mobile network prefix is delegated from its home network (i.e., from its home agent) and assigned to the mobile network. The mobile router sends to its home agent a binding update including its home address and the mobile network prefix and establishes a bi-directional tunnel as same as Mobile IPv6. The home agent intercepts the packets not only destined to the home address but also to the mobile network prefix. The packets from any nodes inside the mobile network are tunneled to the home agent by the mobile router. Whenever the mobile router changes its attachment, it updates the binding information and the tunnel end-points so that the mobile network is always reachable with the same prefix (i.e., mobile network prefix).

The NEMO Basic Support protocol is expected to deploy in transportation systems such as trains, automobiles and buses. Passengers will get Internet reachability from a mobile router installed in each vehicle. In the WIDE project, we have implemented the NEMO Basic Support protocol on NetBSD. This implementation has been confirmed interoperability with several other implementations provided by different organizations. We also demonstrated and evaluated the NEMO Basic Support protocol several times [6].

3. Testbed Topology

Figure 3 shows the network topology of our testbed and Table 2 shows the specification of each equipment.

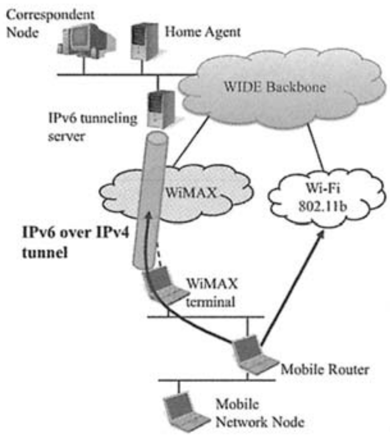

Figure 3 Network topology of our testbed

As the wireless network access technologies, mobile WiMAX and Wi-Fi (IEEE 802.11b) are used. A home agent and a correspondent node are placed at Keio University over the WIDE IPv4 and IPv6 Backbone network. A Wi-Fi access point is setup with the native IPv6 network, but the WiMAX infrastructure installed in Keio University is operated with

Table 2 The specification of each equipment

machine	CPU	memory	OS
Correspondent Node	AMD sempron(TM) Processor 2800+	1 GB	FreeBSD 6.2
Home Agent	Intel(R) Celeron(R) CPU 2.66 GHz	512 MB	NetBSD 4.99.4
IPv6 tunneling server	Genuine Intel(R) CPU	1 GB	Windows XP
WiMAX terminal	Intel(R) Xeon(TM) CPU 3.60 GHz	3 GB	Windows XP
Mobile Router	Intel(R) Pentium(R) M processor 1400 MHz	256 MB	NetBSD 4.99.4
Mobile Network Node	Intel(R) Pentium(R) M processor 1400 MHz	256 MB	NetBSD 4.9.22

IPv4. Wireless mobility services are expected to use IPv6 due to enormous number of mobile terminals and mobility protocols developed in Keio University are based on IPv6. IPv6 transition mechanism requires to operate IPv6 mobility service in the existing wireless access networks, though mobile operators may switch to the native IPv6 service in their wireless access networks in the near future. An IPv6 over IPv4 tunnel is selected for our WiMAX testbed. An IPv6 tunneling server which is an IPv4/IPv6 dual stack router establishes the IPv6 over IPv4 tunnel to the WiMAX terminal. The IPv6 over IPv4 tunnel is established by using the *netsh* command for IPv6 interface. Any WiMAX terminals can send IPv6 packets over the tunnel.

A PCMCIA card for WiMAX is used in this experiment. While the device driver for the WiMAX card is not available for NetBSD, our mobile router is developed on NetBSD. Therefore, in this experiment, the WiMAX terminal (which is a Windows XP machine) is treated as a wireless bridge to connect the mobile router to the Internet over WiMAX. On the other hand, we used a wireless LAN card (PC Card Type II) for 802.11b. The device driver for this card is available for NetBSD and the mobile router is able to connect directly to the Internet over 802.11b.

A WiMAX base station and an antenna are installed on the rooftop of the building in the center of Keio SFC campus. The base station is the 802.16e compliant system with 10 MHz channel in 2.5 GHz band. In order to ensure robust wireless communication, we used the lowest modulation: QPSK 1/2 for both downlink and uplink. As for a frame format, 30 subchannels are assigned for downlink and 8 subchannels are assigned for uplink, in which we fixed these subchannels and modulation for wireless nodes in order to operate. The maximum output power of this base station is 43 dBm and the antenna gain is 14 dBi. The maximum output power of the WiMAX PCMCIA card is 23 dBm.

4. Network Performance

In this section, we compare the network performance of IPv4, IPv6 and the Network Mobility protocol over WiMAX.

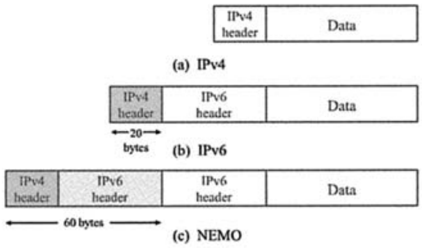

Figure 4 Packet headers

Figure 4 shows the packet headers in IPv4, IPv6 and Network Mobility communication. An IPv6 packet is encapsulated in an IPv4 packet at the end points of IPv6 over IPv4 tunnel, and an IPv4 header (20 bytes) is added (in Figure 4(b)). In addition, in Network Mobility communication an IPv6 packet is encapsulated in an IPv6 packet due to bi-directional tunnel between the mobile router and its home agent as explained in Section 2. 2. An IPv4 header and an IPv6 header (20 + 40 bytes) are added (in Figure 4(c)).

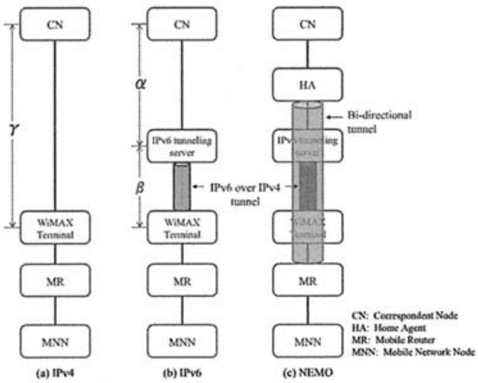

Figure 5 Path between MNN and CN

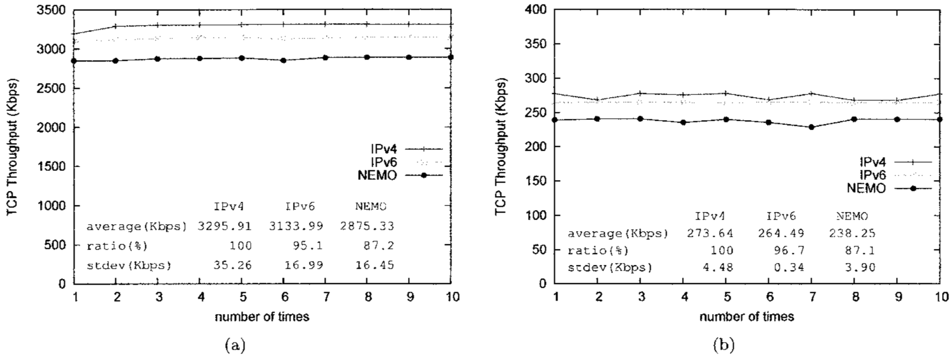

Figure 6 TCP throughput on (a) downlink and (b) uplink

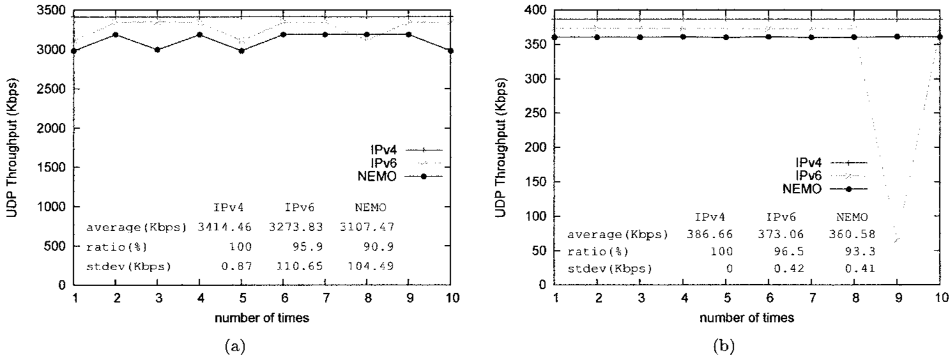

Figure 7 UDP throughput on (a) downlink and (b) uplink

Figure 5 shows the path of between the mobile network node and the correspondent node. An IPv4 packet is routed to the destination directly (in Figure 5(a)). This route is an optimal path. On the other hand, an IPv6 packet is routed to the IPv6 tunneling server and forwarded to the destination through the IPv6 over IPv4 tunnel (in Figure 5(b)), and so this path is one hop longer than IPv4 path. A packet in Network Mobility is routed to the home agent and the IPv6 tunneling server (in Figure 5(c)) and forwarded to the destination through the bi-directional tunnel and IPv6 over IPv4 tunnel, and so this path is two hops longer than IPv4 path. Thus, packets take a non-optimal path, which is inefficient compared to a route computed by normal Internet routing mechanisms. As shown in Figure 5, we assume that the distance between the correspondent node and the IPv6 tunneling server is α and the distance between the IPv6 tunneling server and the WiMAX terminal is β with IPv6. And the distance between the correspondent node and the WiMAX terminal, which is an optimal path, is γ with IPv4. In IPv6 communication, the distance between the correspondent node and the WiMAX terminal is $\alpha + \beta$ because a packet is routed to the IPv6 tunneling server. The more distant the location of the IPv6 tunneling server is, the more $\alpha + \beta$ increase and the greater the difference between $\alpha + \beta$ and γ is (i.e., $\alpha + \beta >= \gamma$). Consequently, we analyze the effect of the header overhead and the non-optimal path from the experimental results of the network performance.

Figures 6 and 7 show TCP and UDP throughput when the mobile router uses WiMAX. Throughput, which is between the correspondent node and the mobile network node with IPv6 and network mobility and between the correspondent node and the WiMAX terminal with IPv4, is measured using netperf [7] which is a benchmark software that can be used to measure the performance of many different types of networking.

We observe in Figures 6 and 7 that the IPv4 throughput is the highest of the three and the Network Mobility throughput is the worst. The experimental results show that the throughput deteriorates because of the header overhead and the non-optimal path. The ratio of the TCP throughput in Network Mobility to that in IPv4 is about 87 %, which is particularly bad performance. This is because that IP fragmentation of the TCP datagrams occurred at the home agent or the mobile router. Normally, IP fragmentation dose not occur due to the Path MTU discovery [8]. But, the Path MTU discovery is not correctly handled for Network Mobility due to multiple tunnels. The total packet size becomes bigger than the link MTU by adding an extra IPv6 header for bi-directional tunneling and IP fragmentation occurs. For example, on downlink each IPv6 packet is divided into two fragments at the home agent, and thereby each fragment must be encapsulated and decapsulated at the end points of the IPv6 over IPv4 tunnel. Then, these fragments are reassembled at the mobile router. In addition, if one of the fragments divided by IP fragmentation drops by error, the sender needs to retransmit the whole IP datagram. IP fragmentation has a significant influence on TCP throughput. To provide Network Mobility over WiMAX with high performance, if we configure the MTU size of the sender manually smaller than the minimum link MTU size, we can prevent IP fragmentation of TCP datagrams. However, it is difficult for the sender to detect that there are tunnels along the path to the destination and so this solution is not realistic.

We observe in Figure 7 that the standard deviation of UDP throughput on downlink is just about 0 Kbps with IPv4 but is nearly 100 Kbps with IPv6 and the Network Mobility protocol. This is because that it takes time to encapsulate or decapsulate packets at the end points of the IPv6 over IPv4 tunnel and the bi-directional tunnel. Thus, the packet delay jitter increases in such a bursty traffic environment.

Consequently, throughput degrades when we communicate with a tunnel and tunneling is not appropriate way for the operation of Network Mobility from the header overhead and the non-optimal path point of view. WiMAX can be operated with the IPv4 and IPv6 service according to circumstances as mentioned in section 2. 1. Therefore, IPv6 service should be delivered in order to provide Network Mobility over WiMAX with high performance, not using the IPv6 over IPv4 tunnel.

5. Media Handover

We measured the Round Trip Time (RTT) and the number of packet losses in media handover. Network topology is the same as shown in Figure 3 and the communication areas over WiMAX and Wi-Fi are shown in Figure 8. We moved at speed of 10-20 km/h along a circular path by COMS (an electric vehicle). The photo of COMS and experimental equipments is shown in Figure 9.

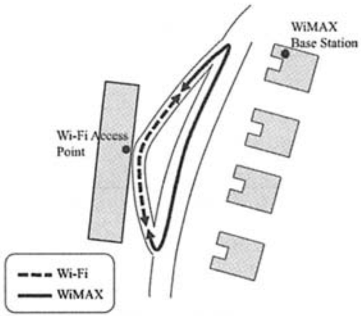

Figure 8 The communication areas over WiMAX and Wi-Fi

Figure 9 COMS and Experimental Equipments (WiMAX terminal, Mobile Router and Mobile Network Node)

Figure 10 shows the RTT between the correspondent node and the mobile network node while the mobile router switches the media between WiMAX and Wi-Fi. The Received Signal Strength Indication (RSSI) of Wi-Fi with the *wiconfig* command triggers a media handover. The mobile router switches from Wi-Fi to WiMAX when the RSSI value changes less than or equal to -69 dBm and from WiMAX to Wi-Fi when the RSSI value changes greater than or equal to -49 dBm. The RTT is measured every 0.01 sec by sending 56 bytes ICMP6 echo request and reply messages with the *ping6* command. The average RTT of WiMAX is 47.0 msec, while that of Wi-Fi is 3.1 msec.

Whenever the mobile router switches the media, a Binding Update (BU) message and a Binding Acknowledgement

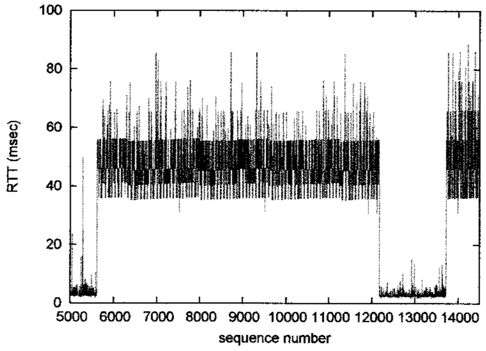

Figure 10 RTT during media handover

(BA) message are exchanged between the mobile router and the home agent for the binding registration. During the binding registration, the mobile router temporarily disables the tunnel until it receives the BA. When the mobile router switches from Wi-Fi to WiMAX, 3.2 packets are lost in average and the total time for the binding registration is 47.4 msec in average. Consequently, this result shows the mobile router is smoothly switching form Wi-Fi to WiMAX. On the other hand, when a mobile router switches from WiMAX to Wi-Fi, 10.6 packets are lost in average and the total time for the binding registration is 4.4 msec in average. Although the total time for the binding registration in switching from WiMAX to Wi-Fi is shorter than that from Wi-Fi to WiMAX, the number of packet losses is greater. In switching from WiMAX to Wi-Fi, BU sent over Wi-Fi arrives faster than ICMP6 echo reply messages sent over WiMAX due to the long RTT of WiMAX. Because the previous bi-directional tunnel is tore down once the home agent receives BU, the home agent cannot receive these ICMP6 echo reply messages and packet loss occurs. Moreover, the mobile router switches the media in 100 msec. The media handover latency depends on the binding registration time which can be estimated by the RTT between a mobile router and a home agent. There are another technologies to shorten this latency such as Fast Handovers for Mobile IPv6 (FMIPv6) [9] and multiple care-of address (MCoA) [10].

6. Conclusion

This paper has presented two experiments, protocol evaluation and media handover over WiMAX.

First, we measured TCP and UDP throughput on IPv4, IPv6 and Network Mobility over WiMAX. According to the experiment, we found that the throughput with IPv6 and the Network Mobility protocol deteriorates because of the tunneling processing and the non-optimal path.

Secondly, we measured the RTT and the number of packet losses in media handover between WiMAX and Wi-Fi. There is a difference between the RTT of WiMAX and that of Wi-Fi, and thereby there is a problem that several packets drop in media handover. Moreover, the mobile router switches the media in 100 msec which is not negligible for seamless handover. For this purpose, there are another technologies to shorten this latency such as FMIPv6 and MCoA. We may apply these extensions in future experimentations.

Consequently, although we successfully operated the Network Mobility protocol over WiMAX, we need more efforts such as IPv6 native service over WiMAX and seamless handover IP technology support to achieve the future IP mobility service over WiMAX.

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