MITSUBISHI ELECTRIC RESEARCH LABORATORIES
http://www.merl.com

Location Aware Fast Handover Between WiMax and WiFi Networks

Jianlin Guo, Tsutomu Tsuboi, Jinyun Zhang

TR2010-112 December 2010

Abstract

Next generation mobile communications will rely on integrated networks consisting of multiple wireless access technologies such as WiFi, WiMAX, GSM and UMTS. With variety of access technologies, mobile users want to take diverse advantage without any disruptions when they move from one place to another. Seamless handover in between homogeneous or heterogeneous wireless access networks will be a key to provide mobile users with required QoS. To achieve seamless handover in vehicular environment, total handover delay must be very short. This paper proposes a location aware fast handover technique for vertical handover between WiMAX and WiFi networks to minimize target network detection delay, select proper target network for handover and eliminate Ping-Pong effect. The proposed technique aims to reduce the total handover latency and can be applied to realize seamless handover between WiMAX and WiFi networks.

ITS World Congress 2010

LOCATION AWARE FAST HANDOVER BETWEEN WiMAX AND WiFi NETWORKS

Jianlin Guo
Principal Researcher, Mitsubishi Electric Research Laboratories
201 Broadway, 8th Floor, Cambridge MA 02139, USA
1-617-621-7541, guo@merl.com
Tsutomu Tsuboi
Senior Manager, Renesas Technology Corp.
Nippon Bldg. 2-6-2, Ote-machi, Chiyoda-ku, Tokyo 100-0004, Japan
81-3-5201-5063, tsuboi.tsutomu@renesas.com
Jinyun Zhang
Manager, Mitsubishi Electric Research Laboratories
201 Broadway, 8th Floor, Cambridge MA 02139, USA
1-617-621-7595, jzhang@merl.com

ABSTRACT

Next generation mobile communications will rely on integrated networks consisting of multiple wireless access technologies such as WiFi, WiMAX, GSM and UMTS. With variety of access technologies, mobile users want to take diverse advantages without any disruption when they move from one place to another. Seamless handover in between homogeneous or heterogeneous wireless access networks will be a key to provide mobile users with required QoS. To achieve seamless handover in vehicular environment, total handover delay must be very short. This paper proposes a location aware fast handover technique for vertical handover between WiMAX and WiFi networks to minimize target network detection delay, select proper target network for handover and eliminate Ping-Pong effect. The proposed technique aims to reduce the total handover latency and can be applied to realize seamless handover between WiMAX and WiFi networks.

INTRODUCTION

The key requirement of handover is to provide mobile users with desirable QoS when they roam from one network to another network. Handover procedure should be transparent to upper layer user applications. Continuation of user applications should be guaranteed. In other words, handover should be seamless. A handover can be initiated by either network side or mobile node (MN) side based on the decision maker algorithm. The handover process is no longer limited to the boundaries of a single access network. In fact, the emerging concept of Always-Best-Connected has blurred the line between different access networks. The handover can take place for cost, data rate, service availability, etc.

For seamless handover, network condition detection for handover decision, fast handover and connection maintenance are three key issues to be addressed. The network condition should always be made available by appropriate handover metric and handover decision algorithm. Network condition detection in vertical handover presents more challenges than it does in horizontal handover. Horizontal handover schemes in the homogeneous wireless networks can not be directly applied to vertical handover. In heterogeneous wireless network environment, there is no comparable signal strength existing to be utilized as vertical handover decision metrics due to the different physical techniques. It is further complicated by the fact that different wireless access technologies offer different QoS parameters such as available access bandwidth and access delay. When a mobile user moves from a large scale network such as WiMAX network to a small scale network such as WiFi network, since large scale network is usually always on, the handover can not be triggered by signal decay of serving network as in horizontal handover. Once the vertical handover decision has been made, the next key issue is to perform handover process as fast as possible such that the total handover latency is minimized. Vertical handover process is more complicated due to asymmetric network properties such as network entry procedures, link layer characteristics, link layer switching time, and authentication methods. After a vertical handover, mobility management is other key issue, which can maintain a connection's continuity. In vertical handover, mobility management mechanism must be able to properly maintain network connection continuity from one network to another network by adaptively applying different mobility management schemes.

This paper focuses on vertical handover between WiMAX and WiFi networks. WiMAX (based on IEEE 802.16 standards) is a broadband wireless access technology designed for metropolitan area networks. WiFi (based on IEEE 802.11 standards) is a wireless access technology for local area networks. A WiMAX base station (BS) covers an area whose radius is of the magnitude of several miles. A WiFi access point (AP) covers an area whose radius is about 100 meters. WiMAX performs better, but WiFi is more cost efficient. WiMAX and WiFi networks can be deployed considering their complementarities in terms of performance, cost, and coverage. WiMAX can guarantee user mobility in a large area, while WiFi is selectively deployed in hot spots with a concentration of mobile users and heavy network traffic. WiFi can also be deployed indoor or in tunnel to extend the coverage.

WiMAX and WiFi standards support mobility in vehicular speed [1], [2]. Horizontal handover mechanisms have been developed for both WiMAX and WiFi networks. Fast Base Station Switching and Macro Diversity Handover are two horizontal handover protocols proposed in WiMAX standard [1]. For WiFi, Fast Basic Service Set Transition and Fast Basic Service Set Transition Resource Request are defined as two horizontal handover protocols [3]. To complement WiMAX and WiFi's horizontal handover mechanisms, we have proposed the fast link layer handover protocols and high speed IP layer handover schemes for WiMAX and WiFi networks in [4]. This paper presents fast handover techniques to minimize target network probing delay for vertical handover between WiMAX and WiFi networks.

HANDOVER LATENCY

Handover latency is the consequent on the processing time involved in each step of the handover procedure. In general, total handover latency L_{HO} can be expressed as

$$L_{HO} = L_D + L_L + L_N \quad (1)$$

where L_D represents time used to detect target access network for handover, L_L represents link layer switching time and L_N represents network layer switching latency.

Target network detection is a very time consuming operation, especially in multi-channel wireless access networks such as WiFi and WiMAX networks. In WiFi networks, an AP may operate on any channel among the supported channels. For example, an IEEE 802.11a AP supports 12 channels. WiFi APs broadcast beacons typically every 100 milliseconds. A MN might need to scan through all operable channels in order to obtain network information from beacons. In homogeneous IEEE 802.11b networks, research shows that detection time is about 800 milliseconds [5]. The AP detection delay occupies the largest proportion of the L_D + L_L handover latency for horizontal handover in IEEE 802.11 networks [6]. WiMAX also supports multiple channels. In WiMAX networks, access to the channel is synchronized and network resource usage is controlled by the BSs, which broadcast downlink and uplink map messages typically every 5 milliseconds. The average time used by a MN to scan for downlink and uplink map messages from a 3 channel WiMAX BS is about 10 milliseconds.

Link layer handover delay includes time used for authentication, (re)association in WiFi, (re)registration in WiMAX, QoS negotiation, etc. In vertical handover, authentication time plays an important role in handover latency. IEEE 802.1X authentication could take seconds to complete [7]. A MN needs to be authenticated for each access technology while it roams. In vertical handover, each access technology may deploy its own authentication mechanisms. The impact of authentication time is more critical.

Network layer handover latency in IP network is affected by IP connectivity latency resulting from the time for movement detection, new IP configuration, and binding update. IP layer handover latency could last seconds [8].

To achieve seamless handover, total handover latency must be small. It has been pointed that the total delay should be no more than a few hundred milliseconds [9]. Therefore, it is critical to reduce the latency for each step of handover procedures. For horizontal handover in WiFi networks, [10] presented solutions to skip detection phase and a DeuceScan approach to reduce probe delay was proposed in [6]. This paper presents techniques to minimize detection delay for vertical handover between WiMAX and WiFi networks.

LOCATION UTILIZATION IN HANDOVER

Location information is very important for fast handover, especially in handover from a large scale network to a small scale network since a visit to small scale network is more likely short and a short visit may result in Ping-Pong effect. Location can be used to reduce network probing time, estimate connection time with candidate network, and select proper target network. The connection time can be used to avoid the Ping-Pong effect.

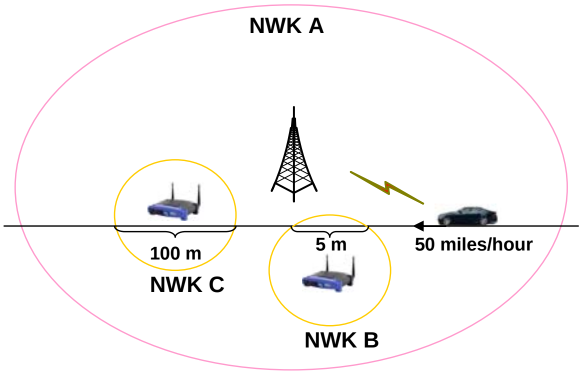

Figure 1 – A Heterogeneous Network Environment

Figure 1 shows a heterogeneous network environment consisting of three access networks and a car moves with a speed of 50 miles per hour along the path indicated. Network A is a large scale network overlapping two small scale networks B and C. Car is connected to network A. Networks B and C are ahead of the car along the moving path. A handover to network B will result in a Ping-Pong effect since the maximum connection time is about 225 milliseconds. If the car is handed over to network B, it needs to be immediately handed over back to network A. However, the maximum connection time to network C is about 4.5 seconds. Thus, network C is a proper candidate network for handover.

Location information has been utilized to achieve fast handover. For WiFi networks, a location based horizontal handover scheme was introduced to reduce handover latency [11]. A location aided vertical handover approach between UMTS and WiFi networks was proposed to support next generation system integration [12]. The location information is utilized in this paper to minimize network detection delay, avoid Ping-Pong effect and select proper target network for vertical handover between WiMAX and WiFi networks.

PROPOSED WiMAX AND WiFi NETWORK ENVIRONMENT

A basic requirement for vertical handover among heterogeneous access networks is the capability to detect and survey other networks. Dedicated scanning procedures are defined by the different access technologies. However, scanning has drawbacks like latency, power consumption, etc. Another way to obtain neighboring network information is to broadcast information periodically by serving network. This approach offers a great economic potential since scanning procedures can be minimized or skipped. WiMAX BSs supporting mobile functionality transmit neighbor BS information periodically in MOB-NBR-ADV management message for MN seeking initial network entry or handover [1]. Upon receiving a neighbor report request, WiFi APs return a neighbor report containing information about known neighbor APs that are roaming candidates for a service set transition [13]. However, WiMAX MOB_NBR-ADV message and WiFi neighbor report do not include information about overlaying or neighbor networks of a different type. This paper proposes a scheme to include neighbor network information of different types as well.

Research activities carried on in vertical handover context suggest the need for some modifications in the underlying network architectures [14]. We define a WiMAX-WiFi domain (WWD) as a connected geometric domain covered by a set of WiMAX BSs and WiFi APs. Figure 2 shows an example of the WWD.

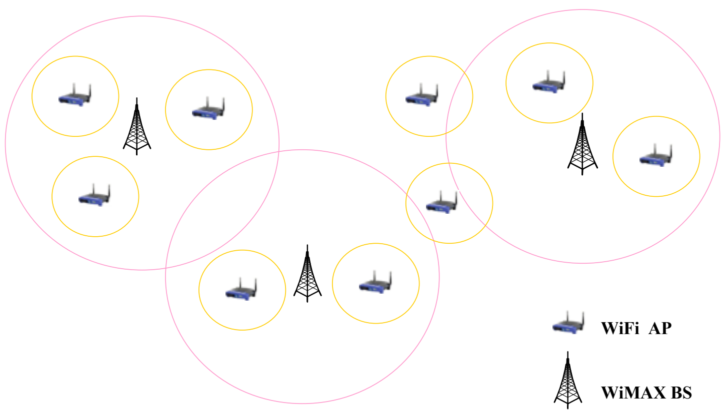

Figure 2 – A WiMAX-WiFi Domain

We assume that a WiMAX BS in a WWD is connected to its neighbor (overlapping) WiFi APs via a backbone network, and vise versa. A WiMAX BS and a WiFi AP are said to be neighbors if they overlap each other in coverage.

For mobile users, location of the WiMAX BS or WiFi AP is useful for target network detection and selection. WiFi has defined mechanism to provide location information [13]. Available bandwidth is important for achieving desirable amount of data transformation. WiMAX is a controlled system. BS controls and allocates both downlink and uplink bandwidth. BS can compute available downlink/uplink bandwidth at any time. WiFi is different in medium access. Although a controlled channel access mechanism called HCCA has been standardized, WiFi is typically a contention based system. To measure radio resources, WiFi provides channel load information [13], which can be used to estimate available bandwidth. Therefore, we propose to add location and bandwidth in existing WiMAX MOB_NBR-ADV message and WiFi neighbor report element for horizontal handover. We also define a new WiMAX MOB_NBR_AP-ADV message and a new WiFi neighbor BS report element for vertical handover.

We define WiMAX MOB_NBR_AP-ADV management message as follows:

Syntax	Size	Notes
MOB_NBR_AP-ADV_message_format() {		
Management Message Type	8 bits	
N_NBR_APS	8 bits	Number of neighbour APs
for(i=0; i < N_NBR_APS; i++) {		For each neighbour AP
Length	8 bits	Length of each AP description
BSSID	48 bits	As defined in [13]
BSSID Information	32 bits	As defined in [13]
Regulatory Class	8 bits	As defined in [13]
Channel Number	8 bits	As defined in [13]
PHY Type	8 bits	As defined in [13]
Location	72 bits	Geometric location of the AP
Channel Load	8 bits	Channel utilization measurement of the AP
TLV optional sub-element information	Variable	TLV specific
}		
}		

Two new fields in this message definition are location and channel load. Location field can be expressed in (latitude, longitude, altitude) format or Cartesian coordinate (x, y, z) format. For convenience, we use the later and each coordinate is described in the unit of meter. Channel load is defined as the percentage of channel busy time and its value is an integer from 0 to 255 with 255 representing 100% busy.

We define a new WiFi neighbor BS report element as following three tables:

Element ID	Length	BSID	PHY Profile ID	FA Index	BS EIRP
1 octet	1 octet	3 octets	1 octet	1 octet	1 octet

Preamble Index/ Subchannel Index	HO Process Optimization	Scheduling Service Supported	DCD Configuration Change Count
1 octet	1 octet	1 octet	4 bits

UCD Configuration Change Count	BS Location	Available Downlink Bandwidth	Available Uplink Bandwidth	TLV Encoded information
4 bits	9 octets	12 bits	12 bits	Variable

BS Location is the geometric location of the neighbor WiMAX BS. Available downlink and uplink bandwidth fields are expressed in the unit of mbps. Other fields are described in [1].
A WiMAX BS in a WWD communicates with its neighbor WiFi APs via backbone network about information needed to build up WiMAX MOB_NBR_AP-ADV management message. A neighbor WiFi AP updates WiMAX BS if any information is changed. WiMAX BS periodically broadcasts MOB_NBR_AP-ADV management message to all devices it is serving. Similarly, neighbor WiMAX BSs of a WiFi AP in a WWD send the latest information needed to compose Neighbor BS Report information element to the AP via backbone network. Upon receiving a neighbor report request, AP includes the Neighbor BS Report element in the response too.

A MN in a WWD collects neighbor WiFi AP and WiMAX BS information through its serving network as shown in Figure 3.

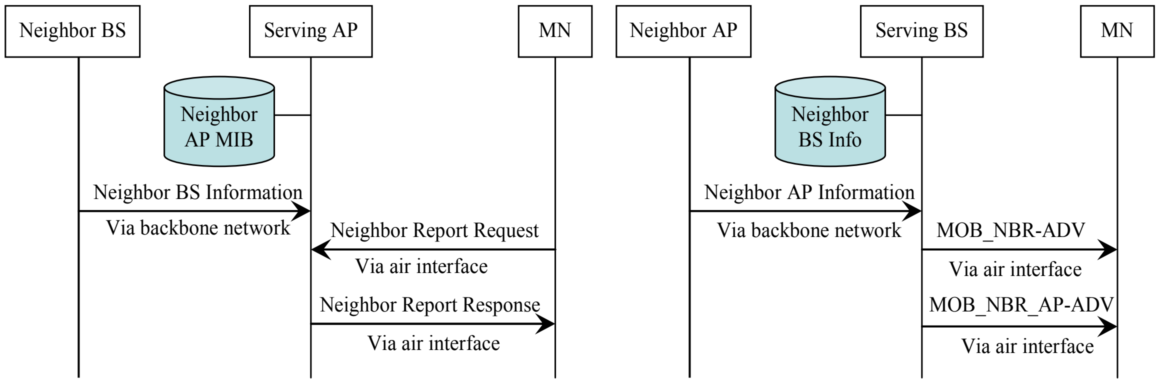

Figure 3 – Neighbor BS/AP Information Collection

HANDOVER BETWEEN WiMAX AND WiFi NETWORKS

There are two types of vertical handovers, upward handover and downward handover. Upward handover is a handover from a small scale network to a large scale network such as from a WiFi network to a WiMAX network. The small scale network (e.g., WiFi) is usually cost efficient compared with the large scale network (e.g., WiMAX). Also, the small scale network (e.g., WiFi) usually has high data rate compared with the large scale network (e.g., UMTS or GSM). It is typically desirable to remain connection to small scale network for as long as possible. An upward handover usually becomes necessary when the MN is exiting the current serving small network. Therefore, discovering large network is more delay sensitive. Downward handover is a handover from a large network to a small scale network such as from a WiMAX network to a WiFi network. Discovering small network is usually less delay sensitive since MN is typically not at the risk of exiting the network it is currently connected to. Instead, the handover is typically initiated for cost optimization, higher data rate, service availability, performance improvement, etc. Downward handover needs to avoid the Ping-Pong effect.

HANDOVER FROM WiMAX TO WiFi

A handover from WiMAX network to WiFi network is downward handover. Therefore, the MN can select a proper WiFi network for handover without the risk of exiting the network. For downward handover, the handover trigger algorithm must be smart enough to avoid or reduce Ping-Pong effect. Handover from a WiMAX network to a WiFi network should only be triggered if MN's visit to WiFi network is long enough to:

1. complete the reconfiguration and mobility management procedures, the security procedures, and the accounting procedures
2. allow the recovery of the upper layer protocols and the applications after the handover
3. transfer sufficient data packets to compensate for the interruption in data transfer, which takes place during the handover procedures

For a handover from WiMAX network to WiFi network, the MN is currently served by a WiMAX BS. Let $\boldsymbol{A} = \{AP_1, AP_2, \ldots, AP_N\}$ be the set of APs announced by serving BS in its WiMAX MOB_NBR_AP-ADV message, where $N \geq 0$ with $N = 0$ indicating no AP overlapping the BS. Let (X_1,Y_1,Z_1), (X_2,Y_2,Z_2), …, (X_N,Y_N,Z_N) be the locations of APs in set $\boldsymbol{A}$, respectively. The MN collects neighbor AP information and maintains a set of candidate APs for potential handover. Let $\boldsymbol{C}_A = \{AP_1, AP_2, \ldots, AP_Q\}$ be candidate set, where $Q \leq N$, $AP_k \in \boldsymbol{A}$ $(1 \leq k \leq Q)$ with $Q = 0$ indicating an empty candidate set. The MN dynamically updates its candidate set while it is roaming. Candidate AP selection is important for pre-handover preparation, reducing handover delay, network management, application QoS, performance, etc. especially for achieving seamless handover. APs in candidate set $\boldsymbol{C}_A$ of a MN can be used for link layer pre-authentication and IP address pre-configuration [4].

To select candidate AP, the MN first estimates its moving direction by utilizing its location information. The MN measures its M (≥ 2) locations (x_1,y_1,z_1), (x_2,y_2,z_2), …, (x_M,y_M,z_M) via GPS or other mechanism. Using these M points, a smooth curve Γ can be found by employing algorithm such as the least-square scheme. The curve Γ, as shown in Figure 4, approximates the path along which the MN roams.

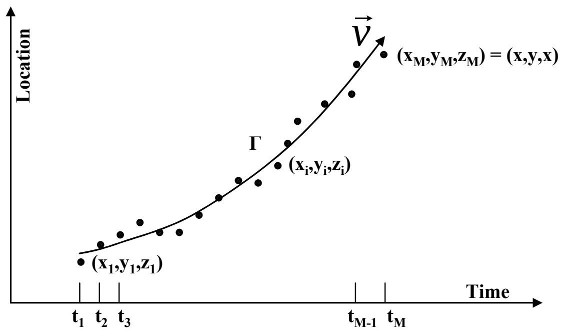

Figure 4 – MN Moving Direction and Curve Estimation

Let Γ be expressed with parametric equation

$$\Gamma:\ x = x(t), y = y(t), z = z(t), t_1 \leq t \leq t_M \quad (2)$$

where time t is the parameter, t_1 and t_M represent the beginning time and the ending time, respectively. Notice that time t_M is the time performing estimation and $(x_M,y_M,z_M) = (x,y,z)$ is the MN's current location. Using this smooth curve, we can estimate the MN's roaming direction $\vec{v}$. With its moving direction known, the MN can select the candidate APs from set $\boldsymbol{A}$. An $AP_i \in \boldsymbol{A}$ belongs to set $\boldsymbol{C}_A$ if the MN is located in AP_i's coverage area or if AP_i's location satisfies following condition

$$\frac{\vec{v} \bullet (X_i - x, Y_i - y, Z_i - z)}{|\vec{v}|\sqrt{(X_i - x)^2 + (Y_i - y)^2 + (Z_i - z)^2}} > \cos\theta \quad (3)$$

where (x,y,z) and (X_i,Y_i,Z_i) are the locations of the MN and AP_i, respectively, and θ is an angular threshold. Figure 5 shows an example of candidate set $\boldsymbol{C}_A$ = {AP_1, AP_3, AP_5}.

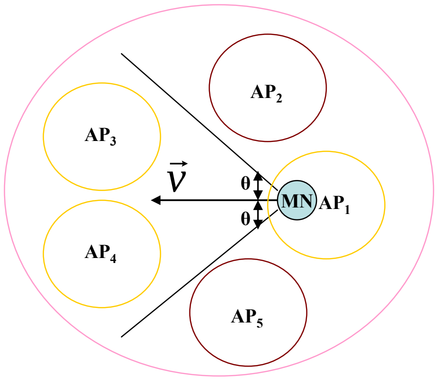

Figure 5 – Candidate AP Selection

To select a target AP from set $\boldsymbol{C}_A$, MN needs to make sure no Ping-Pong effect. That is, connection time T_t with target AP_t must be greater than a pre-defined threshold T_{th}, which could be in hundreds of milliseconds. The MN's connection time with a candidate AP_c is computed by employing the length of MN's moving path within AP_c's coverage area and the MN's speed. The MN's moving speed can be estimated as follows

$$v = \frac{L}{t_M - t_1} \quad (4)$$

where L is the length of the curve Γ, which can be calculated by

$$L = \int_{t_1}^{t_M} \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2}\, dt \quad (5)$$

or approximated by

$$L = \sum_{i=1}^{M-1} \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2 + (z_{i+1} - z_i)^2} \quad (6)$$

With given moving speed and moving direction, the MN's estimated connection time with a candidate AP_c is evaluated by

$$T_c = \frac{\| P_1 P_2 \|}{v} \quad (7)$$

where $\| P_1P_2 \|$ denotes the length of line segment P_1P_2 as shown in Figure 6.

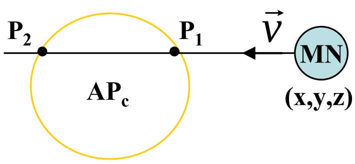

Figure 6 – MN's Moving Path within a Candidate AP_c's Coverage Area

Let $\boldsymbol{C}_{AT}$ = {AP_1, AP_2, …, AP_K } be a subset of set $\boldsymbol{C}_A$ such that

$$T_c^{\,k} \ge T_{th}, \forall AP_k \in C_{AT} \quad (8)$$

where $1 \le k \le K$ and $K \le Q$ with K = 0 indicating set $\boldsymbol{C}_{AT}$ empty.

There are many factors to be considered for a MN to choose a target AP_t. Those factors include cost, data rate, handover delay, service availability, load balance, user preference, etc. The best solution is an optimization over all factors. Accounting for fact that WiFi uses unlicensed frequency band, which makes WiFi cost efficient, this paper presents a scheme to get the maximum amount of data during a visit to a WiFi network. That is, target AP is selected such that

$$\max_k\{B_k * T_c^{\,k}\}, \forall AP_k \in C_{AT}, 1 \le k \le K \quad (9)$$

where $T_c^{\,k}$ is the estimated connection time and B_k is the estimated available bandwidth given by

$$B_k = \left(1 - \frac{ChannelLoad_k}{255}\right) * R_k \quad (10)$$

R_k is the data rate of the WiFi network and depends on the type of AP_k in use. For an 802.11a WiFi network, R_k is 54 mbps.

Once target AP_t is selected, the MN configures its WiFi air interface according to the target AP's parameters. Using its speed and distance to the target AP_t, the MN dynamically estimates time needed to enter target AP's coverage. The MN activates its WiFi air interface before entering target AP_t's coverage area. Therefore, the MN skips the scanning process and total handover latency is reduced.

HANDOVER FROM WiFi TO WiMAX

In the standards, WiMAX is allowed to use either licensed or unlicensed frequency band. Deployment of the WiMAX infrastructure is costly and current WiMAX implementation is in licensed frequency band. It means that services in a WiMAX network are expensive. Therefore, we present a cost efficient scheme to select a target WiMAX network for handover.

For a handover from WiFi network to WiMAX network, the MN is currently served by a WiFi AP. A WiFi AP covers a small area. Therefore, once connecting to serving AP, the MN sends a neighbor report request to serving AP. Upon receiving the neighbor report response from serving AP, the MN needs to select the target BS for potential handover.

Let $\boldsymbol{B} = \{BS_1, BS_2, \ldots, BS_M\}$ be the set of BSs overlapping the serving AP. It should be pointed out that set $\boldsymbol{B}$ is a small size set. Similarly, a candidate set $\boldsymbol{C}_B$ can also be selected based on the MN's moving direction and a subset $\boldsymbol{C}_{BT}$ of the set $\boldsymbol{C}_B$ can be selected using the estimated connection time. The angular threshold θ and connection time threshold T_{th} can be different from those used to select target WiFi AP. Figure 7 shows an example of set $\boldsymbol{C}_{BT}$.

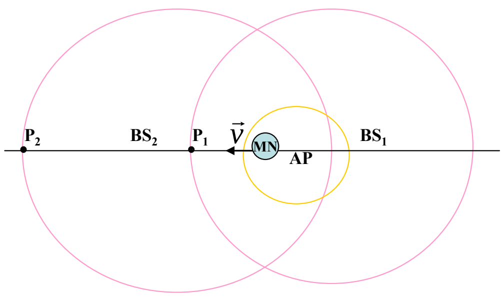

Figure 7 – Candidate BS Selection

Let $\boldsymbol{C}_{BT}$ be expressed as $\boldsymbol{C}_{BT} = \{BS_1, BS_2, \ldots, BS_K\}$, $K \le M$. The target BS is selected from set $\boldsymbol{C}_{BT}$ for the least cost as follows

$$\min_k\{(R_d + R_u) * T_c^{\ k} * C_k\}, \forall BS_k \in C_{BT}, R_d \le B_d^{\ k}, R_u \le B_u^{\ k}, 1 \le k \le K \quad (11)$$

where R_d and R_u are the MN's desired downlink and uplink data rates, C_k, B_d^k and B_u^k are BS_k's data cost, available downlink bandwidth and available uplink bandwidth, respectively.

With target BS_t being selected, the MN configures its WiMAX air interface based on the parameters of the target BS_t. Once a handover is triggered by decision algorithm, the MN activates its WiMAX air interface. Similarly, the scanning procedure is eliminated and total handover delay is reduced.

CONCLUSION

The mobile devices with capability to operate on multiple wireless access networks have been emerging. These devices should roam freely from one air interface to another and maintain their network connections. The continuation of the higher layer applications should be guaranteed to provide mobile users with satisfactory QoS. Seamless handover technologies must be developed to meet mobile user's demand for transiting in between homogeneous or heterogeneous wireless access networks with continuous network services. A variety of homogeneous and heterogeneous handover mechanisms have been proposed to address mobility management, handover triggers, handover decision making, and handover process. This paper proposes fast handover techniques to minimize target network detection delay, eliminate Ping-Pong effect and select proper target network for vertical handover between WiMAX and WiFi networks. The proposed techniques are expected to improve overall handover performance and can be utilized to accomplish the seamless handover between WiMAX and WiFi networks.

REFERENCES

[1] IEEE802.16 Working Group, "Air Interface for Fixed and Mobile Broadband Wireless Access Systems, Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands", IEEE802.16e-2005

[2] IEEE802.11 Working Group, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 7: Wireless Access in Vehicular Environments", IEEE802.11p-D9.0, September 2009

[3] IEEE802.11 Working Group, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 2: Fast Basic Service SET (BSS) Transition", IEEE802.11r-2008

[4] J. Guo, R. Yim, et al, "Fast Handover between WiMAX and WiFi Networks in Vehicular Environment", 16th ITS World Congress, Stockholm, Sweden, September 2009

[5] H. Velayos and G. Karlsson, "Techniques to Reduce IEEE 802.11b MAC Layer Handover Time, KTH Technical Report", ISSN 1651-7717, Stockholm, Sweden. April 2003.

[6] Y.S. Chen, M.C. Chuang, C.K. Chen, "DeuceScan: Deuce-Based Fast Handoff Scheme in IEEE 802.11 Wireless Networks", IEEE Transaction on Vehicular Technology, Vol.57, No.2, March 2008

[7] R. Fantacci, L. Maccari, T. Pecorlla, "Analysis of Secure Handover for IEEE 802.1X-Based Wireless Ad Hoc Networks", IEEE Wireless Communications, October 2007

[8] S. Thomson, T. Narten, T. Jinmei, "IPv6 Stateless Address Autoconfiguration", IETF RFC 4862, September 2007

[9] G. Lampropolos and A. K. Salkintzis, ”Media-Independent Handover for Seamless Service Provision in Heterogeneous Networks”, IEEE Communication Magazine, January 2008
[10] N. Jordan, R. Fleck, C. Ploninger, “Fast Handover Support in Wireless LAN based Networks”, Proceeding of the Fifth IFIP-TC6 International Conference on Mobile and Wireless Communications Networks (MWCN'03) p.:49-52, ISBN:981-238-686-6, Singapore, October 2003
[11] C.C Tseng, K.H. Chi, et al, “Location-based Fast Handoff for 802.11 Networks”, IEEE Communications Letters, Vol. 9, No. 4, April 2005
[12] M. Siebert, M. Schinnenburg, et al, „Location Aided Handover Support for Next Generation System Integration“, 5th European Wireless Conference, Mobile and Wireless System beyond 3G (EW2004), p.p 195-202, Barcelona, Spain, 2004
[13] IEEE802.11 Working Group, “Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 1: Radio Resource Measurement of Wireless LANs”, IEEE802.11k-2008
[14] IEEE802.21 Working Group, “Draft Standard for Local and Metropolitan Area Networks: Media Independent Handover Services”, IEEE802.21-D14.0, September 2008