Predictive Handover Mechanism based on Required Time Estimation in Heterogeneous Wireless Networks

Sang-Jo Yoo*, David Cypher**, Nada Golmie **

* Inha University, Korea,   ** National Institute of Standards and Technology, Gaithersburg, MD
sjyoo@inha.ac.kr , {david.cypher, nada.golmie}@nist.gov

Abstract— **In most conventional layer 2 triggering approaches, a pre-defined threshold for a specific perspective such as the received signal strength is used so that it may cause too late or too early handover executions. In this paper we propose a new predictive handover framework that uses the neighbor network information to generate timely the link triggers so that the required handover procedures can appropriately finish before the current link goes down. First we estimate a required handover time for the given neighbor network conditions, then using a predictive link triggering mechanism the handover start time is dynamically determined to minimize handover costs. The handover costs are analyzed in terms of the total required handover time and the service disruption time. The numerical analysis and simulation results show that the proposed method significantly enhances the handover performance.**

INTRODUCTION

Handovers typically cause layer 2 scanning and switching and/or layer 3 IP mobility latencies and hence may disrupt current services. This is unacceptable for time-sensitive and real-time applications. For handovers to be seamless, timely information accurately characterizing the network conditions are needed in order for appropriate actions to be taken. This is provided by the so-called link layer triggers that are fired at the MAC layer and communicated either to a handover management functional module such as the Media Independent Handover Function (MIHF) of IEEE 802.21 [1]. Link layer information is critical to layer 3 and above entities in order to better streamline handover-related activities such as the initiation and the execution of fast mobile IP procedures. Hence effective link-layer trigger mechanisms and the timely firing of link triggers can significantly influence the handover performance and is a key in determining whether the handover completes successfully. In particular, in "break before make" networks such as WLAN [2] and WiMAX [3], the role of link triggers in the initiation of a proper handover is significant in mitigating handover service disruptions.

A number of methods have been proposed for generating Link_Going_Down (LGD) triggers [4-8]. However, most of these methods use a pre-defined threshold (TH_{LGD}) of a specific metric such as received signal strength indication (RSSI) or QoS metrics. For example, if the received signal strength is less than a pre-defined threshold, the LGD trigger is generated. When the minimum link quality (TH_{LD}) is given (i.e., if the received link quality is less than TH_{LD}, then the current link is considered as broken), usually the pre-defined threshold for the LGD trigger is calculated as

$$TH_{LGD} = \alpha \times TH_{LD}, \quad \alpha \geq 1.0 \qquad (1)$$

However, due to several parameters changing over time such as the wireless channel conditions, the mobile node (MN) speed, and the time required for performing a handover, determining the optimal threshold in advance is difficult, often resulting in either an early or late handover initiation.

In this paper we propose a predictive handover architecture based on neighbor network information. First, we discuss methods for estimating the required handover time for different neighbor network topologies and current network conditions. In this estimation step for the required handover time, we also set up an appropriate handover policy and determine the exact handover procedures used to achieve a seamless handover. The estimated handover time is used to generate timely link going down triggers. A predictive link trigger mechanism is used to start and finish the required handover procedures before the link actually goes down.

The remainder of this paper is organized as follows: Section II presents the proposed predictive handover architecture. In Section III, estimates for the time it takes to complete a handover are derived for different handover types and various neighbor network conditions. In Section IV, analysis for the horizontal and vertical handover costs are derived. In Section V, numerical analysis and simulation results show that the proposed method significantly enhances the performance of handovers. We conclude this paper in Section VI.

PREDICTIVE HANDOVER MECHANISM

For seamless handover in heterogeneous wireless networks, service continuity and minimal handover disruption time are the primary goals for handovers. To achieve this goal, link layer triggers to aid the handover preparation and execution [1][2][9]. Link triggers are delivered to a handover decision module and a mobility control protocol in layer 3 to indicate

changes in link quality. Specifically, the LGD trigger that implies "broken link is imminent" greatly influences the handover performance because it is generally used to start the required handover procedure.

Too late LGD trigger leads to a long service disruption, and some incoming packets are lost or delayed during this outage. Cost function can be determined using the total required handover latency and the total service disruption time. The cost for LGD trigger that was generated too early is also significant. It may force the handover execution to a new interface even when the link quality of the old interface is still strong enough to decode data, resulting in a loss of the benefits of the preceding interface, which can include such factors as the bandwidth, QoS, and communication price. When there is a large time gap between the LGD and the LD, frequent event roll-backs or handover cancellations may occur.

In the proposed architecture, before the handover, MN estimate the exact required handover time (t_h) based on the current neighbor network conditions. The neighbor network information can be obtained by the information service of the IEEE 802.21 MIHF [1] that provides a query/response type of mechanism for neighbor network information transfer. It contains both static (e.g., neighbor network topology) and dynamic (e.g., QoS condition) information. From this neighbor information, the MN (or point of attachment (PoA)) can estimate the required handover type and the required handover time to finish all handover procedures. The estimated handover time and neighbor network information can be also used to set up a dynamic handover policy.

In our mechanism, the LGD trigger is adaptively generated based on the estimated handover required time. The LGD trigger should be invoked prior to an actual link down event by at least the time required to prepare and execute a handover. Unlike the previous triggering methods using a pre-defined threshold, in our approach the MN forecasts whether the current link goes down or not after t_h time. If it is predicted, then LGD is generated. Once the handover decision engine receives the LGD event, it starts the required handover procedures both on the MAC/physical layer and network layer.

As shown in Fig. 1, the predictive handover consists of three steps: i) the initial configuration and measurement step, ii) the neighbor discovery and prediction step, and iii) the handover execution step.
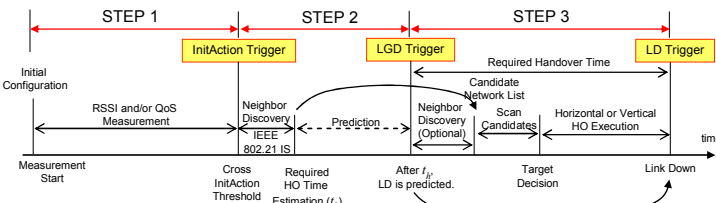

Figure 1. Predictive handover time sequence.

i) STEP 1: *Initial Configuration and Measurement Step*
During this step, some initial parameters for measurement

and handover are configured. Measurement related parameters may include the required link quality, measurement metrics, measurement interval, and so on. Typical handover related parameters are *InitAction* (T_{init}) and *Link_Down* (T_{LD}) thresholds. InitAction threshold is used to start neighbor discovery and prediction (STEP 2) and it is configured to a conservative value to ensure enough time for STEP 2 before the LGD trigger. Any performance metrics for a handover decision can be used for a link quality measurement such as the received signal strength indication (RSSI) or a set of QoS measurements (QoS satisfaction degree).

ii) STEP 2: *Neighbor Discovery and Prediction Step*
If the measured link quality crosses the pre-defined InitAction threshold, then the neighbor network discovery procedure starts using the IEEE 802.21 information server. However this does not trigger the actual execution of a handover. After obtaining the neighbor information, the MN (or PoA in case of network initiate handover) can form a candidate network list. From this information, the MN can decide handover type (horizontal or vertical), the number of candidate PoAs (or channels) to be scanned, and whether the layer 3 handover is required or not. The MN estimates the required handover time t_h based on the neighbor information. During this estimation, if the expected handover time or service disruption time is greater than the user requirement, then the handover decision engine can change the handover policy. The required handover time is configured in layer 2 using MIHF primitives and t_h-ahead prediction starts. If after t_h a Link_Down event is expected, then a predictive LGD trigger is generated to initiate the required handover procedure. Prediction is performed at each t_m measurement interval. For discrete time prediction process, we define a prediction interval k_h as in (2). Δ_h is a marginal time (≥ 0).

$$k_h = \left\lceil \frac{t_h + \Delta_h}{t_m} \right\rceil \tag{2}$$

Any prediction mechanism can be used to trigger the LGD event. Two prediction techniques *p*-th order Least Mean Square (LMS) adaptation algorithm of (3) and as a simpler prediction method, a linear slope estimation of link quality degradation of (4) are considered in this paper.

$$\hat{x}(n+k_h) = \sum_{l=0}^{p-1} w_n(l)x(n-l) = \mathbf{W}_n^T \mathbf{X}(n) \tag{3}$$

$$\hat{x}(n+k_h) = \overline{a}(n) \cdot k_h + x(n) \tag{4}$$

$$\overline{a}(n) = \eta \cdot s(n) + (1-\eta) \cdot \overline{a}(n-1) \tag{5}$$

where $\mathbf{W}_n$ is the time-varying coefficient vector; $s(n)$ is the service degradation slope at time n, $s(n) = x(n) - x(n-1)$; $\overline{a}(n)$ is the average service degradation slope; η is a weight for the current measured slope.

iii) STEP 3: *Handover Execution Step*
After the LGD trigger, the MN can optionally re-perform the neighbor network discovery. Especially, this is useful

when there is large time gap between the InitAction trigger and LGD trigger so that the MN needs to obtain updated neighbor information. When there are multiple candidate PoAs (or channels) and/or the MN needs to check the connectivity and resource availability of PoAs, the MN starts scanning procedure with the candidate neighbor network list. After the MN decides on a target PoA, a horizontal or vertical handover is followed.

The proposed predictive handover approach has two main benefits for seamless handovers. i) Since the MN can know the handover type to perform and the neighbor network list to scan, the handover preparation and execution time can be optimized and it also minimizes the service disruption time. During the required handover estimation, the MN can setup a handover policy to meet the user requirement based on the estimated handover time. ii) Based on the estimated required handover time, the MN generates the LGD trigger at the appropriate time that ensures to finish all the required handover procedures before the actual link goes down. Therefore, it successfully reduces possible service disruptions due to the link break before finishing the handover procedures.

REQUIRED HANDOVER TIME ESTIMATION

In this section, the required handover time estimation methods for various neighbor network conditions are presented. For some case studies, we use WLAN and WiMAX overlay network environments, but it should be noted that the following estimation methods can be applied to any other wireless networks. Since the link layer switching of WLAN and WiMAX networks are typically operated in a "break before make" manner, accurate handover time estimation is more important for achieving seamless handovers. As was mentioned earlier, an LGD trigger should be fired at least in the required handover time before the Link_Down event. The required handover time is different according to the network topologies, layer 3 handover protocols, and handover policies of the neighbor networks. Due to the mobility involved, these parameters can be dynamic in time so that t_h is configurable adaptively.

A. HO_Case 1: horizontal handover

For the case of a horizontal handover and using a single interface (hard handover), the MN cannot be serviced in parallel by more than one PoA and therefore has to break its communication with its current PoA before establishing a connection with a new one. Service disruption cannot be avoided. To reduce the service disruption time and possible packet loss and delay, the MN needs to finish the layer 3 handover before the link breaks. FMIPv6 [9] is designed to reduce the handover delay by preparing the layer 3 handover in advance. An LGD trigger is required for this anticipation and handover initiation. The handover required time for the horizontal handover consists of the L3 handover time (t_{L3}) and the L2 handover preparation time (t_{L2p}) before the actual link switching to the new PoA.

$$t_{L3} = \begin{cases} t_{FH} \text{ (fast handover execution time)} \\ 0, \quad \text{if the target PoA is on the same subnet.} \end{cases} \quad (6)$$

t_{L2p} at the current PoA may include:

- $t_{L2p-nbr}$: Message exchange time to obtain the neighboring information. The IEEE 802.11k and IEEE 802.16e have defined frame formats for this. The IEEE 802.21 defines query/response messages to/from the information server.

- $t_{L2p-scn}$: Scanning time to scan the candidate PoAs

$$t_{L2p-scn} = N_{p-nbr} \times t_{p-s} \quad (7)$$

where N_{p-nbr} is the number of candidates and t_{p-s} is the scanning time for one candidate.

- $t_{L2p-ind}$: Handover indication message exchange time to the current PoA. For the IEEE 802.16e handover mechanism it includes sending a MOB_HO-IND MAC frame to the old BS. The IEEE 802.21 specification also defines messages to indicate the handover execution.

After the scanning, the MN can select a target PoA. $t_{L2p-nbr}$ and $t_{L2p-scn}$ can be performed earlier than the LGD trigger using periodic message exchanges and channel scanning. In this case t_{L2p} includes only $t_{L2p-ind}$.

The maximum and minimum required handover times for horizontal handover are given in (8). Fig. 2 shows the WiMAX horizontal handover scenario combined with FMIPv6.

$$t_h = t_{L2p} + t_{L3}, \begin{cases} t_{h-\max} = t_{L2p-nbr} + t_{L2p-scn} + t_{L2p-ind} + t_{FH} \\ t_{h-\min} = t_{L2p-ind} \end{cases} \quad (8)$$
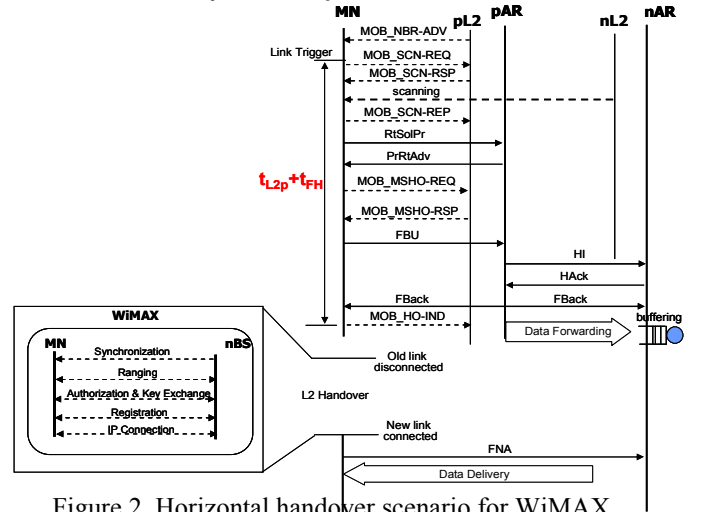

Figure 2. Horizontal handover scenario for WiMAX and the required handover time.

B. HO_Case 2: vertical handover

For a vertical handover, before the current link is down, a new link with the target network can be established if the LGD trigger is generated on time in a "make before break" manner. During the set up period for the new link, the MN can continue to send and receive data using the current network link. Therefore, a service disruption can be avoided by an appropriate estimation of t_h . The required vertical handover

time consists of (as shown in Fig. 3):

- t_{hp}: Handover preparation time for L2 and L3 with the current network PoA. For a vertical handover between WLAN and WiMAX, t_{L2p} does not include $t_{L2p-scn}$ because scanning is performed at a different network interface and the t_{FH} time is typically required for the layer 3 handover because the target PoA is generally not on the same subnet of the previous PoA.

$$t_{hp} = t_{L2p} + t_{FH} = t_{L2p-nbr} + t_{L2p-ind} + t_{FH} \qquad (9)$$

- t_{hn}: Handover execution time with the new network PoA using the new interface. For WLAN, t_{hn} includes vertical interface scanning, authentication, and association times. For WiMAX it includes scanning, synchronization & ranging, basic capability negotiation, key exchange & authorization, and registration times.

$$t_{hn} = \begin{cases} t_{L2n-scn} + t_{auth} + t_{assc}, & \text{WLAN} \\ t_{L2n-scn} + t_{rng} + t_{cap} + t_{key} + t_{reg}, & \text{WiMAX} \end{cases} \qquad (10)$$

After the neighbor information exchange using the previous interface and scanning the candidate PoAs using the new interface, the MN can select the target PoA. The required procedures in the previous and new interface can be performed separately using different interfaces. Therefore, the total required handover time for a vertical handover is given in (11).

$$t_h = t_{L2p-nbr} + t_{L2n-scn} + \max\{t_{L2p-ind} + t_{FH}, t_{hn}^*\}$$
$$t_{hn}^* = \begin{pmatrix} t_{auth} + t_{assc} : \text{WLAN} \\ t_{rng} + t_{cap} + t_{key} + t_{reg} : \text{WiMAX} \end{pmatrix} \qquad (11)$$
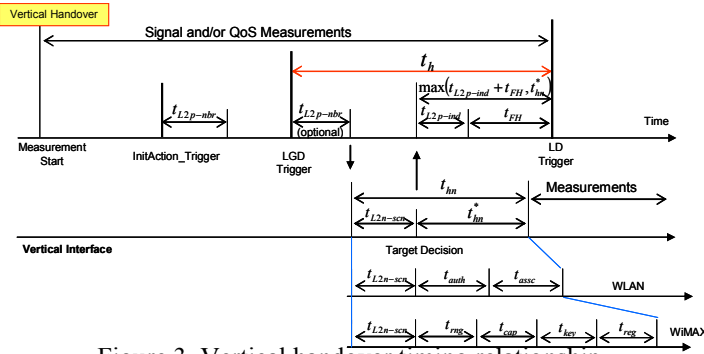

Figure 3. Vertical handover timing relationship.

C. HO_Case 3: horizontal or vertical handover

If the MN can not determine the exact handover type using the candidate PoAs, then the MN should estimate the required handover time that is enough to scan all candidate PoAs for both horizontal and vertical interfaces and to perform any of horizontal or vertical handover. The required handover time is derived in (12). We assume that vertical scanning is performed only if there is no PoA for horizontal handover after horizontal scanning.

$$t_h = t_{L2p-nbr} + t_{L2p-scn} + t_{L2n-scn} + \max\{t_{L2p-ind} + t_{FH}, t_{hn}^*\} \quad (12)$$

D. HO_Case 4: without the neighbor network information

When the MN does not have the neighbor information for a handover, the horizontal scanning ($t_{L2p-scn}$) is performed first for all possible channels of the current communication system. If the MN cannot find a horizontal handover target, it starts the vertical scanning ($t_{L2n-scn}$) and executes a vertical handover. Therefore, the required handover time in this case should be sufficient, as in (13).

$$t_h = t_{L2p-nbr} + t_{L2p-scn(\max)} + t_{L2n-scn(\max)} + \max\left[(t_{L2p-ind} + t_{FH}), t_{hn}^*\right] (13)$$

where $t_{L2p-scn(\max)}$ and $t_{L2n-scn(\max)}$ are the maximum scanning time for the current and new interface types, respectively.

HANDOVER COST ANALYSIS

In this section, we evaluate the handover costs in terms of the total handover time and the total service disruption time during the handover for various handover conditions for the network model of Fig.4. In our analysis the handover costs measure the amount of time required to perform the handover.
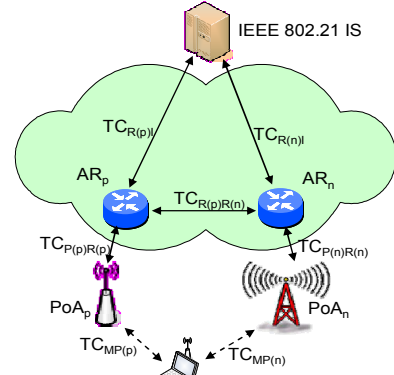

Figure 4. Network model for handover cost analysis.

A. Cost Analysis for Each Handover Procedure

Let ϕ be the unit message transmission cost and δ be the weight for a wireless link to capture some overhead in wireless medium such as access delay and collisions. It is assumed that the transmission costs of the paths on the previous and new networks are the same as,

$$TC_{MP(p)} = TC_{MP(n)}, TC_{P(p)R(p)} = TC_{P(n)R(n)}, TC_{R(p)I} = TC_{R(n)I} (14)$$

The transmission cost is proportional to the hop count on the path as (15).

$$TC_{MP} = \delta \cdot \phi, TC_{PR} = \phi, TC_{RR} = \phi \cdot H_{RR}, TC_{RI} = \phi \cdot H_{RI} \quad (15)$$

In the following, we derive the handover cost HC_{χ} for each procedure χ of Section III. First for the neighbor network discovery, we only consider the message exchanges to query and to respond between the MN and the IEEE 802.21 information server. The neighbor discovery cost is derived as

$$HC_{nbr} = t_{L2p-nbr} = TC_{MP} + TC_{PR} + TC_{RI} + TC_{IR} + TC_{RP} + TC_{PM}$$
$$= 2 \times (\delta\phi + \phi + \phi H_{RI}) = 2\phi(\delta + 1 + H_{RI}) \qquad (16)$$

The handover cost for the handover indication is to send and to receive handover commitment request and response messages to/from the target PoA through the current PoA (MN↔PoA(p)↔AR(p)↔AR(n)↔PoA(n)) as in (17).

$$HC_{ind} = t_{L2p-ind} = 2 \times (\delta\phi + \phi + \phi H_{RR} + \phi) = 2\phi(\delta + 2 + H_{RR}) (17)$$

The scanning cost includes the MAC level media scanning and/or the explicit resource query to the candidate PoAs using IEEE 802.21 MIHF. It depends on the communication system scanning mechanism and implementation parameters. Let γ_ξ and $N_{\xi-nbr}$ be the scanning time for one PoA and the number of neighbor PoAs to scan for communication system type ξ, respectively. Then the scanning cost is given as,

$$HC_{scn} = \begin{cases} t_{L2p-scn} = N_{p-nbr} \times \gamma_p & : \text{horizontal scan} \\ t_{L2n-scn} = N_{n-nbr} \times \gamma_n & : \text{vertical scan} \end{cases} \quad (18)$$

The fast handover cost of (19) is for layer 3 message exchanges from RtSolPr (Router Solicitation for Proxy Advertisement) to FBack (Fast Binding Acknowledgement) between the MN, previous AR, and new AR.

$$\begin{aligned} HC_{FH} &= TC_{RtSolPr} + TC_{PrRtAdv} + TC_{FBU} + TC_{HI} + TC_{HACK} + TC_{FBack} \\ &= 3TC_{MP} + 3TC_{PR} + 2TC_{RR} + \max[TC_{RR}, (TC_{RP} + TC_{PM})] \quad (19) \\ &= \phi\{3\delta + 3 + 2H_{RR} + \max[H_{RR}, (1+\delta)]\} \end{aligned}$$

The handover execution cost is a time amount for a connection establishment using a new communication interface. It depends on the network type, used AAA (Authentication, Authorization, and Accounting) mechanism, and network topology. Let θ_ξ be the handover execution delay for the communication system ξ.

$$HC_{HO-exe} = t_{hn}^* = \begin{cases} t_{auth} + t_{assc} = \theta_{WLAN} & : \text{WLAN} \\ t_{rng} + t_{cap} + t_{key} + t_{reg} = \theta_{WiMAX} & : \text{WiMAX} \end{cases} \quad (20)$$

B. Horizontal and Vertical Handover Cost Analysis

The horizontal handover cost in terms of the handover time (t_{HO}) for the proposed mechanism is given in (21). Since the service disruption only occurs during the link scanning time in the horizontal handover of the proposed mechanism when the Link_Down prediction is correct, the handover cost in terms of the service disruption time (t_{SD}) is given in (22).

$$t_{HO} = t_{L2p} + t_{L3}$$

$$\begin{cases} t_{HO-max} = t_{L2p-nbr} + t_{L2p-scn} + t_{L2p-ind} + t_{FH} \\ = \phi(7\delta + 9 + 4H_{RR} + 2H_{RI}) + N_{p-nbr}\gamma_p + \phi\{\max[H_{RR}, (1+\delta)]\} \quad (21) \\ t_{HO-min} = t_{L2p-ind} = 2\phi(\delta + 2 + H_{RR}) \end{cases}$$

$$t_{SD} = t_{L2p-scn} = N_{p-nbr}\gamma_p \quad (22)$$

For the vertical handover of the proposed method, the handover time is derived in (23) and the service disruption time is zero when the Link_Down prediction is correct.

$$\begin{aligned} t_{HO} = 2\phi(\delta + 1 + H_{RI}) + N_{n-nbr}\gamma_n + \\ \max\{\phi[3\delta + 3 + 2H_{RR} + \max\{H_{RR}, (1+\delta)\}], \theta_n\} \end{aligned} \quad (23)$$

C. Handovers with a Pre-defined LGD Threshold and no Neighbor Information

Without neighbor information, the MN cannot know whether it should perform a horizontal or vertical handover in advance. Therefore, first it should scan all horizontal channels and if there is no available channel, then it will activate vertical interface and scan the vertical channels. And when the MN uses a pre-defined LGD threshold, the LGD time may too early or too late. The LD can occur any time from the LGD trigger to the actual handover finishing time. Fig. 5 shows the

vertical handover timing diagram. If the LD occurs before or during FMIPv6 procedure, it is assumed that the MN needs to start a reactive fast handover operation [9] for data forwarding from the previous access router after it registered to the target network. The additional handover time for the reactive mode is derived as (24) to send an FBU (Fast Binding Update) and to receive an FBack to/from the previous access router.

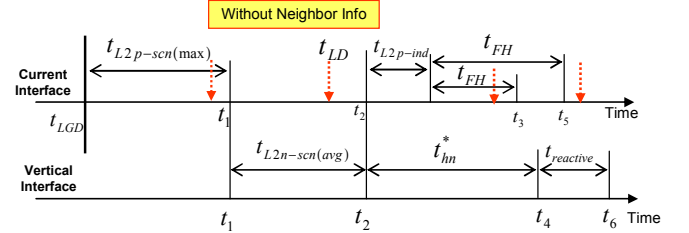$$t_{reactive} = t_{FBU} + t_{FBack} = 2\phi(\delta + 1 + H_{RR}) \quad (24)$$

Figure 5. Vertical handover timing diagram.

Time points from t_1 through t_6 of Fig. 4 are derived as,

$$\begin{cases} t_1 = t_{L2p-scn(max)} = N_{p(max)} \times \gamma_p \\ t_2 = t_{L2p-scn(max)} + t_{L2n-scn(avg)} = N_{p(max)} \times \gamma_p + N_{n(avg)} \times \gamma_n \\ t_3 \text{ or } t_5 = t_{L2p-scn(max)} + t_{L2n-scn(avg)} + t_{L2p-ind} + t_{FH} \\ \quad = N_{p(max)} \times \gamma_p + N_{n(avg)} \times \gamma_n + 2\phi(\delta + 2 + H_{RR}) \\ \quad + \phi\{3\delta + 3 + 2H_{RR} + \max[H_{RR}, (1+\delta)]\} \\ t_4 = t_{L2p-scn(max)} + t_{L2n-scn(avg)} + t_{hn}^* = N_{p(max)} \times \gamma_p + N_{n(avg)} \times \gamma_n + \theta_n \\ t_6 = t_{L2p-scn(max)} + t_{L2n-scn(avg)} + t_{hn}^* + t_{reactive} \\ \quad = N_{p(max)} \times \gamma_p + N_{n(avg)} \times \gamma_n + \theta_n + 2\phi(\delta + 1 + H_{RR}) \end{cases} \quad (25)$$

where $N_{p(max)}$ and $N_{n(avg)}$ are the maximum number of channels for the horizontal scan and the average number of channels to be scanned until the MN first finds an available channel during the vertical scan, respectively.

The total handover time and service disruption time are,

i) $t_{L2p-ind} + t_{FH} \leq t_{hn}^*$

$$t_{HO} = \begin{cases} t_6 - t_{LGD}, & \text{if } t_{LD} < t_3 \\ t_4 - t_{LGD}, & \text{if } t_{LD} \geq t_3 \end{cases} \quad (26)$$

$$t_{SD} = \begin{cases} t_6 - t_{LGD}, & \text{if } t_{LD} \leq t_1 \\ (t_1 - t_{LGD}) + (t_6 - t_{LD}), & \text{if } t_1 < t_{LD} < t_3 \\ (t_1 - t_{LGD}) + (t_4 - t_{LD}), & \text{if } t_3 \leq t_{LD} < t_4 \\ t_1 - t_{LGD}, & \text{if } t_4 \leq t_{LD} \end{cases} \quad (27)$$

ii) $t_{hn}^* < t_{L2p-ind} + t_{FH}$

$$t_{HO} = \begin{cases} t_6 - t_{LGD}, & \text{if } t_{LD} \leq t_4 \\ (t_{LD} - t_{LGD}) + t_{reactive}, & \text{if } t_4 < t_{LD} < t_5 \\ t_5 - t_{LGD}, & \text{if } t_5 \leq t_{LD} \end{cases} \quad (28)$$

$$t_{SD} = \begin{cases} t_6 - t_{LGD}, & \text{if } t_{LD} \leq t_1 \\ (t_1 - t_{LGD}) + (t_6 - t_{LD}), & \text{if } t_1 < t_{LD} \leq t_4 \\ (t_1 - t_{LGD}) + t_{reactive}, & \text{if } t_4 < t_{LD} \leq t_5 \\ t_1 - t_{LGD}, & \text{if } t_5 < t_{LD} \end{cases} \quad (29)$$

SIMULATION RESULTS

In this section, handover costs including the total handover time and the service disruption time are evaluated for various network conditions. We compare the handover costs for two handover mechanisms: i) the proposed predictive handover and ii) the handover without neighbor information and with a pre-defined LGD threshold. For this simulation, as in Fig. 4 the MN moves away from the WLAN to the WiMAX network so that a vertical handover is expected. Table 1 shows the parameter values [10][11] that are used in this section.

Table 1. Simulation parameters

ϕ	2	$N_{WLAN(max)}$	11 channels
δ	3 ms	$N_{WiMAX(max)}$	10 channels
γ_{WLAN}	10 ms	H_{MP}	1
γ_{WiMAX}	8 ms	H_{PR}	1
θ_{WLAN}	20 ms	H_{RR}	2(horizontal), 5(vertical)
θ_{WiMAX}	100ms,250ms	H_{RI}	5

First, the total handover time and the service disruption time for this network condition are evaluated as numerical analysis. Without the neighbor network information, the MN performs scanning of all 11 WLAN channels and then it starts to find an available WiMAX channel. In average it will find an available WiMAX channel after $N_{WiMAX(max)}/2 = 5$ channel scanning trials. When a pre-determined LGD trigger threshold is used, the LD occurs any time after the LGD trigger time. Depending on the LD time, the total handover time is different as we derived in (26) and (28). Basically, the latter LD time causes the shorter handover time as shown in Fig. 6. The total service disruption time is shown in Fig. 7. The later LD time causes the shorter service disruption time. For the proposed mechanism, if the predictive LGD trigger is timely generated, then there is no service disruption because no horizontal scanning is necessary.
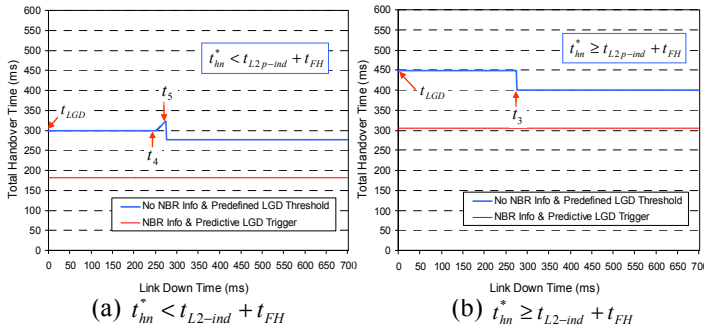

Figure 6. The total handover time.

Second, signal strength based handover simulation is performed. The link quality is measured by the received signal strength and it is obtained from the following Fritz path loss model.

$$\left.\frac{P_r(d)}{P_r(d_0)}\right|_{dB} = -10\beta\log\left(\frac{d}{d_0}\right) \quad (30)$$
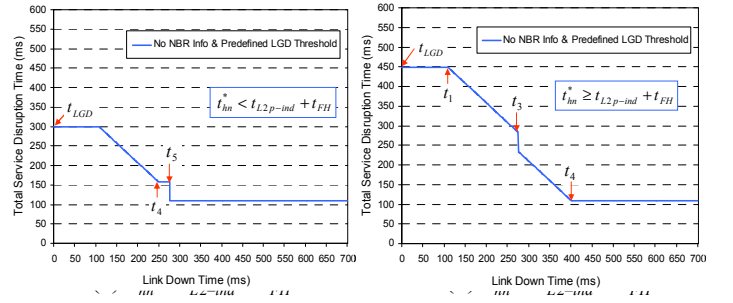

Figure 7. The total service disruption time.

Where the received signal power depends on the path loss exponent β and distance d from the transmitter; $P_r(d)$ denotes the received signal power level in watts at distance d; $P_r(d_0)$ is the received power at the close-in reference distance d_0. Table 2 shows the simulation parameters.

Table 2. Parameters for signal generation and prediction

$P_r(d_0)$	9.74*10⁻⁶ W	T_{init}	-70 dBm
T_{LD}	-75 dBm	$N_{WiMAX(max)}$	10 channels
Δ_h	10 ms	LMS order p	10
α	1.0 to 2.0	LMS step size	0.015
η	0.3	β	3 to 5
MN speed v	1 m/s to 5 m/s		

For the performance comparison, a pre-determined LGD threshold method of (1) is compared with the proposed mechanism. In this paper, *LDTimeDifference* is defined as the time difference between the desired LD time and the actual LD time. The desired LD time means the smallest LD time that can minimize the service disruption time after LGD trigger. The negative and positive *LDTimeDifference* values indicate the early- and the late- LGD triggering, respectively. *EarlyLGDTriggerCost* is defined as the time difference between the handover finishing time and the actual LD time.

Fig. 8, Fig. 9, and Fig. 10 show performance comparisons for *LDTimeDifference*, the total service disruption time, and *EarlyLGDTriggerCost*, respectively. As shown in Fig. 8, in the proposed mechanism the desired LD time is always close to the actual LD time. Therefore, the total service disruption time is also very small compared with the pre-determined LGD threshold case as in Fig. 9. For SET 7 through SET 10, the actual link down occurred little before the expected LD time for LMS prediction case about 45 ms to 55 ms so that after the vertical handover a reactive mode fast handover is required. The *EarlyLGDTriggerCost* of the proposed method is close to ideal value (zero) as shown in Fig.10. For the pre-determined LGD threshold method, depending on the α values, large performance variations are observed. The more conservative α (larger value) shows the smaller service disruption time but the larger LD time difference and early LGD triggering cost.Table 3 shows the parameter sets for various channel and movement condition simulations.

Table 3. Simulation cases and parameter sets

Set	Initial β	Fina β	Initial v	Final$v$	θ_{WiMAX}
SET 1	3	3	1	1	100 ms
SET 2	3	3	1	1	250 ms
SET 3	3	3	5	5	100 ms
SET 4	3	3	5	5	250 ms
SET 5	5	5	1	1	100 ms
SET 6	5	5	1	1	250 ms
SET 7	5	5	5	5	100 ms
SET 8	5	5	5	5	250 ms
SET 9	5	3	5	1	100 ms
SET 10	5	3	5	1	250 ms
SET 11	3	5	1	5	100 ms
SET 12	3	5	1	5	250 ms

Figure 8. LD Time Difference.

Figure 9. Total service disruption time.

Figure 10. Early LGD Trigger Cost.

CONCLUSIONS

In this paper, a new predictive handover mechanism is proposed for the seamless handover across heterogeneous wireless networks. From the analysis of the required handover procedures based on the obtained neighbor information, we presented the required handover time estimation methods for various handover types. To generate timely the LGD trigger, the estimated required handover time (t_h) is applied to the link down prediction. Unlike the previous pre-defined threshold-based LGD triggering in which the LGD trigger may result in too late or too early handover initiation depending on the channel condition and movement pattern, in the proposed method, if the Link_Down event is expected after t_h, then the predictive LGD trigger is generated to initiate the required handover procedures. Handover cost analysis is performed for horizontal and vertical handovers. In the simulation study for the WLAN to WiMAX vertical handover case, the service disruption time of the compared conventional method is at most 450 ms while the proposed method is at most 55 ms. Several experimental case studies demonstrate that the proposed method achieves seamless and proactive mobility for various network environments.

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[11] Richard Rouil and Nada Golmie, "Effect of IEEE 802.16 Link Parameters and Handover Performance for Select Scenarios", IEEE 802.21 Contrib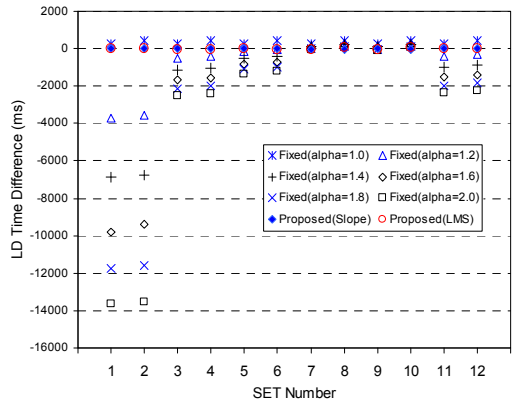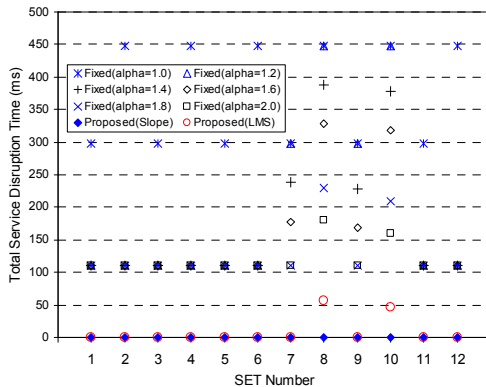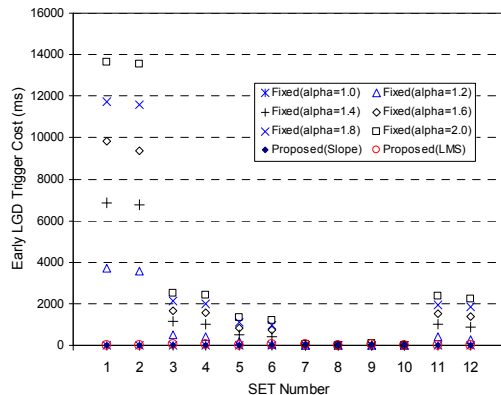ution DCN 21-06-0524-00-0000, February 10, 2006.