# Timely Effective Handover Mechanism in Heterogeneous Wireless Networks

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## Abstract

Next-generation wireless networks should be able to coordinate and integrate different communication systems. It has been a challenging problem to support a seamless handover in these diverse wireless network environments. Link level triggers can provide information about events which can help handover decision and layer 3 entities better streamline their handover related activities. In most conventional layer 2 triggering approaches, a pre-defined threshold for a specific perspective such as the received signal strength is used. This 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 in heterogeneous wireless networks.

Key words: *seamless handover, link triggers, prediction, heterogeneous wireless networks*

## I. Introduction

The rapid expansion of mobile communications over the last decade has spawned a number of different wireless communication systems. Also wireless devices are becoming increasingly multimodal, containing multiple communication interfaces such as the Wireless Local Area Network (WLAN) [1] and the Worldwide Interoperability for Microwave Access (WiMAX) [2][3]. This allows users to communicate without the geographical coverage limitations of individual communication systems and to choose an optimum wireless network interface in accordance with the desired requirements in terms of transmission rate, quality of service (QoS), communication price, and so on. In the new generations of wireless networks, seamless mobility support across heterogeneous networks is very important. Seamless mobility is referred to as the event when all sessions of an MN continue to maintain their connection even as an MN changes its point of attachment (PoA). If seamless mobility is supported, an MN can roam

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across heterogeneous networks and keep its connections active.

Handovers typically cause layer 2 (L2) 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 is needed in order for appropriate actions to be taken. This is provided by the so-called link layer triggers that are fired at the Medium Access Control (MAC) sub-layer and communicated either to a handover management functional module such as the Media Independent Handover Function (MIHF) of IEEE 802.21 [4], or to a network control layer protocol. 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 key in determining whether the handover completes successfully [5]. In particular, in several "break before make" networks such as WLAN and WiMAX, the role of link triggers in the initiation of a proper handover is significant in mitigating handover service disruptions. The Link_Going_Down (LGD) trigger implies that a broken link is imminent. The Link_Going_Down trigger time greatly influences the handover performance in terms of the packet loss rate, handover delay, and communication cost. Essentially, the handover process will not make the correct decision and execution unless adequate and timely Link_Going_Down trigger information is delivered. Therefore, a method that effectively and adaptively detects the link quality decay in order to trigger a handover is a key issue.

A number of methods have been proposed for generating LGD triggers [6-11]. However, most of these methods use a pre-defined threshold of a specific metric such as received signal strength indication (RSSI). For example, if the received signal strength is less than a pre-defined threshold, the Link_Going_Down trigger is generated. 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.

The IEEE 802.21 media independent handover (MIH) framework [4] currently under development provides link layer intelligence and other related network information to upper layers to optimize handovers between heterogeneous media. It supports cooperative use of information available at the mobile node and within the network infrastructure. The information service of the IEEE 802.21 provides a framework and corresponding mechanisms by which a MIH function entity can discover and obtain network information available within a geographical area to facilitate the handovers. In the proposed handover architecture, we make use of the IEEE 802.21 functionality.

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, QoS support, 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 LGD triggers. A predictive link trigger mechanism is used to start and finish the required handover procedures before the link actually goes down. Unlike the handover initiations of most

previous handover algorithms that depend on a specific measurement metric and generate link triggers with pre-determined trigger thresholds, in our proposed handover mechanism, any link quality metric can be applied and the LGD trigger is adaptively invoked based on the estimated required handover time.

The remainder of this paper is organized as follows: Section II presents the proposed predictive handover architecture. Neighbor network aware handover procedure is shown with an example scenario based on IEEE 802.21 MIHF. 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 accordance with the different link down time, the corresponding service disruption time and total handover time are presented. 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.

## II. Predictive Handover Architecture Based on Neighbor Network Information

In this section we propose a cross-layer based predictive handover architecture and mechanism after investigating late or early link trigger costs for handovers. The proposed mechanisms are implemented in the context of the IEEE 802.21 media independent handover architecture.

### A. Link Trigger Costs

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 aid the handover preparation and execution [1-4][12][13]. Link triggers are delivered to a handover decision module and a mobility control protocol in layer 3 to indicate changes in link quality (signal strength, link level QoS, or link connectivity). Specifically, the Link_Going_Down trigger that implies "broken link is imminent" greatly influences the handover performance because it is generally used to start the required handover procedure. Essentially, the handover process will not make the correct decision and execution unless adequate and timely Link_Going_Down trigger information is delivered. Most previous LGD trigger algorithms [6-11] are based on pre-defined thresholds associated with the received signal strength or QoS metrics. If the measured link quality crosses a pre-defined threshold $TH_{LGD}$, then the Link_Going_Down trigger is generated and the handover process starts.

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

$$TH_{LGD} = \alpha \times TH_{LD}, \quad \alpha \geq 1.0 \tag{1}$$

The wireless link quality depends on many time varying factors: wireless channel conditions due to fading and shadowing, MN moving speed and direction, traffic loads, network types, and so on. For example, the link quality slowly decreases as the MN moves away from the current point of attachment (PoA) assuming free space channel

condition, slow MN speed, and low traffic load. However in the urban area, high MN speed, and high network loads, the link quality of the current PoA will rapidly drop to the minimal level within a short time. Therefore, it is very difficult to formulate the $\alpha$ value in advance.

Fig. 1 shows the cost of an improper Link_Going_Down trigger. In Fig. 1-(a) the LGD trigger occurs too late to initiate the vertical handover from WLAN to WiMAX properly, and before finishing the handover to the WiMAX network, the connection to the WLAN is lost. This may lead to a long service disruption, and some incoming packets may be lost or delayed during this outage. A cost function can be determined using the total required handover latency and the total service disruption time. The different time gaps between the LGD and Link_Down (LD) triggers can cause different handover latencies also different service disruption times. In Section IV we will show the handover cost analysis for late triggering.
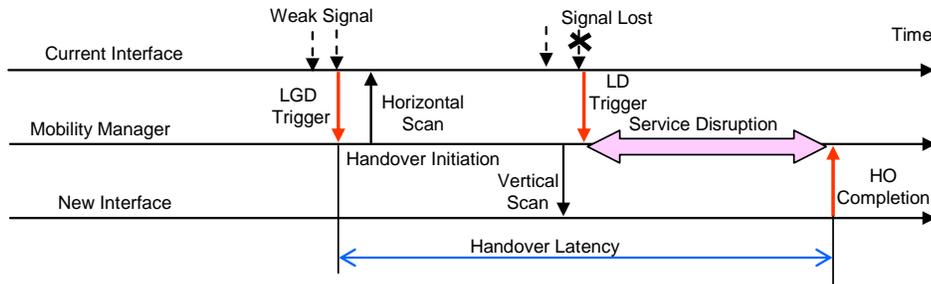


(a) Too late LGD triggering.
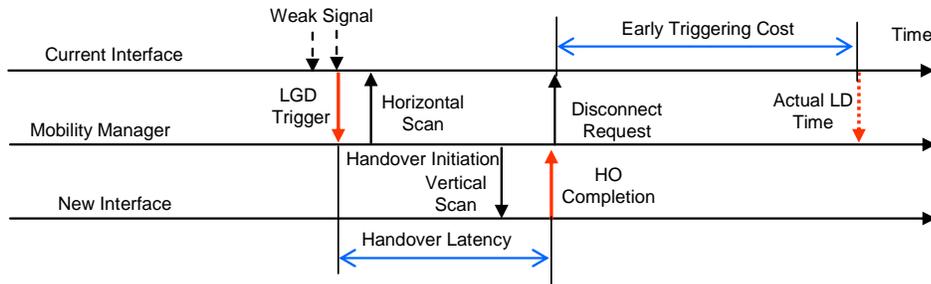


(b) Too early LGD triggering.

Figure 1. Link_Going_Down trigger cost.

The cost for an LGD trigger that was generated too early is also significant as shown in Fig. 1-(b). 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 also occur. Early LGD triggering cost is a function of the time difference between the handover completion time and the actual link down time. The actual link down time is the time that the current link goes down when the MN does not perform a handover. In fact, in real communications we cannot measure the exact actual link down time because the MN already changed its PoA. In Section V, we will show the early trigger cost comparisons for some simulation scenarios.

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## B. *Neighbor Information based Predictive Handover Architecture*

In this section, we present a new timely effective handover architecture based on the neighbor network information. Fig. 2 shows the proposed predictive handover architecture based on the cross layer design for the seamless handover. The PHY/MAC layer is responsible for the link quality measurement, channel switching, link prediction, and trigger generation. Below the L3 mobility protocol, there exist the handover decision engine and the media independent handover function module that are for obtaining neighbor network information, configuring handover related parameters, estimating the required handover time, and deciding a handover target and policy.
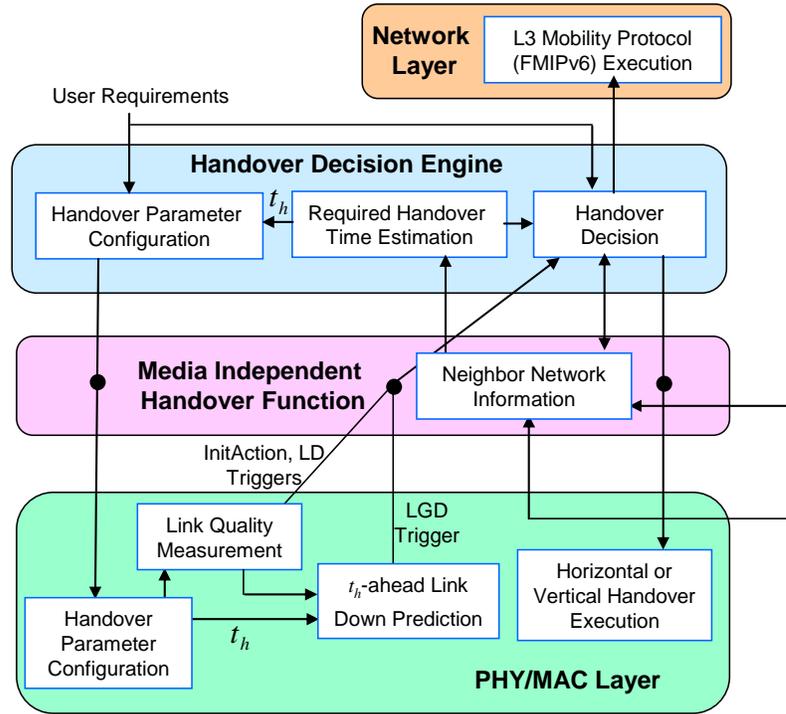


Figure 2. The proposed predictive handover architecture based on the neighbor network information.

In the proposed architecture, we 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 [4] 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. In addition to the IEEE 802.21 MIHF, some wireless MAC protocols such as WLAN [13] and WiMAX [2] also provide a certain level of neighbor network information for the network systems of the same type. The neighbor network information may include:

- The list of neighbor networks: neighbor network types, MAC and IP level addresses, currently used channel id, and other system parameters (e.g., modulation method and timing information);

- QoS support level: current network loads, supportable QoS classes, currently supported QoS performance, and other QoS related metrics;

- Network layer information: mobility support protocol types and mobility related parameters.

From this neighbor information, the MN (or PoA) can estimate the required handover type (horizontal or vertical) 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. For example, if the estimated service disruption time due to the required horizontal scanning is greater than the user requirement, then MN may decide an immediate vertical handover to meet the desired performance instead of a possible horizontal handover. The required handover time, $t_h$, is delivered to the MAC layer to configure the condition for the LGD trigger.

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 trigger event, it starts the required handover procedures both on the MAC/physical layer and network layer.

As shown in Fig. 3, 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.
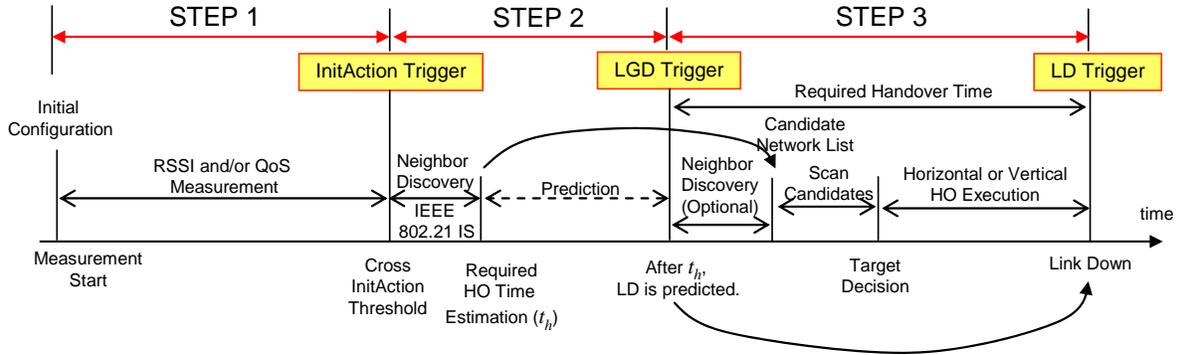


Figure 3. Predictive handover time sequence.

### 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 and Link_Down 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. The proposed mechanism does not depend on a specific measurement metric. 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. Weak RSSI caused by deep fading or moving away from

the current PoA may cause a handover. Handovers due to the poor QoS performance in terms of packet delay, delay jitter, loss rate, and transmission rate can be caused by weak RSSI, heavy network load, or strong interference from other systems. For QoS based handover, a "*QoS satisfaction degree*" is defined as a link quality metric in this paper. It is a function of QoS metrics as defined in (2). The QoS satisfaction degree can be defined as a minimum value from all the QoS components or a weighted average as shown in (3) depending on the user requirements.

$$QoS_{m,c}^{n,k}(t) = F(\text{delay}, \text{loss}, \text{jitter}, \text{rate}) \tag{2}$$

$$F(\bullet) = \min\left\{\frac{R\_delay_c}{M\_delay_{m,c}^{n,k}(t)}, \frac{R\_loss_c}{M\_loss_{m,c}^{n,k}(t)}, \frac{R\_jitter_c}{M\_jitter_{m,c}^{n,k}(t)}, \frac{M\_rate_{m,c}^{n,k}(t)}{R\_rate_c}\right\}$$

$$\text{or} \quad = w_c(d)\frac{R\_delay_c}{M\_delay_{m,c}^{n,k}(t)} + w_c(l)\frac{R\_loss_c}{M\_loss_{m,c}^{n,k}(t)} + w_c(j)\frac{R\_jitter_c}{M\_jitter_{m,c}^{n,k}(t)} + w_c(r)\frac{M\_rate_{m,c}^{n,k}(t)}{R\_rate_c} \tag{3}$$

$$w_c(d) + w_c(l) + w_c(j) + w_c(r) = 1 \left(\forall c \in \overline{C}\right)$$

where, $m$ is a mobile node index; $c$ is a service class index from the service class set $\overline{C}$; $n$ is a network type (e.g., WLAN or WiMAX); $k$ is the current PoA index; $w_c(\Theta)$ is a weight for the QoS metric $\Theta$ of class $c$. $M\_\Theta_{m,c}^{n,k}(t)$ is the measured QoS value for the metric $\Theta$ for the class $c$ of the mobile node $m$ at the $k$th PoA of the network type $n$ at time $t$. $R\_\Theta_c$ is the required QoS performance for the metric $\Theta$ for the class $c$.

## 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 (4).

$$k_h = \left\lceil \frac{t_h + \Delta_h}{t_m} \right\rceil \tag{4}$$

where $\Delta_h$ is a marginal time $(\geq 0)$.

Any prediction mechanism can be used to trigger the LGD event. In this paper we consider two prediction techniques. Least mean square (LMS) adaptation algorithm monitors the prediction error $e(n)$ and attempts to minimize the mean squared prediction error, $E\left\{e(n)^2\right\}$, by adapting prediction weights, as (5). The $p$th-order linear

predictor defined in (5) is concerned with the estimation of $x(n+k_h)$, the link quality $k_h$ step ahead, using a linear combination of the current and previous values of link quality vector $\mathbf{X}(n)$, which is defined in (6). $\mathbf{W}_n$ is the time-varying coefficient vector shown in (6) along with its adaptation formula. Considering that at time $n$ the value of $x(n+k_h)$ is not available to compute $e(n)$, $e(n-k_h)$ is used instead as in [14]. The step size $\mu$ is an adaptation parameter that determines convergence speed. In a normalized LMS, if $0 < \mu < 2$, then the LMS will converge to the mean.

$$\hat{x}(n+k_h) = \sum_{l=0}^{p-1} w_n(l)x(n-l) = \mathbf{W}_n^T \mathbf{X}(n) \tag{5}$$

$$\mathbf{X}(n) = [x(n), x(n-1), \cdots, x(n-p+1)]^T$$
$$\mathbf{W}_n = [w_n(0), w_n(1), ..., w_n(p-1)], \mathbf{W}_{n+1} = \mathbf{W}_n + \mu \times e(n)\frac{\mathbf{X}(n)}{\|\mathbf{X}(n)\|^2} \tag{6}$$
$$e(n) = x(n+k) - \hat{x}(n+k_h) \approx e(n-k_h) = x(n) - \hat{x}(n)$$

As a simpler prediction method, a linear slope estimation of link quality degradation is considered in this paper. We assume that during the relatively short time period (handover time – from hundreds of milliseconds to a few seconds) the link quality degradation can be approximated as a line with respect to time $n$. With the $n$-th and $(n-1)$th link quality measurements, the service degradation slope at time $n$ is derived as (7).

$$s(n) = x(n) - x(n-1) \tag{7}$$

And the expected service degradation slope $\bar{a}(n)$ using the previous slope estimations is given in (8).

$$\bar{a}(n) = \eta \cdot s(n) + (1-\eta) \cdot \bar{a}(n-1) \tag{8}$$

where $\eta$ is a weight for the current measured slope. Therefore, the predicted link quality value for $k_h$ time ahead is derived as (9).

$$\hat{x}(n+k_h) = \bar{a}(n) \cdot k_h + x(n) \tag{9}$$

iii) STEP 3: *Handover Execution Step*

After the LGD trigger, the MN can optionally re-perform the neighbor network discovery. This is especially useful when there is a 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) or the MN needs to check the connectivity and resource availability of PoAs, the MN starts the scanning procedure with the (updated) candidate neighbor network list. After the MN decides on a target PoA, a horizontal or vertical handover follows.

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. This 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 finishing all

the required handover procedures before the actual link goes down. Therefore, it successfully reduces possible service disruptions that would be caused by a link break before the handover procedures could be completed.

## C. Implementing the Predictive Handover Mechanism in the Context of the IEEE 802.21 Media Independent Handover Architecture

The IEEE 802.21 defines two link configure thresholds: i) InitAction threshold to start "setup-type" activities and ii) ExecuteAction threshold to take appropriate action for a handover. For the proposed mechanism, the IEEE 802.21 concept can be used as shown in Fig. 4.
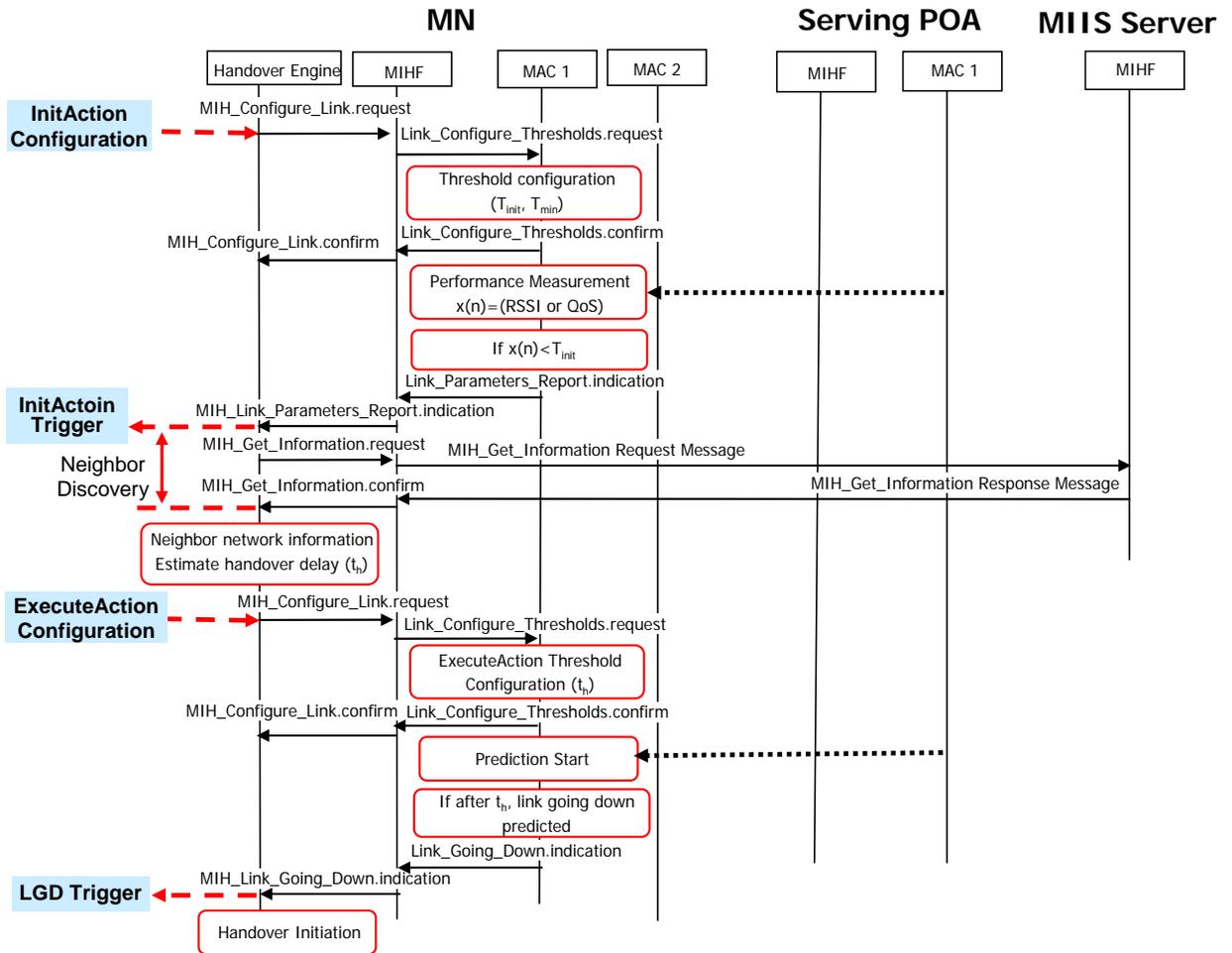


Figure 4. Predictive handover scenario using IEEE 802.21 MIHF architecture.

In the proposed predictive handover mechanism, the InitAction threshold $(T_{init})$ is used to initiate a neighbor discovery procedure and to start link quality prediction. Any link quality metric, such as the received signal strength or QoS satisfaction degree, can be used for the threshold configuration. The MIH_Configure_Link.request and Link_Configure_Threshold.request primitives carry $T_{init}$ , $T_{min}$ (the minimum link quality level), and the

measurement related parameters. If the measured link quality is less than $T_{init}$, then InitAction trigger is generated by the link layer and it is delivered to MIHF user by Link_Parameter_Report.indication and the MIH_Link_Parameter_Report. indication primitives. The MIHF user initiates the neighbor network discovery by sending an MIH_Get_Information Request message to the IEEE 802.21 information server. Based on the neighbor information returned in a MIH_Get_Information Response message from the MIIS (Media Independent Information Service) server, the MN estimates the required handover time $(t_h)$ and then the MIHF user configures $t_h$ at the link layer as an ExecuteAction threshold. Upon receipt of the Link_Configure_Threshold.request primitive for the ExecuteAction threshold configuration, the link layer starts $t_h$-ahead link quality prediction. It should be noted that in this approach, a pre-determined threshold is not used for LGD threshold configuration. Instead, the MIHF user passes the required handover time $t_h$ that is dynamically computed based on the neighbor network information. During the prediction, if after $t_h$ Link_Going_Down is expected, then Link_Going_Down.indication primitives are delivered to the MIHF user and the MIHF user initiates the required handover procedure. MAC layer scanning to the candidate PoAs is followed. The IEEE 802.21 has defined a handover indication message exchange procedure when a target PoA is determined. The MN sends an MIH_MN_HO_Commit Request message to the current PoA and the current PoA forwards it to the target PoA with an MIH_NET_HO_Commit Request message. The handover indication is finished by receiving a MIH_MN_HO_Commit Response message from the target PoA through the current PoA.

## III. 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 type of 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 considered, 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.

Depending on the neighbor information, we have classified the handover estimation cases as follows:

- HO_Case 1 (horizontal handover): When the MN knows that there exists at least one candidate PoA with the same link type that can support the MN's link quality requirements, the MN estimates the required handover time for the horizontal handover.

- HO_Case 2 (vertical handover): When the MN knows that there is no available PoA for a horizontal

handover but there exists at least one PoA with a different link type, the MN estimates the required handover time for the vertical handover.

- HO_Case 3 (horizontal or vertical handover): The MN obtains candidate PoAs both of the same and different link interface systems, but the MN is not able to decide whether a horizontal handover or vertical handover should be executed.

- HO_Case 4 (no neighbor information): In this case, the MN does not have the neighbor information. It may be caused by some network conditions such that the IEEE 802.21 information server is not reachable or neighbor networks are not connected to the information server. The MN estimates the required handover time to the maximum value to prepare for the worst case scenario.

## A. HO_Case 1 (the required time estimation for a 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 (access point (AP) or base station (BS)) and therefore has to break its communication with its current PoA before establishing a connection with a new one. This break in communication is from a layer 2 perspective. 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 [12] 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. If FMIPv6 is used as a layer 3 mobility protocol and the target PoA is not on the same subnet, then the L3 handover time is a fast handover execution time ($t_{FH}$).

$$t_{L3} = \begin{cases} t_{FH} \\ 0, & \text{if the target PoA is on the same subnet.} \end{cases} \tag{10}$$

The L2 handover preparation time 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 (or channels).

$$t_{L2p-scn} = N_{p-nbr} \times t_{p-s} \tag{11}$$

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 message exchanges to indicate the handover execution.

The scanning is required when there is one or multiple candidate PoAs and the MN needs to check the connectivity (or resource availability) to the PoAs after obtaining the neighbor information. In this paper, the term

scanning is used to check the availability of the PoAs for any media type. The scanning is a media dependent behavior. For WiMAX, scanning includes all processing sequences from the scan request to the scan report. For WLAN, it includes active or passive scanning procedures. With the help of IEEE 802.21 MIHF protocol, the MN may check the resource availability for candidate PoAs during the scanning period. After the scanning, the MN can select a target PoA. The operations associated with $t_{L2p-nbr}$ 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 (12). Fig. 5 shows the WiMAX horizontal handover scenario combined with FMIPv6, in which pAR and nAR indicate the previous and new access routers, respectively; pL2 and nL2 represent the previous and new layer 2 interface, respectively.

$$t_h = t_{L2p} + t_{L3}, \quad \begin{cases} t_{h-\max} = t_{L2p-nbr} + t_{L2p-scn} + t_{L2p-ind} + t_{FH} \\ t_{h-\min} = t_{L2p-ind} \end{cases} \tag{12}$$
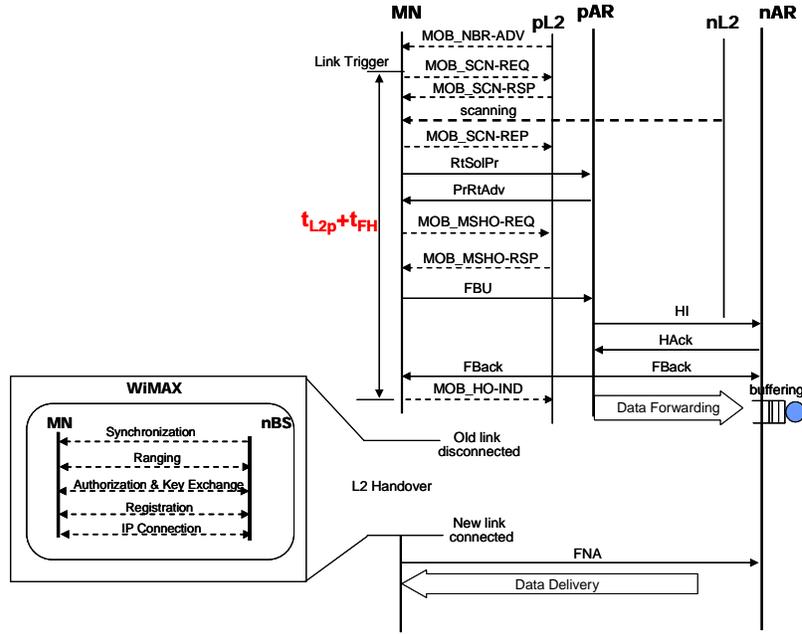


Figure 5. Horizontal handover scenario for WiMAX and the required handover time.

## B. HO_Case 2 (the required time estimation for a 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 $t_h$. Fig. 6 shows a vertical handover timing relationship for WLAN and WiMAX. The generation times shown in the figure contribute to the average required vertical handover time as follows.

- $t_{hp}$ : Handover preparation time for L2 and L3 with the current network PoA. For a vertical handover

between WLAN and WiMAX, unlike a horizontal handover case, $t_{L2p}$ does not include $t_{L2p-scn}$ because scanning is performed at a different network interface. The $t_{FH}$ time is typically required for the layer 3 handover because the target PoA is generally not on the same subnet as the previous PoA. Thus we have $t_{hp}$ in (13).

$$t_{hp} = t_{L2p} + t_{FH} = t_{L2p-nbr} + t_{L2p-ind} + t_{FH} \qquad (13)$$

- $t_{hn}$: Handover execution time with the new network PoA using the new interface. For WLAN, $t_{hn}$ includes vertical interface scanning, authentication, and association times given in (14). For WiMAX it includes scanning, synchronization & ranging, basic capability negotiation, key exchange & authorization, and registration times.

$$t_{hn} = \begin{cases} t_{L2n-scn} + t_{auth} + t_{assc}, & \text{WLAN} \\ t_{L2n-scn} + t_{rng} + t_{cap} + t_{key} + t_{reg}, & \text{WiMAX} \end{cases} \qquad (14)$$

$$t_{L2n-scn} = N_{n-nbr} \times t_{n-s} \qquad (15)$$

where $N_{n-nbr}$ and $t_{n-s}$ are the number of candidate PoAs (or channels) and the scan time per one candidate with the new link interface, respectively.

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 on the previous and new interfaces can be performed separately using different interfaces –for example the handover indication and fast mobile IP handover can be performed using the previous interface while synchronization and association (registration) can be done using the new interface. Therefore, the total required handover time for a vertical handover is given in (16). The handover execution using the new interface can be finished before or after the fast handover procedure using the current interface.

$$t_h = t_{L2p-nbr} + t_{L2n-scn} + \max\{t_{L2p-ind} + t_{FH}, t_{hn}^*\}$$
$$t_{hn}^* = \begin{pmatrix} t_{auth} + t_{assc} : \text{WLAN} \\ t_{rng} + t_{cap} + t_{key} + t_{reg} : \text{WiMAX} \end{pmatrix} \qquad (16)$$
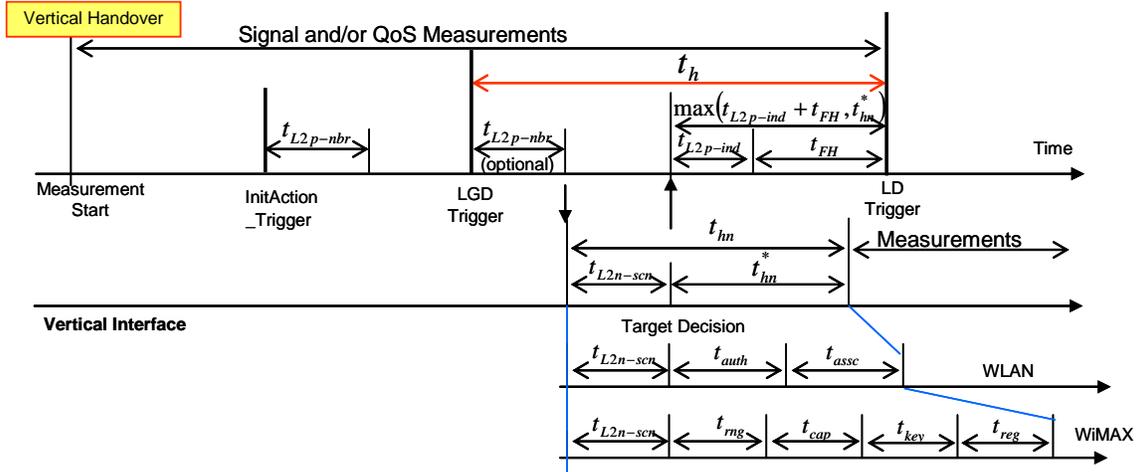


Figure 6. Vertical handover timing relationship.

## C. HO_Case 3 (the required time estimation for a 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 the possible horizontal or vertical handovers. The required handover time is derived in (17). We assume that vertical scanning is performed only if there is no PoA for horizontal handover after horizontal scanning.

$$t_h = t_{L2p-nbr} + t_{L2p-scn} + t_{L2n-scn} + \max\left\{t_{L2p-ind} + t_{FH}, t_{hn}^*\right\} \tag{17}$$

## D. HO_Case 4 (handover 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 to account for the maximum scan times, as in (18).

$$t_h = t_{L2p-nbr} + t_{L2p-scn(\max)} + t_{L2n-scn(\max)} + \max\left\{(t_{L2p-ind} + t_{FH}), t_{hn}^*\right\} \tag{18}$$

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

In WLAN, the scanning time requires 10 ms to 80 ms [15][16] depending on the number of channels to scan when active scanning is used; for authentication and association it may require less than 10 ms [10]. In [15], it is shown that Mobile IPv6 (MIPv6) layer 3 handover latencies range from 80 ms to 150 ms. When FMIPv6 is used with link layer triggers, the layer 3 handover delay (data forwarding delay) can be much shorter than that of MIPv6. In WiMAX, from the scanning to the registration this requires from tens of ms to a few seconds [17] [18]. The dominant measurement of this time is for synchronization, and this depends on the UCD/DCD (Uplink/Downlink Channel Descriptor) broadcasting interval of the target BS.

# IV. 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. In our analysis the handover costs measure the amount of time required to perform the handover. First we will derive an analytic cost function for the proposed mechanism. Then, we will show the handover costs for the case in which a predefined LGD threshold is used and no neighbor network information is available.

## A. Cost Analysis for Each Handover Procedure

In this section we present a handover cost model and derive a handover cost for each handover time component

of Section III. In this analysis a transmission cost represents a time delay for handover control message exchanges including transmission, propagation, and processing delays. For this analysis, the network model in Fig. 7 and model parameters of Table 1 are used.
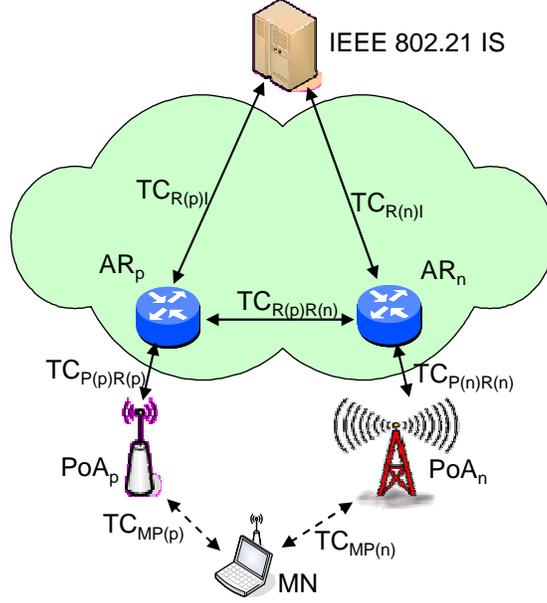


Figure 7. Network model for handover cost analysis.

Table 1. Network model parameters

| Parameter | Definition |
|---|---|
| $TC_{RI}, TC_{IR}$ | Transmission cost between access router (AR) and IEEE 802.21 information server (IS) |
| $TC_{RR}$ | Transmission cost between current and target access routers |
| $TC_{PR}, TC_{RP}$ | Transmission cost between PoA and access router |
| $TC_{MP}, TC_{PM}$ | Transmission cost between MN and PoA |
| $H_{RI}$ | Hop count between access router and information server |
| $H_{RR}$ | Hop count between current and target access routers |
| $H_{PR}, H_{RP}$ | Hop count between PoA and router |
| $H_{MP}$ | Hop count between MN and PoA |
| $\phi$ | Transmission cost per one hop |
| $\delta$ | Weighing factor for wireless link |
| $N_{p-nbr}, N_{n-nbr}$ | The number of candidate PoAs to scan for horizontal and vertical handovers, respectively |
| $\gamma_p, \gamma_n$ | Scanning cost (time) per single PoA for horizontal and vertical systems, respectively |
| $\theta_n$ | Association or registration cost (time) after scanning with the new communication interface |
| $HC_\chi$ | Handover cost for procedure $\chi$ |

Let $\phi$ be the unit message transmission cost and $\delta$ be the weight for a wireless link to capture some overhead in wireless medium such as access delay and collisions (for the wired link, the weight is 1). It is assumed that the link between the MN and PoA is wireless with one hop and the link between PoA and access router is wired with one hop. Other assumptions include the following. The transmission costs are symmetric for up and down links; the transmission costs of the paths on the previous and new networks are the same as in (19).

$$TC_{MP(p)} = TC_{MP(n)}, TC_{P(p)R(p)} = TC_{P(n)R(n)}, TC_{R(p)I} = TC_{R(n)I} \qquad (19)$$

The transmission cost is proportional to the hop count on the path as (20).

$$
\begin{aligned}
TC_{MP} &= TC_{PM} = \delta \cdot \phi \cdot H_{MP} = \delta \cdot \phi \quad \leftarrow H_{MP} = 1 \\
TC_{PR} &= TC_{RP} = \phi \cdot H_{PR} = \phi \quad \leftarrow H_{PR} = 1 \\
TC_{RR} &= \phi \cdot H_{RR}, \quad TC_{RI} = TC_{IR} = \phi \cdot H_{RI}
\end{aligned}
\qquad (20)
$$

In the following, we derive the handover cost $HC_{\chi}$ for each time component $\chi$ 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 as shown in Fig. 7 (MN↔PoA(p)↔AR(p)↔IS). The **neighbor discovery cost** is derived as (21).

$$
\begin{aligned}
HC_{nbr} &= t_{L2p-nbr} = TC_{MP} + TC_{PR} + TC_{RI} + TC_{IR} + TC_{RP} + TC_{PM} \\
&= 2 \times (\delta\phi + \phi + \phi H_{RI}) = 2\phi(\delta + 1 + H_{RI})
\end{aligned}
\qquad (21)
$$

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)). The **handover indication cost** is given in (22).

$$
\begin{aligned}
HC_{ind} &= t_{L2p-ind} = TC_{MP} + TC_{PR} + TC_{RR} + TC_{RP} + TC_{PR} + TC_{RR} + TC_{RP} + TC_{PM} \\
&= 2 \times (\delta\phi + \phi + \phi H_{RR} + \phi) = 2\phi(\delta + 2 + H_{RR})
\end{aligned}
\qquad (22)
$$

In real communication environments, for the neighbor discovery and handover indication the MN may perform additional network dependent MAC level frame exchanges.

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 $\gamma_{\xi}$ and $N_{\xi-nbr}$ be the scanning time for one PoA and the number of neighbor PoAs to scan for communication system type $\xi$, respectively. Then the scanning cost is given as (23).

$$
HC_{scn} = \begin{cases} t_{L2p-scn} = N_{p-nbr} \times \gamma_p & : \text{horizontal scan} \\ t_{L2n-scn} = N_{n-nbr} \times \gamma_n & : \text{vertical scan} \end{cases}
\qquad (23)
$$

If the neighbor network information is not available, then the number of PoAs to scan is the maximum number of channels operated by the communication system.

The **fast handover cost** of (24) 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.

$$HC_{FH} = t_{FH} = TC_{RtSolPr} + TC_{PrRtAdv} + TC_{FBU} + TC_{HI} + TC_{HACK} + TC_{FBack}$$
$$= (TC_{MP} + TC_{PR}) + (TC_{RP} + TC_{PM}) + (TC_{MP} + TC_{PR}) + TC_{RR} + TC_{RR} + \max[TC_{RR}, (TC_{RP} + TC_{PM})]$$
$$= 3TC_{MP} + 3TC_{PR} + 2TC_{RR} + \max[TC_{RR}, (TC_{RP} + TC_{PM})]$$
$$= \phi\{3\delta + 3 + 2H_{RR} + \max[H_{RR}, (1+\delta)]\}$$
(24)

The **handover execution cost** of (25) 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. In case of WLAN it includes authentication and association time. For WiMAX, it is for synchronization & ranging, basic capacity negotiation, key exchange & authorization, and registration. Layer 3 FNA (Fast Neighbor Advertisement) message transmission to the new PoA after the MN established a new link connection is included in this cost. Let $\theta_\xi$ be the handover execution delay for the communication system $\xi$.

$$HC_{HO-exe} = t_{hn}^* = \begin{cases} t_{auth} + t_{assc} = \theta_{WLAN} : \text{WLAN} \\ t_{rng} + t_{cap} + t_{key} + t_{reg} = \theta_{WiMAX} : \text{WiMAX} \end{cases}$$
(25)

## 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 (26). 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 (27)

$$t_{HO} = t_{L2p} + t_{L3}$$
$$= \begin{cases} t_{HO-\max} = t_{L2p-nbr} + t_{L2p-scn} + t_{L2p-ind} + t_{FH} \\ \quad = 2\phi(\delta + 1 + H_{RI}) + N_{p-nbr}\gamma_p + 2\phi(\delta + 2 + H_{RR}) + \phi\{3\delta + 3 + 2H_{RR} + \max[H_{RR}, (1+\delta)]\} \\ \quad = \phi(7\delta + 9 + 4H_{RR} + 2H_{RI}) + N_{p-nbr}\gamma_p + \phi\{\max[H_{RR}, (1+\delta)]\} \\ t_{HO-\min} = t_{L2p-ind} = 2\phi(\delta + 2 + H_{RR}) \end{cases}$$
(26)

$$t_{SD} = t_{L2p-scn} = N_{p-nbr}\gamma_p$$
(27)

For the vertical handover of the proposed method, the handover time is derived in (28) and the service disruption time is zero when the Link_Down prediction is correct.

$$t_{HO} = t_{L2p-nbr} + t_{L2n-scn} + \max\left\{ t_{L2p-ind} + t_{FH}, \begin{pmatrix} t_{auth} + t_{assc} : \text{WLAN} \\ t_{rng} + t_{cap} + t_{key} + t_{reg} : \text{WiMAX} \end{pmatrix} \right\}$$
$$= 2\phi(\delta + 1 + H_{RI}) + N_{n-nbr}\gamma_n + \max\{\phi[3\delta + 3 + 2H_{RR} + \max\{H_{RR}, (1+\delta)\}], \theta_n\}$$
(28)

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

In this section, we derive the handover cost for a vertical handover without neighbor network information and using a pre-defined LGD threshold. 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. When the MN uses a pre-defined LGD threshold, due to the dynamic nature of the wireless channel, the MN speed, and the network conditions the LGD time may be too early or too late. In late LGD trigger, the MN cannot finish the necessary handover procedures before the actual link down. This causes long handover delay and service disruption time.

The Link_Down can occur any time from the LGD trigger to the actual handover finishing time. Fig. 8 shows the vertical handover timing diagram. Because we have assumed that the MN does not use neighbor network information with IEEE 802.21 information server, the neighbor discovery handover cost $t_{L2p-nbr}$ is not included in the total handover time. In Fig. 8 the dotted arrows indicate some of the possible Link_Down times. If the LD occurs before or during FMIPv6 procedure, it is assumed that the MN needs to start a reactive fast handover operation [12] 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 (29) to send an FBU (Fast Binding Update) and to receive an FBack to/from the previous access router.

$$t_{reactive} = t_{FBU} + t_{FBack} = (TC_{MP} + TC_{PR} + TC_{RR}) + (TC_{RR} + TC_{RP} + TC_{PM}) = 2\phi(\delta + 1 + H_{RR}) \tag{29}$$
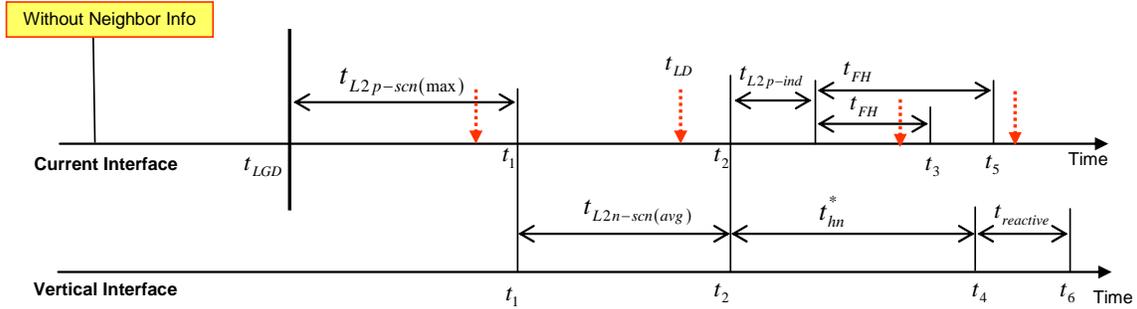


Figure 8. Vertical handover timing diagram.

Time points from $t_1$ through $t_6$ of Fig. 8 are derived as,

$$\begin{cases} t_1 = t_{L2p-scn(\max)} = N_{p(\max)} \times \gamma_p \\ t_2 = t_{L2p-scn(\max)} + t_{L2n-scn(avg)} = N_{p(\max)} \times \gamma_p + N_{n(avg)} \times \gamma_n \\ t_3 \text{ or } t_5 = t_{L2p-scn(\max)} + t_{L2n-scn(avg)} + t_{L2p-ind} + t_{FH} \\ \qquad = N_{p(\max)} \times \gamma_p + N_{n(avg)} \times \gamma_n + 2\phi(\delta + 2 + H_{RR}) + \phi\{3\delta + 3 + 2H_{RR} + \max[H_{RR}, (1+\delta)]\} \\ t_4 = t_{L2p-scn(\max)} + t_{L2n-scn(avg)} + t^*_{hn} = N_{p(\max)} \times \gamma_p + N_{n(avg)} \times \gamma_n + \theta_n \\ t_6 = t_{L2p-scn(\max)} + t_{L2n-scn(avg)} + t^*_{hn} + t_{reactive} = N_{p(\max)} \times \gamma_p + N_{n(avg)} \times \gamma_n + \theta_n + 2\phi(\delta + 1 + H_{RR}) \end{cases} \tag{30}$$

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 is,

i) $t_{L2p-ind} + t_{FH} \le t^*_{hn}$

$$t_{HO} = \begin{cases} t_6 - t_{LGD}, & \text{if } t_{LD} < t_3 \\ t_4 - t_{LGD}, & \text{if } t_{LD} \ge t_3 \end{cases} \tag{31}$$

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

$$t_{HO} = \begin{cases} t_6 - t_{LGD}, & \text{if } t_{LD} \leq t_4 \\ (t_{LD} - t_{LGD}) + t_{reactive}, & \text{if } t_4 < t_{LD} < t_5 \\ t_5 - t_{LGD}, & \text{if } t_5 \leq t_{LD} \end{cases} \tag{32}$$

As in (31) and (32), if the LD occurs before finishing the FMIPv6, then after vertical handover the reactive mode fast handover is followed so that the total handover time is increased.

The total service disruption time is given as,

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

$$t_{SD} = \begin{cases} t_6 - t_{LGD}, & \text{if } t_{LD} \leq t_1 \\ (t_1 - t_{LGD}) + (t_6 - t_{LD}), & \text{if } t_1 < t_{LD} < t_3 \\ (t_1 - t_{LGD}) + (t_4 - t_{LD}), & \text{if } t_3 \leq t_{LD} < t_4 \\ t_1 - t_{LGD}, & \text{if } t_4 \leq t_{LD} \end{cases} \tag{33}$$

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

$$t_{SD} = \begin{cases} t_6 - t_{LGD}, & \text{if } t_{LD} \leq t_1 \\ (t_1 - t_{LGD}) + (t_6 - t_{LD}), & \text{if } t_1 < t_{LD} \leq t_4 \\ (t_1 - t_{LGD}) + t_{reactive}, & \text{if } t_4 < t_{LD} \leq t_5 \\ t_1 - t_{LGD}, & \text{if } t_5 < t_{LD} \end{cases} \tag{34}$$

Basically, since during the horizontal channel scanning $(t_1 - t_{LGD})$ the MN cannot send and receive data, the service is disrupted. As the worst case, if the LD occurs during the horizontal scanning, then the service will be disrupted during the entire handover time up to $t_6$ time point.

# V. 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. Three case studies are performed. First, the required handover time variations for different network model parameter values are evaluated. Second, the handover time and service disruption time are analyzed using equation (31)~(34) for a given handover scenario. Third, we have simulated the handover performance when the mobile node speed and channel condition vary in time.

Fig. 9 shows the handover scenario applied to 'Case Study 2' and 'Case Study 3' in which the MN moves away from the WLAN to the WiMAX network so that a vertical handover is expected. Table 2 shows the simulation parameter values [10][15-18] that are used in this section.
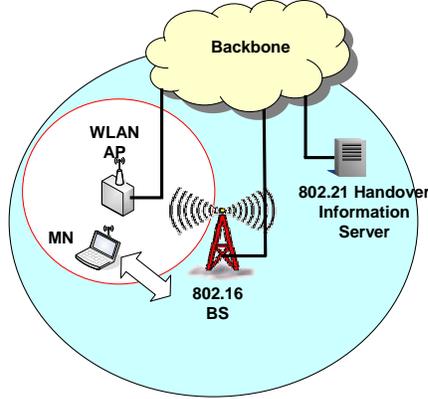
Figure 9. Handover scenario for 'Case Study 2' and 'Case Study 3'.

Table 2. Simulation parameters

| $\delta$ | 2 | $\phi$ | 3 ms | $\gamma_{WLAN}$ | 10 ms |
|---|---|---|---|---|---|
| $\gamma_{WiMAX}$ | 8 ms | $\theta_{WLAN}$ | 20 ms | $\theta_{WiMAX}$ | 100 ms, 250 ms |
| $N_{WLAN(\max)}$ | 11 channels | $N_{WiMAX(\max)}$ | 10 channels | $H_{MP}$ | 1 |
| $H_{PR}$ | 1 | $H_{RR}$ | 2 (horizontal), 5(vertical) | $H_{RI}$ | 5 (Case Study 2 and 3) |

## A. Case Study 1: The Required Handover Time for Different Network Conditions

For horizontal and vertical handovers within and between the WLAN and WiMAX, the required handover time of the proposed method is evaluated. The hop counts between the previous access router and the new access router are set to 2 and 5 for horizontal and vertical handovers, respectively. Fig. 10 shows the required handover time variations of WLAN horizontal handover case for different $\phi$ and $\delta$ values. $N_{p-nbr} = 5$ and $H_{RI} = 5$ are used. As shown in Fig. 10, the required handover time depends more on $\phi$ than $\delta$ because of many message exchanges on the backbone. Fig. 11 shows the required handover time variations for different $H_{RI}$ values and different number of neighbor PoAs for both WLAN and WiMAX.
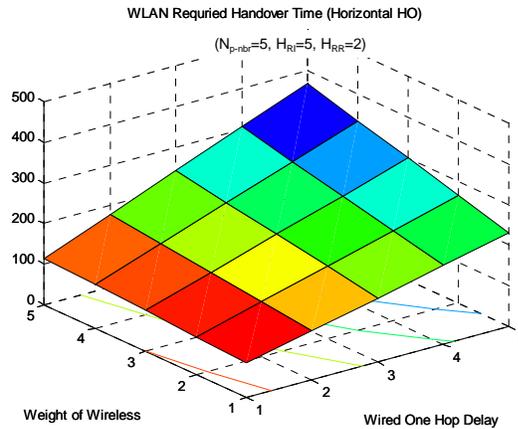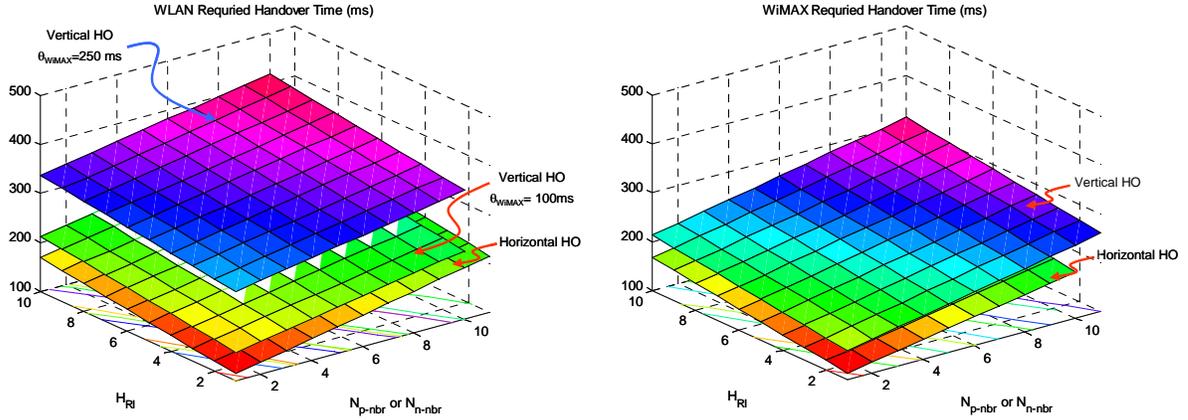


Figure 10. The required handover time for different $\delta$ and $\phi$ values.

(a) WLAN  (b) WiMAX

Figure 11. The required handover time for WLAN and WiMAX.

## B. Case Study 2: Actual Handover Time and Service Disruption Time

For this case study, we use the handover scenario of Fig. 9 in which the MN moves away from the WLAN AP to the WiMAX network domain. The total handover time and the service disruption time for this network condition are evaluated. 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 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 (31) and (32). Basically, the later LD time causes the shorter handover time as shown in Fig. 12.
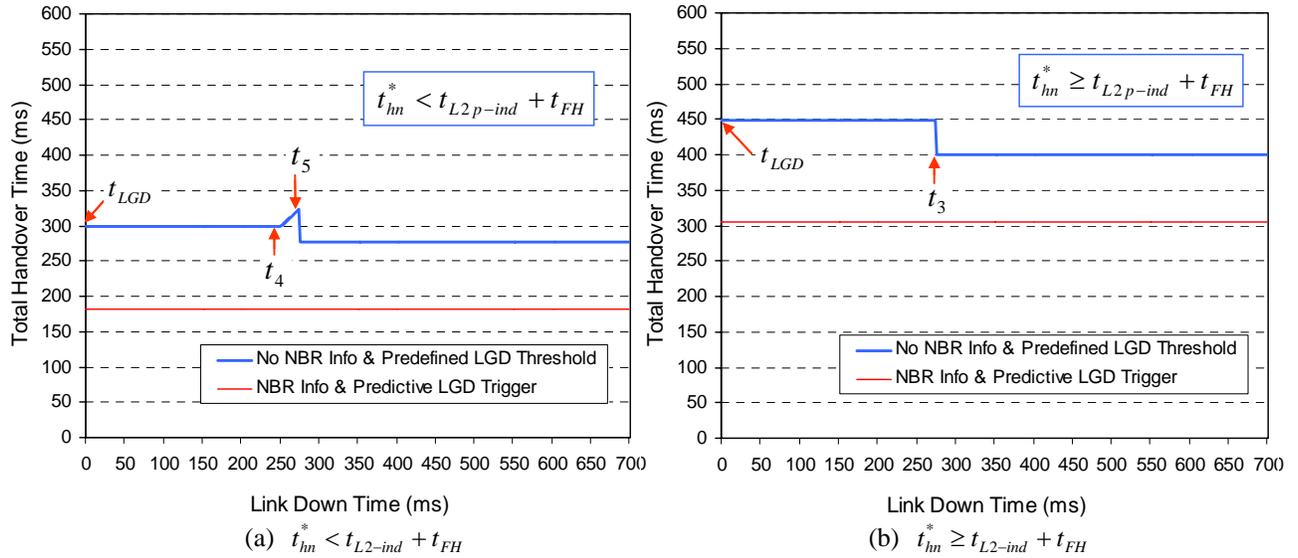


(a) $t_{hn}^{*} < t_{L2-ind} + t_{FH}$  (b) $t_{hn}^{*} \geq t_{L2-ind} + t_{FH}$

Figure 12. The total handover time.

During $t_4$ and $t_5$ of Fig. 12-(a), the MN has finished the required procedures at the vertical interface but it

waits to finish the FMIPv6 operation with the current interface. Since the LD occurs before finishing FMIPv6, the MN starts a reactive mode FMIPv6 with the new interface. In the proposed mechanism, if the predictive LGD trigger is timely generated, then the required handover time is derived as (35).

$$t_h = 2\phi(\delta + 1 + H_{RI}) + \gamma_{WiMAX} + \max\{\phi(5\delta + 7 + 5H_{RR}), \theta_{WiMAX}\} \tag{35}$$

The total service disruption time is shown in Fig. 13. 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.
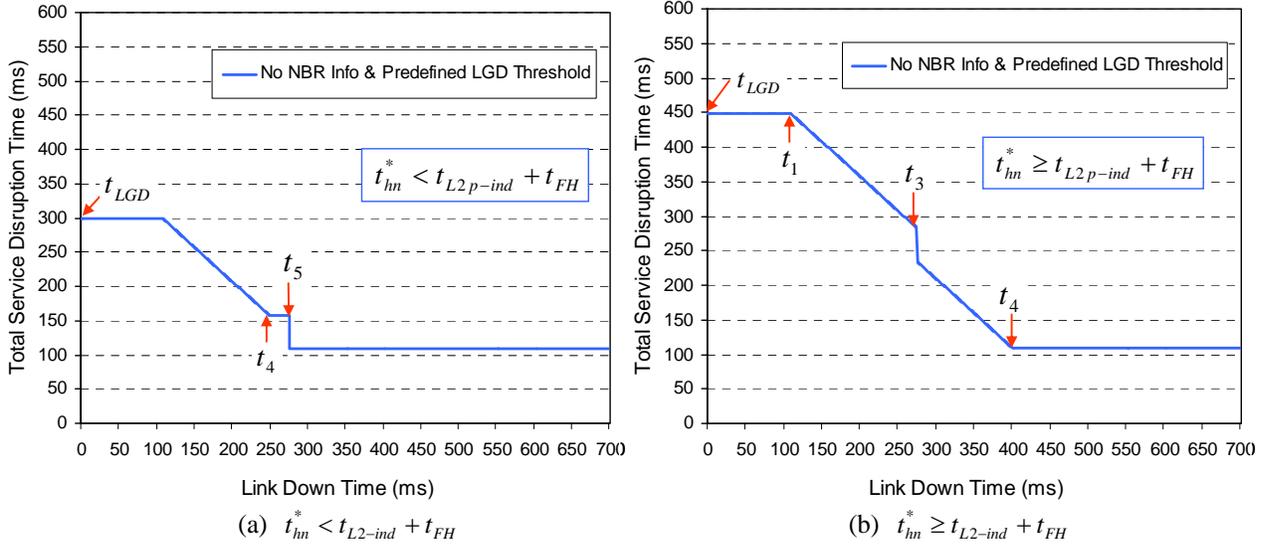


Figure 13. The total service disruption time.

## C. Case Study 3: Signal Strength-based Handover Simulation

In this case study, the link quality is measured by the received signal strength and it is obtained from the following Fritz path loss model [19] of (36), in which the received signal power depends on the path loss exponent $\beta$ and distance $d$ from the transmitter.

$$\left.\frac{P_r(d)}{P_r(d_0)}\right|_{dB} = -10\beta \log\left(\frac{d}{d_0}\right), \; P_r(d_0) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d_0^2 L} \tag{36}$$

where, $P_r(d)$ 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 $d_0$; $P_t$ is the transmitting power, $G_t$ and $G_r$ are the transmitting and receiver antenna gains, respectively; $\lambda$ is the wavelength of the radio signal; $L$ is the system loss factor.

For the performance comparison, a pre-determined LGD threshold method of (37) is compared with the proposed mechanism.

$$TH_{LGD} = \alpha \times T_{LD} \tag{37}$$

The performance is evaluated in terms of i) the signal prediction accuracy using the LMS and the linear slope estimation, ii) LD time difference, iii) actual service disruption time, and iv) early triggering cost. In this section, the

22

following three performance metrics are defined. $PredError_{dB}$ is the average dB scale prediction error. $P_r(i)$ and $\hat{P}_r(i)$ are the observed signal power and $k_h$-step predicted signal power, respectively; $n_p$ and $n_d$ are the sample sequence number at the prediction start time and at the actual Link_Down time, respectively. In (39), the desired LD time means the smallest LD time that can minimize the service disruption time after LGD trigger. The negative and positive $LD\_Time\_Difference$ values indicate the early- and the late- LGD triggering, respectively. The early triggering cost simply represents the loss of benefit of the previous network in terms of time. $Early\_LGD\_Trigger\_Cost$ represent the degree of the loss of benefit of previous interface. In (40) the actual link down time implies the time that the received signal power crosses the minimum power level $T_{LD}$ if the MN does not explicitly perform the vertical handover.

$$PredError_{dB} = \left( \sum_{i=n_p}^{n_d} \left[ \left[ \frac{P_r(i)}{\hat{P}_r(i)} \right] \right]_{dB} \right) \bigg/ (n_d - n_p) \tag{38}$$

$$LD\_Time\_Difference = (\text{the desired LD time}) - (\text{the actual link down time}) \tag{39}$$

$$Early\_LGD\_Trigger\_Cost = \max\{(\text{the handover finishing time}) - (\text{the actual link down time}), 0\} \tag{40}$$

Table 3 shows the parameter values used in this simulation. Table 4 shows the parameter sets for various channel and movement condition simulations. From SET 9 to SET 12, $\beta$ and $v$ are changed over time linearly during the simulation time of 100 seconds.

Table 3. Simulation parameters

| $P_t G_t$ | 100 mW | $G_r$ | 1 |
|---|---|---|---|
| $L$ | 1 | $d_0$ | 1 m |
| $\lambda$ | 0.124 m | $T_{min} = T_{LD}$ | $3.162 \times 10^{-11}$W=-75 dBm |
| $T_{init}$ | -70 dBm | LMS prediction order $p$ | 10 |
| $\Delta_h$ | 10 ms | LMS step size $\mu$ | 0.015 |
| $\alpha$ | 1.0 to 2.0 | $\eta$ | 0.2,0.3 |
| $\beta$ | 3 to 5 | MN speed $v$ | 1 m/s to 5 m/s |

Table 4. Simulation cases and parameter sets

| Parameter SET | Initial $\beta$ | Final $\beta$ | Initial $v$ | Final $v$ | $\theta_{WiMAX}$ | Parameter SET | Initial $\beta$ | Final $\beta$ | Initial $v$ | Final $v$ | $\theta_{WiMAX}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SET 1 | 3 | 3 | 1 | 1 | 100 ms | SET 7 | 5 | 5 | 5 | 5 | 100 ms |
| SET 2 | 3 | 3 | 1 | 1 | 250 ms | SET 8 | 5 | 5 | 5 | 5 | 250 ms |
| SET 3 | 3 | 3 | 5 | 5 | 100 ms | SET 9 | 5 | 3 | 5 | 1 | 100 ms |
| SET 4 | 3 | 3 | 5 | 5 | 250 ms | SET 10 | 5 | 3 | 5 | 1 | 250 ms |
| SET 5 | 5 | 5 | 1 | 1 | 100 ms | SET 11 | 3 | 5 | 1 | 5 | 100 ms |
| SET 6 | 5 | 5 | 1 | 1 | 250 ms | SET 12 | 3 | 5 | 1 | 5 | 250 ms |

Fig. 14 shows the prediction performance of LMS and the linear slope estimation. The mean power difference between the observed signal and $k_h$- ahead predicted signal is very small for both predictors at less than 0.35 dB. The simple linear slope estimation method is little better than the LMS prediction because channel and movement

condition is monotonically decaying function so that the linear slope estimation well follows the observed signal traces. Also LMS needs a convergence time. As shown in Fig. 14, the predictions at the large $\beta$ and fast mobile movement conditions give the worse errors.
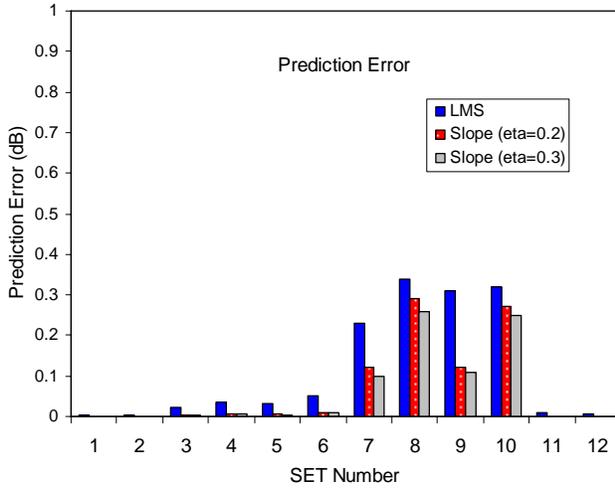


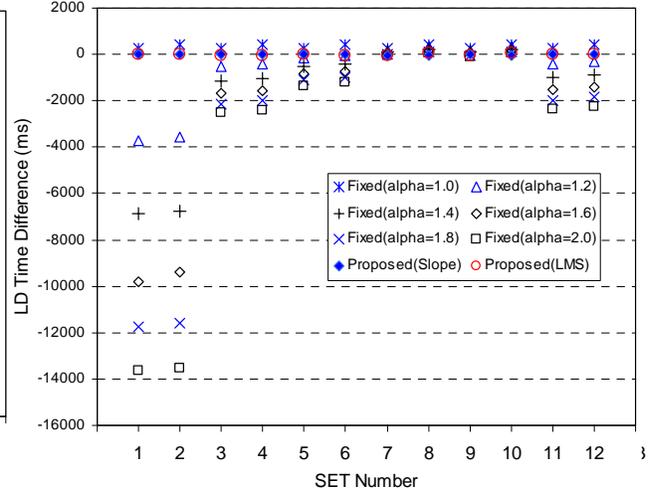Figure 14. Prediction performance.



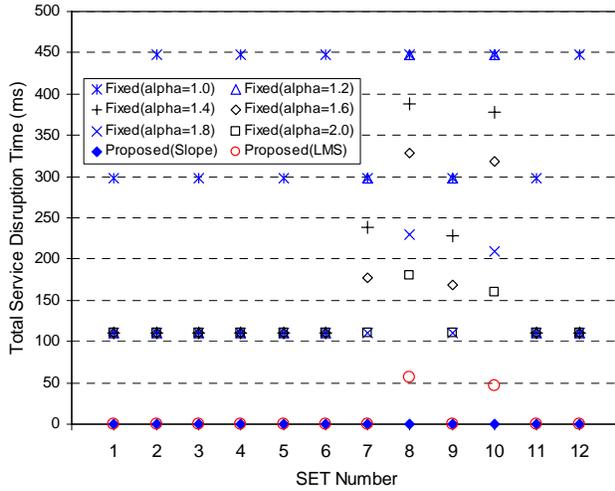Figure 15. LD_Time_Difference.



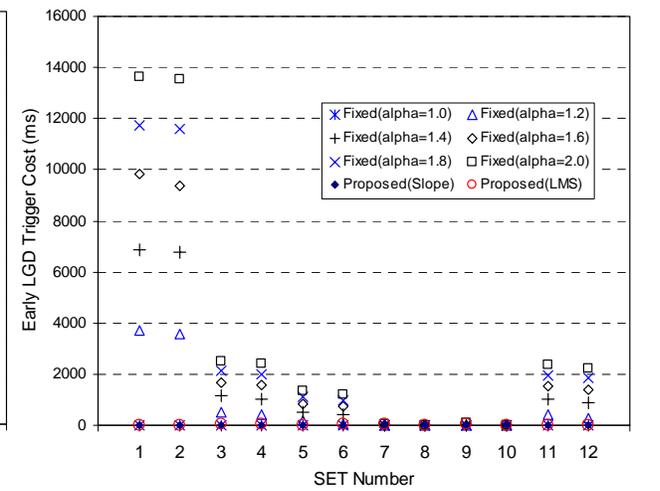Figure 16. Total service disruption time.



Figure 17. Early_LGD_Trigger_Cost.

Fig. 15, Fig. 16, and Fig. 17 show performance comparisons for *LD_Time_Difference*, the total service disruption time, and *Early_LGD_Trigger_Cost*, respectively. For the linear slope estimation, $\eta = 0.3$ is used. As shown in Fig. 15, 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. 16. 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 *Early_LGD_Trigger_Cost* of the proposed method is close to ideal value (zero) as shown in Fig.17. For the

pre-determined LGD threshold method, depending on the $\alpha$ values, large performance variations are observed. The more conservative $\alpha$ (larger value) shows the smaller service disruption time but the larger LD time difference and early LGD triggering cost.

## VI. Conclusions

In this paper, a new predictive handover mechanism is proposed for the seamless handover across heterogeneous wireless networks. The neighbor network information is used to decide the desired handover policy and the required handover procedure. 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 the LGD trigger in a timely manner, the estimated required handover time $(t_h)$ is applied to the link down prediction. Inthe previous pre-defined threshold-based LGD triggering, 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. The proposed predictive handover mechanism can be successfully implemented within the new IEEE 802.21 media independent handover architecture.

This adaptive and accurate LGD trigger time control provides the low handover cost in terms of the total handover time and the service disruption time. Handover cost analysis is performed for horizontal and vertical handovers. In the simulation study, we evaluate the prediction performance of the LMS and the linear slope estimation. Both prediction methods can estimate $t_h$ future link quality at less than 0.35 dB error for various conditions so that LGD trigger is timely generated to finish the required handover procedures before the current link goes down. 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. For the early triggering cost, the proposed method is very close to zero, but the compared method shows large variation in accordance with the pre-defined LGD threshold values. Several experimental case studies demonstrate that the proposed method achieves seamless and proactive mobility for various network environments.

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