LMS PREDICTIVE LINK TRIGGERING FOR SEAMLESS HANDOVERS IN HETEROGENEOUS WIRELESS NETWORKS

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ABSTRACT

Effective and timely link layer trigger mechanisms can significantly influence the handover performance. In this paper, a predictive link trigger mechanism for seamless horizontal and vertical handovers in heterogeneous wireless networks is proposed. Firstly, the time required to perform a handover is estimated based on the neighboring network conditions. Secondly, the time to trigger a Link_Going_Down to initiate a handover is determined using a Least Mean Square (LMS) linear prediction in which the prediction interval (k_h) is dynamically determined based on the estimated handover time. Simulation results of the proposed predictive link triggering mechanism show that it provides a timely proactive handover. The packet loss rate observed in a Gaussian fading channel remains low during a handover.

INTRODUCTION

The rapid expansion of mobile communications has spawned a number of different wireless communication systems including the Wireless Local Area Network (WLAN), the Worldwide Interoperability for Microwave Access (WiMAX), and the Universal Mobile Telecommunication System (UMTS). In addition, mobile devices are increasingly incorporating multiple wireless interfaces leading to an increased need for these devices to move freely among different network systems and perform handovers seamlessly across heterogeneous wireless networks.

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 Medium Access Control (MAC) layer and communicated either to a handover management functional module such as the Media Independent Handover Function (MIHF) developed by the IEEE 802.21 [1], 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 [2]. 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. A number of methods have been proposed for generating LGD triggers [3]-[5]. However, most of these methods use pre-defined Received Signal Strength Indication (RSSI) thresholds. With these thresholds, if the received signal strength is less than a pre-defined threshold, the LGD 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.

In this paper, a novel link trigger mechanism using a Least Mean Square (LMS) linear prediction is proposed. With the help of the neighbor network information provided by the current serving base station (BS), access point (AP) and/or the IEEE 802.21 MIHF information server, the MN (or alternatively the network side BS or AP in the case of network-controlled handover) can determine the type of handover that should occur in addition to the amount of time required to perform it before the current link is broken. The LMS linear prediction technique is used to predict, given the required handover time, the viability of the current link. If a k_h time-ahead Link_Down event is expected, then the predictive LGD trigger is generated to initiate the required handover procedures. All prediction- and handover-related parameters are self-configurable.

The remainder of this paper is organized as follows. In Section II, estimates for the time it takes to complete a handover are derived for different handover types. In Section III the proposed predictive link triggering method is presented. In Section IV, the packet loss rate during a

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handover is estimated and numerical results are discussed. In Section V, we conclude this paper.

REQUIRED HANDOVER TIME ESTIMATION BASED ON NEIGHBOR NETWORK INFORMATION

An important factor for timely link triggering is the required handover time (t_h). 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. This required handover time is different depending on the handover type (horizontal or vertical), the neighbor point of attachment (PoA) topology, and the current and neighbor network handover policies.

For the case of a horizontal handover using a single interface (hard handover), the MN cannot be serviced in parallel by more than one AP (or BS) and therefore has to break its communication with its current PoA before establishing a connection with a new one. To reduce the service disruption time and possible packet loss and delay, the MN needs to finish the layer 3 handover (if the target PoA is on the same subnet as the current PoA) before the link breaks. FMIPv6 [6] was proposed 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 (e.g., FMIPv6) handover time (t_{L3}) and the L2 handover preparation time (t_{L2p}). t_{L2p} includes the neighbor discovery ($t_{L2p-nbr}$) (for example using the IEEE 802.21 information server or current PoA), scanning the candidate PoAs ($t_{L2p-scn}$), handover indication to the previous or target PoA ($t_{L2p-ind}$). The L3 handover time includes message exchanges for the fast mobile IP operation (t_{FH}). The neighbor discovery and scanning can be performed earlier than the LGD by periodic message exchanges and channel scanning. In this case t_{L2p} includes only $t_{L2p-ind}$.

$$t_h = t_{L2p} + t_{L3}, \quad \begin{cases} t_{h-\max} = t_{L2p-nbr} + t_{L2p-scn} + t_{L2p-ind} + t_{FH} \\ t_{h-\min} = t_{L2p-ind} \end{cases} \tag{1}$$

For a vertical handover between different networks, 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 t_{hp} (handover preparation time for L2 and L3 with the current network PoA) and t_{hn} (handover execution time with the new network PoA using the new interface). The processes for obtaining t_{hp} and t_{hn} can be performed separately using different interfaces – for example the handover indication and FMIPv6 handover can be performed using the previous interface and synchronization and association can be done using the new interface. Therefore, the total required handover time for a vertical handover is given as

$$t_h = t_{L2p-nbr} + t_{L2n-scn} + \max\{t_{hp}, t_{hn}\} \tag{2}$$

The IEEE 802.21 specifications provide a useful framework in order to estimate the required handover time, including a set of primitives and messages to inform the MN of the neighbor network conditions and the handover policies. In addition, the IEEE 802.21 information service provides a framework and corresponding mechanisms by which an MIH functional entity can discover and obtain network information available within a geographical area to facilitate the handover. Once the MN has acquired information about neighbor networks and their availability using the MIHF messages, it can identify whether a horizontal or vertical handover is required and which processes should be followed. In accordance with the handover association policies between the current and target networks, some handover processes may be skipped or reduced. For example, the WLAN [7] and WiMAX [8] standards have defined a number of MAC frames to broadcast or to query and reply the neighbor AP (or BS) information. This neighbor information can be obtained by the MN before the handover initiation.

PREDICTIVE LINK TRIGGER MECHANISM

In order to generate the LGD event based on the required handover time t_h, an LMS (Least Mean Square) adaptive prediction technique is applied. This provides an automatic method for tracking the signal strength continuously. Therefore, the MN does not need to know the path-loss model parameters or its moving speed to determine the trigger threshold and is not required to set a fixed power level for LGD triggering. Instead, depending on the required handover time (t_h), the triggering point is adaptively adjusted.

The signal strength data is noisy and is occasionally inconsistent; thus, filtering is needed in order to avoid erratic results. At each measurement interval t_m the MN measures the received signal strength $m(q)$, and every N_m measurement signals, the prediction sample sequence $x(n)$ is constructed, as shown in Fig. 1. $t_s = t_m \cdot N_m$ is the filtered sample interval. Any filtering technique can be used, such as moving window or weighted average. The use of filtered samples can also reduce the prediction overhead.

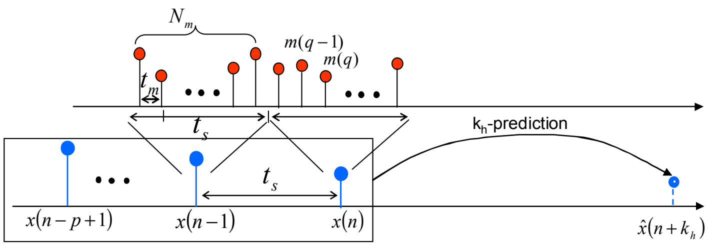


Figure 1. Filtered samples and prediction.

In this paper, the prediction step k_h is determined based on the required handover time. If the k_h ahead predicted power is less than the minimum power level $P_{r-\min}$ to decode data, the LGD trigger is then generated.

$$k_h = \left\lceil \frac{t_h + \Delta_h}{t_s} \right\rceil \tag{3}$$

where Δ_h is the handover marginal time (≥0) to trigger the LGD slightly earlier than the required handover time.

The LMS adaptation algorithm monitors the prediction error $e(n)$ and attempts to minimize the mean squared prediction error, $E\{e(n)^2\}$, by adapting prediction weights, as shown in Fig. 2. The k_h-step linear predictor is concerned with the estimation of $x(n+k_h)$ using a linear combination of the current and previous values of $\mathbf{X}(n)$. A pth-order predictor has the form of Equation (4). $\mathbf{W}_n$ is the time-varying coefficient vector. The step size μ is an adaptation parameter that determines convergence speed. In a normalized LMS, if $0 < \mu < 2$, then the LMS will converge on the mean. For the simulation study in this paper, a fixed μ is used for various conditions.

$$\hat{x}(n+k_h) = \sum_{l=0}^{p-1} w_n(l)x(n-l) = \mathbf{W}_n^T \mathbf{X}(n) \tag{4}$$

$$\mathbf{X}(n) = [x(n), x(n-1), \cdots, x(n-p+1)]^T$$

$$\mathbf{W}_n = [w_n(0), w_n(1), ..., w_n(p-1)] \tag{5}$$

$$\begin{cases} \mathbf{W}_{n+1} = \mathbf{W}_n + \mu \times e(n) \dfrac{\mathbf{X}(n)}{\|\mathbf{X}(n)\|^2} \\ e(n) = x(n+k) - \hat{x}(n+k_h) \approx e(n-k_h) = x(n) - \hat{x}(n) \end{cases}$$

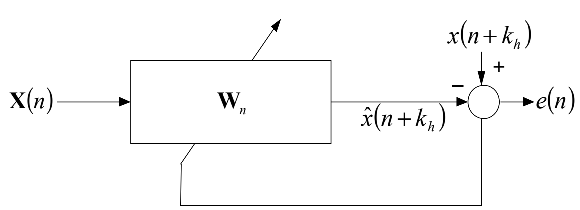


Figure 2. k_h-step LMS predictor.

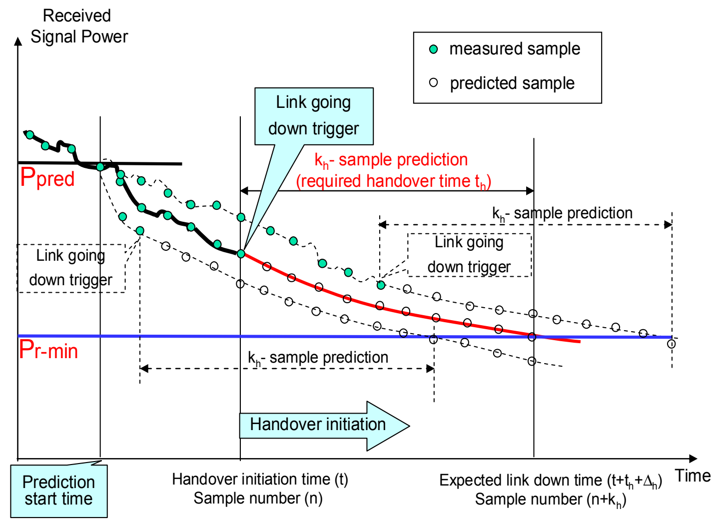


Figure 3. Predictive Link_Going_Down trigger points.

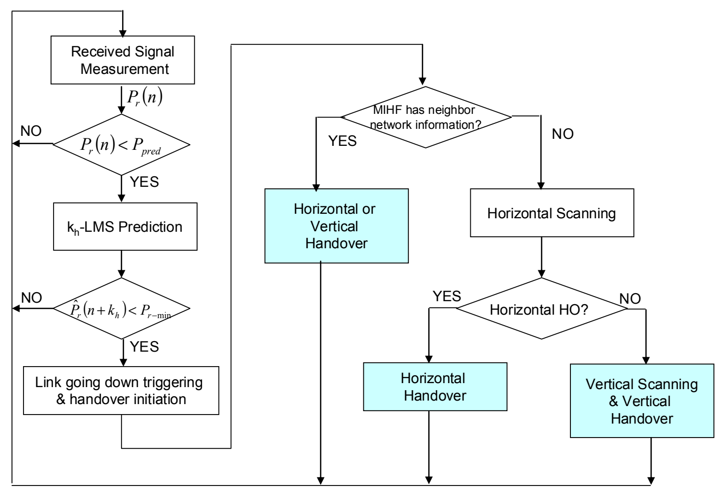


Figure 4. Predictive handover procedure.

Fig. 3 and Fig. 4 show the proposed predictive LGD triggering mechanism. Let P_{pred} be the prediction start threshold. P_{pred} is adaptively determined based on the required handover time; thus it is not a pre-defined fixed value. P_{pred} is introduced to reduce the prediction overhead. Only when the filtered sample power is less than P_{pred}, the prediction process using Equation (4) starts. For each sample prediction, if the k_h ahead prediction value is less than $P_{r-\min}$, then the proper handover procedure is initiated. P_{pred} should be determined conservatively to guarantee that the time interval from the prediction start to the actual Link_Down event is always greater than the required handover time. Let t_p be the time interval between P_{pred} and $P_{r-\min}$. Then t_p is defined as

$$t_p = t_h + \Delta_p \tag{6}$$

where Δ_p is the prediction start time margin. From the path loss model of Equation (7)[9],

$$\left[\frac{P_r(d)}{P_r(d_0)}\right]_{dB} = -10\beta\log\left(\frac{d}{d_0}\right) \quad (7)$$

where d is the distance between the receiver and the transmitter expressed in meters, $P_r(d)$ denotes the received signal power level in watts at distance d, β is the path loss exponent, and $P_r(d_0)$ is the received power at the close-in reference distance d_0; t_p is derived as

$$t_p = \frac{d_0}{v}\left(\frac{P_r(d_0)}{P_{r-\min}}\right)^{\frac{1}{\beta}}\left[1 - 1\Big/\left(\frac{P_{pred}}{P_{r-\min}}\right)^{\frac{1}{\beta}}\right] \quad (8)$$

where v is the MN moving speed. Given that MN is generally not able to identify the current speed and the path loss exponent value β, to auto-configure the P_{pred} value from (8), the most conservative parameters are used. Thus,

$$P_{pred} = P_{r-\min}\left[1\Big/\left\{1 - t_p\frac{v_{\max}}{d_0}\left(\frac{P_{r-\min}}{P_r(d_0)}\right)^{\frac{1}{\beta_{\max}}}\right\}\right]^{\beta_{\max}} \quad (9)$$

where $v_{\max}$ and $\beta_{\max}$ are the maximum MN speed and path loss exponent, respectively. These factors can be configured using the history of the MN movement pattern by the mobility manager or simply can be set using typical initial values. Using the prediction start time margin and conservative parameters, the prediction procedure can start early enough and before the actual required handover start time.

PERFORMANCE EVALUATION

1) Estimating the packet loss rate during a handover

To study the service disruption time and packet loss rate during a handover for an ideal decaying signal, fading effects were investigated. The fading effects can be modeled by introducing an additional variable, X_σ, to the Fritz path loss model of Equation (7).

$$\left[\frac{P_r(d)}{P_r(d_0)}\right]_{dB} = -10\beta\log\left(\frac{d}{d_0}\right) + X_\sigma \quad (10)$$

where X_σ is a random variable with Gaussian distribution having a zero mean and a standard deviation of σ dB.

To accommodate the fading noise, the $P_{r-\min}$ threshold value that is used to determine the prediction start power and LGD trigger time should aim to reduce the service disruption time and the packet loss rate. Let C_σ be the compensation power, c be the compensation factor, and $P_{r-\min}^{comp}$ be the compensated minimum power level.

$$\left[\frac{P_{r-\min}^{comp}}{P_{r-\min}}\right]_{dB} = C_\sigma = c\cdot\sigma \quad (11)$$

Therefore, the LGD prediction condition is changed to

$$\hat{P}_r(n + k_h) < P_{r-\min}^{comp} \quad (12)$$

The service disruption time (t_{sd}) during the handover is defined in this paper as the total amount of time during which the actual received power is less than $P_{r-\min}$.

$$t_{sd} = \text{sum}\left\{t_k\big|_{P_r(t_k)<P_{r-\min}}\right\}, \quad t_{hs} \le t_k \le t_{hf} \quad (13)$$

where t_{hs} and t_{hf} are the handover start time and handover finish time, respectively; t_k is the *k*-th measurement interval; and $P_r(t_k)$ is the received power level at *k*-th measurement point.

Given that X_σ follows a Gaussian distribution $f(x)$ with a zero mean, only negative X_σ random values impact the service disruption. The probability that the received power at the handover finishing time is less than $P_{r-\min}$ is given as

$$\Pr\left[P_r(t_{hf}) < P_{r-\min}\right] = F(-c\sigma) = \int_{-\infty}^{-c\sigma} f(x)dx$$
$$= \int_{-\infty}^{-c\sigma}\frac{e^{-x^2/2\sigma^2}}{\sigma\sqrt{2\pi}}dx = \begin{cases} 0.15865, & c=1 \\ 0.02275, & c=2 \\ 0.00135, & c=3 \\ \vdots & \vdots \end{cases} \quad (14)$$

Eq. (14) is only valid at the handover finishing time t_{hf}, if it is assumed that the received power is monotonically decreasing during the handover. In this case,

$$\Pr\left[P_r(t) \le P_{r-\min}\right] \le F(-c\sigma), \quad t_{hs} \le t \le t_{hf} \quad (15)$$

If the signal prediction is correct and the packet loss during the handover is caused only due to an un-decodable received power level, the packet loss rate during a horizontal or vertical handover can then be approximated by Equation (16).

$$PLR_{HO} = \frac{\text{sum}\left\{t_k\big|_{P_r(t_k)<P_{r-\min}}, t_{hs} \le t_k \le t_{hf}\right\}}{t_{hf} - t_{hs}} \le F(-c\sigma) \quad (16)$$

2) Numerical results

In this section, the effectiveness of the proposed predictive link-trigger handover mechanism is demonstrated. In Fig. 5, the simulation handover scenario is shown, where vertical handovers between WLAN and WiMAX are considered. A WLAN AP or WiMAX BS can obtain the neighbor network information from a handover information server using the IEEE 802.21 information service function. Table I shows the simulation parameters.

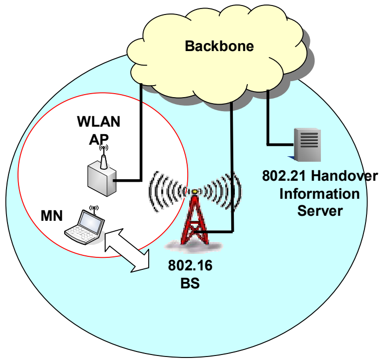


Figure 5. Simulation scenario.

Table I. Simulation parameters

β	3– 4	$P_{r-\min}$	$3.162*10^{-11}$ W
$\beta_{\max}$	5	t_m, t_s	1 ms, 10 ms
v	1 m/s to 4 m/s	t_h	250 ms, 500 ms
$v_{\max}$	5 m/s	Δ_h, Δ_p	0
σ	0 dB to 2 dB	c	0 to 2
p	10	μ	0.01

In the following numerical experiments, we show how the LMS predictor can achieve reliable k_h-step prediction performance to estimate LGD event. For Fig. 6 and Fig. 7 we used fixed β and v in time. The traces for a predicted and observed signal are shown in Fig. 6.

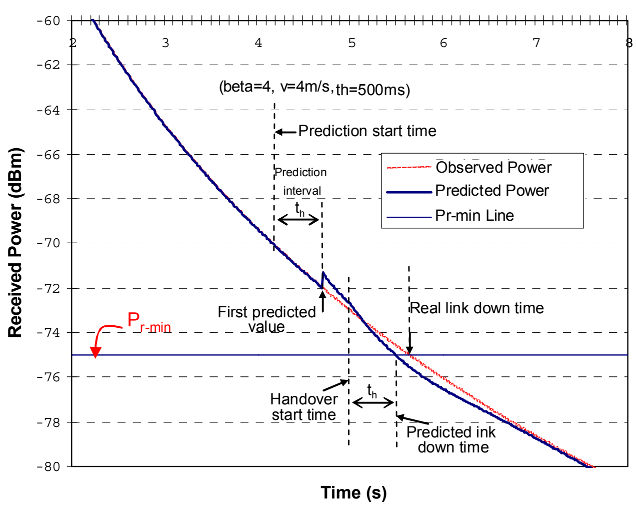


Figure 6. Predicted signal and real measured signal.

It is shown that the predicted signal trace estimates the real decaying signal relatively well. To verify the prediction accuracy for seamless handovers, the k_h-step prediction error were evaluated. In this paper, the following metric is defined for dB level comparison.

$$PredError_{dB} = \left(\sum_{i=n_p}^{n_d} \left[\frac{P_r(i)}{\hat{P}_r(i)} \right]_{dB} \right) \Big/ (n_d - n_p) \qquad (17)$$

where n_p is the sample sequence number at the prediction start time, and n_d is the sample sequence number at the actual Link_Down time.

As depicted in Fig. 7, from the prediction start to the actual Link_Down event, the mean power difference between the observed signal and k_h-ahead predicted signal is very small at less than 0.35 dB. Generally, for a higher β and v values, a larger average prediction error is observed. As the fixed LMS step size μ is used here for all simulations, for some channel and movement conditions, this may not be optimal value and may differ somewhat from the general trend.

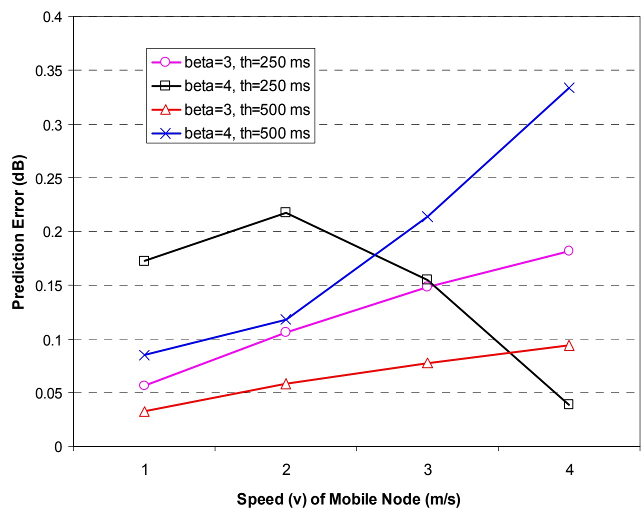
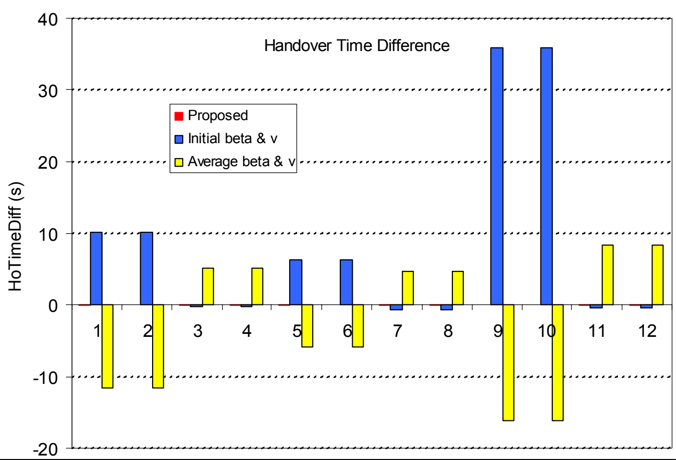


Figure 7. k_h-step prediction performance.

For the following experiments, to evaluate the system adaptation performance to dynamic network conditions the path loss exponent β and MN speed v are changed over time. β and v increase or decrease linearly during the simulation time, 100 s. $PredError_{dB}$ of the proposed method ranges from 0.08 dB to 0.3 dB when β and v are time-varying functions. In order to further evaluate the performance of the proposed triggering mechanism, a new metric, "*HoTimeDiff*", is defined. This metric represents the time difference between the handover finishing time (t_{hf}) and the actual link down time (t_{ld}). A negative *HoTimeDiff* value implies that the handover has finished before the actual Link_Down event occurs. In contrast, a positive value indicates that the handover finishing time is after the actual Link_Down event, implying that a handover service disruption and packet loss are likely. For a seamless handover, a small negative value is desired. For comparative analysis' sake, we compare our method to the case where the handover start times (i.e., Link_Going_Down trigger times) are derived with predetermined and fixed β and v values as in [5]. In that case, the LGD trigger time is analytically derived by assuming that the channel conditions and the MN movement speed are known in advance and are constant in time, which is not realistic since the MN does not have accurate measurements for the β and v values in advance.

In Fig. 8, the results using the analytical triggering with the initial and average parameters are compared with the proposed method. The *HoTimeDiff* values of the proposed predictive method are mostly small negatives that are close to the optimal value (zero) for various channels, MN movements, and handover time conditions from Case 1 to Case 12. However, the two compared methods show large variations from +36 s to -17 s.



	1	2	3	4	5	6	7	8	9	10	11	12
β start	3.5	3.5	3.5	3.5	3.0	3.0	4.0	4.0	3.0	3.0	4.0	4.0
β final	3.5	3.5	3.5	3.5	4.0	4.0	3.0	3.0	4.0	4.0	3.0	3.0
v start(m/s)	1	1	4	4	2.5	2.5	2.5	2.5	1.0	1.0	4.0	4.0
v final (m/s)	4	4	1	1	2.5	2.5	2.5	2.5	4.0	4.0	1.0	1.0
t_h (ms)	250	500	250	500	250	500	250	500	250	500	250	500

Figure 8. *HoTimeDiff* comparisons.

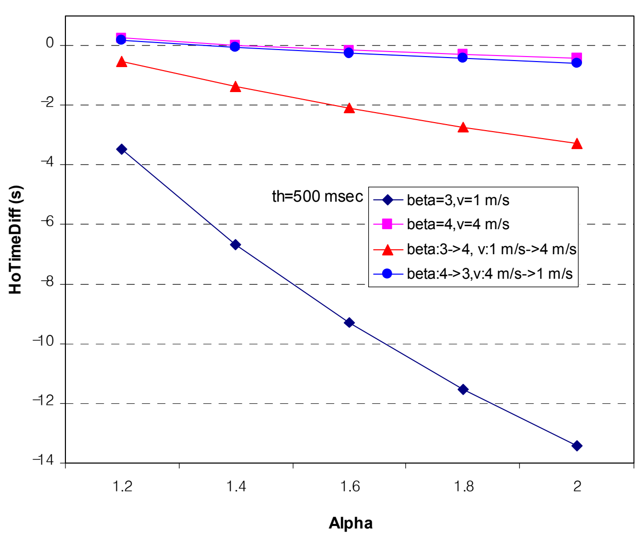
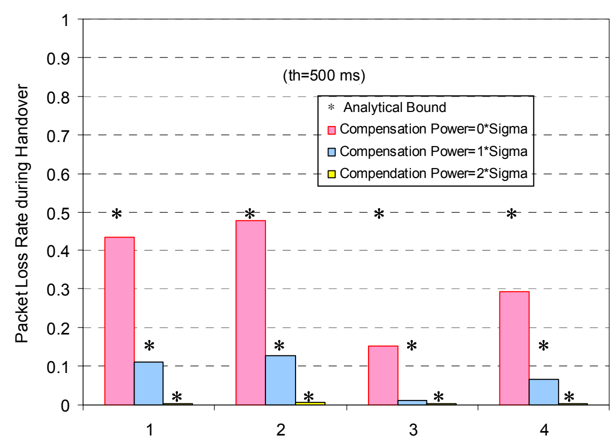


Figure 9. *HoTimeDiff* for the fixed LGD threshold.

Fig. 9 shows the *HoTimeDiff* measurement results when the LGD trigger is generated based on the pre-determined threshold as $\alpha * P_{r-\min}$. For various α values from 1.2 to 2.0, it can be observed that a larger α results in the larger negative *HoTimeDiff* values and a smaller β and v results in the earlier handover start time. Compared with the performance of the proposed method in Fig. 8 in which the *HoTimeDiff* values vary from -0.01 s to -0.17 s, the *HoTimeDiff* value of the fixed LGD trigger threshold method ranges from +0.25 s to -12 s.

Finally, the packet loss rate during the handover time was evaluated. Gaussian noise was added to model the fading effect. Fig. 10 illustrates the received signal and the predicted signal for Gaussian fading channel with a standard deviation of $\sigma = 2$ dB. In Fig. 10, the measured packet loss rates of the proposed method are shown. For CBR traffic, 200 byte packets at 10 ms interval were generated. The measured packet loss rates for various channel conditions and movement patterns are less than the analytical bounds of Equation (16). This indicates that the proposed predictive link trigger mechanism can timely trigger the Link_Going_ Down event to finish the required handover procedure before the actual link goes down. When a larger compensation power $C_\sigma = c \cdot \sigma$ is used, a smaller packet loss rate is observed, as expected. In addition, to achieve less than a 10^{-3} packet loss rate, the compensation power for prediction should be greater than three times the standard deviation of the fading noise.



	1	2	3	4
β start	3	3	4	4
β final	4	4	3	3
v start(m/s)	1	1	4	4
v final (m/s)	4	4	1	1
Sigma	1 dB	2 dB	1 dB	2 dB

Figure 10. Packet loss rates during the handover time.

CONCLUSION

In this paper, a predictive link triggering mechanism for seamless handover in heterogeneous wireless networks is proposed. Given that various newly defined IEEE standards support information exchanges for neighbor networks before the handover, it is possible to derive the required handover time in advance. The LMS linear prediction technique is used to predict, given the required handover time, the viability of the current link. If a k_h time-ahead Link_Down event is expected, the predictive LGD trigger is then generated to initiate the required handover procedures. Packet loss-rate bounds during the handover time are derived in a Gaussian fading condition. For a fading wireless channel, to determine the proper LGD time to minimize the packet loss rate, it was shown that the minimum power level should be offset for the prediction. In the simulation results, the average power difference between the observed signal and the k_h-step predicted signal is very small at less than 0.35 dB for various channel and movement conditions. The proposed handover method with the predictive link triggers can complete the required handover procedure before the actual link goes down.

REFERENCES

[1] IEEE P802.21/D05.00, "Draft Standard for Local and Metropolitan Area Networks: Media Independent Handover Services", April 2007.

[2] Lila Dimopoulou, Georgios Leoleis, Lakovos S. Venieris, "Fast Handover Support in a WLAN Environment: Challenges and Perspectives", IEEE Network, Vol.19, No.2, pp.14-20, 2005.

[3] Ping-Jung Huang, Yu-Chee Tseng, Kun-Cheng Tsai, "A Fast Handoff Mechanism for IEEE 802.11 and IAPP Networks", IEEE VTC'06, pp. 966-970, 2006.

[4] Vivek Mhatre, Konstrantina Papagiannaki, "Using Smart Triggers for Improved User Performance in 802.11 Wireless Networks", ACM Mobisys'06, pp.246-259, 2006.

[5] S. Woon, N. Golmie, Y.A. Sekercioglu, "Effective Link Triggers to Improve Handover Performance", IEEE PIMRC06, pp.1-5, 2006.

[6] R. Koodli, "Fast Handover for Mobile IPv6", IETF RFC 4068, July 2005.

[7] IEEE P802.11k/D7.0, "Draft Standard for Local and Metropolitan Area Networks– Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment: Radio Resource Measurement", January 2007.

[8] IEEE Std 802.16e, "IEEE Standard for Local and Metropolitan Area Networks – Part 16: Air Interface for Fixed Broadband Wireless Access Systems, Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands", February 2006.

[9] Theodore S. Rappaport, "Wireless Communications: Principles and Practice", Personal Education International, 2002.