Mobility Management of IEEE 802.16e Networks

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Summary
With the fast proliferation of mobile Internet, the wireless community has been increasingly looking for a framework that can provide seamless mobility. In this paper, we propose a fast cross-layer handover scheme based on movement prediction in mobile WiMAX environment. Prediction is achieved by linear regression model with keeping track of the signal strength of mobile users. With the help of the prediction, layer-3 handover activities are able to occur prior to layer-2 handover, and therefore, total handover latency can be reduced. The experiments conducted with system parameters and propagation model defined by WiMAX Forum demonstrate that the proposed method predicts the future signal level accurately and reduces the total handover latency.

Key words:
Handover, Cross-layer, WiMAX.

1. Introduction

During the past few years, IEEE 802.16 networks over IP-backbone have gained attention as an infrastructure for both data and real-time traffic such as VoIP. To provide seamless VoIP service in such a wireless mobile communication environment, delay or disruption in dealing with mobility must be minimized. However, offering VoIP services on IEEE 802.16 networks [1], [2] is considered problematic due to very long handover latency both in layer 2 (i.e., IEEE 802.16e Air Interface) and 3 (i.e., Mobile IP). IEEE 802.16 handover latency is composed of latencies for neighbor cell scanning, handover message exchange (especially, via backbone), and network re-entry.

To shorten the handover latency, cell scanning is usually performed prior to handover initiation. Network re-entry procedures can be shortened by handover optimization process as defined in [2]. Thus, pure MAC-layer handover latency is expected to be small to serve real-time traffic. However, it has been shown that Mobile IP handover latency is relatively long against layer-2 latency because of the address resolution and the home network registration. The handover latency resulting from standard Mobile IP procedures is often unacceptable to real-time applications. Furthermore, the strict separation between IEEE802.16e MAC and Mobile IP handover scheme has negative consequences for total handover latency.

Over the last few years, techniques based on cross-layer design have attracted wide spread interest in reducing built-in delay of Mobile IP. The protocols [3] – [5] enable a mobile station (MS) to quickly detect that it has moved to a new subnet by providing the new access point and the associated subnet prefix information when the MS is still connected to its current subnet. Cross-layer mobility management protocols reduce movement detection delay using link layer information such as signal strength. L2 trigger is a signal of a layer-2 event and it is early notice of an upcoming change in the layer-2 point of attachment of the MS to the access network. L2 trigger can be utilized by the MS to start layer-3 handover-related activities in parallel with or prior to those of layer-2 handover. The L2 trigger may come explicitly from 802.16e MAC in a solicited or unsolicited manner, or it may be directly derived from IEEE 802.16 MAC management messages.

It has been observed that prediction-based approaches [6] – [8] may reduce handover latency. The common goal of those works is to predict the future location of mobile user according to the previous movement patterns. Hsieh et al.,[6] proposed an architecture which minimizes the handover latency by using software-based movement tracking technique. To predict future location of mobile users, Akyildiz and Wang [7] proposed a mobility model which is characterized not only by historical records but also by stochastic behaviors of mobile users. In most forecasting environment with non-stationary data (e.g., signal strength fluctuation of mobile users), time series analysis technique such as auto regressive integrated moving average (ARIMA) model seems to work quite well. Although these schemes were evaluated extensively, the complexities of the algorithms and computational overheads often make them impractical.

In this paper, we propose a cross-layer handover scheme based on movement prediction for mobile WiMAX networks. Movement prediction is achieved by simple linear regression model without any assumption on the statistical properties of the movement. By keeping track of the signal strength between mobile users and base

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stations (BS's), estimated regression line is updated to predict future signal level. With the help of the prediction, layer-3 handover activities are able to occur prior to layer-2 handover, and therefore, total handover latency can be reduced.

The rest of this paper is organized as follows. We first briefly describe linear regression model. We then present the fast handover method based on linear regression model together with experimental results. Finally, conclusions follow.

2. Linear Regression Model

The proposed fast handover scheme is designed to operate on the existing Mobile IP extension frameworks [3] – [5]. They commonly require layer-2 trigger as an early notice of an upcoming change in the layer-2 point of attachment. This paper focuses on issuing the appropriate L2 Trigger based on prediction algorithm. Using the signal strength samples obtained through scanning process, movement pattern of MS can be analyzed and predicted. We use simple linear regression line for movement prediction.

Suppose that the responses Y_i corresponding to the input values $t_i, i = 1, \ldots, n$,are to be observed and used to estimate the parameters α and β in a simple linear regression model

$$Y = \alpha + \beta t + e \qquad (1)$$

To determine estimators of α and β, we reason as follows: If *A* and *B* were the respective estimators of α and β, then the estimator of the response corresponding to the input value t_i would be $A + Bt_i$. Since the actual response is Y_i, it follows that the difference between the actual response and its estimated value is given by

$$\varepsilon_i = Y_i - (A + Bt_i) \qquad (2)$$

We choose *A* and *B* to minimize the value of $\sum_{i=1}^{n} \varepsilon_i^2$, the sum of the squares of the errors. For a given pairs of $(t_i, Y_i), i = 1, \ldots, n$, the least-square estimators of α and β are the values of *A* and *B* that make

$$\sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n} (Y_i - A - Bt_i)^2 \qquad (3)$$

as small as possible. It can be shown that the least-square estimators of α and β, which are *A* and *B*, are given by

$$A = \bar{Y} - B\bar{t}, B = \frac{\sum_{i=1}^{n} (t_i - \bar{t})(Y_i - \bar{Y})}{\sum_{i=1}^{n} (t_i - \bar{t})^2} \qquad (4)$$

The line $y = A + Bt_i$ is the estimated regression line (shown in Fig. 1.). The line is used for prediction of the signal strength of an MS.

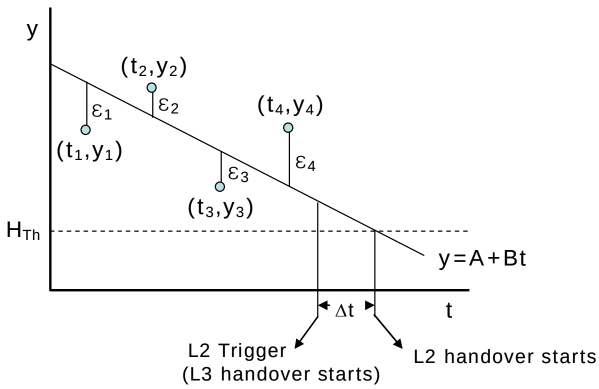

Fig. 1 Estimated regression line and handover forecasting.

3. L2 Trigger for Fast Handover

An MS scans neighbor BS's to determine their suitability, along with other performance considerations as a handover target. In general, MS obtains received signal strength indicator (RSSI) periodically through the scanning process. Without prediction method that we proposed in this paper, an MS may start handover process when the current RSSI value is below a certain handover threshold H_{Th}.

This MAC-layer handover initiation may also trigger layer-3 handover process in parallel - the total handover latency will be Max(L2 handover delay, L3 handover delay).

In our work, we propose a prediction-based handover scheme. The flowchart for the proposed method is depicted in Fig. 2. Using the obtained RSSI samples, the MS draws scatter diagram and obtains estimated regression line for each MS and neighbor BS pair. Each time the MS obtains a new RSSI sample, the MS adds the sample to the scatter diagram and recalculates the estimated regression line. Based on the estimated regression line, the MS predicts the future RSSI values between the MS and neighbor BS's, which are a response of $t = t_c + \Delta t$, where t_c is current timer, and Δt is prediction interval.

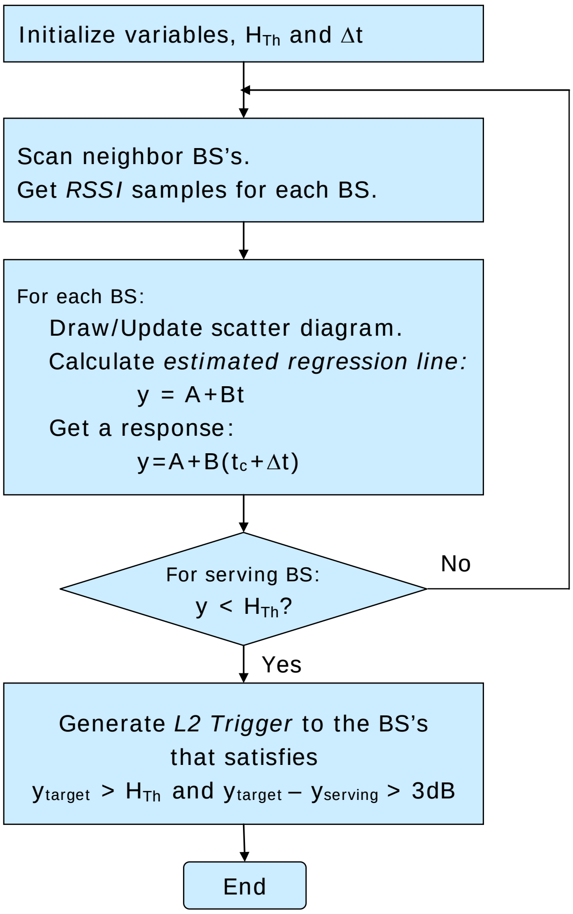

Fig. 2 Flow chart for obtaining L2 Trigger.

If the predicted value of RSSI between the MS and the serving BS is less than the predetermined level H_{Th} (that is $A + B(t_c + \Delta t) < H_{Th}$), this means that the MS is expected to initiate handover after Δt time. To determine handover direction [1] the MS should consider not only minimum downlink signal level of potential target BS's (i.e., H_{Th} 's) but also hysteresis margin (e.g., -3 dB) between the serving and target BS. For example, the MS determines handover to the target BS only when

$RSSI_{target} \geq H_{Th}$ and

$RSSI_{target} - RSSI_{serving} \geq 3dB$.

If the MS determines the target BS, it generates L2 Trigger. That way, Mobile IP handover process is able to start earlier than layer-2 handover and total handover latency can be reduced by Δt time against the parallel procedures.

4. Experimental Results

In this section the performance evaluation of the proposed prediction scheme is presented in terms of total handover latency. WiMAX Forum has proposed system evaluation methodology for simulating mobile WiMAX performance [10]. We have performed experiments on an example network (illustrated in Fig. 3) with system parameters and path loss model (i.e., The COST 231-Hata model) defined in [10]. The COST 231-Hata propagation model is based on empirical results in the 2GHz band and tends to make very conservative prediction for 2.5GHz. The simulation conditions used in the experiments are summarized in Table 1.

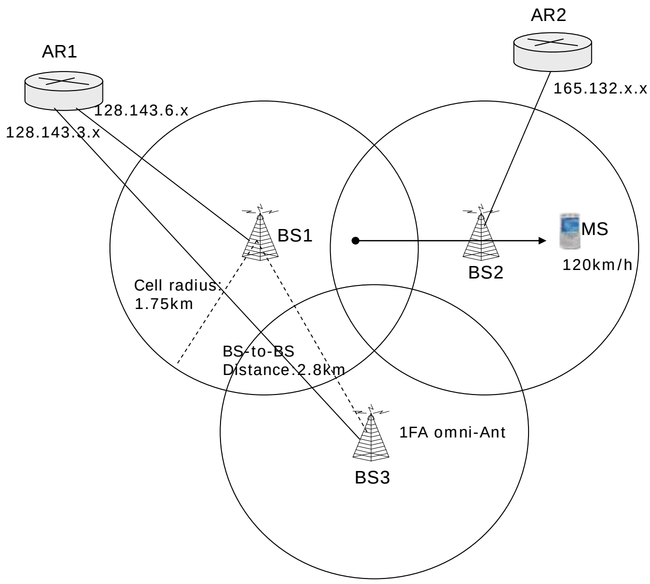

Fig. 3 Network Topology for Experiments

As shown in Fig. 3, BS1 and BS3 are connected to the same access router AR1, while BS2 is connected to a different access router AR2. Therefore, when an MS moves from BS1 or BS3 to BS2, corresponding layer-3 handover is required. In our simulation the MS moves from the edge of the Cell 1 to the center of the Cell2 at the

[1] In the conventional handover schemes, various thresholds are used to determine handover direction [9].

speed of 120km/h. Once the MS learns that it is going to move to different subnet, the next challenge is to estimate the right time to start Mobile IP registration.

Without prediction, when the RSSI of the serving BS drops below H_{Th}, the MS starts layer-2 and 3 handover procedures. Since layer-3 handover delay is usually far greater than layer-2 handover delay, starting layer-3 handover together with layer-2 is not effective in terms of total handover latency.

The handover trigger method discussed in Section 3 uses the linear prediction method based on the previous RSSI samples. With the help of prediction algorithm, the MS is able to start layer-3 handover prior to layer-2 handover. Thus, the total handover latency can be shortened by the amount of Δt.

Table 1: Summary of experiment conditions

	Parameters	Values
System Parameters	BS-to-BS Distance	2.8 Km
	MS speed	120 Km/h
	Antenna Pattern	70°(-3 dB) with 20 dB
	BS Antenna Gain	15 dBi
	MS Antenna Gain	-1 dBi
	BS Maximum PA Power	43 dBm
	MS Maximum PA Power	23 dBm
Propagation Model	Propagation Model	COST 231 Suburban
	Log-Normal Shadowing SD (σ_s)	5.56 dB
	BS Shadowing Correlation	0.5
	Penetration Loss	10 dB
Handover Parameters	Handover Threshold H_{Th}	-232 dB
	Hysteresis Margin	-3 dB

The purpose of this experiment is to monitor total handover latency as well as the prediction accuracy. The experiment was performed with the following parameters: MAC frame length = 5ms, neighbor scan duration: 100ms, interleaving interval: 100ms, prediction of future RSSI Δt : 100ms ahead, number of samples for calculating regression line: recent 50 samples, movement speed: 120km/h, handover threshold H_{Th} : -232 dB, and handover hysteresis: -3dB. According to the parameters, MS measures the RSSI value[1] from the neighbor BS's including serving BS during the scan duration 100ms.

With 50 RSSI samples, the MS obtains estimated regression line and predicts the future (100ms ahead) RSSI level.

[1] In this paper, we only consider MS-initiated handover scenario. For BS-initiated handover, there are two possible channel measurement methods. One is to use channel measurement report/response (REP-REQ/RSP) MAC messages, the other is to watch channel quality information channel (CQICH).

When t = 21.8s, the predicted RSSI value was below the handover threshold H_{Th} = -232 dB. At this time estimated hysteresis margin between the BS2 and BS1 was greater than 3 dB. The corresponding L2 Trigger was issued at t = 21.8s, while the actual L2 handover initiates at t = 21.9s. Since the Mobile IP (pre-)registration process started earlier than L2 handover, the total handover latency was shortened by the amount of 100ms.

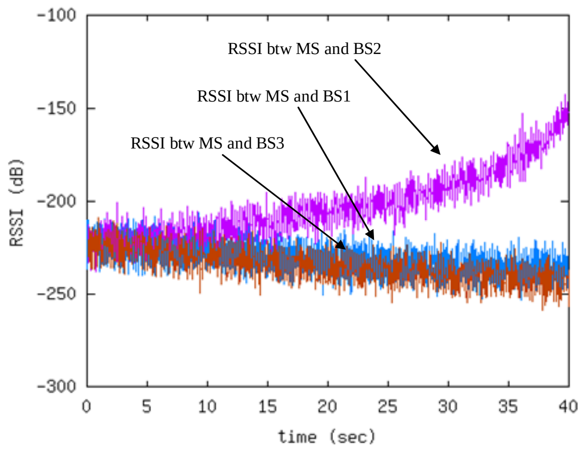

Fig. 4 The measured RSSI

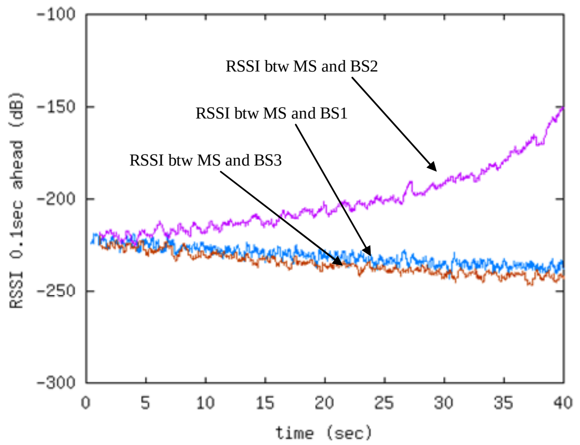

Fig. 5 The predicted RSSI for 100ms into the future

Figure 4 shows the actual signal strength measured by the MS through neighbor scanning. Since the MS crosses the center of the BS2 at around 42 seconds, the MS has the peak values of RSSI at this time while the signal strength values from the BS1 and BS3 continue to decrease.

Figure 5 shows the estimated signal strength derived from the linear regression line and it represents future values of the actual RSSI quite well.

It should be noted that overshoot or undershoot can be monitored around peak values because of abrupt changes in sample values. The regression fallacy is often observed when the pattern of the current samples do not conform to the previous one (e.g., the MS accelerates or decelerates abruptly.).
Prediction with small number of samples over long time interval may also give us wrong inference. For the best prediction, the faster an MS moves, the smaller scan interval is required. For our experiments (BS-to-BS distance: 2.8km, MS speed: 120km/h), the scanning interval smaller than 1.5s is enough to keep correlation among the samples.

Mathematically, rather than give a single number as the predicted value, it is able to present an interval that the prediction lies within, with a certain degree of confidence. With $100(1-\gamma)$ degree of confidence, the response Y at the input value $t = t_c + \Delta t$ will lie in the interval $A + B(t_c + \Delta t) \pm t_{n-2,\gamma/2} W$, where where $t_{n-2,\gamma/2}$ is the $100(1-\gamma/2)$ th percentile of the t-distribution with n-2 degree of freedom and W is

$$W = \sqrt{\left[1 + \frac{1}{n} + \frac{(t_c + \Delta t - \bar{t})^2}{S_{tt}}\right] \frac{SS_R}{t-2}}$$

For example, at t = 21.8s the predicted RSSI value lies within (-232.23dB, -232.01dB) with 95% confidence, which is clearly below the handover threshold H_{Th} = -232 dB. One disadvantage of our scheme is that false alarm causes unnecessary Mobile IP (pre-)registration - increases signaling overhead on the networks.

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