IP Mobility Performance Enhancement Using Link-Layer Prediction

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Abstract. In this paper, a prediction-based *L2 Trigger* approach is proposed for enhancing the performance of IP mobility in an integrated mobile Internet (e.g., Mobile WiMAX) and fast mobile IPv6 (FMIPv6) environment. The time series model of auto-regressive integrated moving average (ARIMA) is used to make short-term forecasting of mobile user's signal strength. Through the forecast of the signal strength, layer-3 handover activities occur prior to the start of layer-2 handover process, and therefore, total handover latency as well as service disruption time can be reduced.

Keywords: FMIPv6, prediction, cross-layer, time series analysis.

1 Introduction

One of the key challenges both in 3G and Mobile WiMAX is to provide seamless service for users moving at vehicular speeds. In order to support IP mobility, Mobile IP (MIP) has been adopted by 3GPP and WiMAX Forum. However, due to the very long handover latency of MIP, real-time services such as video streaming and VoIP are still hard to provide on those mobile networks.

Recently, cross-layer design techniques have been widely adopted for the purpose of reducing built-in delay of MIP. The protocols [1] and [2] enable a mobile station (MS) to quickly detect its movement into a new subnet by providing the new access router (AR) and the associated subnet prefix information when the MS is still connected to its current subnet. They commonly require *L2 trigger* as an early notice of an upcoming change in the layer-2 point of attachment. *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. In work [3], the interaction

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between IEEE802.16 and Fast MIPv6 (FMIPv6) is presented with the primitives proposed by IEEE 802.21 for cross-layer handover design.

In this paper, we focus on issuing the appropriate *L2 Trigger* based on ARIMA prediction model. Using the signal strength samples obtained through scanning or periodic measurement report process, signal strength from serving base station (BS) and neighbor BS's can be predicted. Signal strength prediction is achieved by ARIMA(p, d, q) model without any assumption on the statistical properties of the movement. Although *L2 trigger* may come explicitly from MAC handover messages, it is more efficient to be derived from scanning process through the link layer prediction in terms of reducing handover latency and packet drops.

The rest of this paper is organized as follows. We first briefly describe the MAC-layer handover procedures specified in the IEEE standard, and the recent works on cross-layer handover protocols studied in the IETF standard. We then present our fast handover method based on ARIMA model together with experiment results. Finally, conclusions follow.

2 Background and Related Works

2.1 Layer 2: IEEE 802.16 Handover

The Mobile WiMAX system basically supports the *hard handover* (also known *as break-before-make*) scheme, but it also optionally supports the soft handover schemes such as macro-diversity handover (MDHO), and fast base station switching (FBSS). Handover is performed in two main processes: one is the network topology acquisition process and the other is handover execution process.

Network topology acquisition refers to periodically updating the parameter values needed for making handover decisions between the MS and the base station (BS). An MS may acquire neighbor BS information from a broadcast `MOB_NBR-ADV` message, or may actively scan target neighbor BS's and optionally try association in order to determine their suitability, along with other performance considerations as a handover target. The MS may incorporate information acquired from a `MOB_NBR-ADV` message to give insight into available neighbor BS's for cell reselection consideration.

A handover execution begins with a decision for an MS to handover from a serving BS to a target BS. The decision may originate either at the MS, or at the serving BS. The handover decision is notified to the BS through `MOB_MSHO-REQ` message or to the MS through `MOB_BSHO-RSP` message. The MS synchronizes to the DL transmissions of the target BS and obtain DL and UL transmission parameters. The MS and target BS may also conduct initial ranging. The final step in handover process is sending `MOB_HO-IND` message to the serving BS.

MS conducts network re-entry process, which is identical to initial network entry process, right after sending `MOB_HO-IND` message. Network re-entry process, however, may be shortened by the target BS's possession of MS information obtained from the serving BS over the backbone network. Network re-entry process completes with re-establishment of provisioned connections.

2.2 Layer 3: Recent Works on Cross Layer Handover Design

Mobile IP Low Latency Extension. Reference [2] proposed three methods to achieve low-latency MIP handovers: *pre-registration*, *post-registration*, and *combined method*. The *pre-registration* approach allows the MS to communicate with the new foreign agent (nFA) while still connected to the old FA (oFA). Therefore, MS can pre-build its registration state on the nFA prior to an underlying layer-2 handover. The pre-building process is initiated by an *L2 trigger*, which is an early notice of an upcoming change in the L2 point of attachment of the mobile node to the access network. Standard MIP registration process is performed between nFA and home agent (HA). If the registration is successful then packets for the MS are tunneled from the HA to the nFA where the MS has moved to.

The *post-registration* handover method proposes extensions to the MIP protocol to allow the oFA and nFA to utilize L2 triggers to set up a bidirectional tunnel between oFA and nFA that allows the MS to continue using its oFA while on nFA's subnet. This enables a rapid establishment of service at the new point of attachment which minimizes the impact on real-time applications. The MS must eventually perform a formal MIP registration after layer-2 communication with the new FA is established. Until the MS performs registration, the FAs will setup and move bidirectional tunnels as required to give the MS continued connectivity.

The *combined method* involves running a pre-registration and a post-registration handover in parallel. Reference [4] evaluated three low-latency schemes and compared their performances in terms of disruption time for VoIP services.

Fast Mobile (FMIP) IPv4/v6. Reference [1] proposed fast handover techniques, which eliminates signaling traffic between MS and HA. The handover mechanism is as follows:

1. MS receives proxy router advertisement (PrRtAdv) messages from the previous access router (PAR) either a solicited or unsolicited manner.
2. With the information provided by in the PrRtAdv message, the MS formulates a prospective new care-of-address (NCoA) and send a fast binding update (FBU) message, when it is still present on the PAR's link.

The purpose of FBU is to authorize PAR to bind previous CoA (PCoA) to NCoA, so that arriving packets can be tunneled to the new location of the MS. Fast binding acknowledgement (FBack) message is sent by PAR in response to FBU message. Depending on whether an FBack is received or not on the previous link, there are two modes of operation.

– *Predictive mode* of operation: The MS receives FBack on the previous link. This means that packet tunneling would already be in progress by the time the MS handovers to NAR. The MS should send unsolicited neighbor advertisement (UNA) message immediately after attaching to NAR, so that arriving as well as buffered packets can be forwarded to the MS right away.

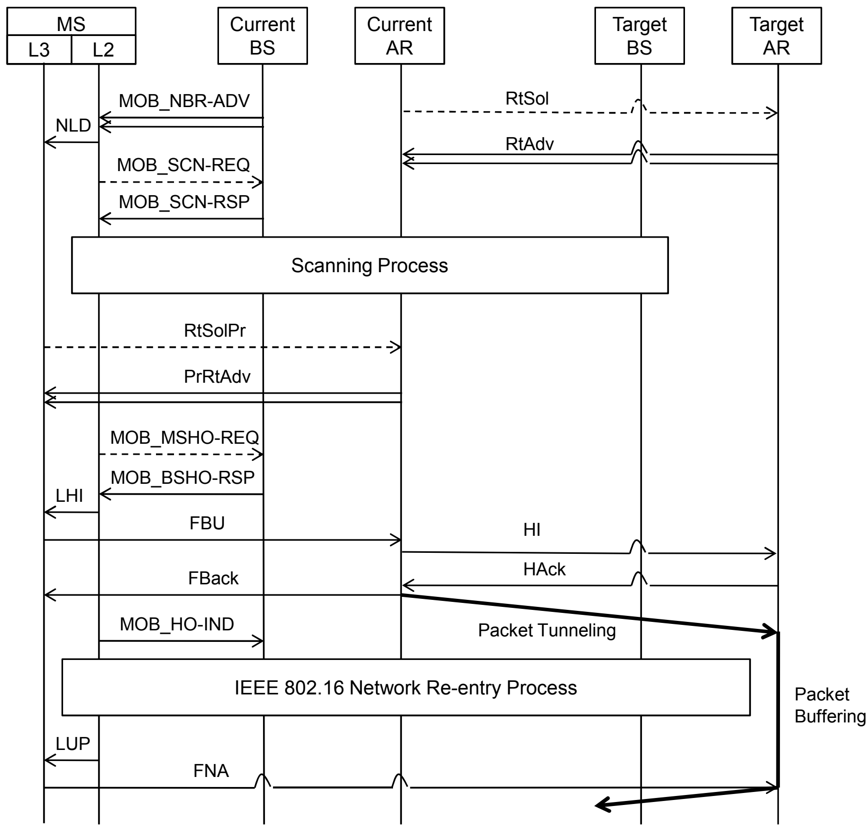

Fig. 1. Message sequence diagram of integrated FMIPv6 and IEEE 802.16 networks: *predictive-mode* operation scenario

– *Reactive mode* of operation: The MS does not receive FBack on the previous link. One reason for this is that the MS has not sent the FBU. The other is that the MS has left the link after sending the FBU, but before receiving an FBack. The MS announces its attachment immediately with an unsolicited neighbor advertisement (UNA) message that allows the NAR to forward packets to the MN right away, so that arriving as well as buffered packets can be forwarded to the MS right away.

Reference [3] describes FMIPv6 handovers on IEEE802.16e networks. In work [3], the interaction between IEEE802.16e and FMIPv6 is presented with the primitives proposed by IEEE 802.21 for cross-layer handover design. An example handover scenario utilizing the L2 triggers (e.g., New Link Detected (NLD), Link Handover Impend (LHI), and Link Up (LUP)) in FMIPv6 over Mobile WiMAX environment is illustrated in Fig. 1.

3 L2 Trigger Using Signal Strength Prediction

Let $\{x_m(t)|1 \le t \le n\}$ is the time series of measured received signal strength indiction (RSSI) values for which we want to predict their amount between a given MS and BS_m as shown in Fig. 2.

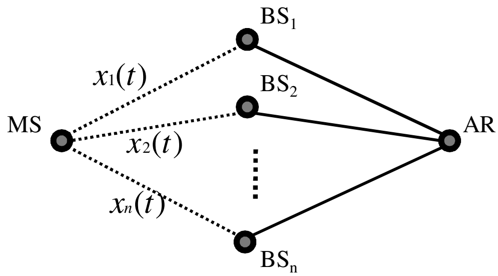

Fig. 2. Time series of signal strength $x_i(t)$

In order to obtain the time series, we monitor signal strength between a given MS and neighbor BS's at regular interval. The time series $\{x_m(t)|1 \le t \le n\}$ is expressed by previous observations $x_m(t-i)$, and noise term $e_m(t)$ which typically correspond to external events. The noise processes $e_m(t)$ are assumed to be uncorrelated with a zero mean and finite variance. The general ARIMA(p, d, q) model has the form

$$\phi(B)\nabla^d x_m(t) = \theta(B)e_m(t) \tag{1}$$

where B is the backward-shift operator defined by $B^j x_m(t) = x_m(t-j)$ and $B^j e_m(t) = e_m(t-j)$. $\nabla^d = (1-B)^d$ is the d^{th} order difference operator. $\phi(B)$ and $\theta(B)$ are the auto-regressive (AR) and moving average (MA) operators of order p and q, respectively, which are defined as $\phi(B) = 1 - \phi_1 B - \phi_2 B^2 - ... - \phi_p B^p$ and $\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - ... - \theta_q B^q$, where $\phi_i(i = 1, 2, ..., p)$ are the AR coefficients, and $\theta_j(j = 1, 2, ..., q)$ are the MA coefficients.

According to the Box-Jenkins methodology [5], we identify the model parameters (p, d, and q) and coefficients (ϕ_i and θ_j). To make a prediction, minimum mean square error (MMSE) forecast method is used. Let's denote the k-step-ahead prediction as $\widehat{x}_m(t+k)$. In this paper, we performed one-step-ahead prediction. Each time the MS obtains a new RSSI sample, the coefficients $\phi_i(i = 1, 2, ..., p)$ and $\theta_j(j = 1, 2, ..., q)$ are updated and corresponding predicted RSSI value, $\widehat{x}_m(t+1)$ is obtained. If $\widehat{x}_s(t+1) \le H_{Th}$ and $\widehat{x}_n(t+1) - \widehat{x}_s(t+1) \ge 3dB \;\; for \;\; \exists n$, *L2 Trigger* is issued. The subscripts s and n stand for serving BS and target BS, respectively. The threshold H_{Th} is the signal strength threshold to start layer-2 handover process. We assumed that hysteresis margin for preventing ping-pong is -3 dB.

4 Simulation Results

4.1 Mobility Models and Network Topologies

We assumed that each BS is connected to a different AR so that when an MS changes BS attachment, corresponding layer-3 handover is always required. We consider three mobility models - *Manhattan*, *Freeway*, and *Random Waypoint* model.

In *Manhattan Mobility Model (MM)* [6] the vehicle is allowed to move along the grid of horizontal and vertical streets. At an intersection the vehicle can turn left, right or go straight with probability 0.25, 0.25, and 0.5, respectively. The velocity of a vehicle at a time slot is dependent on its velocity at the previous time slot. In our simulation, we use the following parameters: total grid area is $5,000m \times 5,000m$, road-to-road distance is 50m, average speed is 40km/h, BS-to-BS distance is 1,000m, and simulation time is 1h. In *Freeway Mobility Model (FM)* [6], a vehicle follows a highway in constant direction at average speed of 90km/h. As was in Manhattan model, the velocity of a vehicle is temporally dependent upon its previous velocity. In *Random Waypoint Model (RWM)*, a vehicle moves along the grid of horizontal and vertical roads in $5,000m \times 5,000m$ area, average speed is 20km/h, maximum pause time is 1s, and simulation time is 1h.

4.2 Numerical Results

For each particular mobility model, the signal strength values of a given MS and neighbor BS's including serving BS are periodically measured and represented as time series $x_i(t)$. In our simulation, we chose both sampling period and prediction interval as 100ms. For all time series $x_i(t)$, we used the first 80 samples (8-second data) to do the time series model fitting. We observed that the time series $x_i(t)$ is nonstationary. We obtained the first-order differencing of actual time series $x_i(t)$ to generate new times series, $w_i(t) = x_i(t) - x_i(t-1)$. This new time series was found to be stationary in the case of most of the data sets, and therefore, we fixed $d = 1$ in our ARIMA model. After analyzing ACF and PACF plots of $x_i(t)$, we observed that ARIMA$(1, 1, 1)$ is the best fitting model. Fig. 3 shows the observed RSSI and predictions that result from the ARIMA$(1, 1, 1)$ model for $x_s(t)$ and $x_n(t)$ in *Freeway* model. For the clarity of presentation, only 1,000 ms of data are shown in Fig. 3. It is seen that ARIMA$(1, 1, 1)$ follows the time series quite narrowly.

In our simulation, the predictive-mode operation probabilities of the proposed scheme are compared to those of the existing FMIPv6 protocol. We assumed that the existing FMIPv6 protocol start layer-3 handover process based on measured RSSI values, while the proposed scheme start layer-3 handover process if the equation (5) and (6) are satisfied. Note that the predictive-mode operation probabilities have a strong impact on the performance of total handover latency.

We conduct the experiments on the following cases: MAC frame length = 5ms, neighbor scan duration = 100ms, interleaving interval = 100ms, prediction

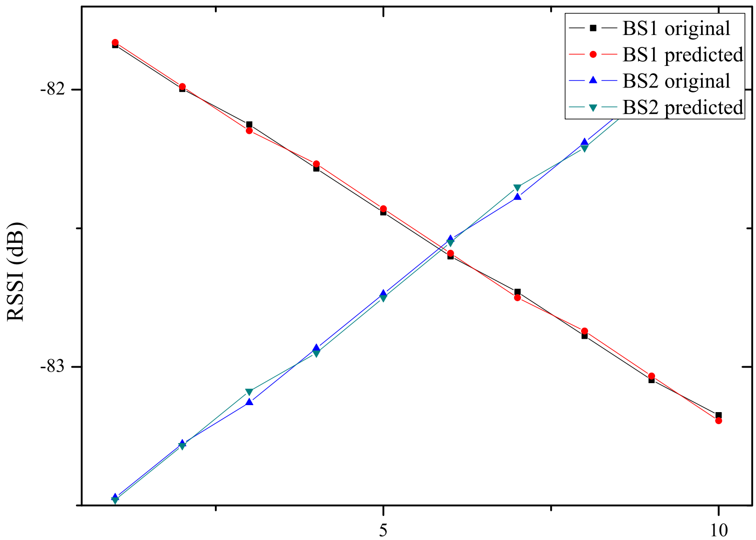

Fig. 3. The observed RSSI and predictions that result from the ARIMA(1,1,1) model for $x_s(t)$ and $x_n(t)$

interval = 100ms ahead, number of samples for calculating ϕ_i and θ_j: recent 80 samples, handover threshold H_{Th} = -80 dB, and handover hysteresis margin = -3dB. The results of the predictive-mode operation probabilities are given in Fig. 4(a).

When the randomness of the movement direction is low, causing more correct prediction, the improvement of predictive-mode probabilities is more visible in *Manhattan* and *Freeway* model. For example, the gain of *predictive-mode* operation probability in Freeway model is 0.95-0.81 = 0.14, while that of Random Waypoint model is just 0.96-0.88 = 0.08. Accordingly, the proposed scheme is more effective and more important in Freeway or Manhattan model than in Random Waypoint model.

Fig. 4(b) compares the handover latencies of two handover protocols with three different mobility models. The figure shows that original FMIPv6 has high handover latency due to low predictive-mode operation probabilities. Because the proposed scheme adopts forecasting method to increase *predictive-mode* operation probabilities, the handover latency decreases. For example, the handover latencies in our proposed scheme are below 297ms, while they are over 303ms in the original FMIPv6 for all three mobility models.

Fig. 4(c) compares the number of lost bytes during handover. For two handover schemes, there is no packet loss in predictive-mode because we assume that the buffer in NAR is not overflowed. The reactive mode still suffers packet drops because packets can be forwarded after the FBU message arrives at the PAR. Since the proposed scheme increases the predictive-mode operation probabilities, the total packet loss can be reduced.

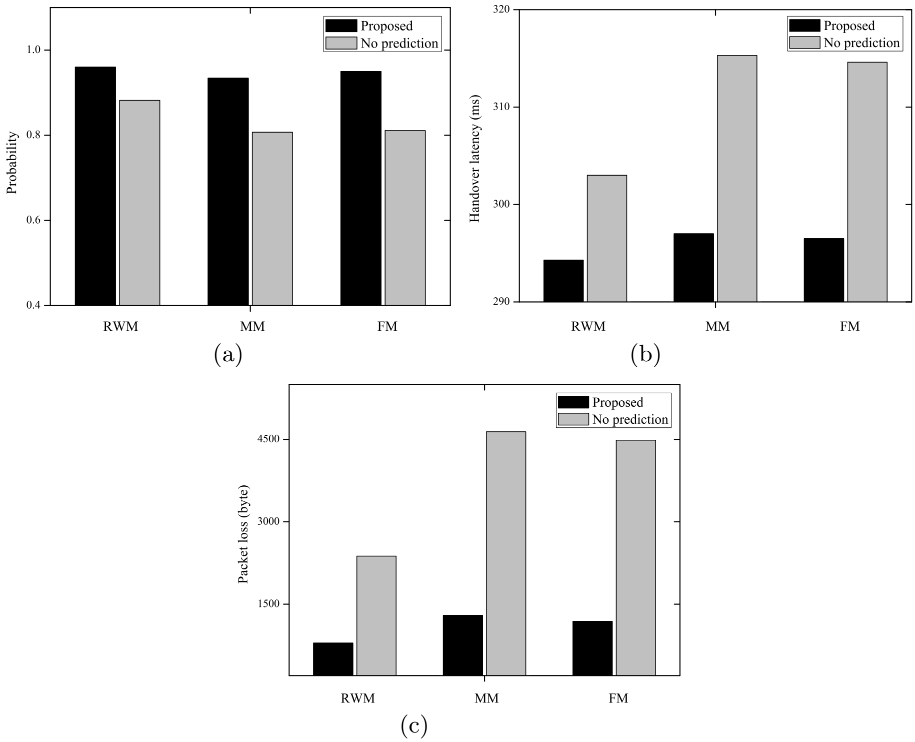

Fig. 4. Comparison of (a) the probability of predictive-mode operation, (b) handover latency, and (c) packet loss

5 Conclusions

In this paper, we have presented ARIMA-based L2 Trigger approach in the integrated FMIPv6 and mobile Internet environment. Simulation results have shown that the proposed scheme outperforms existing conventional scheme in terms of handover latency and packet drops. Since the performance gains are more visible in MM and FM model, our approach is highly attractive for fast moving nodes.

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