2010 16th Asia-Pacific Conference on Communications (APCC)

Mobility-Based Handover Decision Mechanism to Relieve Ping-Pong Effect in Cellular Networks

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***Abstract*—In order to guarantee quality of service (QoS) and seamless communications to nomadic users, it is important to prevent unnecessary handovers occurred during a short interval, so-called ping-pong effect. Considering mobility is one of the useful methods to relieve ping-pong effect in cellular networks since a mobile device can efficiently determine whether it should perform handover or not through the estimation of its moving direction or velocity. In this paper, we propose a mobility estimation method that estimates radial velocity of mobile device directed to the neighboring base stations based on the received signal strength (RSS). In addition, we propose an efficient handover decision mechanism based on the estimated mobility to relieve ping-pong effect. From performance evaluation based on simulations, we find that the proposed mobility estimation mechanism can accurately estimate mobility of moving devices and the proposed handover mechanism can effectively relieve ping-pong effect and reduce handover delay.**

I. Introduction

Handover enables a nomadic user with ongoing communication to move to another cell without any interruption of connectivity. However, in the situation that the user moves around cell border between two cells or strong shadow fading exists around the user, a series of handovers may occur during a short duration, so-called ping-pong effect [1] [2]. Since a handover procedure consists of various message exchanging, decision making, and operations in related network entities, ping-pong effect may decrease the overall network performance. Moreover, ping-pong effect can affect the seamless communication of moving users because the handover procedure requires some times to be committed.

In order to prevent ping-pong effect in cellular networks, many researches have been performed. In LTE standards, handover mechanisms adopting handover hysteresis margin (HOM) and time-to-trigger handover (TTT) are considered [3] [4]. On the other hand, if we can know users' mobility, ping-pong effect can be significantly relieved since the mobility helps to efficiently decide a handover timing. Especially, measuring the mobility of the mobile user and executing a handover procedure in the appropriate timing based on the estimated mobility may increase the performance of handover procedure [5]. Thus, research on estimation of users' mobility is required in order to guarantee quality of service (QoS) and seamless communications to nomadic users.

Researches on estimation of the mobility can be categorized into direct and indirect methods. In direct mobility estimation method, in-build global positioning system (GPS) is used to estimate mobility of a device. The direct mobility estimation method may spend more energy for operation of GPS equipment, increase the cost of mobile devices and not operate in indoor environments, while in-build GPS can accurately estimate mobility of the mobile device. Therefore, the mobility estimation which consider indirect information on the mobility of devices, e.g. RSS and signal to interference-noise ratio (SINR), are more attractive than the direct mobility estimation method [6]–[9].

In order to efficiently execute handover between different base stations in cellular networks, we propose a mechanism to estimate mobility of mobile devices using averaged cumulative RSSs. The averaged cumulative RSSs can be obtained by calculating sample RSSs. In addition, we propose an algorithm to relieve the ping-pong effect in the cellular networks and reduce the delay during handover decision process based on the estimated mobility.

The rest of this paper is organized as follows: Section II describes related works for the mobility estimation methods and handover decision mechanisms. The proposed mobility estimation method is introduced in Section III and in Section IV, the proposed handover decision mechanism to avoid ping-pong effect is illustrated. Section V evaluates performance for the proposed schemes. Finally, the conclusion is given in Section VI.

II. Related Work

A. Handover Decision Mechanisms in 3GPP LTE

3GPP LTE uses handover hysteresis margin (HOM) and time-to-trigger handover (TTT) for handover [3] [4] in order to relieve ping-pong effect. In HOM, a certain value of RSS for handover hysteresis margin, $P_{Th_{HOM}}$, is used for handover decision. It can reduce occurrence of ping-pong effect since it makes the handover decision condition stricter. In handover decision with TTT, when RSRP from candidate BS becomes larger than serving RSRP as $P_{Th_{HOM}}$, the device starts to check that RSRP from candidate BS satisfies the handover decision condition during T_{TTT} [*sec*]. If the RSRP from the candidate BS is larger than serving RSRP as $P_{Th_{HOM}}$ during

TTT, the device will perform handover to the candidate cell. Otherwise, the device does not handover to the candidate cell and continues to communicate with the conventional BS. The procedure of handover decision mechanism in LTE is shown in Fig. 1.

Let P_{RX_0} be received signal power from the current serving BS and P_{RX_i} $(i \in \{1, 2, \cdots, M\})$ be received signal power from ith candidate BS. Device starts the handover decision procedure when RSS of the serving cell (P_{RX_0}) satisfies

$$P_{RX_i} - P_{RX_0} > P_{Th_{HOM}}. \quad (1)$$

If the condition is satisfied for T_{TTT} [sec], the device performs handover to the ith candidate BS. Otherwise, the device will not execute handover procedure and stay in the current cell. In this mechanism, occurrence of ping-pong effect reduces as $P_{Th_{HOM}}$ and T_{TTT} increases. The reason is that the handover mechanism does not sensitively reflect short-term or small-scale changes of channel quality. However, since HOM and TTT suppress execution of handover, high $P_{Th_{HOM}}$ or T_{TTT} may cause disconnection of wireless link between mobile device and BS.

B. Path-loss Model and Representation of Velocity

RSSs vary with different locations and different times since many interruptions exist in wireless communication channel. Representative interruptions include path-loss, shadow-fading (shadowing), multi-path fading, and so on. Path-loss is the natural phenomenon in the wave propagation model because the energy of the wave tends to decrease against increasing distance. However, the exact order of energy reduction cannot be defined. Thus, some researchers have investigated path-loss models such as Okumura model [11], Hata model [12], and COST 231 model [13]. Although there are various path-loss models, we considers the Okumura-Hata model in this paper [14] [15]. The basic form of the Okumura-Hata model can be expressed as

$$P_m(r)\ [dBm] = P_{TX_0} - K_1 - K_2 \log_{10}(r/1000), \quad (2)$$

where $P_m(r)$ and P_{TX_0} denote RSS from the serving BS and TSS(transmitted signal strength) of the serving BS, respectively. K_1 and K_2 represent path-loss coefficients which are determined by the height of an antenna and the carrier frequency.

In the model, path-loss is mostly affected by the distance between BS and device (r). Thus, we use polar coordinates (r, θ) for representing positions of devices in the paper. To represent velocity of a device in vector form, let the differentiations of r and θ are $v_r[m/sec]$ and $v_\theta[rad/sec]$, respectively. Let an unit vector which is directed from BS to the mobile device be $\hat{r}$ and an unit angle vector directed counter-clockwise be $\hat{\theta}$. Then, we can express the velocity of the mobile device in polar coordinate as

$$\vec{v} = v_r\hat{r} + v_\theta\hat{\theta}. \quad (3)$$

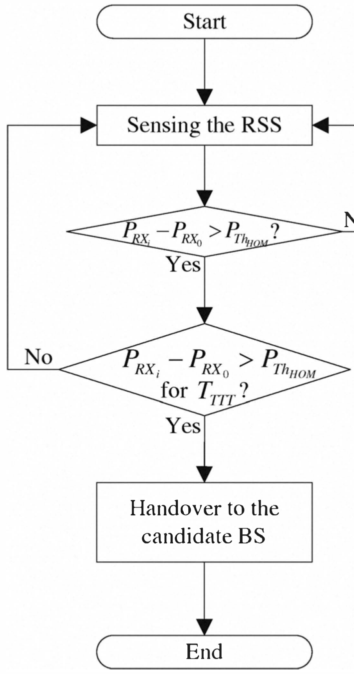

Fig. 1. An example of handover decision procedure with HOM and TTT

III. Mobility Estimation Method

Channel capacity for a device may be determined by its RSS. In general, RSS depends on the distance between the device and its attached BS. Therefore, v_r, so-called radial velocity, can be considered as an important metric in handover decision mechanisms. Assume that two devices, devices A and B, are moving at the speed of $|\vec{v^A}|$ and $|\vec{v^B}|$ ($|\vec{v^A}| > |\vec{v^B}|$), and they are moving along with θ-increasing direction and r-increasing direction within the same cell, respectively. Then v_r of devices A and B become $v_r^A = 0$ and $v_r^B = v^B$. In this case, device B may escape from the cell earlier than device A although $|\vec{v^A}|$ is larger than $|\vec{v^B}|$. Thus, considering v_r is more helpful for appropriate handover decision than considering $|\vec{v}|$. Therefore, we estimate v_r by using the values of RSSs rather than estimating whole components of $\vec{v}$.

Let $P_m(t)$ be the RSS measured at time t. For the time interval ΔT between t_0 and t_1, the integrated dB-scale received power from a BS ($I_{\Delta T}$) is obtained as

$$I_{\Delta T} = \int_{t_0}^{t_1} P_m(t)dt. \quad (4)$$

Suppose that v_r is constant during ΔT and $r(t)$ be the distance between the mobile device and the BS at time t. Then, $r(t)$ is simply represented by

$$r(t) = r(t_0) + v_r(t - t_0). \quad (5)$$

Even though the mobile device continuously measures RSS at arbitrary time t, $I_{\Delta T}$ cannot be directly calculated in digital computer. Therefore, a method is needed to approximate $I_{\Delta T}$.

Suppose that ΔT is equally divided N subintervals with the length T_m. Then, we can approximate $I_{\Delta T}$ as

$$I_{\Delta T} \approx \sum_{n=0}^{N-1} (P_m(t_1 - n \cdot T_m) \cdot T_m). \tag{6}$$

If we consider Okumura-Hata path-loss model for the mobility estimation, RSS at time t can be represented as

$$P_m(t) = P_{TX_0} - K_1 - K_2 \cdot log_{10}((r(t_0) + v_r(t - t_0))/1000). \tag{7}$$

If we substitute Eq. (7) into Eq. (4), $I_{\Delta T}$ becomes

$$\begin{aligned} I_{\Delta T} &= (P_{TX_0} - K_1) \cdot \Delta T \\ &+ \frac{1}{v_r} \cdot [K_2 \cdot \Delta T \cdot (3 + \log_{10} e) \\ &+ K_2 \cdot t_1 \cdot \log_{10}(1 - \Delta T/t_1) \\ &- K_2 \cdot \Delta T \cdot log_{10}\{(r(t_1) - v_r \Delta T)/1000\}]. \end{aligned} \tag{8}$$

In case of $r(t_1) \gg v_r \cdot \Delta T$, v_r can be approximately given by

$$v_r \approx \frac{C}{I_{\Delta T} - (P_{TX_0} - K_1) \cdot \Delta T}, \tag{9}$$

where

$$\begin{aligned} C &= K_2 \cdot \Delta T \cdot \{3 + log_{10} e\} \\ &+ K_2 \cdot t_1 \cdot log_{10}(1 - \Delta T/t_1) \\ &- K_2 \cdot \Delta T \cdot log_{10}(r(t_1)/1000). \end{aligned}$$

By rearranging Eq. (2), we can estimate the distance between the mobile device and BS at time t_1

$$r(t_1) = 1000 \cdot \exp((P_{TX_0} - P_m(t_1) - K_1)/K_2). \tag{10}$$

By inserting Eq. (6) and (10) into Eq. (9), we can finally find v_r of the device.

IV. Mobility-Based Handover Mechanism

As we mentioned in Section II, handover mechanism in LTE uses HOM and TTT to relieve ping-pong effect. However, it is difficult to determine values of $P_{Th_{HOM}}$ and T_{TTT} since those values are closely related with the performance of handover mechanism. Therefore, in the proposed handover mechanism, we consider radial velocity introduced in Section III instead of using HOM and TTT.

Procedure of the proposed handover decision mechanism is shown in Fig. 2. At first, device triggers handover decision when the value of RSS of the serving cell P_{RX_0} satisfies

$$P_{RX_0} < P_{Th}, \tag{11}$$

where P_{Th} is threshold value for handover triggering. Let's assume that M BSs exist around the mobile device. Then the device measures RSS (P_{RX_i}) and estimates the mobility (V_i) (=$-v_r$) for $1 \leq i \leq M$. In case that $\arg\max V_i$ is same as the serving cell, device does not commit a handover and go back to the first stage of procedure. If $\arg\max P_{RX_i}$=$\arg\max V_i$, the device executes the handover to the cell $\arg\max P_{RX_i}$ (= $\arg\max V_i$). Otherwise, the mobile device estimates the P_m again, and handover to cell $\arg\max P_{RX_i}$ after Δt.

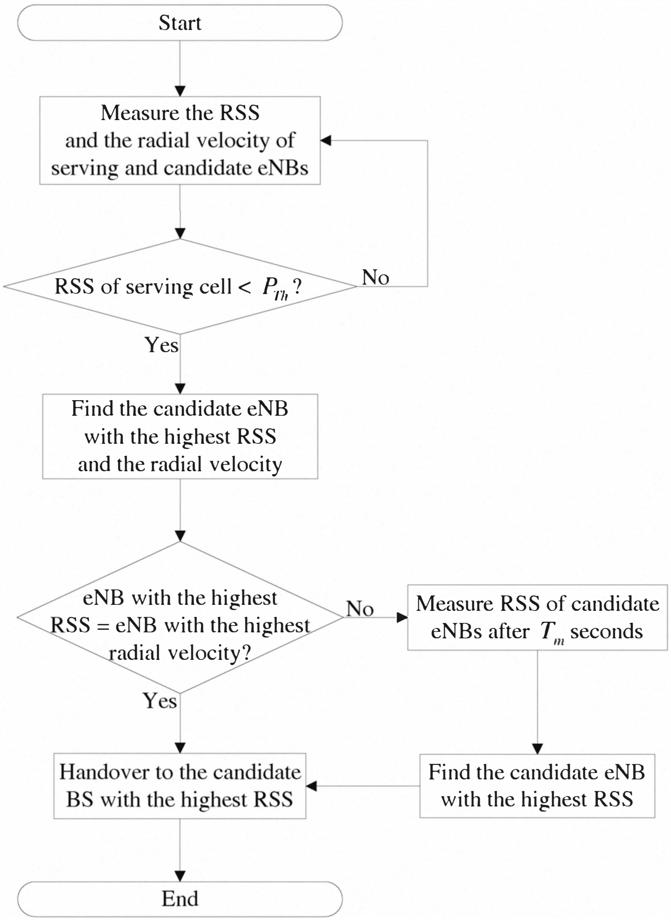

Fig. 2. Handover decision procedure for proposed mobility-based handover method

V. Performance Evaluation

To evaluate performance of the proposed mobility estimation and handover decision methods, we perform simulations considering a cell with path-loss, shadowing, and multi-path fading. We consider Okumura-Hata model as path-loss model in Eq. (2) and the shadowing with 8 dB standard deviation in wireless channel. In addition, the negative exponential correlation function ($R(\Delta x)$) in [3] is adopted to generate spatially correlated shadowing samples. $R(\Delta x)$ is calculated as

$$R(\Delta x) = \exp(-\frac{|\Delta x|}{d_{corr}} \cdot \ln 2), \tag{12}$$

where d_{corr} denotes shadowing correlation distance. Multi-path fading used in the simulation is describe as

$$m(r) = \log_{10} U, \tag{13}$$

TABLE I
SIMULATION PARAMETERS

Parameters	Value
ΔT	1 sec
Δt	0.05 sec
N	20
P_{TX}	46 dBm
ψ_{dB}	8 dB
K_1	128.1 dB
K_2	37.6 dB
Shadowing Correlation Distance	50 m
Cellular Environments	Hexagonal grid, 3 sites, wrap around
Carrier Frequency	2 GHz

where U is random variable uniformly distributed between [0, 1]. In addition, we consider some system parameters referring to [3] and [16] as shown in Table 1.

First, we evaluate the accuracy of the proposed mobility estimation method. Results of 100,000 independent simulations are averaged for each point in Fig. 3. Moreover, speeds and directions of mobile devices are uniformly distributed between 0$\sim$360 km/h and 0$\sim$$2\pi$ rad, respectively. In the performance evaluation of the proposed mobility estimation method, estimation error (estimated radial velocity $-$ actual radial velocity) becomes larger as radial velocity of the mobile devices increases. The reason of the error is the approximation process ($r \gg v_r \cdot \Delta T$) which we assumed in Eq. (9). However, we consider that the 7% error at the speed of 360 km/h can be tolerated for handover performances.

The proposed mobility-adaptive handover mechanism utilizes the proposed mobility estimation method. It can be useful for reducing ping-pong effect although some errors exist in the mobility estimation procedure. For the performance evaluation on the proposed handover decision mechanism, we consider three hexagonal cells and use the wrap-around method for users' mobility. Random walk mobility model is applied for each mobile user, whose velocity and direction are uniformly distributed between 0$\sim$144 km/h and 0$\sim$$2\pi$ rad, respectively. We locate 30 users in the cells and execute the simulation for 10,000 seconds. Fig. 4 shows the CDF of inter-handover interval for the proposed handover and conventional handover mechanism using HOM with $P_{Th_{HOM}} = 0\ dB$ and TTT with $T_{TTT} = 200\ ms$.

In the handover mechanism which has been introduced in Section II, many ping-pong handovers exist during the simulation. These are resulted from the respect that HOM and TTT cannot predict long-term and large-scale changes of wireless channel quality. On the other hand, the proposed handover mechanism can not only acquire an information about moving direction of the mobile device but also predict long-term variation of channel quality. These characteristics help the proposed mechanism to reduce occurrence of the ping-pong effect. Thus, in the proposed handover mechanism, handover intervals are concentrated on long term intervals. Handovers with short term duration less occur in the proposed mechanism than in the existing mechanism. These are resulted from that the device can predict the moving direction of user

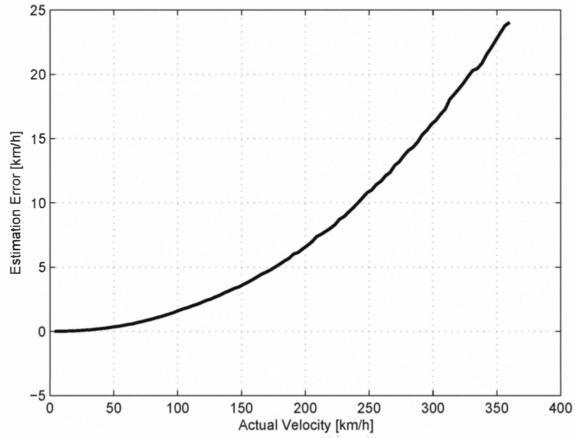

Fig. 3. Estimation error of the proposed mobility estimation method

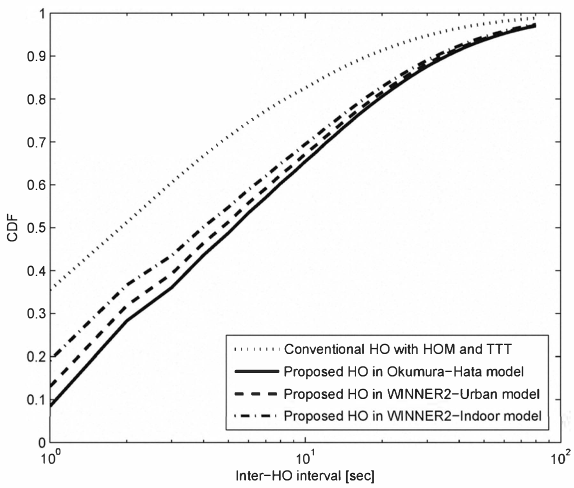

Fig. 4. CDF of handover execution intervals

through the mobility. Though the RSS of a cell is the largest values, if the mobile device goes against the cell, the proposed mechanism needs not to perform handovers because the device does not tend to go to the cell when we see the direction of its moving. At the phase of handover decision delay performance, the conventional mechanism should wait T_{TTT} at least, which are normally set to 200 ms [3]. However, after the condition is satisfied, the proposed mechanism starts the handover at once or wait the next RSS sampling time ($\Delta t = 0.05\ sec$). This shows that the proposed mechanism guarantees less delay in handover procedure. In summary, the proposed mechanism has better performance than the conventional mechanism from the point of view of the performance of reducing ping-pong effect and handover delay time.

VI. CONCLUSION

In this paper, we proposed the mobility estimation method based on RSS. Since the proposed mobility estimation method requires only the measured RSSs during a certain period, which is the basic measurement parameter for mobile devices, it will not cause additional loads on mobile devices. From the simulation results, we found that precision of the proposed method is high for mobile devices, especially for the mobile devices moving with slow velocity. In addition, we proposed a handover mechanism based on the estimated mobility. Since the proposed mechanism considers relative moving direction of mobile device and the outgoing speed against BS, it can effectively reduce the number of occurrences of ping-pong effect. Also, the proposed mechanism has less delay for the handover decision than the handover mechanism with TTT.

ACKNOWLEDGMENT

This work was supported by the IT R&D program of MKE/KEIT. [KI001484, Research on service platform for the next generation mobile communication]

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