An enhanced information server for seamless vertical handover in IEEE 802.21 MIH networks

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Abstract

Seamless vertical handover is a key requirement in heterogeneous wireless networks where different networks are integrated. In this paper, we introduce an enhanced information server (EIS) to accelerate vertical handover procedures in IEEE 802.21 media independent handover (MIH) networks. Based on the EIS, we propose an improved vertical handover procedure in which wireless channel conditions are estimated by exploiting spatial and temporal locality at the EIS, and therefore time consuming channel scanning procedures can be skipped. Simulation results demonstrate that the proposed scheme can reduce the vertical handover latency under diverse environments.

1. Introduction

In future wireless/mobile networks, heterogeneous wireless networks will be available, e.g., IEEE 802.11a/b/g Wireless Fidelity (WiFi), IEEE 802.11p Wireless Access in Vehicular Environments (WAVE), IEEE 802.16 World Interoperability for Microwave Access (WiMAX), Universal Mobile Telecommunications Systems (UMTS), High-Speed Downlink/Upplink Packet Access (HSDPA/HSUPA), Long Term Evolution (LTE), and so on. In such heterogeneous wireless networks, vertical handover (VHO) is a critical challenge to achieve always best connectivity (ABC) services, and extensive research has been carried out [1–3].

For VHO signaling framework, IEEE 802.21 media independent handover (MIH) has been introduced [4]. To facilitate vertical handover in heterogeneous networks, IEEE 802.21 MIH defines three services: Media Independent Event Service (MIES), Media Independent Command Service (MICS), and Media Independent Information Service (MIIS). MIES provides event reporting, event filtering, and event classification services depending on the link dynamics. On the other hand, MICS supports methods to send commands from higher layers to lower layers. MIIS defines a mechanism for an MIH entity to discover available neighboring network information within a geographical area.

In the current 802.21 MIIS specification, a mobile node (MN) gets the neighborhood information by requesting information elements (IEs) from the information server (IS). The IS can provide both static and dynamic information. The names of service providers, medium access control (MAC) addresses, and channel information of the MN’s current network neighborhood are examples of static information. On the contrary, dynamic information includes link-layer parameters such as data rate, throughput, and other higher layer service information to make an intelligent handover decision. However, the currently
defined IEs focus on the static information and therefore how to define and make use of dynamic information in the IE is a still remaining issue.

In this paper, we introduce an enhanced IS (EIS) architecture where spatial and temporal localities are exploited for seamless vertical handover. Specifically, an MN periodically reports its location, link conditions (e.g., received signal strength (RSS)), and the timing information to the EIS. The update procedures are performed by all MNs and the accumulated information can be utilized by the EIS in a collaborative manner. That is, for a handover trigger event, the EIS estimates the MN’s current link condition by means of the information at the EIS, and determines the best point of attachment (PoA) for the MN. Consequently, it is possible to skip time-consuming channel scanning procedures for a handover trigger event. Through extensive simulations, we evaluate the hit probability, which is the probability that the selected PoA by the proposed scheme is the same as the one decided by the full scanning procedure, and vertical handover latency. Simulation results demonstrate that the EIS architecture guarantees higher hit probability with remarkably lower vertical handover latency under different situations.

The remainder of this paper is organized as follows. Section 2 summarizes related works and Section 3 presents the overview of IEEE 802.21 MIH. Section 4 and Section 5 describe the enhanced IS architecture and propose vertical handover with the EIS, respectively. Finally, simulation results and concluding remarks are given in Sections 6 and 7, respectively.

2. Related works

Unlike horizontal handover, since vertical handover is a process of performing the handover between different wireless technologies, it involves the following three phases: network discovery, handover decision, and handover execution. In the network discovery phase, an MN gets the neighbor network information such as cost, network security, jitter, bit error rate (BER), and so on. Using the obtained neighbor network information, the MN (or the IS) decides the target network which will be connected in the handover decision phase. After that, during the handover execution phase, the MN does handover to the target network. Among the three phases, IEEE 802.21 MIH can be used for both system discovery and handover decision. Hence, related works on IEEE 802.21 MIH can be classified into two categories: 1) how to select an appropriate target network [5–8] and 2) how to reduce handover delay in IEEE 802.21 MIH [9–11].


On the other hand, to reduce handover delay in IEEE 802.21 MIH, [9] improved Fast Handover for Mobile IPv6 (FMIPv6) by employing MIH in vehicular environments. [10] introduced a pre-binding update scheme, which uses the target network information from the IS. In [11], experiment results on PMIPv6 handover delay in IEEE 802.21 networks were reported.

However, in these previous works, little attention has been paid to the design of the IS architecture and the development relevant algorithms for seamless vertical handover, which are main contributions of this work.

3. IEEE 802.21 media independent handover (MIH)

IEEE 802.21 MIH is an evolution to support vertical handover by providing capabilities to detect and initiate handover from one network to another [4]. Also, MIH provides services to assist handover between two 802 networks (e.g., from 802.3 to 802.11) or an 802 network and a non-802 network (e.g., from 802.11 to HSDPA). To support vertical handover, MIH defines a logical functional entity called MIH function (MIHF), which provides three services: media independent event service (MIES), media independent command service (MICs), and media independent information service (MIIS).

Fig. 1 shows MICS and MIES models. MICS enables MIH users to manage and control link behavior relevant to handover. As shown in Fig. 1, MICS is initiated by higher layers, and MICS commands are sent to lower layers through the MIHF. “MIH Scan”, “MIH Configure”, and “MIH Switch” are typical examples of MICS. On the other hand, MIES defines the functions of event classification, event filtering, and event reporting to upper layers. Specifically, different events such as “Link Up”, “Link Down”, “MIH Link Up”, and “MIH Link Down” are defined. “Link Up” and “Link Down” events are generated by lower layers (layer 1 or layer 2), and these events are notified to the MIHF. Then, the MIHF reports this situations to upper layers by triggering “MIH Link Up” and “MIH Link Down” events.

MIIS provides information about neighboring networks for MIH user. This information, such as neighbor maps, link

![Fig. 1. MICS & MIES models.](image-url)
layer information, and availability of services, can be used to select the target network when vertical handover is needed. To maintain neighboring network information and offer it to the MNs, IEEE 802.21 MIH has defined an information server (IS). However, the design and implementation of the IS are beyond scope of the standard. Hence, in this work, we introduce a novel design of the IS to decide an appropriate target network for the MN without any channel scanning procedure. More details will be elaborated in Section 5.

Fig. 2 illustrates the vertical handover procedure in IEEE 802.21 MIH [12]. Detailed procedures are as follows.

1. When a handover is triggered, an MN sends a neighbor list query message, which requests the neighboring network list from the IS. Then, the IS sends a neighbor list response message containing the neighboring network information such as network type, subnet prefix, point of attachment (PoA) address, and so on.
2. After receiving the response message, the MN scans for nearby PoAs to measure the up-to-date channel states.
3. Once the MN completes the scanning procedure, the MN sends a target list query message containing the measured channel state values to the IS. Then, the IS evaluates the suitability of each network as the handover target network by means of vertical handover decision functions. After completing the evaluation, the IS sends a target list response message to the MN.
4. Finally, the MN executes a handover to the target network with the highest priority, i.e., Mobile WiMAX in Fig. 2, in the target list.

As illustrated in Fig. 2, the MN should perform multiple scanning procedures to measure the channel states from neighboring networks. As reported in [13], these scanning procedures lead to significant handover latency. Especially when the number of available networks is large, drastically increased handover latency can be observed.

4. Enhanced IS architecture

Although the IS provides the neighboring network information, the scanning procedure occupies a significant portion in the handover latency. Hence, we introduce a novel IS architecture, i.e., enhanced information server (EIS) where the channel state can be estimated by exploiting temporal and spatial localities in the channel state. Consequently, vertical handover delay can be reduced by the EIS since the MN does not need to perform time-consuming scanning procedures.

To describe the EIS architecture, we have several assumptions. First, an MN can measure its current location by means of localizing techniques or GPS. Note that specific localization techniques are beyond the scope of this paper. Then, an extended channel state information (ECSI) can be described as four-tuple,

\[
ECSI = (id, t, (x, y), \delta),
\]

where \(id\) is the PoA identifier, \(t\) is the link quality measurement time, and \((x, y)\) is the MN’s location. \(\delta\) represents the

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1 Of course, the MN can maintain the connection with the old PoA during scanning procedures and thus no disruption occurs. However, since the link quality with the old PoA will decrease significantly after the handover trigger, it is important to minimize the latency from the time of handover trigger to the time of actual handover to a new PoA. Therefore, we consider this latency as the handover latency.
link quality (i.e., RSS) to the PoA id\(^2\). Hereinafter, ECSI.id, ECSI.t, ECSI.(x,y), and ECSI.\(\delta\) refer to id, t, (x,y), and \(\delta\) of a ECSI, respectively.

To construct the EIS, every MN should measure its location and the RSS to available PoAs, and then it should notify the information to the EIS by sending a message with ECSI\(^3\). Then, as time goes, the EIS keeps more ECSIs measured at various locations and times. By collecting this information, without any channel scanning procedure, the RSS with a PoA can be estimated. How to estimate the channel state will be given in the next section.

Fig. 3 shows the network model with the EIS. Assume that an MN is currently connected to Mobile WiMAX PoA. At the same time, the MN lies on in the service areas of HSDPA and CDMA networks. Hence, the MN reports ECSIs on the Mobile WiMAX PoA, HSDPA PoA, and CDMA PoA to the EIS. On the other hand, the MN can receive the signals from the CDMA PoA as well as the Mobile WiMAX PoA, when the MN moves to another area as the dotted arrow. Therefore, the MN reports ECSIs on the Mobile WiMAX PoA and CDMA PoA to the EIS.

### 5. Improved VHO procedure with EIS

As mentioned in Section 4, MNs report the ECSIs to the EIS periodically. Based on ECSIs, the EIS estimates the channel condition with PoAs nearby the MN, and therefore vertical handover latency can be reduced. However, vertical handover latency may be high if accuracy of channel estimation is not sufficiently high. Hence, it is important for the EIS to estimate the RSS with high accuracy. In this section, we present a RSS estimation algorithm and an improved VHO procedure.

Let \((x_0, y_0)\) and \(t_0\) represent the location and time when the MN triggers a vertical handover, respectively. When a vertical handover is triggered, the MN sends a target list query message including \((x_0, y_0)\) and \(t_0\) to the EIS. Then, the EIS estimates the RSS by exploiting spatial and temporal localities in the wireless channel state.

First, for a ECSI, the elapsed time is computed as \(t_0 - ECSI.t\). By considering the time correlation in the channel state (i.e., recent channel state information is more closely related to the current channel state information than the old one), only ECSIs within a time period (i.e., \(t_0 - ECSI.t < W\), where \(W\) is the time window) are considered in the RSS estimation (temporal locality). For efficient management of the EIS, out-of-date ECSIs will be evicted from the EIS.

In a similar context, the spatial locality is investigated. Since the RSS information in a location far away from \((x_0, y_0)\) has less impact on the RSS estimation (spatial locality), only ECSIs within a radius \(R_M\) are selected (i.e., \(\sqrt{(x_0 - ECSI.x)^2 + (y_0 - ECSI.y)^2} < R_M\)). Moreover, different

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\(^1\) This notification can be performed periodically or can be piggybacked with other messages. Therefore, the additional overhead due to the notification can be controlled and minimized.

\(^2\) This paper focuses on how to estimate link quality by means of EIS information, i.e., which link quality metric is used is beyond the scope of this paper. In other words, the proposed scheme can be applied to different link quality metrics such as signal-to-noise ratio (SNR) and signal-to-interference plus noise ratio (SINR). In this paper, since RSS is widely used as a vertical handover parameter as in [14–16], we assume the use of RSS as a link quality metric.

\(^3\) This notification can be performed periodically or can be piggybacked with other messages. Therefore, the additional overhead due to the notification can be controlled and minimized.
weights are assigned depending on the locations by means of an exponentially weighted moving average (EWMA) scheme.

Detailed procedure for estimating the RSS from ECSIs in the EIS is illustrated in Algorithm 1. Let $N$ and $n_i$ be the number of available PoAs and the number of ECSIs of the $i$th PoA (i.e., PoA$i$), respectively. Also, $ECSI(j)$ denotes the $j$th ESI of PoA$i$. Then, the EIS selects $ECSI(j)$ s satisfying two conditions on spatial and temporal localities, and stores the chosen $ECSI(j)$ s to a buffer $\theta$ (see lines 7–8). If there are no $ECSI(j)$ s satisfying the above conditions, the existing vertical handover procedure is performed, as shown in Fig. 2 (see lines 13–14). Otherwise, the EIS sorts the buffer $\theta$ in an ascending order (see line 16). Note sort $(a,b)$ function sorts $a$ depending on $b$. Finally, the expected RSSes of PoA$i$, $\hat{d}_i^k$, can be obtained by the EWMA scheme (see lines 19–22).

**Algorithm 1. RSS estimation**

```
1: initiate $RM_W, W, N$;
2: $i \leftarrow 0$;
3: while $i < N$ do
4:     $j \leftarrow 0$;
5:     $m \leftarrow 0$;
6:     while $j < n_i$ do
7:         if $t_0 - ECSI(j)_t < W \& \&$
8:             $(x_0 - ECSI(j)_x)^2 + (y_0 - ECSI(j)_y)^2 < R_M$ then
9:             $\theta(m) \leftarrow ECSI(j)$
10:            $m++$;
11:        $j++$;
12:     end while
13:     if $m == 0$ then
14:         exit;
15:     end if
16:     sort $(0, \sqrt{(x_0 - \theta(k)_x)^2 + (y_0 - \theta(k)_y)^2})$, for $0 \leq k \leq m - 1$;
17:     $\hat{d}_i^k = \theta(0)_\theta$;
18:     $j \leftarrow 1$;
19:     while $j < m$ do
20:         $\hat{d}_i^k = \alpha \cdot \hat{d}_i^k + (1 - \alpha) \cdot \theta(j)_\theta$;
21:         $j++$;
22:     end while
23:     $i++$;
24: end while
```

As shown in Fig. 4, the overall vertical handover procedure in the proposed scheme can be described as follows:

1. When a vertical handover is triggered, an MN sends a target list query message that includes the MN’s location $(x_0, y_0)_t$ information and the current time $t_0$ to the EIS.
2. On the receipt of the query, the EIS estimates the RSSes for each PoA by using Algorithm 1. After that, based on the vertical handover decision criteria, the EIS constructs a target network list sorted by the priority.
3. Then, the EIS sends a target list response message to the MN.
4. Finally, the MN executes a vertical handover to the network with the highest priority. If the handover is failed, another network with the second highest priority is tried.

**6. Simulation results**

In this section, we describe performance evaluation results. We have developed an event-driven simulator and performed extensive simulations. For credible simulations, we have conducted ten simulation runs with independent and identically distributed parameters (e.g., location, velocity, pause time, etc.) using random seed values.

**6.1. Simulation environment**

For a wireless channel model, COST-231 Hata model is chosen since it is widely used for predicting path loss in mobile wireless systems [17]. Although COST-231 Hata model is designed for the frequency band from 500 MHz to 2000 MHz, it can be used up to 3 GHz. Under COST-231 Hata model, the path loss is given by

$$PL(d)_{dB} = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - a(h_t) + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d) + c_m, \quad (2)$$

where $f$ is the carrier frequency, $h_b$ is the antenna height of a PoA, and $d$ is the distance between the PoA and MN. $a(h_t)$ is the MN’s antenna height correction factor and, for urban environments, it can be obtained from

$$a(h_t) = 3.20(\log_{10}(11.75h_t))^2 - 4.97. \quad (3)$$

On the other hand, for suburban environments, $a(h_t)$ can be obtained as

$$a(h_t) = (1.1\log_{10}(f) - 0.7)h_t - (1.56\log_{10}(f) - 0.8), \quad (4)$$

where $h_t$ is the MN’s antenna height. The parameter $c_m$ is 3 dB and 0 dB for urban and suburban environments, respectively. Then, from (2)–(4), the RSS $\gamma$ at a distance $d$ can be computed as

$$\gamma(d)_{dB} = P_{dB} - PL(d)_{dB}, \quad (5)$$

where $P_{dB}$ is a transmitting power in dB.

In terms of mobility model, we use the random way-point mobility model where an MN chooses two parameters, i.e., direction and speed, before moving from an initial location. The direction and the speed are uniformly distributed $0 \sim 2\pi$ (rad) and $0 \sim V_{\max}$ (m/s), respectively. The
MN moves from an initial location to the selected direction with the chosen constant speed during $T_M$, where $T_M$ is a random moving time. When the MN reaches at the destination, it waits for a pause time $T_P$, and then the MN chooses another direction and speed. These processes are iterative. In addition, each MN sends an $ECSI$ to the EIS with an interval $T_I$. Table 1 summarizes simulation parameters based on [18,19]. In Table 1, $T_M$ and $T_P$ are uniformly distributed in [1,60] s and [1,10] s. Also, $R_H$ and $R_W$ which represent the radius of HSDPA and Mobile WiMAX networks are set to 4 km and 1 km, respectively.

### 6.2. Hit probability

As mentioned before, we define the hit probability $P_H$ as the probability that the PoA selected by the EIS is the same as the PoA determined by the full scanning procedure.

![Fig. 4. Vertical handover procedure with EIS.](image)

![Fig. 5. Effect of $R_M$ on $P_H$.](image)
Fig. 5 shows the hit probability under different $R_M$. As the simulation time goes, more updates to the EIS are performed and thus the EIS can increase $P_H$. Also, Fig. 5 shows that $P_H$ becomes almost 100% after some time, e.g., about 60 min when $R_M \geq 30$ m. This result reveals that the proposed vertical handover scheme can work well after some convergence time. However, if $R_M$ is too small, $P_H$ has poor performance because there are few ECSIs satisfying spatial locality.

From Fig. 6, the effect of velocity $V_{MAX}$ can be observed. Higher velocity indicates that the channel information can be collected from more diverse locations for a given time. Hence, higher velocity will increase $P_H$. However, it can be found that there is no significant difference between the cases of $V_{MAX} = 10$ m/s and $V_{MAX} = 20$ m/s.

Fig. 7 illustrates $P_H$ as a function of $R_M$. It can be found that $P_H$ drastically increases as $R_M$ increases until $R_M = 50$ m, since the number of ECSIs satisfying temporal and spatial localities increases. However, since a large $R_M$ may include more ECSIs measured at far away locations, the efficiency of the RSS estimation based on the spatial locality can be lowered. Therefore, $P_H$ decreases slightly when $R_M$ exceeds 150 m. Also, it can be seen that the temporal locality affected by $W$ has minor impact on $P_H$.

Table 2 shows the standard deviation of $P_H$ under different $R_M$. When $R_M$ is 100 m, all standard deviations are less
than 2.044%, which reveals that our simulations produce quite stable results. On the other hand, for RM of 30 m, it can be shown that results become stable as the simulation time goes. When RM is 10 m, larger standard deviations are obtained because sufficient ECSI s are not accumulated at the EIS. However, it is expected that the simulation results will become stable after longer simulation time.

6.3. Vertical handover latency

To derive the expected vertical handover latency, we have the following notations based on [20]:

- Delay between the MN and the Node B/radio access station (RAS) is \( t_{mr} \).
- Delay between the Node B/RAS and the gateway GPRS support node (GGSN)/access control router (ACR) is \( t_{ra} \).
- Delay between the GGSN/ACR and the IS/EIS is \( t_{ai} \).

From Fig. 2, the expected vertical handover delay with the existing IS, \( D_{VHO}^{IS} \), can be expressed as

\[
D_{VHO}^{IS} = 4(t_{mr} + t_{ra} + t_{ai}) + S_H + S_W + VHO_{EXEC}. \tag{6}
\]

where \( S_H \) and \( S_W \) are the average scanning delay for HSDPA and Mobile WiMAX, respectively. Also, \( VHO_{EXEC} \) is the average vertical handover execution time.

In the proposed vertical handover with the EIS, if there are no ECSIs satisfying the conditions for spatial and temporal localities (see line 7 in Algorithm 1), the EIS sends the neighbor list response message instead of the target list response message to the MN. In other words, in this case, the MN follows the existing vertical handover procedure. On the other hand, the chosen PoA may not be the best PoA due to the inaccurate estimation from the EIS. Under this situation (with probability \( 1 - P_E \)), the MN should perform vertical handover execution steps multiple times. If there are \( M \) PoAs, in such a case, \( M \) vertical handover execution steps may be carried out. Consequently, the expected vertical handover delay in the proposed scheme, \( D_{VHO}^{EIS} \), can be obtained as Eq. (7), where \( P_E \) is the probability that there is at least one ECSI within \( R_M \) and it can be obtained as Appendix A.

\[
D_{VHO}^{EIS} = (1 - P_E) \cdot D_{VHO}^{IS} + P_E \cdot (2(t_{mr} + t_{ra} + t_{ai}) + P_H \cdot VHO_{EXEC} + (1 - P_H) \cdot (2VHO_{EXEC})). \tag{7}
\]

For numerical analysis, we assume that \( t_{mr} = 60 \) ms, \( t_{ra} = 2 \) ms, and \( t_{ai} = 20 \) ms. Also, \( S_W, S_H \) and \( VHO_{EXEC} \) are set to 100 ms, 50 ms, and 2000 ms, respectively [20–22]. Fig. 8 shows the vertical handover latency under different \( R_M \). From Fig. 8, it can be observed that the expected vertical handover latency decreases as the simulation time goes because of the increased \( P_H \) (as indicated in Fig. 5). Note that the vertical handover latency of the proposed scheme does not exceed that of the existing scheme even at the beginning of simulation. This is because \( P_E \) is almost 0 at the beginning of simulation and therefore Eq. (7) can be approximated as \( D_{VHO}^{EIS} \) (i.e., the vertical handover latency of the existing scheme). In particular, the proposed scheme outperforms the existing scheme regardless of simulation time if \( R_M \) is less than 100 m.
Fig. 9 illustrates the effect of $V_{\text{MAX}}$ on the vertical handover latency when $R_M$ is set to 30 m. The expected VHO delay of $V_{\text{MAX}} = 1$ m/s is larger than the cases of $V_{\text{MAX}} = 10$ m/s and $V_{\text{MAX}} = 20$ m/s because it has lower $P_H$ as shown in Fig. 6. However, even when $V_{\text{MAX}} = 1$ m/s, the expected vertical handover latency of proposed scheme is less than the delay of the previous scheme.

On the other hand, Fig. 10 demonstrates the effect of $R_M$. It can be found that the expected vertical handover latency exceeds that of previous scheme when $R_M > 250$ m. This can be explained as follows. As $R_M$ increases, $P_F$ converges to 100% and $D_{\text{VHO}}$ becomes $2(t_{\text{mr}} + t_{\text{ra}} + t_{\text{ai}}) + P_H \cdot V_{\text{HOEXEC}} + (1 - P_H) \cdot (2V_{\text{HOEXEC}})$ (see Eq. (7)). On the other hand, as shown in Fig. 7, $P_H$ decreases as $R_M$ exceeds 150 m. Hence, $D_{\text{VHO}}$ increases if $R_M$ is larger than 150 m due to the reduced $P_H$. That is, multiple VHO procedures are performed when $R_M$ is too large, which result in the increased latency.

6.4. Effect of number of PoAs

Because of popularity of WiFi technologies, extensive works on opportunistic usage of WiFi have been conducted. Therefore, we have conducted additional simulations with three PoAs: HSDPA, Mobile WiMAX, and WiFi.

To analyze the effect of WiFi PoA, the WiFi coverage is set to 200 m and two hit probabilities are defined: 1) the PoA first selected by the EIS is the same as the one determined by the full scanning procedure, $P_{H1}$, and 2)
the second selected PoA by the EIS is the one by the full scanning procedure, $P_{2nd}^H$.

Fig. 11 illustrates $P_H$ under different $W$. From Fig. 11, it can be observed that $P_{2nd}^H$ is larger than $P_{1st}^H$. This is reasonable since $P_{2nd}^H$ is a conditional probability given the failure at the first selection (i.e., the probability of $1 - P_{1st}^H$). On the other hand, unlike Fig. 6, $P_{1st}^H$ decreases when $R_M$ exceeds around 40 m. A similar trend can be observed in Fig. 12, which shows the vertical handover delay when the average scanning delay for WiFi is assumed as 250 ms. That is, the expected vertical handover latency decreases as $R_M$ reaches to a certain point, i.e., about 40 m. On the contrary, the vertical handover latency increases drastically when $R_M$ exceeds the point. This is because fine-grained $R_M$ is required for accurate RSS estimation in WiFi with a smaller coverage. In conclusion, the optimal value of $R_M$ should be set depending on the network coverage (i.e., the smallest network coverage).

7. Conclusion

In this paper, we proposed the enhanced information server (EIS) and the EIS-based vertical handover procedure to reduce the vertical handover latency by eliminating time-consuming channel scanning procedure. From exten-
sive simulation results, it can be shown that the proposed scheme achieves the reduced vertical handover latency under the stable EIS and high mobility. It can be also found that the channel estimation algorithm should consider network characteristics and mobility.

Acknowledgements

This work was supported in part by BLS project funded by Seoul Metropolitan City (Seoul R& BD Program: WR080951), in part by NRF grants (2009-0064397 and R33-2008-000-10044-0), and in part by ITRC program by NIPA (NIPA-2010-C1090-1011-0004).

Appendix A. Derivation of $PE$

The key idea of the proposed vertical handover is to eliminate the scanning delay by estimating the wireless channel condition. However, if there are no ECSIs for adjacent areas (see lines 13–14 in Algorithm 1), the MN should perform the full scanning procedure, which will increase the vertical handover latency. Hence, we first derive the probability $P_E$ that there is at least one ECSI within $R_m$.

To derive $P_E$, we consider a network topology where there are two PoAs: HSDPA PoA with a larger coverage and Mobile WiMAX PoA with a smaller coverage (see Fig. 13). Definitely, a vertical handover can be triggered at the Mobile WiMAX area in which MNs can receive the

![Fig. 13. Simulation topology.](image)

![Fig. 14. $P_E$ under different $R_m$.](image)
signals from the Mobile WiMAX PoA as well as the HSDPA PoA, and they can send ECSI for both the HSDPA PoA and the Mobile WiMAX PoA to the EIS. Form Fig. 13, the Mobile WiMAX area is $\pi R_{W}^2$ and thus the probability that an ECSI has been reported outside the radius $R_{M}$ is given by $1 - \pi R_{M}^2/\pi R_{W}^2$. If the total number of ECSI is $N$, then $P_E$ can be obtained as

$$P_E = 1 - \left(1 - \frac{\pi R_{M}^2}{\pi R_{W}^2}\right)^N.$$  \hspace{1cm} (A.1)

Fig. 14 shows the existence probability $P_E$ where analytical and simulation results are plotted by the dotted and solid lines, respectively. As shown in Fig. 14, $P_E$ increases with the simulation time and $P_E$ converges to 100% after some time. Intuitively, the convergence time for a large $R_M$ is fast since more ECSIs are evaluated for deciding $P_E$. It can also be found that analytical and simulation results are consistent.

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