A Performance Evaluation of Vertical Handoff Scheme between IEEE 802.16e and cdma2000 Networks

Seongsoo Park[*], Seokhoon Kim[**], Jinsung Cho[**], Intae Ryoo[**], Donghahk Lee[*], Jaehwang Yu[*], Jongtae Lim[*], Sehyun Oh[*]
* Mobile & Access Technology R&D Office, SK Telecom, KOREA
** School of Electronics and Information, KyungHee University, KOREA

Abstract – Interworking technologies in heterogeneous network environments has become a hot issue these days. This interworking technology would provide optimized services to users and also benefit service operators by reducing network construction and maintenance costs. This paper proposes network architecture for fast handoff between IEEE 802.16e and cdma2000 networks. The smoothly-coupled integration (SCI) scheme proposed in this paper adopts the advantages of both loosely-coupled integration and tightly-coupled integration schemes. Also, the proposed scheme can be implemented with minimal modification of existing IEEE 802.16e and cdma2000 networks.

Key words: Interworking network, Fast handoff, IEEE 802.16e, 3G

1. Introduction

Recent advances in wireless communication technologies have provided driving forces behind the emergence of various wireless services. First of all, the mobile communication systems have been developed and evolved into the third generation [1]. As a result of CDMA's enhanced capabilities and simplified migration path, the cdma2000 3GPP2 mobile communication system, one of the IMT-2000 standards, has been nation-widely deployed in Korea since the early of 2000, which is the world's first successful commercial deployment. Moreover, the number of Internet users has increased rapidly so that voice-centric services have changed into data-centric services. The cdma2000 mobile communication system has been evolved into 1xEV-DO for high speed data services [2]. The cdma2000 1xEV-DO services are also available in several countries including Korea.

As a result of the consecutive successful development of wireless networks, a new network, so-called IEEE 802.16e (Wireless Broadband), has been defined in Korea for higher bandwidth with broader coverage. It has been developed to enable users to access the Internet anywhere anytime with high speed and good quality using portable equipments such as laptops, PDAs, and smart phones. IEEE 802.16e network is based on IEEE 802.16a[3]. It adopts OFDMA/TDD for multiple-access and duplex schemes, and aims to provide mobility rates up to 60km/h and data service rates up to 50Mbps. It has several additional functions to the IEEE 802.16 specification such as handoff, sleeping mode, periodic ranging, and bandwidth stealing [4][5].

In this paper, we propose the smoothly-coupled integration (SCI) scheme which adopts the advantages of both loosely-coupled integration (LCI) and tightly-coupled integration (TCI) scheme. We present the integrated network architecture, protocol stacks, and operation flows considering cdma2000 and IEEE 802.16e network standards.

The remainder of the paper is organized as follows: Section 2 investigates various existing integration schemes between 3G networks and WLANs as previous study. In Section 3, we propose interworking scheme and evaluate its performance through extensive simulations in Section 4. Section 5 presents some conclusions.

2. Previous Studies

As there is no research effort on the integration of IEEE 802.16e and 3G mobile networks to the best of our knowledge, we introduce the integration schemes between 3G networks and WLAN as related work. The early version of several research efforts on the integration of 3G mobile network and WLAN [6-11] can be summarized in Figure 1. This integration model adds a gateway to support authentication and accounting for roaming services, and uses the mobile IP to provide mobility between WLAN and 3G network. Most existing research efforts on the integration of 3G networks and WLANs have focused on the LCI model [6-10] than the TCI approach, because of the service features of WLANs - that the mobility range of mobile nodes is very small. The advantage of the LCI is that it can be simply adapted to the existing communication systems and it thus can minimize the development efforts on making new standards. However, there exist some limitations and problems to be solved to provide continuous services in this approach [11].

On the other hand, in the TCI model, an AP in WLAN is connected to the SGSN or the PDSN in 3G networks as illustrated in Figure 1, and thus it is possible to support integrated authentication, accounting, and network management.

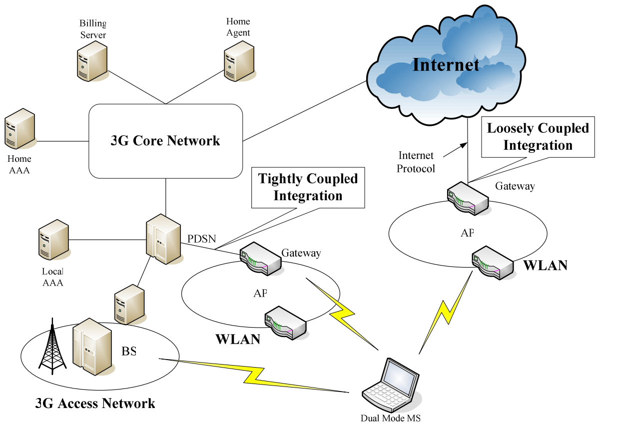

Fig. 1 3G-WLAN interworking architecture

The TCI model requires further standardization work and, thus it may take far longer time to achieve the final step supporting seamless services and service continuity. In the rest of this section, we outline several recent architectures and approaches to the integration of 3G network and WLAN.

The Lucent Bell laboratory built a prototype system, the Integration Of Two Access technologies (IOTA), which is based on a LCI model. The IOTA comprises two new components: an IOTA gateway and service access software on the mobile device. In IOTA, a service provider can support the two access technologies with a single home infrastructure for authentication and mobility management as well as inter-operator handoff using the mobile IP and AAA protocols [7].

Most of currently existing WLAN-cellular network integration models is operator-oriented, which has many limitations such as frequent changes of WLAN configurations on roaming and security configurations of the WLAN adaptor in private WLAN environments. In contrast of the operator-oriented models, AT&T laboratory proposed another integration solution, Internet Roaming system architecture, targeted for VPN-like enterprise. Using a secure mobility gateway (SMG) deployed between the public Internet and the corporate intranet, and virtual single account server (VSA) in the corporate network, as well as the Internet Roaming client (IRC) on the mobile computer, secure roaming across various WLANs and cellular data networks is supported. AT&T laboratory researchers developed a software-based prototype of the Internet Roaming system on Windows OS and a hardware PCMCIA interface prototype IRC. Though they achieved some performance enhancement, their system has several shortcomings such as kernel re-programming [8].

In Europe, to integrate 3GPP UMTS with WLAN based on a LCI model, Ericsson suggested system prototypes to provide mobility based on the mobile IP, as well as user authentication and accounting. Ericsson introduced a concept of “Always Best Connected (ABC)”, which offers user connectivity over multiple access technologies, optimized application performance and seamless mobility, and single logon. In other words, the ABC concept combines the worldwide coverage of cellular systems with the high bandwidth of WLAN hot spots, using the technical solution components and functionality such as access discovery, access selection, AAA support, mobility management, profile handling, and content adaptation [9].

Nokia [10] recently proposed the functionalities of an interworking architecture between public WLAN and the 3GPP cellular networks, which is also basically loosely-coupled. The functionalities relevant to a 3GPP-WLAN interworking bring focus into the reuse of 3GPP subscription, network selection, end-user charging, user data routing, 3GPP-based authentication and security key agreement.

On the other hand, the Motorola laboratory proposed both a LCI and a TCI architecture to integrate GPRS with WLAN [11]. Since the GPRS layer 1 and 2 in the proposed TCI model are simply substituted by the WLAN PHY and MAC, whereas the layer 3 of GPRS is used, the integration system requires additional non-trivial overhead on a mobile node and needs a gateway to support the functions of the GPRS layer 3.

3. The Proposed Scheme

As described in Section 2, the LCI scheme can be implemented just by adding a gateway and it thus can minimize the development efforts. However, there exist problems in vertical handoff performance. On the contrary, the TCI scheme can provide seamless services on vertical handoff but it requires further standardization work and modification of existing communication systems.

By adopting the advantages of both schemes, we propose a hybrid scheme, so called smoothly-coupled integration (SCI) scheme, as shown in Figure 2. In the SCI model, the overall architecture is similar to the LCI model but an IWG (Interworking Gateway) is added for interworking between IEEE 802.16e and cdma2000 networks.

In order to explain our idea, we first describe the PDSN to PDSN (P-P) fast handoff scheme in cdma2000 packet data services [12]. On inter-PDSN handoff cases, a anchor (serving) PDSN setup a tunnel with a target PDSN so that the forward traffic received at the serving PDSN is tunneled to the target PDSN. The target PDSN forwards the traffic to the mobile station. Since the service anchor point is not changed, packet loss can be minimized. This fast handoff scheme can be extended to the case of interworking between IEEE 802.16e and cdma2000 networks simply by adding an IWG which provides a gateway function for protocol adaptation.

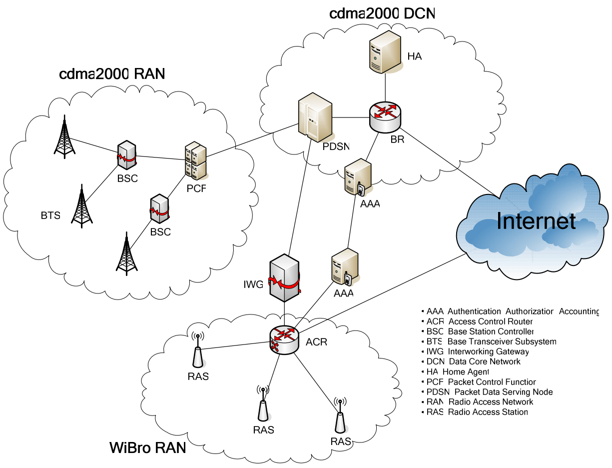

Fig. 2 The smoothly-coupled integration (SCI) architecture

Figure 3 depicts the protocol stacks between network elements in the SCI scheme. Protocol stacks for IWG-PDSN-AAA conform to the cdma2000 standard specifications and those for RAS-ACR-IWG may conform to IEEE 802.16e specifications.

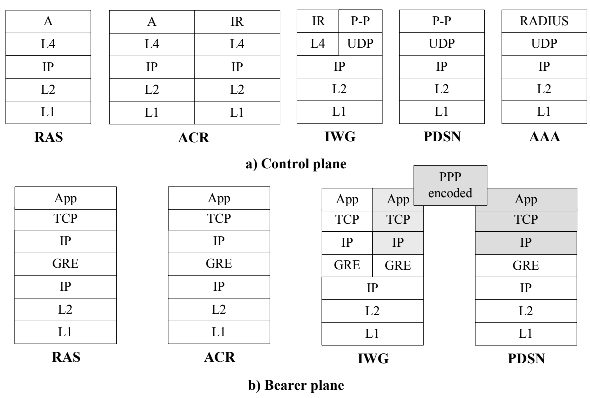

Fig. 3 Protocol stacks in the proposed scheme

However, A and IR interfaces (RAS-ACR and ACR-ACR interface, respectively) are out-of-scope of IEEE 802.16e specifications, although the WiMAX mobility forum (http://www.wimaxforum.org) considers the standardization of those interfaces. As mentioned earlier, IWG translates signaling messages on control plane to adapt protocol stacks and performs PPP encoding/decoding on bearer plane, so that standardization work and modification of existing cdma2000 network elements can be minimized. Figure 4 shows vertical handoff procedures which conforms to cdma2000 and IEEE 802.16e standard specifications except IWG.

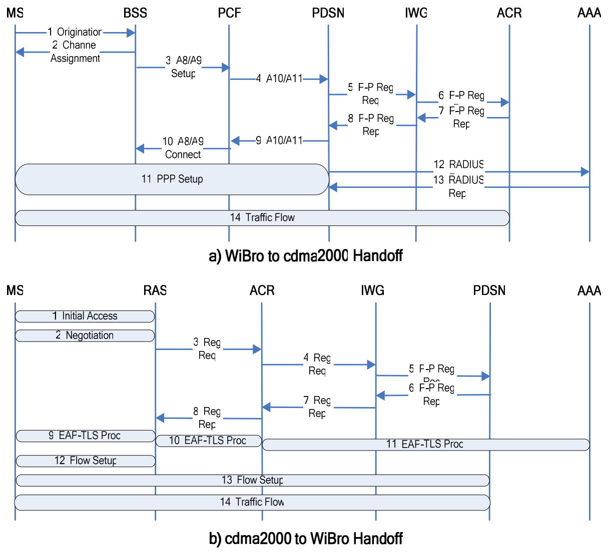

Fig. 4 Signaling and data flows in the proposed scheme

Consider a mobile station moves from IEEE 802.16e to cdma2000 networks as depicted in Figure 4(a). When MS requests a communication channel to BSS, a bearer path MS-BSS-PCF-PDSN-ACR should be setup, where ACR is the service anchor point in IEEE 802.16e network. The origination message in 1 of Figure 4(a) contains PANID (Previous Access Network ID) field so that PDSN can connect to the appropriate anchor ACR using the field. To do this, a mapping function from the base station ID in IEEE 802.16e network to ANID in cdma2000 network is required. A possible solution may be as follows: construct 48-bits base station ID in IEEE 802.16e with SID (16 bits), NID (16 bits), PZID (8 bits), and base station number in a packet zone (8 bits), where SID, NID, PZID comprise ANID in cdma2000 network.

Next, let us consider a mobile station moves from cdma2000 network to IEEE 802.16e in Figure 4(b). Similar to the aforementioned case, when MS requests a communication channel to RAS, a bearer path MS-RAS-ACR-PDSN should be setup, where PDSN is the service anchor point in cdma2000 network. In order for ACR to connect to the right PDSN, PANID field should be delivered to ACR via RAS. It can be implemented by adding PANID filed in MAC management messages of IEEE 802.16e standard specifications.

With this slight modification of standard specifications, the SCI scheme can be implemented as explained in this section. In addition, the fast handoff mechanism between PDSN and ACR will provide seamless services on vertical handoff. In the next section, we validate its performance.

4. Performance evaluation

4.1 Simulation model

The OPNET simulation, as shown in Figure 6, has been conducted to examine the performance of the SIC scheme. We assume that there are 135 mobile stations used in the simulation. Figure 5 shows only a small part of the entire model for simplicity although there are a lot of cdma2000 and IEEE 802.16e cells.

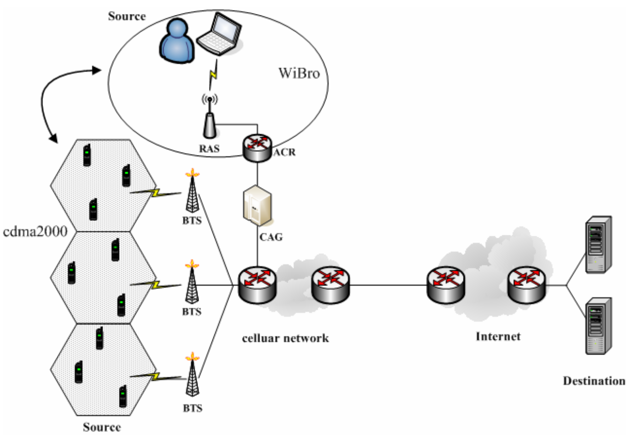

Fig. 5 Simulation model for performance evaluation

IEEE 802.16e network cells and cdma2000 network cells are attached one by another in the simulation. Picocells and microcells are only used to generate frequent handoffs of mobile stations. Since the Markov mobility model used in the simulation, as shown in Figure 6, is designed for mobile stations at low-speed (20~60km/h), and the following probability density function is used, where m represents the average speed of a mobile station in a cell [13].

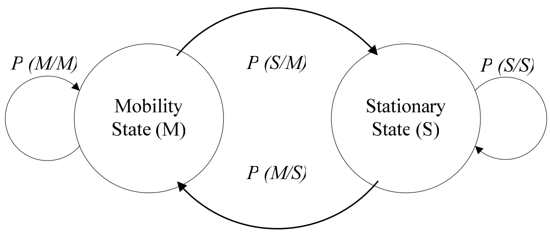

Fig. 6 Mobility model for mobile stations

$$f_{init}(v) = \begin{cases} k \dfrac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(v-m)^2}{2\sigma^2}} & , v \geq 0 \\ 0, v < 0 \end{cases} \quad (1)$$

4.2 Result and Discussion

Both the LCI and SCI schemes are simulated to prove the superiority of SCI over LCI on most popular services in mobile environment, such as streaming, web browsing, and E-mail services. These services are categorized into streaming, interactive, and background traffic class, respectively. In addition, conversational class is also added for video conferencing environment.

Figure 7~10 show that the proposed SCI scheme outperforms the LCI on all kinds of service classes. In fact, performances resulted in each scheme should be the same except when handoffs occur. Therefore, performance differences shown in Figure 7~10 are due to handoff processes. Figures also show that handoff occurrence is very frequent at interval times of 6 to 23, 32 to 35, and 55 to 57.

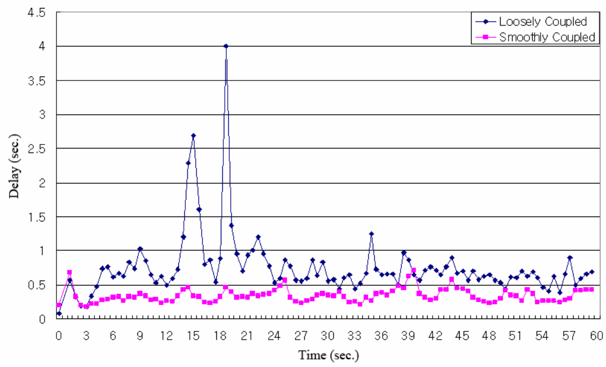

Fig. 7 Packet delay on conversational traffic class

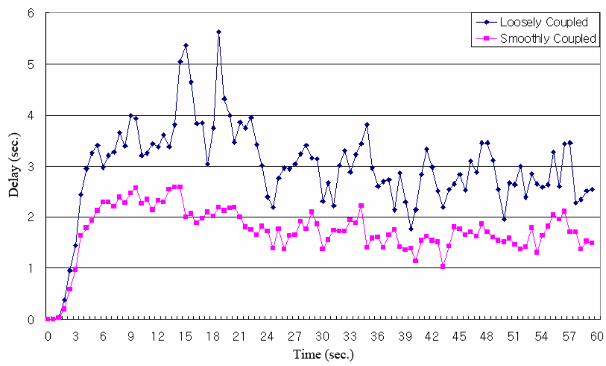

Fig. 8 Packet delay on streaming traffic class

Figure 9 shows the case of interactive traffic class using HTTP, where differences in packet delays between the LCI and the SCI are larger than those of Figure 7 and 8 because of the burst property of web traffic. We can find from Figure 10 that background traffic class like Email shows almost no difference in delay performance because background traffic has the lowest priority.

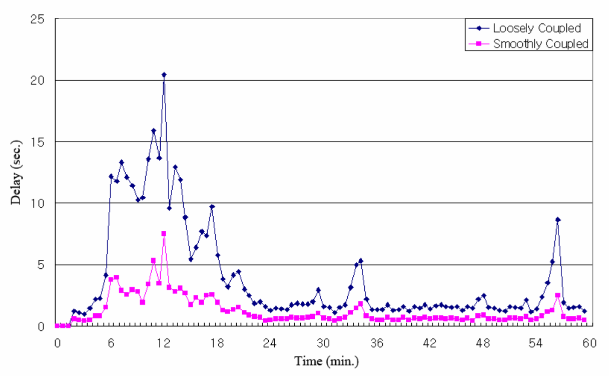

Fig. 9 Packet delay on interactive traffic class

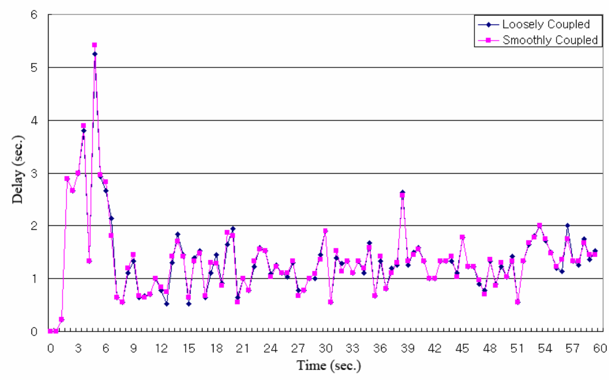

Fig. 10 Packet delay on background traffic class

Both the LCI and SCI schemes are simulated to prove the superiority of SCI over LCI on most popular services in mobile environment, such as streaming, web browsing, and E-mail services. These services are categorized into streaming, interactive, and background traffic class, respectively. In addition, conversational class is also added for video conferencing environment.

In addition, we performed simulations with different moving speed of mobile stations, and find that the faster a mobile station moves, the larger differences in delay performance arise, because the fast moving causes frequent handoffs. We summarize the average packet delay in Table 1.

Table 1. Summary of average delay according to MS's speed

		20Km/h	40Km/h	60Km/h
Conversationa l	LCI	0.495	0.743	1.485
	SCI	0.335	0.537	1.117
Streaming	LCI	2.953	3.839	5.316
	SCI	1.726	2.071	3.020
Interactive	LCI	5.829	8.743	17.487
	SCI	2.459	3.689	8.608
Background	LCI	3.358	4.365	6.549
	SCI	3.371	4.382	6.574

Finally, Figure 11 describes the packet loss ratio in both schemes. Since the LCI scheme employs mobile IP techniques, there may be a lot of packet loss on changing FAs. The SCI scheme, however, fixes the service anchor point (i.e., PDSN in cdma2000 and ACR in IEEE 802.16e) so that the packet loss can be minimized.

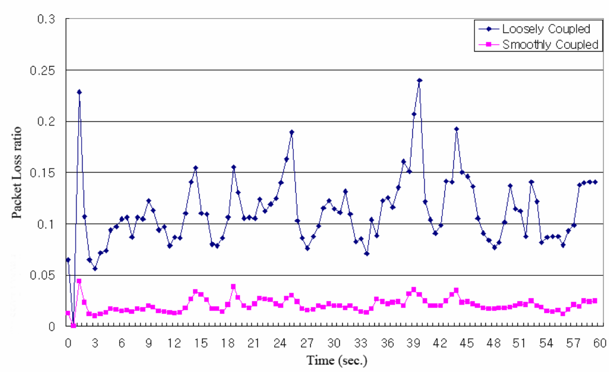

Fig. 11 Packet loss ratio (SCI vs. LCI)

5. Conclusions

In this paper we proposed an interworking scheme for fast handoff between IEEE 802.16e and cdma2000 networks. We have designed a practical model considering the fact that cdma2000 mobile communication networks have already been implemented and widely used. We defined not only an efficient interworking model but also practical implementation methods in node operations, protocols, and interfaces between nodes, standardization issues, and so forth. Thus, this paper can give a theoretical and practical guideline to design IEEE 802.16e which cooperates with current cdma2000 mobile networks.

The proposed SCI scheme adopts the advantages of both LCI and TCI schemes in the linterature. So cdma2000 and IEEE 802.16e networks which are coupled with the SCI scheme provide their own services independently and, on vertical handoff between them, support seamless services by fast handoff. The performance of the SCI scheme has been validated with extensive OPNET simulations. We are currently exploring an extended technological strategy for seamless QoS provisioning.

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