Abstract – We propose a hybrid coupling scheme to connect UMTS and WLAN networks. Under the tight-coupled system, users of WLAN can also use the services of UMTS with guaranteed QoS and seamless mobility, but it is a problem that the capacity of UMTS core network nodes is not enough to accommodate the bulky data traffic from WLAN, since the core network nodes are designed to handle circuit voice calls or short packets. The proposed coupling scheme differentiates the data paths according to the type of the traffic and can accommodate traffic from WLAN efficiently with guaranteed QoS and seamless mobility.

We compare the handover procedures of coupling strategies and analyze the signaling costs during vertical handover. In case of the UMTS and the WLAN are coupled according to the proposed way, it is shown that the handover latency and packet loss decrease.

I. Introduction

Recently, Wireless LANs have been operated as a complementary solution of cellular networks and have enabled the high-speed wireless internet access. It is expected that the connection between narrow coverage high data-rate WLAN and broad coverage low data-rate cellular network enables to provide better services for users [1].

ETSI defined two approaches for the interworking of WLAN and Cellular network: tight-coupled and loose-coupled schemes. The main difference between tight coupling and loose coupling is whether the user’s traffic is delivered through the core network of UMTS or not. That is, in case that UMTS and WLAN are tightly coupled, traffic from WLAN flows into the core network of the UMTS and flows out to the external PDN via SGSN and GGSN. On the other hand, in the loosely coupled case, WLAN doesn’t share any core network nodes of UMTS except AAA functionality. Through tight coupling scheme, the users from WLAN can access the UMTS services with guaranteed QoS and seamless mobility. But it is a problem that the capacity of UMTS core network nodes is not enough to accommodate the bulky data traffic from WLAN, since the core network nodes are designed to handle circuit voice calls or short packets.

When WLAN and UMTS are loosely coupled, each network operates independently and is connected to each other at the Gi reference point, where GGSN is connected to external packet data network. The architecture of loose-coupled network is shown in Fig. 1.

Since each network operates independently, under loose coupling scheme, networks don’t need to change their network architectures or protocol stacks. But loose-coupled network cannot support service continuity to other access network during handover, thus loose-coupled scheme has long handover latency and packet loss.

Fig. 1 Interworking Architecture: Loose Coupling
Fig. 2 shows the network architecture when WLAN and UMTS are tightly coupled. WLAN is connected to UMTS through Iw-interface which is similar to Iu_ps interface connecting RNC to SGSN. To support Iw interface and connecting WLAN to SGSN, a new node named APGW(Access Point Gateway) should be added. In the core network of GPRS, the WLAN is seemed as a kind of radio access network.

II. Proposed Network Architecture

Therefore, we propose a hybrid coupling scheme that differentiates traffic paths according to the type of the traffic. For the real-time traffic, tightly coupled network architecture is chosen, and for the non-real time and bulky traffic, loosely coupled network architecture is chosen. For example, the traffic generated from SIP would be delivered along the path of APGW-SGSN-GGSN to application server in external PDN, but the traffic like FTP would be forwarded to Access Routers. The network architecture for the proposed coupling scheme is shown in Fig. 3.

The proposed coupling scheme enables to accommodate traffic from WLAN efficiently with guaranteed QoS. In addition, it also guarantees mobility and provides seamless service like the tightly coupled scheme while users are moving or need to change their access technologies. Similar to tight-coupled network, APGW should be added to connect WLAN to UMTS network. The functions of APGW are as following:

1. Forward packets to/from AP from/to SGSN or AR.
2. Support Iu_ps-like interface (which is similar to RANAP signaling protocol and Iu data bearer transport)
3. Manage radio resources in WLAN and map them onto radio resources in cellular network.
4. Set data path to SGSN or AR according to the type of traffic.
5. Differentiate service types: UE sets its service type in the TOS(Type of Service) or DSCP(DiffServ Code Point) in the IP header, and APGW checks that and uses to decide path.

Function (1)–(3) are also needed for tight coupling scheme, but the functions related to differentiating service types and paths are needed additionally for implementing hybrid coupling scheme.

In loose-coupled network, real-time traffic could not have appropriate delay and jitter when forwarded through WLAN and internet, and because of long handover latency, traffic experiences large packet loss or whole packet calls are even blocked. But when connecting WLAN to UMTS based on proposed hybrid coupling scheme, it is possible to support quality of service of real-time traffic and service continuity during vertical handover for WLAN users.

When tight-coupling scheme is applied, handover latency and packet loss may decrease, but if bulky data traffic like FTP flows into the cellular core network from WLAN, packet loss rate in core network would abruptly increase. But proposed coupling scheme can prevent core network nodes from traffic overflow by means of detouring non-real time traffic of WLAN and not sharing the capacity of core network nodes.

When WLAN and UMTS are coupled by proposed scheme, it is possible to support seamless handover like tight coupling scheme, using inter-RNC handover-like procedure. In this case, Iu-bearer can be reused and handover procedure doesn’t need the procedure to set up new bearers, so latency, dropping probability and packet loss probability during handover would decrease. And hybrid coupling scheme also supports UMTS services like Location based service and Broadcast/Multicast service to users in WLAN.

To support user’s IP mobility for all of two paths of real-time and non-real time traffic, it is assumed that the mobile IP and its simultaneous binding option are used. That is, when a UE accesses through WLAN, it belongs to two FAs. Then for real-time traffic of WLAN user, FA in UMTS acts as a FA, and in the other case, FA in WLAN acts as a FA. To use simultaneous binding option, HA should have ability to support this option and a user sets the s-bit in Mobile IP.
Packet transmission procedure is the same as the case without simultaneous binding option. To receive packets, two kinds of operations are possible. First, the user receives the same packets twice from two FAs. This is the default operation of simultaneous binding, but has a problem to waste network resources. Second operation needs to use TOS or DSCP in IP header. Users set the TOS or DSCP field according to their traffic type, then HA selects one of two FAs based on value of the field and forwards packets to the FA.

III. Handover Procedures

A. Loose coupling

To support IP-level mobility in loose-coupled network, it is assumed that Mobil IP is applied and WLAN and UMTS networks have their own Foreign Agents. (GGSN acts as an FA in UMTS, and HA and CN are located in external IP network.) Handover procedures to/from WLAN from/to UMTS are shown in Fig. 4 and Fig. 5.

a. Handover to WLAN (Fig. 4)

UE turns its power on, and associates to an AP, and then UE and AP start 802.1x authentication procedure. After completing authentication successfully, an IP address is assigned to UE for MIP registration. Using this IP address, UE registers to the FA in WLAN and restarts transmitting and receiving packets.

b. Handover to UMTS (Fig. 5)

First, UE sets up RRC connection with RNC and starts authentication and ciphering. After successful setup of RRC connection, UE starts GPRS attach and requests to activate PDP context. Then SGSN starts to set up lu bearer to RNC, and requests RNC to assign Radio Access Bearer(RAB) and GGSN to create PDP context with UE. RNC initiates to setup Radio Bearer(RB) and additional Radio Links(RL) for the PDP context. With the IP address assigned by GGSN, SGSN sends back UE the Activate PDP Context message. Now UE can transmit IP packets using new PDP context with assigned IP address. To receive packets from home network, UE sends Registration Request message using MIP, then FA(GGSN) does MIP registration to the HA of UE. Then UE can receive IP packets forwarded by HA.

When a UE leaves UMTS network and moves to WLAN, it is possible to remain PDP context or signaling connection being active for re-use when coming back to UMTS after completing high-rate data transmission in WLAN. That enables to save signaling costs since UE can skip the long and complicated setup procedures. So it is also expected that handover latency and packet loss decrease.

B. Tight coupling

a. Handover to WLAN (Fig. 6)

RNC decides whether to start handover or not based on the measurement results from UE, and if required, sends Relocation Required message to SGSN. Then SGSN sends Handover Required message to appropriate APGW. UE
associates to an AP, and the SGSN requests the APGW Radio Access Bearer setup. After completing bearer setup procedure, SGSN requests GGSN to update PDP context to UE.

b. Handover to UMTS (Fig. 7)
Handover to UMTS is similar to handover to WLAN. After deciding handover to UMTS, APGW sends a Relocation Required message to SGSN to start relocation procedures. After successful setup of PDP context (That means RRC connection and RAB-including RB, RL, Iu bearer- are successfully set up.), UE and GGSN restart transmitting and receiving packets.

C. Hybrid coupling

Vertical handover procedures in hybrid-coupled network are similar to the procedures in tight-coupled network. The only difference is whether the Mobile IP and simultaneous binding option are used or not. In tight-coupled network, it is possible to support user’s IP mobility using tunneling protocols without using Mobile IP protocol. Of course, Mobile IP can also be applied in tight-coupled network, but even in that case, handover between different access networks (i.e. UMTS and WLAN) doesn’t need to change the FA since those access networks belong to the same FA(GGSN). So vertical handover between UMTS and WLAN is one of the intra-FA handover like other inter-RNC handover or inter-AP(APGW) handover, which don’t need to change user’s IP address and to register to FA or HA. But in the hybrid-coupled network, we use Mobile IP and simultaneous binding option to support IP mobility for all of two traffic paths. When UEs in UMTS network, they belong to FA of UMTS network (i.e., GGSN) only, but in WLAN, they belong to two FAs – FA of UMTS and FA of WLAN. So, when a user moves from WLAN to UMTS, it doesn’t need to register to GGSN since it has already registered as shown in Fig. 7. But when moving to WLAN, it is necessary to register to FA in WLAN additionally. This additional registration procedure is shown in Fig. 6, as arrows with dotted line.

IV. Numerical Results and Discussion

We analyze the signaling costs during vertical handover. Define the signaling cost between node A and B as $C_{A,B}$ ($C_{UE-RNC}$ means the signaling cost between UE and RNC), and then define the signaling costs of all other links similarly.

There are 6 cases of handovers: UE moves from UMTS to WLAN or from WLAN to UMTS under 3 kinds of coupled networks. From handover procedures of those 6 cases shown in Fig. 4 ~ Fig. 6, total signaling costs during handover can be calculated as following:

A. Loose coupling
a. Signaling cost during handover to WLAN:

$$= 17C_{UE-AP} + 12C_{AP-GGW} + 6C_{AP-GGW} + 4C_{GW-GGW} + 2C_{GW-GGW}$$

$$= C_{UE-AP} + C_{AP-GGW} + C_{GW-GGW} + C_{GW-GGW}$$
b. Signaling cost during handover to UMTS:
\[ 24 = C_{UE-NC} + 14C_{NC-SCG} + 8C_{SCG-RNC} + 8C_{SCG-GGNSN} + 2C_{FAC-GGNSN} \]
\[ C_{UE-NC} = C_{UE-NAb} \cdot C_{UE-RNC} + C_{NC-SCG} + C_{SCG-GGNSN} \]

B. Tight coupling
a. Signaling cost during handover to WLAN:
\[ 24 = 2C_{UE-NC} + 5C_{NC-AP} + 2C_{AP-GPPGW} + 5C_{AP-GPPGW-SGN} + 2C_{SCG-GGNSN} \]
\[ C_{UE-NC} = C_{UE-NAb} \cdot C_{UE-RNC} \]

b. Signaling cost during handover to UMTS:
\[ 12 = 5C_{UE-NC} + 2C_{NC-SCG} + 2C_{AP-GPPGW-SGN} + 2C_{AP-GPPGW} + 2C_{SCG-GGNSN} \]
\[ C_{UE-NC} = C_{UE-NAb} \cdot C_{UE-NAb} \cdot C_{UE-NAb} \]

C. Hybrid coupling
a. Signaling cost during handover to WLAN:
\[ 24 = 2C_{UE-NC} + 5C_{NC-AP} + 2C_{AP-GPPGW} + 5C_{AP-GPPGW-SGN} + 2C_{SCG-GGNSN} \]
\[ C_{UE-NC} = C_{UE-NAb} \cdot C_{UE-NAb} + C_{AP-GPPGW} + 2C_{FAC-GGNSN} \]

b. Signaling cost during handover to UMTS:
\[ 12 = 5C_{UE-NC} + 2C_{NC-SCG} + 2C_{AP-GPPGW-SGN} + 2C_{AP-GPPGW} + 2C_{SCG-GGNSN} \]
\[ C_{UE-NC} = C_{UE-NAb} \cdot C_{UE-NAb} \]

We define the signaling costs of wireless hop as \( C_{wireless} \) and the signaling costs in between wired nodes as \( C_{wired} \). In Table 1 shows total signaling costs during vertical handover, when the ratio between \( C_{wireless} \) and \( C_{wired} \) varies. When the WLAN and UMTS networks are loose-coupled, 802.1x authentication procedure during handover to WLAN and UMTS call setup procedure during handover to UMTS have the largest portion of each handover procedure. In the tight-coupled and hybrid-coupled networks, 802.1x authentication is processed during initial registration after power-on, and it doesn’t need to be processed again during handover.

Also, when a user moves to UMTS in loose-coupled network, GPRS attach and PDP context activation including RRC connection setup and RAB assignment should be done during handover. But in tight-coupled and hybrid-coupled networks, there is no need to process those procedures because it is possible to reuse signaling and data bearers assigned and used in previous access networks. These explain the gap of the signaling costs in between loose-coupled case and other cases.

In the both tight-coupled and hybrid-coupled cases, handover user experiences the same procedures. But in the case of handover to WLAN, the user in hybrid-coupled network has to register the FAC in WLAN additionally. Thus the signaling costs in case of hybrid-coupled network will increase.

When fixing the signaling cost of wireless links as 1 and increasing the signaling cost of wired links, we find that the increase of total signaling costs during handover are greater than in the opposite cases. That means most of the signaling during handover takes place in wired links. In loose-coupled network, increase of the total signaling costs is much greater than in other cases, since the handover in loose-coupled network has more signaling procedures in wired links compared to the other cases.

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Table 1. Signaling Costs During Handover (1)

<table>
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<th>( C_{wireless} )</th>
<th>( C_{wired} )</th>
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<th>WLAN -&gt; UMTS</th>
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<td>1</td>
<td>77</td>
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</table>

Table 2 shows the signaling costs during handover when the signaling costs of wired network are classified into the costs in UMTS network (\( C_{umts} \)) and those in WLAN network (\( C_{wl} \)). The total signaling costs during handover are calculated similarly with varying the ratio of 3 kinds of costs.

Table 2. Signaling Costs During Handover (2)

<table>
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<tr>
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<th>( C_{umts} )</th>
<th>( C_{wl} )</th>
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<th>WLAN -&gt; UMTS</th>
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V. Conclusions

We proposed the hybrid coupling scheme for interworking between UMTS and WLAN, and compared its handover procedures and signaling costs during handover to previous interworking schemes such like loose coupling and tight coupling scheme. When UMTS and WLAN are connected by hybrid coupling scheme, it is expected that the packet loss probability is lower compared to tight-coupling, and it is shown that the total signaling cost during handover decreases compared to the loose-coupled network. That is, hybrid coupling scheme enables that the interworking network accommodates the real-time traffic from WLAN efficiently without needs of capacity upgrade of core network nodes nor changes in network and protocol architecture of cellular network.

References