Global gateway-based UMTS/WLAN integration for improved delay performance

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This paper proposes a loose coupling-based integration between universal mobile telecommunication system (UMTS) and wireless local area networks (WLANs) using mobile Internet protocol (MIP)-based vertical handoff between the two networks. In loose coupling, an integrated network must provide home agent (HA) functionality when a UMTS subscriber moves to WLAN. The position of HA affects the performance of an integrated network. If HA is deployed at gateway GPRS (general packet radio service) support node (GGSN), delay for data as well as control packets increases when both receiving and transmitting mobile stations (MSs) reside in WLAN. Because each packet travels to GGSN through Gi interface, and routed back to WLAN through the same interface. HA can also be deployed in WLAN Internet protocol (IP) network. This improves delay for data packets, but handoff delay from WLAN to UMTS increases because an MS cannot send MIP registration request to HA before the establishment of packet data protocol context in UMTS network. We propose an efficient integration by fixing the position of HA in a global gateway router which is deployed in WLAN IP network. The proposed interworking technique reduces packet delay when both sending and receiving MSs are in WLANs. The methods also update location of a user in UMTS as well as WLAN so that he/she is always reachable from each network irrespective of current position. ns-2-Based simulation results show that our new handoff methods reduce handoff delay from UMTS to WLAN by 10% and that from WLAN to UMTS by 18%.

Keywords: general packet radio service; loose coupling; Internet protocol; mobile IP; UMTS/WLAN integration; handoff

1. Introduction

Universal mobile telecommunication system (UMTS) [19] and IEEE 802.11-based wireless local area network (WLAN) [3] have some promising complementary features [12]. For example, UMTS provides larger coverage (~0.5–1 km for a micro cell) with higher mobility support and bit rates (144 Kbps for vehicular, 384 Kbps for pedestrian and 2 Mbps for indoor). On the other hand, WLAN provides relatively higher bit rates (802.11b 11 Mbps, 802.11a 54 Mbps) in a smaller area of coverage (50–100 m) such as in a building or office. Since UMTS and WLAN are not designed to work together, there is growing interest for integration of these two networks [2,5,7,8,14,20]. WLAN can provide few more multimedia services (such as video streaming, full-motion video and wireless....
teleconferencing) to cellular users on hotspots such as restaurants, airports, hotels, petrol pumps and shopping malls.

We define the following definitions of the used terms:

- **Access point (AP).** It is a transceiver of a WLAN system. It is analogous to a base station of a cellular system.
- **Hotspot.** This is defined as the radio coverage area around a fixed AP in WLAN systems.
- **UMTS-only coverage.** UMTS cell coverage having no underlying WLAN coverage is called **UMTS-only coverage.**
- **UMTS-only user.** A UMTS-only user has the subscription for only the UMTS services. He/she cannot access WLAN even when residing in a hotspot. Home network of this user is UMTS.
- **Mixed user.** A mixed user is a UMTS user having privileges for hotspot services.
- **Hotspot user.** A mixed user becomes a hotspot user if he/she enters a hotspot and associates with an AP.
- **Backup user.** A mixed user who is currently residing in UMTS-only coverage is called a backup user.
- **WLAN user.** A user whose home network is a WLAN Internet protocol (IP) network is called WLAN user.
- **Mobile station (MS).** A mobile device, such as laptop, personal digital assistance and IP phone, which is equipped with wireless network interface card (WNIC), is called an MS. A user is an owner of an MS. A user having WLAN privileges has an MS equipped with WNICs of both the UMTS and WLAN systems.
- **Tight coupling.** Connecting WLAN to UMTS access or core network through a standard UMTS interface is called tight coupling. In tight coupling, WLAN traffic always travels through UMTS core network.
- **Loose coupling.** Connecting WLAN to UMTS through IP interface is called loose coupling. In loose coupling, WLAN traffic does travel through UMTS core network.
- **Downward handoff.** The vertical handoff from UMTS to WLAN is called downward handoff.
- **Upward handoff.** The vertical handoff from WLAN to UMTS is called upward handoff.
- **WLAN IP network (WIN).** An IP network with WLAN privileges is called WIN.
- **Operator’s integrated network (OIN).** A UMTS–WIN integrated network which is owned and managed by a single UMTS operator is called OIN.

The tight coupling reuses the cellular infrastructures and resources to provide faster handoff, single subscription facility and better security [20]. But the method incurs design and implementation complexity in access network [5,7]. On the other hand, handoffs are less efficient in loose-coupling architecture [10]. But, it supports mobile Internet protocol (MIP) [6,15] and needs minor changes in UMTS standards [16]. Tight coupling generally needs modification in lower level (i.e. below IP level) of protocol stack [18]. It also needs complex interworking function [5] and implementation of additional adaptation layer [7] between WLAN and UMTS. It also injects high-speed WLAN traffic in UMTS access and core network which not only creates congestion in UMTS but also affects the packet delay for UMTS traffic [14]. On the other hand, loose coupling needs modification in IP layer which usually requires description of IP header and new service primitives [20]. It does not require modification in access networks of WLAN and UMTS. Since it yields more delay.
for control and data packets [10], improvement of delay performance, in this method, is still a challenge.

In loose coupling, an external IP network is connected to UMTS through Gi interface as shown in Figure 1(a). Gi is the IP-level interface which connects UMTS to external IP network. Gateway GPRS (general packet radio service) support node (GGSN) is the gateway of UMTS and gateway router is the gateway of external IP network. So, GGSN and gateway router must be connected through Gi interface for interworking between UMTS and external IP networks. The external IP network may be the Internet or WIN. All packets, from external IP network destined for UMTS network, will be routed to gateway router. This router will route all packets to GGSN through Gi interface. Conversely, all packets from UMTS network destined for external IP network will be routed to GGSN which in turn routes packets to gateway router through Gi interface.

Articles [10,11] provide loose coupling between UMTS and WIN as shown in Figure 1(b). Gateway router of the Internet is connected to GGSN. WLAN is connected to UMTS through Internet, i.e. the gateway router of WIN is connected to the Internet. Here, WIN and UMTS are peer networks in [10]. In this architecture, the home network of hotspot users, mixed users and UMTS-only users is UMTS. A mixed user can roam to a hotspot and a WLAN user can roam to UMTS. Gateway router of WIN provides home agent (HA) functionality for WLAN users roaming to UMTS. This also requires GGSN to provide foreign agent (FA) functionality for WLAN users (in UMTS). GGSN provides HA functionality when a mixed user roams to WLAN. Home network of mixed users is UMTS. So, all incoming packets from Internet or WIN addressed to hotspot users will be routed to GGSN. HA at GGSN will route these packets to WLAN. The WIN can also be used as a corporate intranet [11]. In the architectures of [4,7,17], gateway router of WIN

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**Figure 1.** (a) Basic technique for connecting an external IP network to UMTS network, (b) connecting operator’s WIN (OWIN) to UMTS through Internet, (c) connecting Internet to UMTS through OWIN and (d) connecting Internet and OWIN to UMTS through a GGR.
is connected to UMTS at Gi interface (Figure 1(c)). Then, gateway router of the Internet is connected to WIN. In [7], UMTS is the home network of both UMTS-only and mixed users. Although this architecture provides faster handoff, it does not support MIP and it requires modification in link layer. Architecture of [17] provides WLAN facility for mixed users with single subscription. It also implements UMTS subscriber identity module (USIM)-based authentication for a hotspot user. But, handoff between UMTS and WLAN is not supported.

The interworking architecture of [10] (Figure 1(b)) supports upward and downward handoffs with the basis of agreement between UMTS operator and WLAN service provider. In this architecture, GGSN is the gateway of UMTS. All packets from the Internet or WIN, which are addressed to UMTS-only or mixed users, are routed to GGSN. GGSN has to forward the packets to WLAN for the mixed users turned hotspot users. Therefore, in this architecture, HA is deployed at GGSN to support mobility of mixed users to hotspot. HA for WLAN users is deployed in WIN. All packets addressed to WLAN users are routed to HA. In turn, HA forwards these packets to WLAN or UMTS depending upon the current location of the users. From Figure 1(b) and (c), it is obvious that a HA is required to be deployed in WIN to support upward handoff for WLAN users. This needs support of FA functionality in UMTS network because UMTS is the visited network for WLAN users. FA is preferably deployed at GGSN. Therefore, architecture needs two HAs, one at GGSN and the other in WIN. It also needs two FAs, one at GGSN and the other at WLAN. From Figure 1(b) and (c), it is also evident that MIP signals during upward as well as downward handoff will always travel between two gateways across Gi interface. These architectures allocate IP addresses to mixed users from the pool of GGSN and IP addresses to WLAN users from the pool of gateway router of WIN. Mixed users and WLAN users have different home networks. Each network has its own billing system. So, to become a WLAN user, a mixed user has to have separate subscription for WLAN service. Similarly, to become a mixed user, a WLAN user must have separate subscription for UMTS. Therefore, in such systems, implementation of single billing and single subscription for both UMTS and WLAN users is difficult. When WLAN users access the Internet or WIN from UMTS, the usage of Gi interface is unavoidable. So, it is very difficult to reduce hop distance of data packets across Gi interface. On the other hand, when mixed users access the Internet or WIN from WLAN, the usage of Gi interface is not mandatory. The Internet or WIN traffic addressed to a mixed user turned hotspot user can be redirected to WLAN by the gateway router of WIN. So, HA for mixed users can be deployed at the gateway of WIN to skip the Gi interface. We propose the deployment of HA for both mixed users and WLAN users at gateway router. We rename the gateway router as global gateway router (GGR). This facilitates to allocate IP addresses to UMTS-only, mixed and hotspot users from the pool of GGR. Both UMTS and WLAN can be managed by a single operator. It also provides UMTS and WLAN services with single subscription. Integrated network in which HA of mixed users is deployed at GGR is called GGR/HA-based network. A unique HA for mixed users is deployed at GGSN in [10], but it increases packet delay when a mixed user moves to hotspot. The integrated network in which HA of mixed users is implemented at GGSN is called GGSN/HA-based network (Figure 1(c)). Table 1 shows the comparison between GGSN/HA and GGR/HA-based networks. In GGR/HA-based technique, UMTS and WIN are integrated to form an OIN. Since OIN is owned and managed by the UMTS operator, WLAN users are merged with mixed users. However, WLAN users of any other WIN can be supported in UMTS as usual.

In an OIN, mixed users can move freely from UMTS to WLAN and vice versa. Assume that an MS is currently in UMTS-only coverage. Say the MS moves to underlying
hotspot and performs MIP registration with HA. Its location update in UMTS is mandatory. Otherwise, all incoming packets from UMTS-only users will be misrouted to serving GPRS support node (SGSN) based on the packet data protocol (PDP) context maintained in UMTS. Thus, the MS is not reachable from UMTS. For example, a hotspot user may act as a server or he/she may have Voice over IP. So it is necessary for a UMTS-only user to reach the hotspot user without first initiating the session by the hotspot user. Therefore, the location update in the UMTS is mandatory to make a hotspot user reachable from UMTS. The PDP context update in UMTS is also mandatory to handover a data session from UMTS to WLAN. After location update, a hotspot user is reachable from both the Internet and UMTS. All incoming packets from the Internet are received by GGR/HA. GGR/HA tunnels packets to responsible FA. All incoming packets from UMTS are received by GGSN. For hotspot users, there is no active PDP context at GGSN. So, GGSN forwards these packets to HA which, in turn, sends packets to hotspot users. Therefore, efficient location update signalling is needed as soon as mixed users move between UMTS and WLAN. Location update at HA is also needed when hotspot users move to UMTS-only coverage. Otherwise the packets from the Internet can be misrouted to WLAN by HA. So, MIP binding at HA must be deleted for backup users. During upward handoff, a WLAN user has to establish a PDP context for signalling with HA [10]. First PDP signalling in UMTS and then MIP signalling with HA yield larger upward handoff delay. Therefore, efficient handoff technique for upward handoff is essential.

We address the above issues and propose efficient handoff methods taking care of location update for a mixed user moving between UMTS and WLAN. The solution requires simple modifications in IP layer, and GPRS tunnelling protocol (GTP) which is an upper level protocol runs over transmission control protocol (TCP). The technique provides smaller delay for both upward and downward handoffs. The architecture also produces lower delay for both data and control packets for WLAN services.

<table>
<thead>
<tr>
<th>Issues</th>
<th>GGSN/HA-based network</th>
<th>GGR/GA-based network</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. HA</td>
<td>HA for UMTS subscribers is deployed at GGSN. AdditionalHA for WLAN users is deployed</td>
<td>HA for UMTS subscribers is deployed at GGR. Same HA is responsible for hotspot users</td>
</tr>
<tr>
<td></td>
<td>at WIN</td>
<td></td>
</tr>
<tr>
<td>2. FA</td>
<td>One FA at GGSN for upward handoff and another FA in WLAN for downward handoff</td>
<td>Only one FA in WLAN</td>
</tr>
<tr>
<td>3. Subscription</td>
<td>Dual subscription – one for UMTS and another for WLAN</td>
<td>Single subscription for UMTS and WLAN</td>
</tr>
<tr>
<td>4. Upward handoff signals</td>
<td>First PDP signalling and the IP registration request travels across Gi interface</td>
<td>Combined PDP and MIP signalling in UMTS. MIP deregistration request travels across Gi</td>
</tr>
<tr>
<td>5. Downward handoff signals</td>
<td>MIP registration request travels across Gi interface</td>
<td>MIP registration request does travel across Gi interface</td>
</tr>
<tr>
<td>6. WLAN traffic</td>
<td>WLAN traffic travels across Gi interface</td>
<td>WLAN traffic does travel across Gi interface</td>
</tr>
<tr>
<td>7. Hop distance</td>
<td>Hop distance for data packets of WLAN and UMTS traffics remains same as shown in</td>
<td>Hop distance for data packets of WLAN traffic decreases, but for UMTS traffic remains</td>
</tr>
<tr>
<td></td>
<td>Figure 1(c)</td>
<td>the same (Figure 1(c))</td>
</tr>
</tbody>
</table>

Table 1. Comparison between GGSN/HA- and GGR/HA-based networks.
The integration technique facilitates a UMTS operator to deploy its own WIN instead of going for agreement with other WIN operators. A user is always reachable irrespective of his/her location in OIN. To validate the proposed schemes, we provide ns-2-based simulation results.

2. Review of related works

A gateway-based loose-coupling approach [10] proposes an MIP-based solution for integration between WLAN and GPRS. The architecture needs a logical entity, providing HA/FA functionalities, at GGSN. GPRS and WLAN are owned by two independent operators. A user may be subscribed to either GPRS or WLAN networks. Operators have an agreement to provide roaming services across two networks. When a WLAN subscriber moves from WLAN to GPRS, he/she performs MIP registration with HA in the Internet. Here, PDP context creation between SGSN and GGSN is mandatory before MIP registration. This is because each control IP packet is dealt as data packet by GPRS core network. This PDP context needs to be distinguished from standard GPRS PDP context so that GGSN can give the subsequent MIP registration request to FA functionality at GGSN. Although the article presents a good interworking solution between the Internet and GPRS on agreement basis, handoff delay is larger when an MS moves from GPRS to WLAN and vice versa. Further, the architecture of integrated network is required to be designed for a single ownership.

Third generation partnership project gives specifications for interworking between WLAN and UMTS networks [2]. The architecture enables a hotspot user to avail UMTS packet switched (PS)-based services. WLAN authentication, authorisation and accounting (AAA) server in access network controls the access of a hotspot user for UMTS PS-based services. The UMTS AAA server in home UMTS network [16] receives all AAA signalling from hotspot user through WLAN AAA server. It further interfaces with other UMTS components, such as home subscriber server (HSS), charging gateway/charging collection function and online charging system. Thus, a UMTS-based access control is implemented for hotspot user. The establishment of a tunnel from source to destination is mandatory for accessing UMTS PS-based services such as wireless application protocol and IP multimedia services. But the technique does not support the session continuity across UMTS and WLAN.

The USIM-based authentication is useful for operator’s WLAN implementation with single subscription. This needs deployment of extensible authentication protocol (EAP), network access server (NAS), remote authentication dial in user service (RADIUS) and circuit-switched signalling system 7 (SS7) links. For selective WLAN access, an MS needs to do frequent changes in WLAN configuration. An Internet-based roaming architecture [11] can provide secure connections to the corporate networks through an IPSec-based secure mobility gateway which supports MIP for mobility management. But the access to the corporate network from UMTS takes place through the Internet. So, the traffic has to suffer inherent traffic congestion of the Internet.

A mobile extension of stream control transmission protocol (mSCTP)-based handoff [13] between UMTS and WLAN provides network-independent solution for mobility management. It can overcome problem of interruption time during handover with the dual-homing SCTP configuration. Change in IP address due to mobility does not break the mSCTP session. The changed IP dynamically can be bound to mSCTP without breaking the application session. However, efficient signalling in IP layer can further improve the transport layer performance. The mobility management can incorporate the location
of an MS as a security element for location-based service (LBS) [9]. It provides better security for LBS. Therefore, efficient location management technique is highly expected to provide faster access to LBS.

From the extensive review, we understand that the location of an MS must be updated in both UMTS and WLAN networks to make an MS reachable across two networks. Session continuity needs to be supported from UMTS to WLAN and vice versa. So, the UMTS/WLAN interworking needs more efficient solution for handoff from UMTS to WLAN and vice versa. The location of HA in an IP network also needs to be positioned for low end-to-end packet delay.

3. Proposed UMTS/WLAN integrated network

Figure 2 shows the architecture of OIN. GGR is connected with GGSN at Gi interface. The gateway router (Figure 1(b)) of WIN is enhanced with GGR functionality. Internet is connected to GGR. So, hop distance between two networks remains the same as that shown in Figure 1(c). Internet consists of two routers, R3 and AR2. AR2 is the gateway for the WLAN deployed at location L3. However, any number of routers can be deployed in the Internet. We present a WIN consisting of one router AR1 and GGR. However, there may be number of routers in WIN. One WLAN deployed at location L2 is connected to AR1. HA for hotspot users is implemented at GGR. This HA provides MIPv4-based mobility support to a hotspot user. The access router AR1 contains NAS for AAA signalling with home AAA server in WIN [16]. This AAA server communicates with HSS of UMTS for centralised billing and authentication. AR1 in WIN provides FA functionality for hotspot users. Home addresses of UMTS-only as well as mixed users are assigned from the pool of GGR address. The Internet routes all IP packets destined for all users to GGR. Then, GGR checks the MIP binding for each received packet. If MIP binding for destination host does not exist, GGR assumes that the destination user now must be under UMTS network. So, it forwards packets

Figure 2. Architecture of proposed UMTS/WLAN integrated network.
to GGSN. This architecture brings out some degree of scalability. For example, if a UMTS-only user becomes a mixed user through further subscriptions, same network will support mobility across UMTS and WLAN for the user. The operator need not assign separate IP address for hotspot service. Conversely, if a mixed user’s WLAN subscription expires, he/she automatically becomes a UMTS-only user, GGR can route the Internet packets for the MS correctly to UMTS network. Thus, GGR acts as a unique gateway for both the UMTS-only and mixed users.

4. Handoff methods

4.1 Method of downward handoff

Consider a mixed user is residing in UMTS-only coverage in location L1 as shown in Figure 2. He/she is having an Internet data session with a correspondent node (CN) in location L3 in the Internet. Now he/she moves to a hotspot, i.e. from location L1 to L2. His/her data session must be handed over from UMTS to WLAN for continuity of the same session in WLAN. We propose a pure MIPv4-based mobility solution for such downward handoff scenario. GGR provides HA functionality for the hotspot user and AR1 provides the FA functionality. Besides providing usual MIP signalling, HA must initiate necessary signalling with UMTS core network to update the location of a hotspot user because he/she is no longer reachable from UMTS network. Deactivation of PDP context in UMTS for a hotspot user is also necessary to release the UMTS resource. This is mandatory because the mixed user turned hotspot user now uses the WLAN system. The signalling for downward handoff is divided into two phases, Phase I and Phase II. In Phase I, MS performs MIP registration with HA, and in Phase II, GGR performs location update in UMTS network. We present the following steps of signalling (Figure 3) in each phase.

Phase I:

1. The MS performs in association with the AP.
2. The AAA functions are performed using EAP between MS and NAS in WLAN 802.1x access network, using DIAMETER between NAS and AAA server, and using mobile application part over SS7 between AAA server and HSS [17]. DIAMETER is the upgraded version of RADIUS protocol. This step helps USIM-based authentication, centralised billing and service authorisation for hotspot users. Details can be seen in [16].
3. An MS sends solicit router advertisement message to AR1.
4. AR1 sends router advertisement message over WLAN.
5. An MS takes care of address (CoA) from router advertisement message and sends MIP registration request message to HA (at GGR).
6. HA forms MIP binding and sends a MIP registration response message to MS.

Phase II:

1. After sending MIP registration response, HA sends a new ‘IP-Modify-PDP context’ control packet to GGSN. This new IP packet can be specified by the unused bit pattern in the header of an IP packet. It must bear the information about the MS, WLAN AP name and the address of HA.
2. GTP layer in GGSN receives ‘IP-Modify-PDP-Context’ control packet through Gi interface. Destination address of the ‘IP-Modify-PDP-Context’ packet is the address of GGSN itself. So GGSN deals the packet for itself locally. GGSN checks the type field of received packet and it finds that the packet is of ‘IP-Modify-PDP-Context’
It gives the packet to GGSN’s PDP agent (GPA) which is an extended GTP functionality.

3. Before moving to hotspot, an MS was attached to UMTS network. A PDP context remains active in UMTS for a mixed user who has just become a hotspot user. The GPA entity updates this PDP context replacing the address of SGSN by that of HA. It tags the type field of the PDP context as ‘HA-type’ so that UMTS knows that the MS is currently in hotspot.

4. GPA initiates signalling for location update within UMTS network. This includes signalling with HSS for location update and signalling with old SGSN for PDP-context deactivation. Details can be seen in [1]. GPA need not compose new signalling with SGSN and HSS. It calls the standard service primitives of GTP providing the necessary user’s profiles.

The registration of CoA with HA is completed in Phase I. Since CN is in the Internet, the handed over data session can resume just after Phase I. The packets from CN will be routed to GGR. Now GGR holds the live MIP binding for the hotspot users. So, it forwards the packets to FA using MIP tunnelling. If the CN resides in the UMTS network, then the handed over data session can resume only after the completion of Phase II. In this case, GGSN receives all packets destined for hotspot users. It reads the type field of PDP context. If it sees the type field as ‘HA-type’, it understands that the MS is in hotspot. It retrieves the address of HA from the PDP context and sends the packet to HA through
Gi interface. Thus, whenever an MS moves to a hotspot, it is always reachable from the UMTS as well as from the Internet.

4.2 Method of upward handoff

Now consider a hotspot user in location L2 (Figure 2). He/she has already done MIP registration with the HA. UMTS also holds updated location of this user.

Assume that the hotspot user moves from WLAN to UMTS-only coverage, i.e. from location L2 to L1. The MS automatically switches to UMTS mode. The ongoing data session must be handed over from WLAN to UMTS. The MIP binding at HA must be deregistered so that packets are not misrouted to WLAN. The complete signalling is divided into two phases, Phase I and Phase II. In Phase I, PDP context is established in UMTS network, and in Phase II, HA deletes MIP binding. The following steps of signalling are required for Phase I and Phase II (Figure 4).

Phase I:

1. The MS performs attachment signalling with UMTS access network. The user becomes a backup user.
2. The MS sends an Activate PDP-context request (APCR) message to SGSN. The last information element (IE) in the original APCR message is an optional element (Table 1) and it is used to send protocol configuration option (PCO) for external IP network (i.e. WIN) [1]. This field is used to send necessary information to SGSN so that it can initiate modified create PDP-context request (CPCR) message for GGSN. A new IE identifier (IEI) (e.g. 00100110 or 26H) for this IE can be used

Figure 4. Signalling for upward handoff.
The new IEI is necessary because UMTS has to perform additional signalling for MIP deregistration with HA in WIN.

3. On receipt of APCR message, SGSN composes a CPCR message and sends it to GGSN through Gi interface. The ninth IE in the original CPCR message is PCO field and it is optional (Table 3). This field is used to send the necessary information to GGSN so that it can additionally initiate signalling for MIP deregistration with HA. The PCO information, in CPCR, can be represented as ‘HA-type’ by separate unused bit pattern.

4. On receipt of CPCR message, GGSN creates a PDP context the usual way and sends a Create PDP-context response message to SGSN.

5. SGSN receives the create PDP-context response message and sends an activate PDP-context response message to MS.

Table 3. Format of a CPCR message over GTP.

<table>
<thead>
<tr>
<th>IE</th>
<th>Presence requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routing area identity</td>
<td>Optional</td>
</tr>
<tr>
<td>QoS profile</td>
<td>Mandatory</td>
</tr>
<tr>
<td>Recovery</td>
<td>Optional</td>
</tr>
<tr>
<td>Selection mode</td>
<td>Mandatory</td>
</tr>
<tr>
<td>Flow label data I</td>
<td>Mandatory</td>
</tr>
<tr>
<td>Flow label signalling</td>
<td>Mandatory</td>
</tr>
<tr>
<td>End user address</td>
<td>Mandatory</td>
</tr>
<tr>
<td>AP name</td>
<td>Mandatory</td>
</tr>
<tr>
<td>Address of HA and MS</td>
<td>Mandatory</td>
</tr>
<tr>
<td>SGSN address for signalling</td>
<td>Mandatory</td>
</tr>
<tr>
<td>SGSN address for user traffic</td>
<td>Mandatory</td>
</tr>
<tr>
<td>Mobile station international subscriber</td>
<td>Mandatory</td>
</tr>
<tr>
<td>director number (MSISDN)</td>
<td>Mandatory</td>
</tr>
<tr>
<td>Private extension</td>
<td>Optional</td>
</tr>
</tbody>
</table>
Phase II:

1. When GGSN deals the PCO information of CPCR message, it finds the information identifier as ‘HA-type’. So GTP functionality is enhanced to deal with this new IEI. A new service routine needs to be defined to deal with this new IE. We call this new service routine as GGSN mobility agent (GMA). So, GTP entity triggers the GMA service primitive.

2. GMA takes the address of the MS and HA. It then composes a new packet ‘MIP-GMA deregistration request’. It sends this packet to HA at Gi interface. This new IP packet must be distinguished by a separate header identifier.

3. HA functionality is also extended to process the new IP packet ‘MIP-GMA deregistration request’. On receiving this packet, HA deletes the MIP binding for the MS.

Now all incoming packets for the MS from the Internet are received at HA. If HA does not find any MIP binding, it sends packets to GGSN for onward routing in UMTS.

5. Simulation

To validate the performance of the proposed GGR/HA-based network, we provide the ns-2-based simulation results. We compare the performance of GGR/HA-based network with that of a GGSN/HA-based network.

5.1 Session and traffic description

We define the following four classes of data session for the simulation environment.

- **UMTS down-link session.** A data session in which a **UMTS-only user** receives packets from a CN in the Internet is called a **UMTS down-link session**.
- **UMTS up-link session.** A data session in which a **UMTS-only user** sends packets to a CN in the Internet is called a **UMTS up-link session**.
- **WLAN down-link session.** A data session in which a **hotspot user** receives packets from a CN in the Internet is called a **WLAN down-link session**.
- **WLAN up-link session.** A data session in which a **hotspot user** sends packets to a CN in the Internet is called a **WLAN up-link session**.

The flow of packets in a session is called traffic. Flow of packets in a **UMTS down-link session** is called a **UMTS down-link traffic**. In this simulation, the traffic is expressed in terms of number of data sessions. If the number of data sessions increases, the traffic in the system also increases.

5.2 ns Agents and parameters

The handoff procedures (Figures 3 and 4) incur some new signalling between the nodes (routers). Therefore, handoff cannot be simulated using available version of ns-2. Our simulation requires the following development in ns-2 environment.

- An ns agent is a software entity which implements necessary functionalities to execute a protocol.
- A new ns agent is implemented which works over TCP to support GTP functionality for transporting IP packets through GPRS core network. These agents are deployed at SGSN and GGSN nodes.
A new TCP agent is defined to support new ns agent over TCP for interworking between transport and application layers. These agents are also deployed at SGSN and GGSN nodes.

A new agent is deployed to support HA functionality at GGSN node.

FA functionalities are deployed at AR1.

A new agent in IP layer is also developed to provide location update procedure between GGSN and GGR nodes.

An MS is developed to switch to WLAN mode as soon as it enters in WLAN coverage.

The entire simulation has been carried out in the MIPv4 platform. Typical parameter values are shown in Table 4.

6. Performance computation

We present the simulation-based handoff performance comparison between GGR/HA- and GGSN/HA-based networks. The simulation has been carried out using the network architecture of Figure 2. We compute the performance of the networks in three respects; delay of downward handoff, delay of upward handoff and end-to-end packet delay of WLAN traffic with the effects of increasing UMTS traffic.

6.1 Delay of downward handoff

Figure 5(a) and (b) gives the delays of MIP registration and complete handoff, respectively. Figure 5(a) shows the MIP registration delay with increasing UMTS traffic which is expressed in terms of number of UMTS up-link and same number of UMTS down-link sessions. It is seen that when there is no data session, the MIP registration delay in GGSN/HA-based network is 23% more than that in GGR/HA-based network. This is due to the fact that MIP registration packet in GGSN/HA-based network travels extra hop distance across Gi interface. The MIP registration delay increases 2.3 times when UMTS up-link and UMTS down-link sessions increase by five. But MIP registration in GGR/HA-based network increases only 1.3 times under the same environment. Figure 5(b) shows that for fixed control packet size of 600 bytes, downward handoff delay is 18 ms, but that in GGSN/HA-based network it is 23.3 ms, i.e. downward handoff reduces by 10% in GGR/HA-based network.

<table>
<thead>
<tr>
<th>Parameters/agents</th>
<th>Values/protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna</td>
<td>Omni-antenna</td>
</tr>
<tr>
<td>Interface queue length</td>
<td>2500</td>
</tr>
<tr>
<td>Ad hoc routing</td>
<td>DSDV</td>
</tr>
<tr>
<td>Packet size</td>
<td>500 bytes</td>
</tr>
<tr>
<td>Mean link delay</td>
<td>5 $\mu$s</td>
</tr>
<tr>
<td>Link layer overhead</td>
<td>2 $\mu$s</td>
</tr>
<tr>
<td>power transmitted (pt)</td>
<td>0.28132315w</td>
</tr>
<tr>
<td>Power threshold receiver $(R \times $Thresh)</td>
<td>3.65 $E^{-10}$</td>
</tr>
<tr>
<td>Connection between wired nodes</td>
<td>8 Mb 2 ms DropTail</td>
</tr>
<tr>
<td>Transmission rate in a UMTS up-link or UMTS down-link session</td>
<td>384 Kbps/CBR traffic</td>
</tr>
<tr>
<td>Transmission rate in a WLAN up-link or WLAN down-link session</td>
<td>1 Mbps/CBR traffic</td>
</tr>
</tbody>
</table>

Notes: DSDV, destination sequence distance vector and CBR, constant bit rate.
Figure 5(c) shows the handoff comparison between GGSN/HA- and GGR/HA-based networks under increasing control packet size. It is seen that when average control packet size is 100 bytes, the handoff delay in GGSN/HA-based network is 4 ms more than that in GGR/HA-based network. The difference of handoff delay in the two networks increases with increasing control packet size. For example, for packet size of 1000 bytes, the handoff delay in GGSN/HA-based network is 6 ms more than that in GGR/HA-based network.

Figure 5. In downward handoff (a) MIP registration delay with UMTS traffic, (b) total handoff delay in GGR/HA- and GGSN/HA-based network and (c) total handoff delay with increasing control packet size.
6.2 Delay of upward handoff

Figures 6(a) and 5(b) show that upward handoff delay is much greater than downward handoff delay. This happens due to two reasons. Firstly, bit rate in UMTS access network is quite lower than that in WLAN access network. So, packet transmission delay is much larger. Secondly, an MS cannot send MIP deregistration request to HA before the establishment of PDP context in UMTS network.

Figure 6(a) shows the delays of upward handoffs in GGSN/HA- and GGR/HA-based networks for a fixed control packet size of 500 bytes. It shows that the handoff delay in GGR/HA-based network is 18.65% less than that in GGSN/GA-based network. This happens due to the fact that in GGSN/HA-based network, an MS cannot send MIP registration request to HA before the establishment of PDP context in UMTS network. So, during upward handoff, an MS, in first pass [10], performs standard UMTS signalling for PDP-context establishment and then, in second pass, it needs to send standard MIP registration request to HA. But, in GGR/HA-based network, the modified GTP messages for activate PDP-context and create PDP-context carry necessary information so that GGSN enables GPA at GGSN to initiate MIP deregistration on behalf of the MS. Figure 6(b) shows the upward handoff with increasing control packet size. For a packet size of 100 bytes, the upward handoff delay in GGSN/HA-based network is 22% more than that in GGR/HA-based network. But, for a packet size of 1000 bytes, the upward handoff of GGSN/HA-based network is 26% more.

The signalling for upward handoff across Gi interface is same in both GGSN/HA- and GGR/HA-based networks with the only difference is that (Table 1), in GGSN/HA-based network, GGSN sends MIP registration request to HA (in WIN), and in GGR/GA-based network, GGSN sends MIP deregistration request to HA (in WIN). So, effect of UMTS

![Graph](image-url)

Figure 6. Upward handoff delay in GGSN/HA- and GGR/HA-based networks with (a) fixed control packet size of 500 bytes and (b) with increasing control packet size.
traffic on MIP signalling across Gi interface is almost the same in both the networks. Therefore, delay of upward handoff with varying UMTS traffic is not provided.

6.3 End-to-end packet delay

In a GGSN/HA-based network, UMTS traffic (i.e. UMTS up-link and/or UMTS down-link traffic), WLAN traffic (WLAN up-link and/or WLAN down-link traffic) and MIP-based handoff traffic always travel between the gateway router (of WIN) and GGSN (i.e. travel across Gi interface; Figure 1(c)). It is obvious that increasing WLAN traffic will affect packet delay of UMTS traffic or increasing UMTS traffic will affect the packet delay of WLAN traffic across Gi interface. Handoff traffic is only few control signals. Its effect on other traffic is negligible. But effect of UMTS or of WLAN traffic on handoff signal is severe as shown in Sections 6.1 and 6.2. On the other hand, in a GGR/HA-based network, UMTS traffic travels across Gi interface, but WLAN traffic does not travels across Gi interface (Figure 1(d)). Since UMTS traffic always travels across Gi interface in both GGSN/HA- and GGR/HA-based networks, we opt to observe the effects of UMTS traffic on WLAN traffic and MIP registration. However, performance comparison between the two networks can be estimated taking the effect of WLAN traffic on UMTS traffic as well. WLAN traffic in GGR/HA-based network will obviously have less effect on the delay performance of UMTS traffic because it does not pass through Gi interface to GGSN. So, in GGR/HA-based network, both UMTS and WLAN traffics are less affected by each other particularly across Gi interface. We take interest to observe how the WLAN traffic is less affected by UMTS traffic when HA functionality is shifted from GGSN to GGR.

Figure 7(a) and (b) show the end-to-end delay of WLAN traffic with the effect of UMTS traffic. A hotspot user is in location L2 and CN is in location L3 (Figure 2). It is seen that the packet delay increases by only 0.287 ms in GGR/HA network when UMTS up-link sessions increase by 10. But the delay increases by 0.9 ms in GGSN/HA-based network under the same environment. This arises due to two facts: (1) In GGSN/HA-based network, each packet travels extra hop distance from gateway router to GGSN and back to gateway router across Gi interface. (2) GGSN receives packets from gateway router on its down-link (The link between transmitter of gateway router of WIN and receiver of GGSN). But, GGSN sends these packets to gateway router on its up-link (the link between transmitter of GGSN and receiver of gateway router of WIN). This up-link also handles packets of UMTS up-link sessions. So, besides hop distance between GGSN and gateway router, packets of hotspot users suffer extra queuing delay at the up-link. In a GGR/HA-based network, the packets of WLAN down-link (link between transmitter of GGR and receiver of AR1) session do not pass through any transmission link used by UMTS up-link session. Therefore, in this system, the packet delay is not much affected by UMTS up-link sessions. However, these packets suffer small queuing delay at down-link for GGR. It is observed that WLAN traffic is less affected by UMTS traffic by avoiding the Gi interface for WLAN traffic. So it is obvious that UMTS traffics are surely less affected by WLAN traffic when it avoids Gi interface. Both GGSN/HA- and GGR/HA-based networks provide the same route and hop distance for UMTS traffic. So the packet delay of UMTS traffic with increasing UMTS traffic is the same in both networks. For WLAN traffic, both networks provide the same path except that GGR/GA-based network provides reduced hop distance. So packet delay of WLAN traffic with increasing WLAN traffic changes with similar tendency in both networks. However, delay is less in GGR/HA-based network.

Figure 7(b) shows that the average packet delay for a WLAN down-link session increases with increasing number of UMTS down-link sessions in GGR/HA as well as
When UMTS down-link session increases by 10, the average packet delay increases by 1.3 and 2.2 ms in GGR/HA- and GGSN/HA-based network, respectively.

7. Conclusion

The proposed handoff methods reduce handoff delay from the UMTS to WLAN and vice versa. The architecture allows a UMTS operator to deploy its own IP network providing optional WLAN privileges for its subscribers. The architecture supports USIM-based authentication of a hotspot user. It also facilitates single subscription and one billing for integrated UMTS and WLAN network. Other operator’s IP network can also be connected at GGR through separate IP interface bypassing the Internet. The architecture facilitates to have only one gateway address for UMTS-only and mixed users. The architecture needs new service primitives in HA and GTP functionalities. However, these upper level modifications are less complex than those in the lower level of tight coupling.

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Notes
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References