iGSM: VoIP Service for Mobile Networks

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ABSTRACT

This article proposes iGSM: a voice-over-IP value-added service for mobile network. The iGSM service provides user mobility to subscribers, which allows them to use either GSM handsets or H.323 terminals (IP phones or PCs) to access telecommunications services. We describe how the iGSM registration, deregistration, and call delivery procedures can be implemented without modifying the GSM network. We study how the tromboning effect in the standard GSM system can be avoided when accessing the IP network. Then we investigate the misrouting problem caused by user mobility.

INTRODUCTION

Supporting telephony services over IP network, or so-called voice over IP (VoIP), is considered a promising trend in the telecommunications business. Particularly, integrating mobile phone services with VoIP is becoming an important issue which has been intensively studied [1, 2].

Telecommunications and Internet Protocol Harmonization over Network (TIPHON; see [1] and the series references therein) specifies a mechanism (i.e., mediation gatekeeper) to provide the service control functions for convergence of the IP network, mobile network, fixed wireless, and public switched telephone network (PSTN). Several scenarios are defined in TIPHON to illustrate different ways to integrate IP and mobile networks. In this article we use the Global System for Mobile Communications (GSM) as an example of mobile networks to describe mobile/IP integration where the mobile signaling protocol is GSM Mobile Application Part (MAP) [3]. Our discussion applies to other mobile signaling protocols such as Electronics/Telecommunications Industry Association (EIA/TIA) IS-41 [4].The elements in the GSM network include the mobile station (MS), base transceiver station (BTS), base station controller (BSC),mobile switching center (MSC), home location register (HLR), and visitor location register (VLR). We assume that the reader is familiar with these GSM terms. Details can be found in [3].

A TIPHON scenario that integrates mobile and IP networks to support terminal mobility is described below. The architecture for this scenario is illustrated in Fig. 1a, where the mediation gatekeeper serves as a VLR to support roaming management. The BSC/BTS in the IP network provides wireless access to the IP network. Another TIPHON scenario describes mobile and IP integration to support user mobility. We will elaborate on this scenario later.

Based on a concept similar to TIPHON, *GSM on the Net* [2] utilizes a corporate intranet to integrate an enterprise communications network with the public GSM network. This system supports *user mobility* where, by using various types of terminals, a user can move around the service area without losing contact with the system. The *GSM on the Net* architecture is illustrated in Fig. 1b, and consists of GSM and corporate networks.

All elements in the corporate network are connected to an intranet. They communicate with each other using an intranet protocol. These elements are described below.

The *service node* enables user mobility, controls calls among different types of terminals, and translates addresses between the PSTN and *GSM on the Net.*

The *access node* resembles the MSC, VLR, and BSC.

GSM/BTS provides the GSM MS with wireless access to the IP network.

The *gateway* provides interfaces between *GSM on the Net* and other networks (particularly the GSM network).

This article proposes the iGSM service, which realizes another TIPHON scenario that supports *user mobility* for GSM subscribers to access VoIP services. That is, a GSM subscriber ordering the iGSM service enjoys the standard GSM services when he/she is in the GSM network. When the person moves to the IP network (without a GSM mobile station), he/she can utilize an H.323 terminal (IP phone or PC) to receive call delivery to his/her mobile station ISDN (MSISDN) number.The GSM roaming mechanism determines whether the subscriber is in the GSM or IP network. The iGSM solution is different from *GSM on the Net* in the following aspects. Unlike *GSM on the Net* (which integrates a corporate network with the public GSM network), iGSM is a value-added service to public GSM networks. The iGSM network does not introduce wireless access equipment (i.e., the GSM BTS) into the IP network, and is implemented using standard platforms (a general IP gateway/gatekeeper).
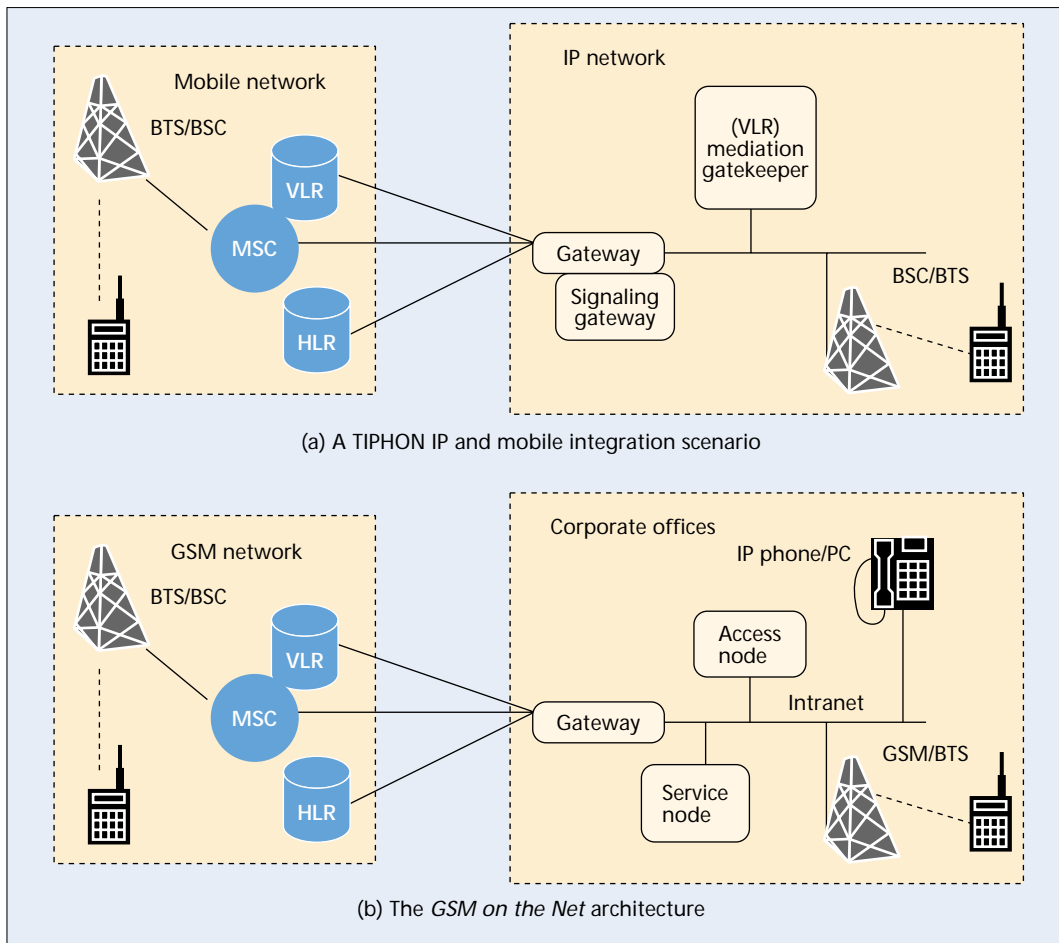
■ Figure 1. *Two mobile and IP integration scenarios.*

This article describes the iGSM architecture and the protocols for location update and call delivery. We discuss how the tromboning effect [5] in a standard GSM system can be avoided when accessing the IP network. Then we investigate the misrouting problem caused by user mobility.
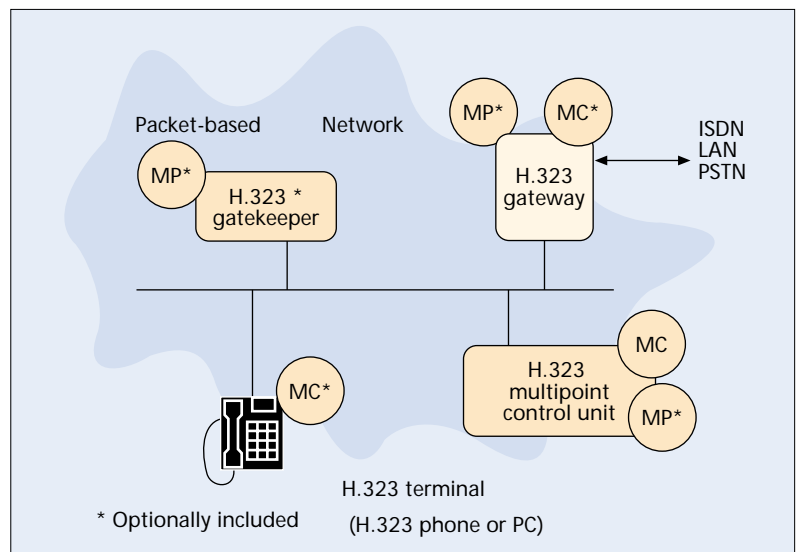
THE IGSM ARCHITECTURE

The iGSM system consists of GSM and H.323 (IP) networks. Although we consider H.323 as the VoIP protocol, our results can be generalized to accommodate other protocols such as *Media Gateway Control Protocol* [6].

We briefly introduce H.323 as follows. International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) H.323 [7] covers the technical requirements for multimedia communications over packet-based networks that may not provide a guaranteed quality of service. Figure 2 illustrates an H.323 system. In this figure the terminal, gateway, gatekeeper, and multipoint control unit are called *endpoints*.

The *terminal* is customer premises equipment that provides audio, video, and data communications capability in point-to-point or multipoint conferences in the H.323 network.

The *gateway* performs call control functions (setup and release) and provides communication

■ Figure 2. *The H.323 architecture.*

protocol translation mechanism between an H.323 endpoint and an endpoint of an external network such as PSTN, ISDN, or LAN. It also translates the transmitted media from one format to another between the IP and circuit-switched networks. Two H.323 endpoints in the same network can communicate without involving the gateway.
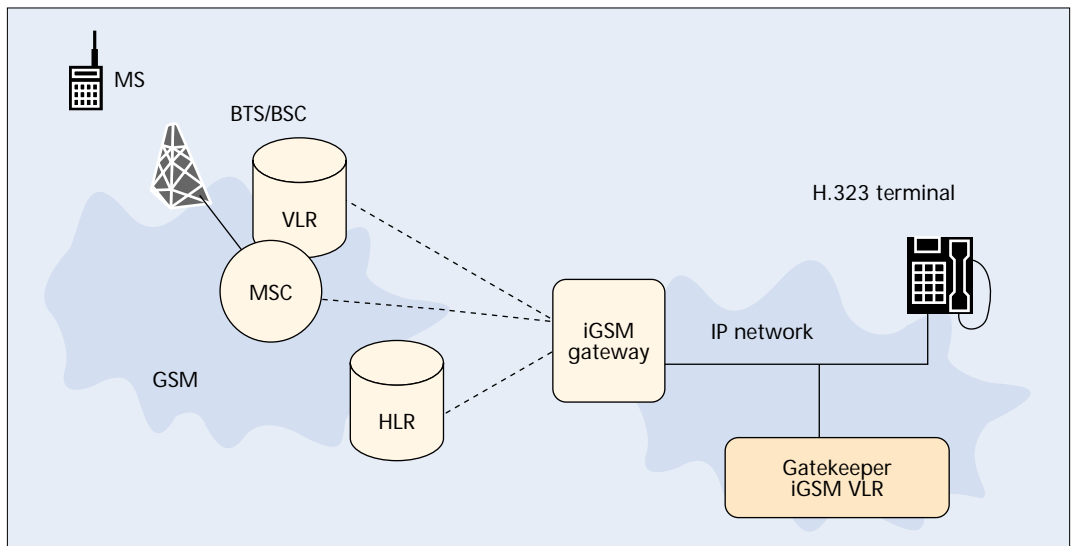
■ **Figure 3**. *The iGSM architecture.*

The *gatekeeper* is optional in an H.323 network, which may be physically collocated with a terminal, gateway, or multipoint control unit. A gatekeeper provides call control services to the H.323 endpoints. The functions of the gatekeeper include address translation, admission control, bandwidth control, and zone management. The gatekeeper may also perform optional functions such as call control signaling, call authorization, and call management.

The *multipoint control unit* (MCU) utilizes multipoint controllers (and optionally multipoint processors)to support multipoint conferences.

The *multipoint controller* (MC) provides control functions to support conferences between three or more endpoints in a multipoint conference. Every MCU contains an MC. Terminals, gateways, and gatekeepers may or may not contain MCs.

The *multipoint processor* (MP) receives audio, video, and/or data streams from the endpoints involved in a multipoint conference. An MP is optionally included in a gateway, gatekeeper, or MCU.

Figure 3 illustrates the iGSM architecture. In this architecture the GSM network is not modified. In the IP network an iGSM gateway is implemented to perform two major functions besides the standard H.323 mechanisms:
• GSM MAP and H.225 [8] Registration, Admission, and Status (RAS) protocol translation
• GSM/PSTN/IP call setup and release

Note that in TIPHON, the signaling gateway (which manages signaling protocols such as SS7 ISUP/TACP, GSM MAP, and ISDN) is separated from the media gateway. To simplify our discussion, we assume that both signaling and media gateways are integrated into an iGSM gateway.

An iGSM gateway is implemented to serve as the VLR for iGSM subscribers who visit the IP network. Thus, every iGSM gatekeeper is assigned an ISDN number that can be recognized by the HLR. The iGSM gatekeeper also maintains a list of all iGSM subscribers (whether they visit the IP network or not). Based on this list, the gatekeeper performs MSISDN to transport address translation (using the standard H.323 alias address into transport address translation mechanism) and GSM roaming management procedures for the iGSM subscribers.

Note that the iGSM architecture is scalable. We can add iGSM gateways and gatekeepers into the system just like the multiple VLRs and MSCs in a GSM network.

iGSM PROCEDURES AND MESSAGE FLOWS

This section describes the registration, the deregistration, and the call delivery procedures for iGSM service.

Logically, the iGSM gatekeeper maintains an iGSM database that stores information for all iGSM subscribers. Physically, the database can be distributed in several gatekeepers. Every iGSM subscriber has a record in the database, which consists of the following fields:
• MSISDN of the MS
• Transport address of the H.323 terminal for the subscriber in the IP network
• Password of the iGSM subscriber
• HLR address (ISDN number) of the iGSM subscriber
• International mobile station identity (IMSI) of the MS
• User profile, which indicates the service features and restrictions of the iGSM subscriber
• Presence indication of the iGSM subscriber in the IP network

Unlike a traditional GSM VLR, an iGSM database does not maintain information such as MSC address, location area identity (LAI), temporary mobile station identity (TMSI), and authentication/encryption information such as K_c, signed result (SRES), and RAND.

To implement the GSM MAP messages in the RAS protocol, the `nonStandardData` field of an RAS message is used to indicate the "type"
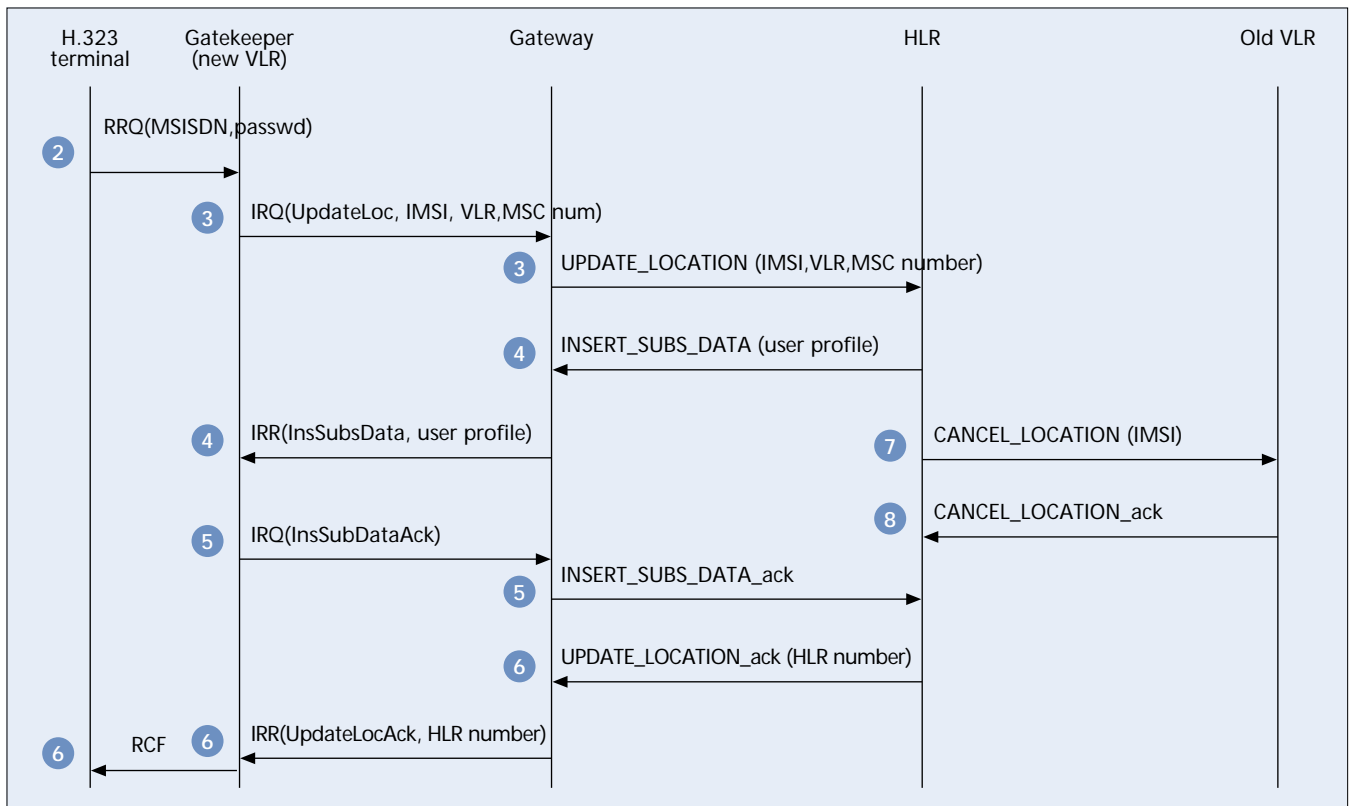
■ Figure 4. *The message flow for iGSM registration.*

and the parameters of a GSM MAP operation. Alternatively, the GSM MAP messages can be implemented by the RAS `non-standard` messages. In this article, we utilize the `nonStandardData` field of RAS messages.

REGISTRATION

If an iGSM user moves around the location areas within the GSM network, the registration procedure follows GSM MAP [3]. When the iGSM user moves from the GSM network to the IP network, the registration procedure is described in the following steps(the message flow is given in Fig. 4).

Step 1 — The iGSM user moves from GSM to the IP network.

Step 2 — When the H.323 terminal is turned on, the user enters the MSISDN and password to activate the iGSM VoIP service. The H.323 terminal initiates the endpoint registration to inform the iGSM gatekeeper of its transport address and alias address (i.e., MSISDN). The RAS `Registration Request` (RRQ) message sent from the H.323 terminal to the iGSM gatekeeper includes the password in the `nonStandardData` field of the message.

Step 3 — The iGSM gatekeeper validates the subscriber with the password. Then it initiates the GSM registration procedure by sending the `Information Request` (IRQ) message to the iGSM gateway. The `nonStandardData` field of the message carries the type of GSM operation (i.e., `UpdateLoc`), IMSI, VLR address (the address of the gatekeeper), and MSC address

(the address of the H.323 terminal). Based on the `UpdateLoc` type indicated in the message, the iGSM gateway translates the `IRQ` message into the GSM MAP message `UPDATE_LOCATION` and forwards it to the HLR.

Step 4 — Based on the received IMSI, the HLR retrieves the user profile and sends it back to the iGSM gateway using the GSM MAP message `INSERT_SUBS_DATA`. The gateway forwards the user profile to the iGSM gatekeeper using the RAS `Information Request Response` (IRR) message with type `InsSubsData`.
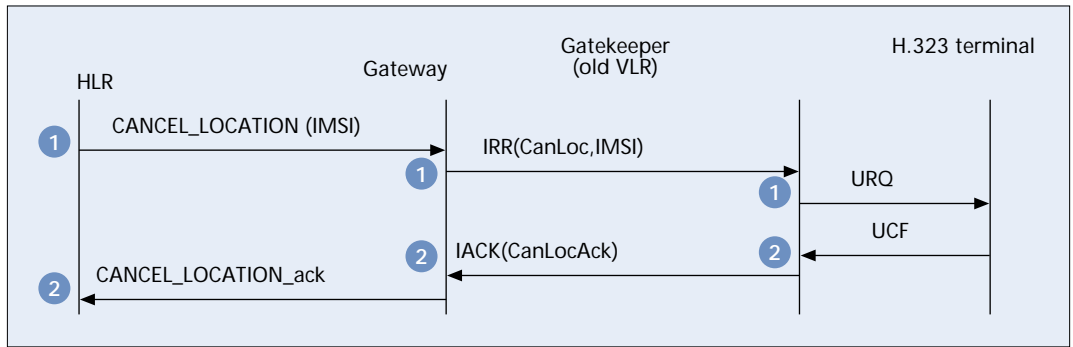
Step 5 — The iGSM gatekeeper records the user profile and acknowledges the operation by sending an `IRQ` message with type `InsSubDataAck`. The iGSM gateway translates the `IRQ` message into `INSERT_SUBS_DATA_ack` and forwards it to the HLR.

Step 6 — The HLR completes the registration operation by sending the GSM MAP message `UPDATE_LOCATION_ack` that contains the HLR address. The gateway translates it into the `Registration Confirm` (RCF) message with type `UpdateLocAck` and forwards it to the gatekeeper.

Steps 7 and 8 — The HLR informs the old VLR of deregistration by sending the `CANCEL_LOCATION` message. The old VLR deletes the VLR record for the iGSM MS.

We note that the GSM authentication and encryption mechanism is disabled in this message flow. The reason behind disabling the GSM security procedures is to avoid distributing GSM secret information (such as K_i) to equipment

■ **Figure 5.** *The essage flow for iGSM deregistration.*

other than the subscriber identity module (SIM) card on the user side. This argument is especially true when the ISP is different from the GSM operator.

DEREGISTRATION

When an iGSM subscriber moves from the IP network to the GSM network, he/she may perform registration at the GSM network (or misrouting may occur, as described later). The standard GSM registration procedure is exercised. In this case, the iGSM gateway is the "old VLR," and the deregistration actions (i.e., steps 7 and 8 described earlier) are modified. The message flow for iGSM deregistration is illustrated in Fig. 5 with the following steps.

Step 1 — When the iGSM gateway receives the CANCEL_LOCATION message (with parameter IMSI), it translates this message into an unsolicited IRR message with type CanLoc and forwards the message to the gatekeeper. The gatekeeper updates the iGSM database to indicate that the subscriber is no longer in the IP network and sends the Unregister Request (URQ) message to the terminal.

Step 2 — The terminal shall respond with an Unregister Confirmation (UCF) message. The gatekeeper responds an Information Request Acknowledgement (IACK) message with type CanLocAck to the gateway, and the gateway forwards this information to the HLR by the CANCEL_LOCATION_ack message.

After sending the UCF message, the terminal may change the alias address associated with its transport address, or vice versa, for other IP applications.

CALL DELIVERY TO THE IP NETWORK

When an iGSM subscriber is in the IP network, call origination to the H.323 terminal follows standard H.323 call setup procedure. When the iGSM subscriber is in the GSM network, call originations from the MS and call deliveries to the MS follow standard GSM procedures [3]. The call setup procedure is described in the following steps (the message flow is given in Fig. 6).

Step 1 — The caller dials the MSISDN of the iGSM subscriber. Consider an MSISDN number 0-936105401 in Taiwan. The first digit, 0, means a special service. The next three digits, 936, are

used to identify the gateway MSC (GMSC) of the MS associated with the MSISDN. The originating switch sends an SS7 Initial Address Message (IAM) to the GMSC to reserve the trunk.

Step 2 — The GMSC queries the location of the iGSM subscriber by sending the GSM MAP message SEND_ROUTING_INFORMATION to the HLR. Based on the received MSISDN, the address in the HLR record indicates that the iGSM subscriber is in the IP network. The HLR sends the PROVIDE_ROAMING_NO message to the gateway. The gateway translates the GSM MAP message into an RAS Location Request (LRQ) message with type RoamNo and sends it to the gatekeeper.

Step 3 — The gatekeeper generates the *mobile station roaming number* (MSRN) based on the address of the gateway and the H.323 terminal. An RAS Location Confirm (LCF) message with type RoamNoAck is sent to the gateway, and the gateway translates this message into the GSM MAP message PROVIDE_ROAMING_NO_ack with MSRN. The HLR forwards the MSRN to the GMSC through the GSM MAP message SEND_ROUTING_INFORMATION_ack.

Step 4 — Based on the received MSRN, the GMSC sets up the trunk to the gateway using the IAM message.

Steps 5 and 6 — The gateway receives the MSRN of the iGSM subscriber. Through the Admissions Request (ARQ) and Admissions Confirm (ACF) message pair exchange, the gateway uses the MSRN to obtain the terminal's call signaling channel transport address from the gatekeeper.

Steps 7 and 8 — The gateway sends the H.225 (Q.931) Set-up message to the H.323 terminal. If the H.323 terminal accepts this call, it replies with the Call Proceeding message to indicate that enough routing information has been received and it does not expect to receive more routing information from the gateway.

Steps 9 and 10 — The H.323 terminal exchanges the ARQ and ACF message pair with the gatekeeper. It is possible that an Admission Reject (ARJ) message is received by the terminal and the call is released.
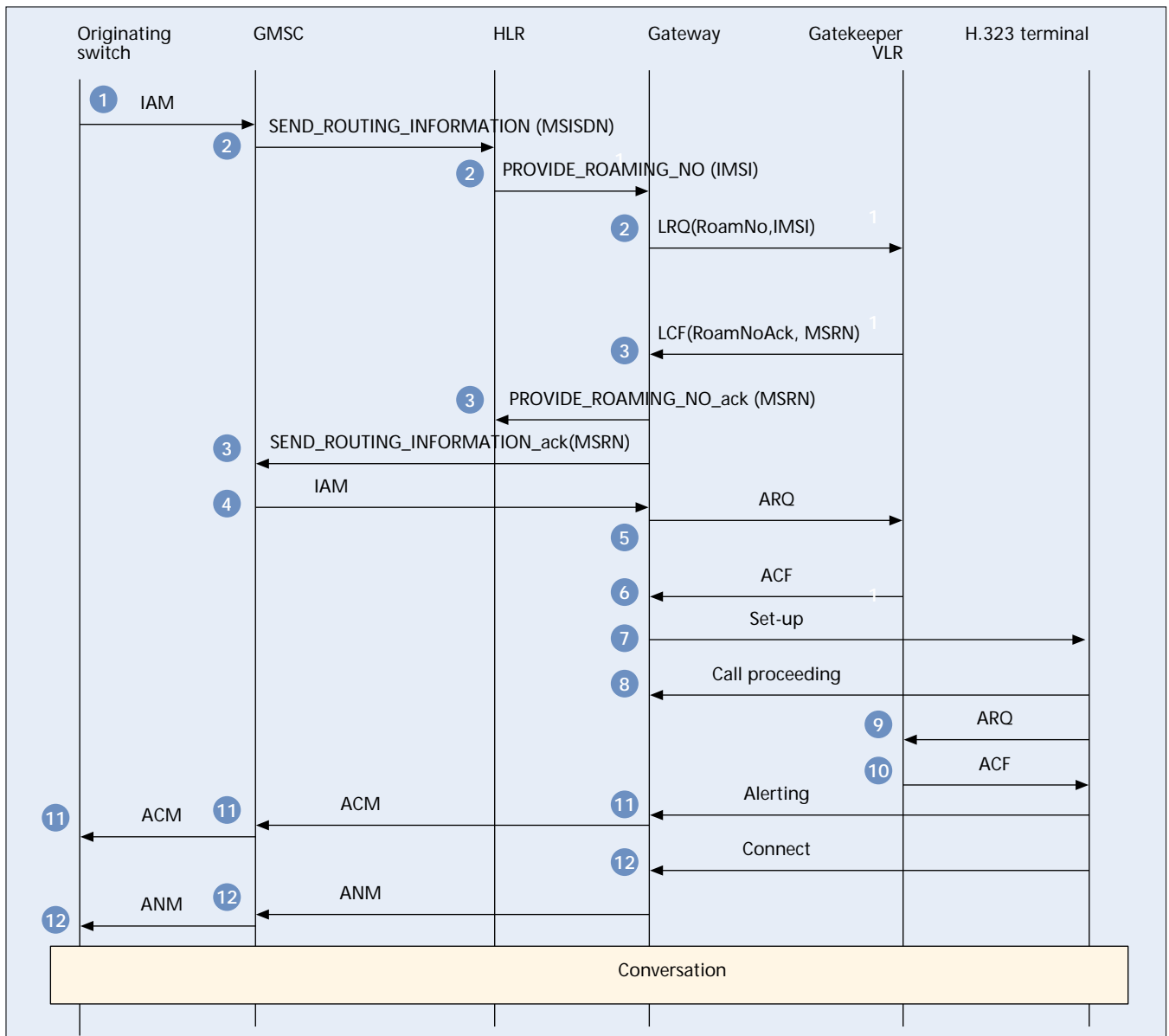
■ **Figure 6**. *Message flow for iGSM call setup.*

Step 11 — A ringing tone is generated at the H.323 terminal to alert the iGSM subscriber. The H.225 `Alerting` message is sent to the gateway. The gateway translates the message into an SS7 `Address Complete` message (`ACM`) and forwards it to the originating switch via the GMSC.

Step 12 — When the iGSM subscriber answers the phone, the H.323 terminal generates the RAS `Connect` message to the gatekeeper. This message is translated into the SS7 `Answer` message (`ANM`) and is forwarded to the originating switch. At this point, the call path is established and the conversation begins.

PSTN-IP call release follows the standard procedures defined in H.323 [7]. There is no need to create a new call release procedure for iGSM. The details are omitted.

IMPLEMENTATION ISSUES

This section discusses two issues regarding the iGSM implementation: reducing the GSM tromboning effect and investigating misrouting of user mobility.

REDUCING THE GSM TROMBONING EFFECT

In the standard GSM call delivery procedure, the tromboning effect occurs if the caller and the called MS are in the same city but the GMSC is in another city (or another country [5]).We assume that both GSM MSCs and iGSM gateways can serve as GMSCs of iGSM subscribers. If an iGSM subscriber is assigned a GSM MSC as his/her GMSC, call delivery follows the procedure described earlier, and the tromboning effect occurs. On the other hand, if the iGSM gateway is assigned as the GMSC of the iGSM subscriber, call delivery tromboning can be avoided. In this case a PSTN-to-iGSM (IP network) call is described in the following steps.

Step 1 — The originating switch routes the call to the iGSM gateway based on the dialed MSISDN.

Step 2 — The iGSM gateway first queries the iGSM gatekeeper to check if the iGSM subscriber is in the IP network. If not, the iGSM gateway queries the HLR and performs the standard GSM call delivery procedure.

Step 3 — If the iGSM subscriber is in the IP network, the iGSM gateway sets up the call to the H.323 terminal following the standard H.323 call setup procedure.

It is clear that at step 3 no resource in the GSM network is consumed, and the call setup cost is cheaper than in Fig. 6. Also, in this case, the cost for an IP-to-iGSM (IP network) call setup is exactly the same as a traditional VoIP call, which is even cheaper than the PSTN-to-iGSM call.

Thus, two kinds of iGSM subscribers are anticipated:
• The GMSCs of the subscribers are standard GSM MSCs. In this case, the subscribers typically subscribe to the standard GSM services at the beginning, and decide to include the iGSM service later.
• The GMSC of the subscribers is the iGSM gateway. In this case, the subscribers typically subscribe to the iGSM service at the beginning.

For the first kind of subscribers, call delivery follows the standard GSM procedure. When the subscribers visit the IP network, tromboning may occur as in a traditional GSM network. The GSM operator would prefer this scenario if the iGSM gateway and gatekeeper are owned by the ISP.

For the second kind of subscribers, call delivery tromboning can be avoided when the subscribers visit the IP network. In this scenario, the GSM operator is likely to own the iGSM gateway and gatekeeper.

MISROUTING DUE TO USER MOBILITY

To support user mobility, the subscriber needs to explicitly perform registration to inform the system in which location area he/she resides if the terminal has been changed. If the subscriber forgets to take this action when he/she changes terminals, call deliveries to the subscriber may be misrouted. This problem can be eliminated if the subscriber always turns off the MS when he/she moves to the H.323 terminal. The "turnoff" action results in a `GSM detach` message to deregister the MS.

The misrouting problem may occur in the following scenario for an iGSM subscriber.

Step I — Subscriber p is in GSM location area (LA) A, and the HLR indicates that the person is in LA A. The subscriber then moves to the IP network(LA B) without turning off the GSM MS.

Step II — The subscriber registers to the IP network with the procedure described earlier. After registration, the HLR record is modified and p's record in VLR A is removed.

Step III — The subscriber moves back to the GSM MS at LA A. Since the GSM MS is still

on, the subscriber p does not notice that an explicit registration is required. Thus, the HLR indicates that subscriber p is still in LA B.

When someone attempts to call p, the call is misrouted to LA B.

The misrouting problem is avoided if the subscriber explicitly or implicitly registers with the GSM MS at step III. Implicit registration occurs in two cases.

Case 1 — The subscriber originates a call. In this case VLR A finds that the VLR record for the subscriber does not exist. VLR A will ask the MS to perform a registration operation as described in the VLR failure restoration procedure [3].

Case 2 — The subscriber moves to another LA in the GSM network. Registration is automatically initiated by the GSM MS.

In both cases, after the HLR has modified p's record, it also cancels p's VLR record in VLR B, as described earlier. We have conducted analytic modeling which indicates that the misrouting probabilities increase as the variance of user LA residence time decreases. Our study also indicates that if subscribers originate calls much more frequently than they receive calls, the misrouting effect is insignificant. If the user LA residence times, intercall origination times, and intercall delivery times are of the same order, the misrouting effect cannot be ignored. This problem exists for all approaches based on the concept of *universal personal telecommunications* [9] to support user mobility. To eliminate the misrouting problem, iGSM subscribers are responsible to perform the explicit registration operation. That is, the subscribers should turn off their MSs when moving to the IP network, and turn on the MSs when they move back to the GSM network. Another alternative is to have the network automatically turn off the MS immediately after the subscriber registers to the IP network. This operation can be achieved as follows. At the end of the registration procedure described earlier, the IP network queries the HLR to see if the MS has been detached (when the MS is turned off by the user, a detach message is sent to the HLR). If not, the IP network sends a GSM short message [10] to the MS. The short message instructs the SIM card of the MS to run an applet that shuts down the MS.

As a final remark, misrouted calls are not necessarily lost. With features such as call forwarding on no reply, these calls can be forwarded to appropriate destinations or mailboxes.

CONCLUSIONS

This article describes iGSM, a VoIP service for GSM. This value-added service supports user mobility. That is, iGSM allows a GSM user to access VoIP service when he/she moves to the IP network. The iGSM tracks the locations of iGSM subscribers as long as the subscribers turn off/on the terminal (GSM MS or IP terminal) when he/she leaves/arrives at the network. To interwork GSM and IP networks, we proposed the iGSM protocol translation mechanism between GSM MAP and H.323. Based on this mechanism, we showed how iGSM registration, dereg-

istration, and call delivery procedures work. The implementation of iGSM does not require modifications to the GSM network. The iGSM protocol translation mechanism can be implemented using the standard H.323 gateway and gatekeeper. We studied how the tromboning effect in a standard GSM system can be avoided when accessing the IP network. Then we investigated the misrouting problem caused by user mobility.

If the iGSM service is provided by an ISP other than the GSM operator, security issues must be addressed to determine what kinds of GSM subscriber data can be accessed and modified by the ISP. Other iGSM issues such as billing and supplementary services are for further study.

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BIOGRAPHIES

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