Reducing the Network Cost of Call Delivery to GSM Roamers

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Abstract

When a GSM user travels to a foreign country, it is anticipated that a call delivery from a caller in that country to the GSM roamer should be a local phone call. Unfortunately, under the current GSM implementation, the call delivery results in two international calls! In this article we explain why current GSM implementation is expensive for this kind of call delivery, and then propose four solutions to reduce the two international calls into one local phone call. Our solutions may significantly reduce the nonnecessary usage of international circuits as well as customer costs.

Global System for Mobile Communications (GSM) is a wireless digital network standard designed by standardization committees from the major European telecommunications operators and manufacturers. The GSM standard provides a common set of compatible services and capabilities to all mobile users across Europe and several million customers worldwide. GSM supports roaming service that allows a user of GSM network A to receive mobile telephony service when the person visits a different GSM network B. If both GSM networks A and B are within the same country, call setup for a roamer can be done efficiently (to be elaborated further). However, if networks A and B are located in different countries, the current GSM implementation for call delivery to the roamer can be very expensive. Before we dig into the technical aspect of the GSM network operation, let us describe this "international roaming" issue from the customer's perspective.

Consider the following scenario. John is a subscriber of the GSM service in Taiwan. Suppose that he travels from Taiwan to Singapore. Singapore and Taiwan have GSM roaming agreement. When John arrives at the airport, he uses his GSM handset (mobile station) to call his friend Jenny to meet him at the airport. A few minutes later, Jenny calls John (by dialing John's GSM phone number) that she will be late due to a traffic jam. Finally, they meet and have a very nice get-together. At the end of the month, John receives the GSM service bill, and finds that he is charged a local GSM call for the first phone call and an international call (from Taiwan to Singapore) for the second phone call. On the other hand, Jenny notices that she is charged an international call (from Singapore to Taiwan) for the second phone call. Both John and Jenny are not very happy. What happened? In the current GSM international roaming implementation, call delivery (call termination) to a GSM roamer results in one or two international calls. Suppose that a GSM user (say John) in Taiwan roams to Singapore. There are three scenarios for call delivery to John:

Scenario 1 — If a person in Taiwan call John, the result is an international call. John is charged for the international call from Taiwan to Singapore.

Scenario 2 — If the caller is from a third country (say, Hong Kong), then the call delivery to John results in two international calls. The caller is charged for the international call from Hong Kong to Taiwan, and John is charged for the international call from Taiwan to Singapore.

Scenario 3 — If the caller (Jenny in our previous example) is in Singapore, then the call delivery results in two international calls although both Jenny and John are in Singapore! This scenario is in fact a special case of Scenario 2.

Scenario 3 discourages call terminations to a GSM roamer. Most likely, John will ask Jenny not to dial his GSM number when he visits Singapore.

In this article, we explain why call delivery (specifically, Scenario 3) to a GSM roamer is so expensive in the current implementation. Then we propose solutions to reduce the network cost for this kind of GSM calls. Basically, our solutions redefine the GSM network signaling procedure for call delivery to roamers so that the nonnecessary two international circuits in Scenario 3 are avoided.

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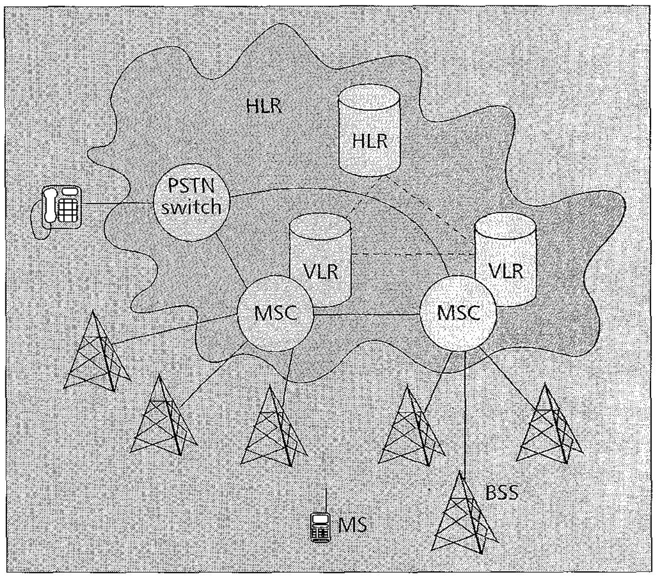


■ Figure 1. *The GSM architecture.*

GSM Network Management

Figure 1 illustrates the GSM architecture. In this architecture, a Mobile Station or MS (the GSM term for handset) communicates with a Base Station Subsystem (BSS) through the radio interface. The BSS is connected to the Network and Switching Subsystem (NSS) by communicating with a Mobile Switching Center (MSC). The NSS supports the switching functions and the subscriber profile/mobility management. The basic switching function in the NSS is performed by the MSC that controls several BSSs. The MSC also communicates with other network elements external to the GSM network.

Location Update

The current location of an MS is usually maintained by a two-level hierarchical strategy with two types of databases [1–3]. The Home Location Register (HLR) is the location register to which a mobile user identity is assigned for record purposes such as mobile user information (e.g., directory number, profile information, current location, validation period). The Visitor Location Register (VLR) is the location register other than the HLR used to retrieve information for handling of calls to or from a visiting mobile user. The VLR typically collocates with an MSC. When a mobile moves from the home system to a visited system, its location is registered at the VLR of the visited system. (The home and the visited systems may be two individual GSM networks or two different service areas of the same GSM service provider.) The VLR then informs the mobile's HLR of its current location. In summary, HLR will always contain up-to-date location information about its "home" mobile stations. HLR gets updates from VLR where the mobile station is currently residing.

To access an MS, the HLR is queried to find the current location of the MS. The details will be provided in the next subsection. The registration process is described in the following steps (Fig. 2). Although the procedures have been described in [4], we will reiterate the procedures for the benefit of readers.

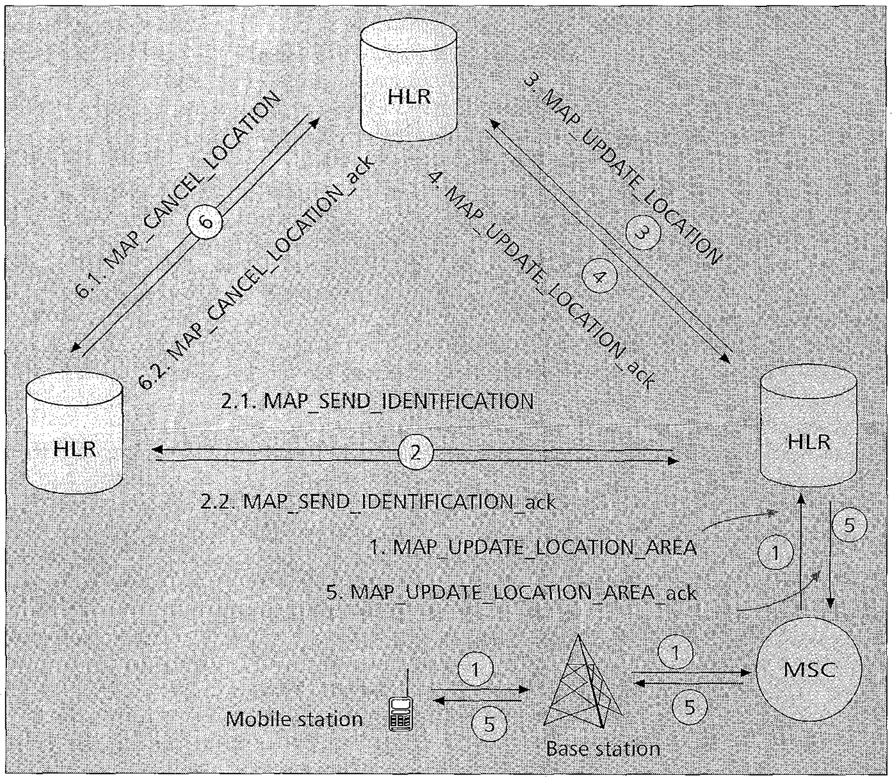
Step 1 — When an MS moves to a new location, the MS sends its Temporary Mobile Subscriber Identity (TMSI) and the identity of the old location area to the new MSC and thus to the new VLR through the `MAP_UPDATE_LOCATION_AREA` message.

TMSI is an alias for the subscriber identity IMSI (to be elaborated further) used to avoid sending the IMSI on the radio path. This temporary identity is allocated to MS by VLR at location registration (see Step 5) and can be changed by VLR after every call setup.

Step 2 — From the TMSI and the old location area identity, the new VLR identifies the old VLR. It sends a message `MAP_SEND_IDENTIFICATION` to the old VLR to obtain the International Mobile Subscriber Identity (IMSI) of the MS. The IMSI is the unique subscriber identity which identifies the HLR of the MS. The old VLR returns the IMSI as well as the authentication parameters in the message `MAP_SEND_IDENTIFICATIONack` to the new VLR. The new VLR performs the authentication process (the details are omitted).

Steps 3, and 4 — If the authentication process is successful, the new VLR sends a `MAP_UPDATE_LOCATION` message to the HLR (the address of the HLR is derived from the IMSI). If the update request is accepted, the HLR acknowledges the location update operation through the acknowledgment message `MAP_UPDATE_LOCATION_ack`.

Step 5 — The new VLR generates a new TMSI and sends it to the MS through the MSC (by the message



■ Figure 2. *The MS registration process.*

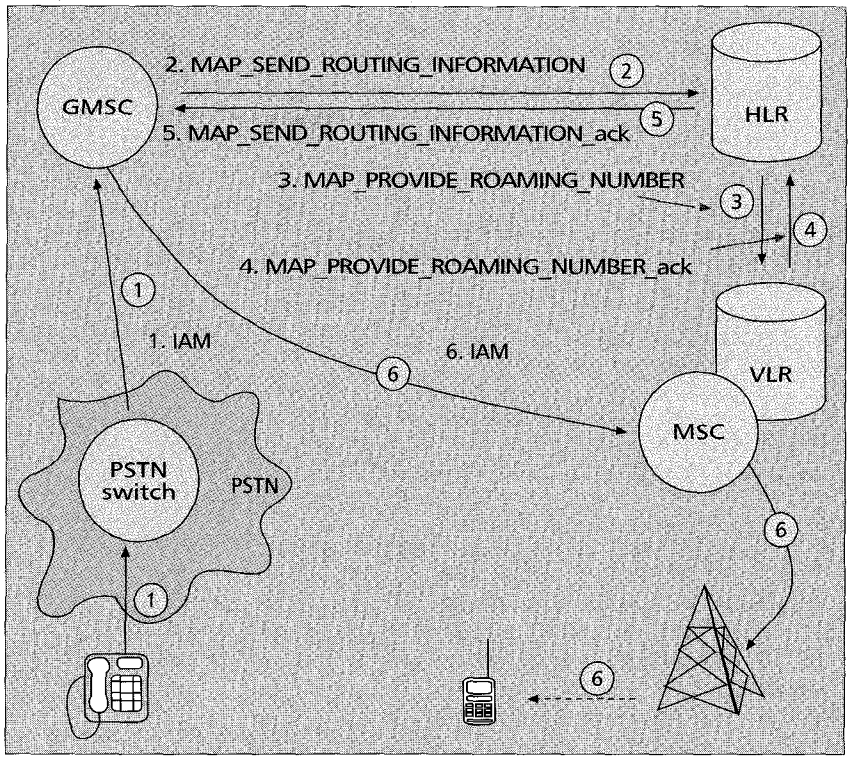
MAP_UPDATE_LOCATION_AREA_ack).

Step 6 — After Step 3, the HLR sends a MAP_CANCEL_LOCATION message to the old VLR. The old VLR cancels the record for the MS and replies an acknowledgment MAP_CANCEL_LOCATION_ack to the HLR for the cancellation.

In the GSM location update, confidential data (IMSI) is not sent over air, which enhances security. Note that the messages delivered in the location update procedure (i.e., the messages with prefix MAP_) are for queries and responses. These messages do not reserve any voice trunk and their delivery can be done efficiently.

Call Delivery

To call a GSM subscriber (e.g., a call delivery or call termination), the Mobile Station ISDN Number or MSISDN (the GSM term for the handset telephone number) of the subscriber is dialed. This number points to the subscriber's record in the HLR. The HLR record contains the information to locate the VLR where the subscriber is currently visiting. The basic call terminating procedure is described in the following steps (Fig. 3).



■ Figure 3. *The call delivery procedure.*

Steps 1 and 2 — When the MSISDN is dialed, the call setup message Initial Address Message (IAM) is used to set up the voice trunk to the Gateway MSC (GMSC).

The GMSC has the capability to interrogate the HLR for routing information (by using the message MAP_SEND_ROUTING_INFORMATION).

Steps 3, 4, and 5 — With the message MAP_PROVIDE_ROAMING_NUMBER, the HLR requests the current VLR of the MS to provide the roaming number. The VLR allocates a Mobile Station Roaming Number (MSRN) and sends this number to the GMSC through the HLR.

The MSRN indicates the location of the visited MSC, and is used to set up the voice trunk toward the MSC where the MS currently resides.

Step 6 — The GMSC uses MSRN to route the IAM message (and thus set up the voice trunk) to the MS through the visited MSC.

We note that after the call is set up, the voice path is (1)→(6) in Fig. 3.

International GSM Call Setup

The call delivery procedure to a GSM roamer is basically the same as the procedure described in Fig. 3 except that two International Switch Centers (ISCs) are involved in the voice path. In telecommunications, every country has a national network. All national networks are connected to an international network. ISCs offer interworking functions between the national networks and the international network. Call path of every international call is composed of three segments, one in the origination country, another in the international network, and the other in the destination country. These circuit segments are interconnected by two ISCs, one in the origination country and the other in the destination country.

Consider the previous example where John roams from Taiwan to Singapore and that Jenny makes a call delivery to John. The call setup message flow is illustrated in Fig. 4.

Step 1 — Since John's GSM home system is in Taiwan, Jenny first dials the International Switch Center Access Code or ISCA (in Taiwan, this code is 002, and in USA, this code is 011), the Country Code or CC (886 for Taiwan, and 1 for USA), then she dials John's MSISDN. In Taiwan, an MSISDN is a Mobile Network Access Code (MNAC) 092 followed by a 6-digit Subscriber Number (SN).

When Switch A interprets the first portion of the dialed digits (the international switch center access code), it identifies the call as an international call, and then routes the trunk (using the IAM message; see (1.1) in Fig. 4) to Singapore's International Switch Center (i.e., ISC B). Based on the country code 886, ISC B routes the voice trunk to Taiwan's International Switch Center (ISC C; see (1.2) in Fig. 4).

ISC C interprets the prefix "092" of the remaining digits as a GSM call, and sets up the voice trunk to GMSC D.

Step 2 — GMSC D queries HLR E to obtain the MSRN.

Steps 3 and 4 — HLR E queries VLR F. Note that the messages travel between Taiwan and Singapore; see (3.1), (3.2), (3.3), (4.1), (4.2), and (4.3).

Step 5 — The MSRN is returned to GMSC D.

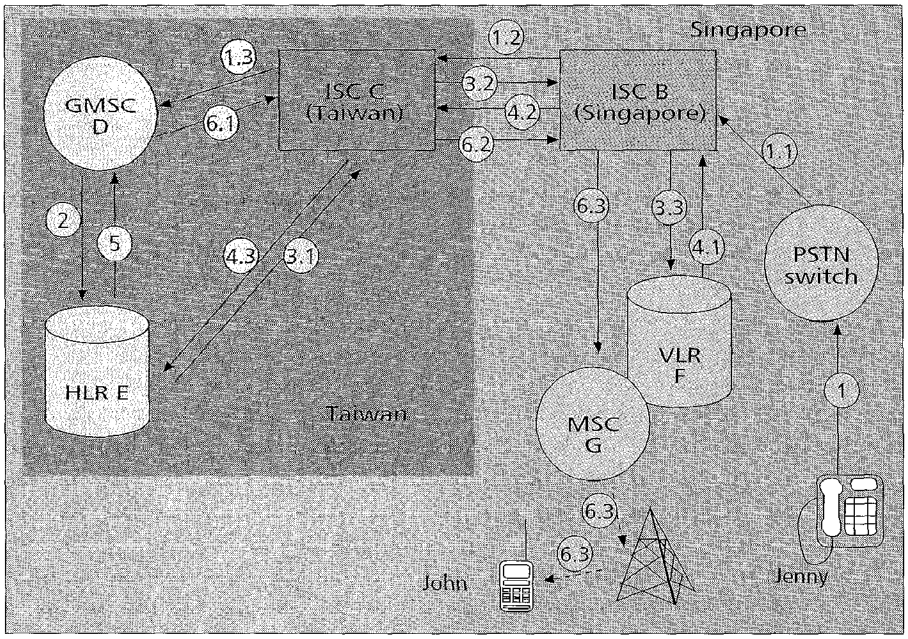
Step 6 — Based on the MSRN, GMSC D uses the IAM message to set up the trunk to MSC G and therefore connects to John.

In the above call setup procedure, the actual circuit path is (1)→(1.1)→(1.2)→(1.3)→(6.1)→(6.2)→(6.3), and two international trunk connections are required. Therefore, Jenny is charged for the international call from Singapore to Taiwan — (1.2) in Fig. 4 — and John is charged for the international call from Taiwan to Singapore — (6.2) in Fig. 4.

Since both John and Jenny are in Singapore, the call delivery is supposed to be local. Thus it is desirable to remove the two international circuits from the call delivery scenario 3. We will address this issue in the next section.

Reducing the Network Cost for Call Delivery to a GSM Roamer

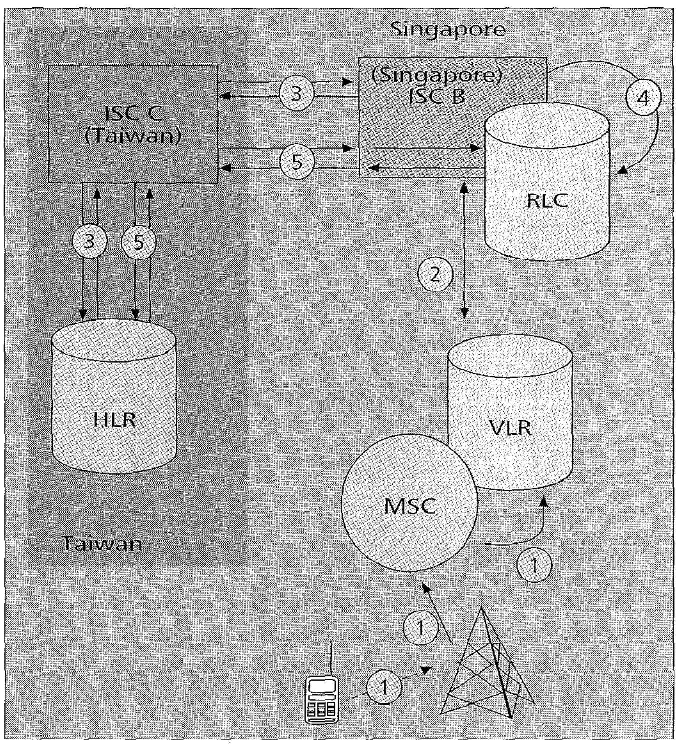
It is clear that to avoid nonnecessary international trunk setup, the IAM message should not travel across the country boundary before the destination is known. We propose four solutions that follow this guideline. A basic restriction is that we should not introduce any new message types to the GSM MAP protocol [5] (i.e., the messages with prefix MAP). In the first three solutions, we utilize the concept of Roamer Location Cache (RLC). The RLC in a visited system maintains the information of all international roamers who are in that visited system (e.g., Singapore). From the view of a VLR in the visited system, RLC functions as the HLR of a roamer. From the view of the HLR in the home system of the roamer, RLC serves as the VLR in visited system. In Solution 4, we introduce a special dialing code that leads the call to GMSC of the visited GSM system. If the GMSC is a general-purpose switching system, it can perform routing translations to access the HLR of the roamer and route the call to the destination MSC directly.



■ Figure 4. *The international call setup procedure.*

Solution One

In this solution, the RLC collocates with the ISC in the visited system. The registration procedure is shown in Fig. 5. To simplify our discussion, the messages MAP_SEND_IDENTIFICATION and MAP_CANCEL_LOCATION (Steps 2 and 6 in Fig. 2) and the authentication procedure are omitted. The location update procedure is described in the following steps.



■ Figure 5. *The registration procedure (solution 1).*

Step 1 — The MS registers to the VLR.

Step 2 — The VLR sends MAP_UPDATE_LOCATION to the roamer's HLR. Since the HLR is in a foreign country, the message is routed to ISC B.

Step 3 — ISC B intercepts the message, and identifies it as a roamer registration operation. The message is forwarded to Taiwan (ISC C) as usual.

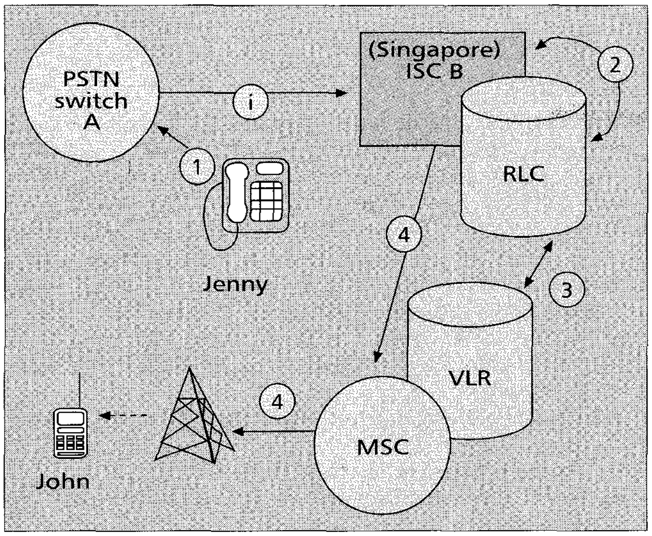
Step 4 — At the same time ISC B duplicates the message and forwards it to the RLC. RLC creates a record to store the IMSI and VLR/MSC address.

Step 5 — After the registration operation is completed, the RLC does not have the MSISDN of the roamer (note that only IMSI is delivered in the standard GSM location update operations). Without the MSISDN information, the RLC cannot handle call delivery to the roamer. Thus, the RLC requests this information from the HLR using the MAP_RESTORE_DATA message. The roamer's MSISDN will be returned from the HLR to the RLC through the MAP_INSERT_SUBSCRIBER_DATA message [2].

If the roamer leaves the visited system, the VLR will receive a MAP_CANCEL_LOCATION message. After removing the obsolete VLR record of the roamer, the VLR will forward the cancellation message to RLC to cancel the obsolete location record in the RLC. Call delivery for Scenario 3 under Solution 1 is illustrated in Fig. 6. The steps are described below.

Step 1 — Jenny first dials the ISCA code, the CC code, then John's MSISDN as before.

When Switch A interprets the first portion of the dialed digits (i.e., ISCA+CC), it identifies the call as an international call, and then routes the trunk (using the IAM message; see (1) in Fig. 6) to ISC B.



■ Figure 6. *Call delivery (solution 1).*

Step 2 — Based on the CC code 886 and the GSM MNAC code 092, ISC B identifies that the called party is a potential roamer. ISC B searches RLC using the MSISDN provided by the `IAM` message. If the entry is not found, then the call delivery is for scenario 2, and ISC B forwards the IAM message to Taiwan.

Step 3 — If the entry for John is found, then the call delivery is for scenario 3. RLC serves as John's HLR to obtain the MSRN.

Step 4 — By using the MSRN, ISC B routes the `IAM` message to John, and the two international circuits are avoided.

The advantage of Solution 1 is that only ISC B needs to be modified. Other network elements (VLR and HLR) remain the same. The disadvantage of this approach are that most ISCs are not equipped with GSM MAP protocol, and thus may not be able to interpret the GSM MAP messages in Step 2. Also, ISC typically belongs to an international telephone carrier different from the GSM service providers. An agreement may have to be made between the two service providers.

We assume that the non-circuit-related signaling (i.e., GSM MAP message delivery) between HLR and VLR goes through the same ISC as the voice circuit does. However, to cope with the increasing non-circuit-related signaling traffic in the international network, many countries have diverted or are diverting non-circuit-related signaling to international Signaling Transfer Points (STPs) [6]. Since this type of STPs do not connect to voice trunks, the arrangement would separate the signaling path from the voice circuit to make Solution 1 inapplicable.

Solution 2

The GSM service provider may want to build its own RLC without involving ISC. In this case, the call delivery to foreign GSM users should not be forwarded to the ISC. Instead, the caller should dial to a switch (collocated with the RLC) in the local GSM system for call forwarding.

The location update in this solution is illustrated in Fig. 7 and the steps are described as follows:

Step 1 — The MS registers to the VLR.

Step 2 — The VLR identifies that the registration is for an international roamer. The VLR sends the message `MAP_UPDATE_LOCATION` to the RLC. The RLC creates a record to store the IMSI and VLR/MSC address.

Step 3 — The RLC sends the `MAP_UPDATE_LOCATION` message to the roamer's HLR (through the international switch centers).

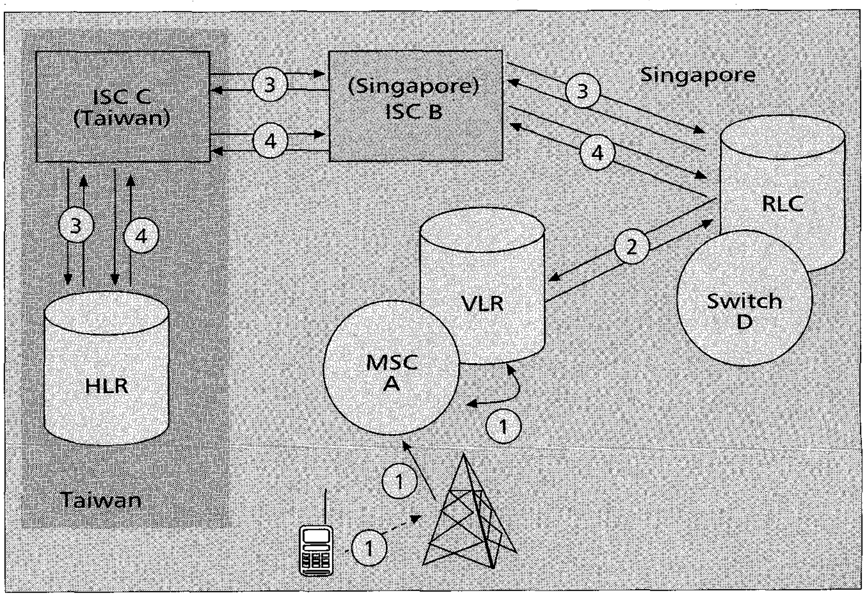
Step 4 — After the registration operation is completed, RLC obtains the MSISDN of the roamer using the `MAP_RESTORE_DATA` message as described in Solution 1.

Call delivery for scenario 3 under Solution 2 is illustrated in Fig. 6. The steps are the same as that for Solution 1 except that Jenny dials the number of Switch D instead of the country code. After Switch D is connected, Jenny will be asked to dial the MSISDN of John. If the MSISDN is not found in the RLC, then Switch D routes the call to the ISC (Scenario 2). If the MSISDN is found in the RLC (Scenario 3), then the call is processed locally as illustrated in Fig. 8. The advantage of this approach is that the modifications are only made within the GSM network. They do not involve international carrier. The disadvantages include the extra modifications to the VLR. Also, the caller should dial the number of Switch D and then the MSISDN. The dialing process is different from the ordinary international call dialing that is familiar to the users.

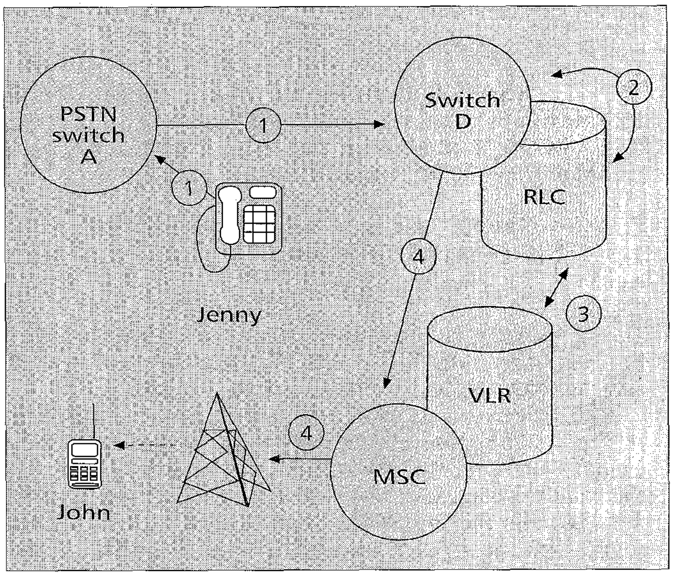
Solution 3

As pointed out previously, Solution 2 may not be attractive because the VLR needs to be modified. An alternative to Solution 2 is to introduce an extractor as illustrated in Fig. 9. The extractor monitors (but does not modify) the messages passing through the signaling links of the VLR, and takes action when a location update message is sent to the HLR in the foreign country. In the registration procedure for Solution 3 (Fig. 9), Step 1 is the same as Steps 1 and 5 of the basic MS registration procedure in Fig. 2, and Step 2 is the same as Steps 3 and 4 in the basic procedure.

When the `MAP_UPDATE_LOCATION` message is delivered from the VLR to the ISC B at Step 2, the extractor will also send a registration message to the RLC, and the RLC will



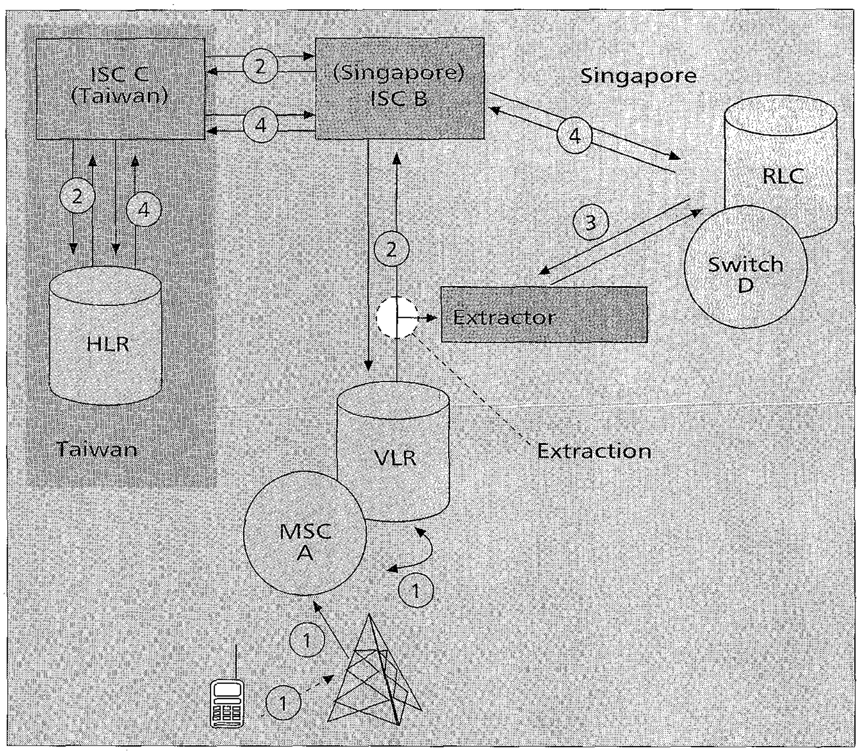
■ Figure 7. *The registration procedure (solution 2).*



■ Figure 8. *Call delivery (solution 2).*

create a roamer record as in Solution 2. Then the RLC obtains the roamer's MSISDN from the HLR as in Solution 2 (see Step 4).

The call delivery procedure for Solution 3 is exactly the same as that for Solution 2. The advantage of Solution 3 over Solution 2 is that the solution is transparent to the VLR. The disadvantage is that a new network component (i.e., extractor) is introduced. We are planning to deploy Solution 3. Our deployment will be based on Lucent Technologies' 5ESS MSC 2000 system [7]. The extractor will be a HP E4250 ACCESS7 (this system is an innovative platform for collecting and analyzing the SS7 data in the network in real time [8]), and the RLC/Switch D will be WinComm's Jupiter PBX [10].



■ Figure 9. *The registration procedure (solution 3).*

Solution 4

In this solution, the registration procedure is the same as the procedure illustrated in Fig. 2. The basic idea of this solution is to divert the land to mobile call (i.e., call termination) into the visited GSM system before it reaches the ISC. The operator of the visited GSM system reserves an International Roamer Access Code (IRAC) in its numbering plan, and announces it to the public that it is a cheaper way to call visiting roamers. To make a call to a visiting roamer from a land line, one dials MNAC1 + IRAC + CC + MNAC2 + SN, where

- MNAC1 is the Mobile Network Access Code to the visited GSM system
- IRAC is the International Roamer Access Code mentioned above
- CC is the Country Code of the home country
- MNAC2 is the Mobile Network Access Code of the home GSM system
- SN is the Subscriber Number for the roamer (given by the home GSM system)

According to the MNAC1, the PSTN routes the call to a GMSC of the visited GSM system. From the IRAC, the GMSC recognizes it as an IR call. Instead of querying the HLR of the visited system, the GMSC translates "CC+MNAC2+SN" into MSISDN, and uses it as the address to reach the roamer's HLR. If there exists a bi-directional signaling path between the GMSC and the roamer's HLR, the call would follow the normal procedure of GSM call delivery. That is, the GMSC in the visited system queries the HLR of the roamer's home system to obtain the MSRN. Since the roamer had registered to a VLR in the visited system, the MSRN would be located at one of the MSCs in the visited system. The GMSC routes the call to the MSC, and eventually reaches the destination MS.

In this scheme, we assume that the signaling path between GMSC in the visited system and the HLR in the home system already exists. Due to the fact that the GMSC and the HLR are located in different countries, the fulfillment of the signaling relationship would become an implementation issue. Basically, if international STP does not exist (which is true in many countries in Europe and Asia Pacific region), every node involved in the international roaming process must have a *Point Code* (PC) in the International SS7 Signaling Network. To fulfill this implementation, the GMSC must be able to connect to more than one SS7 signaling network, equipped with the *Global Title Translation* that translates MSISDNs into *Network Indicator*, Point Code, and *Subsystem Number* for all HLRs with roaming agreement, and be able to route an international MSRN into the national network.

The advantages of this solution are that the GSM call delivery procedure (and thus the VLR software) is not modified and no new network elements are required. Furthermore, the implementation is cost effective (no new network elements such as RLC is introduced). If the GMSC is implemented by a general purpose switching system such as Lucent Technologies' 5ESS, the functions listed above could be achieved at a reasonable cost. A potential limitation is that many existing MSCs may not have the required functions to implement this solution.

Conclusions

Our experience indicates that most call terminations to a GSM user occur when the GSM user is in his/her home system or when the GSM user is in a visited system and the caller is also in the same visited country (i.e., Scenario 3 — call delivery as described previsously). For the second case, the caller and the GSM roamer are both charged an international call in the current GSM implementation. It is desirable to resolve this problem so that two international calls are processed as a local call.

This article proposed four approaches to reduce two potential international calls into one local phone call. In the first three solutions, a roamer location cache called RLC is introduced. These approaches do not introduce any new message types to GSM MAP protocol. Solution 1 requires modifications to the international switch center. Solution 2 requires modifications to the VLR. Solution 3 utilizes an extractor without modifying any existing network elements. Solution 4 does not modify the GSM roamer call delivery procedure. Extra features to the GMSC are required. This solution assumes that the GMSC in the visited system is powerful enough to access the roamer's HLR for call delivery (such powerful switch systems exist; for example, Lucent Technologies' 5ESS). Based on the capability and availability of the existing PSTN/GSM system, one may choose an appropriate solution (among the four solutions) to address Scenario 3. Our solutions may significantly reduce the network traffic and the customer costs.

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