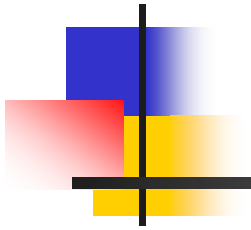
Wireless and Mobile Network Architecture



Chapter 8: GSM Mobility Management

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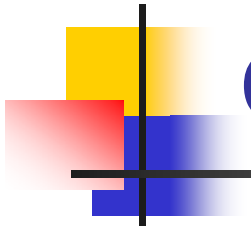


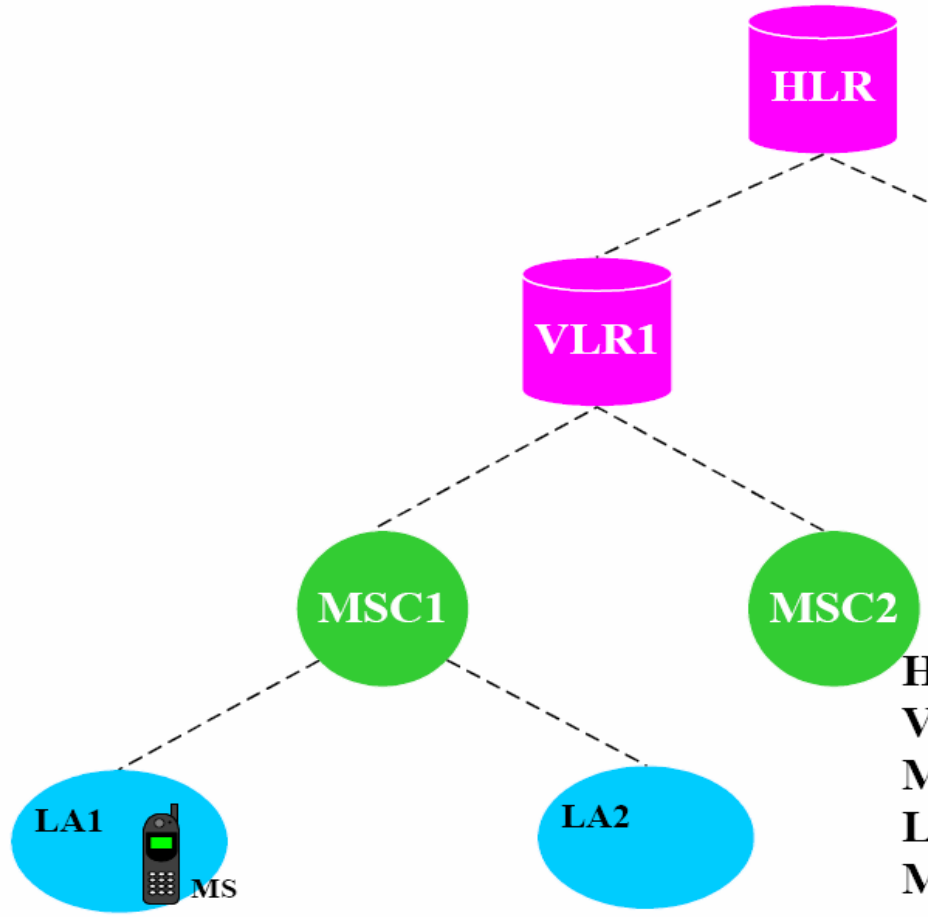
Outline

- Introduction
- GSM Location Update
- Mobility Databases
- **Failure Restoration**
- VLR Identification Algorithm
- VLR Overflow Control
- Summary

Introduction

- GSM networks track the locations of the MSs so that incoming calls can be delivered to the subscribers
- A mobile service area is partitioned into several **location area** (LAs) or registration areas
- LA consists of a group of **base transceiver stations** (BTSs) that communicate with the MSs over radio links

Fig. 11.1 GSM location area hierarchy



HLR : HOME Location Register
VLR : VISITOR Location Register
MSC : Mobile Switching Center
LA : Location Area
MS : Mobile Station

Cont.

- **Location update procedure** (registration): BTSs periodically broadcast the corresponding LA address to the MSs. When an MS receives an LA address different from the one stored in its memory, it sends a registration message to the network
- Location information
  - VLR
    - LA address: temporary record
  - HLR
    - The last VLR visited by MS: permanent record

Cont.

- GSM location area hierarchy (Fig. 11.1)
- **Fault tolerance**
  - Location database failure degrade the service offered to the subscribers
  - Fault restoration procedure
- **Database overflow**: If VLR is full when a mobile user arrives, the user fails to “register”

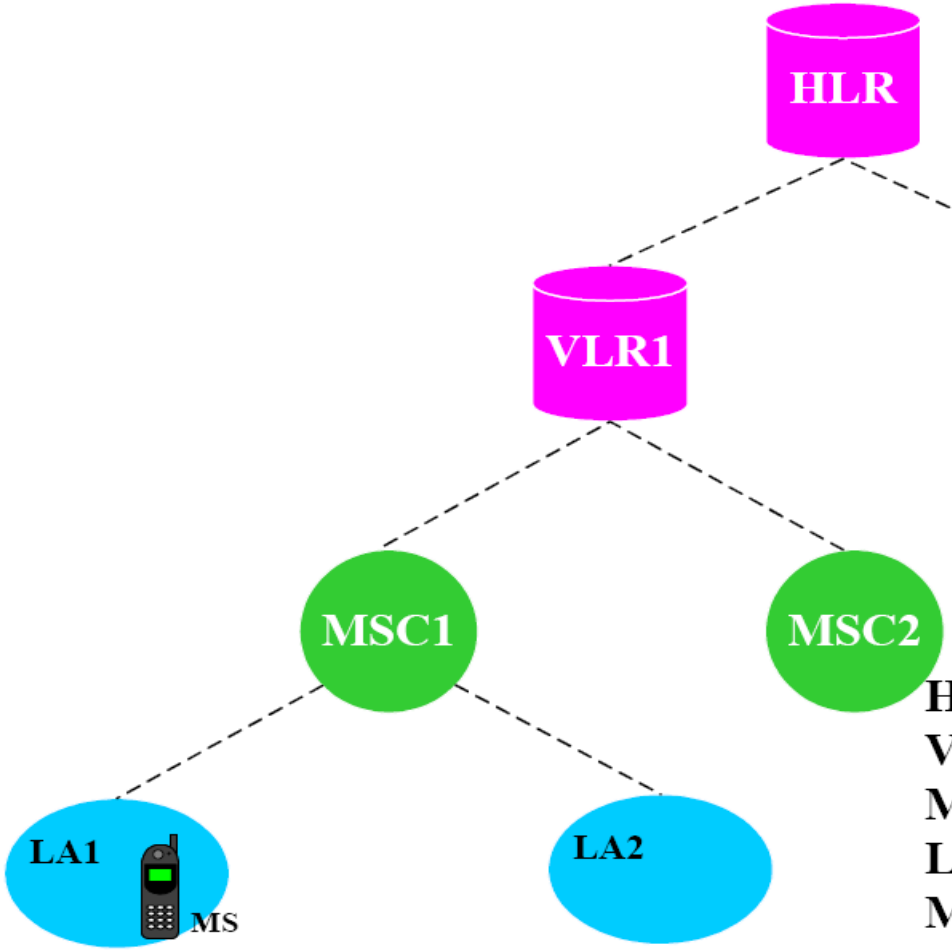
11.1 GSM Location Update

- In GSM, registration or location update occurs when an MS moves from one LA to another

11.1.1 Basic Location Update Procedure

- Basic Location Update Procedure
  - **Inter- LA Movement**
  - **Inter- MSC Movement**
  - **inter- VLR Movement**
- MS cannot distinguish the types of movement

Fig. 11.1 GSM location area hierarchy

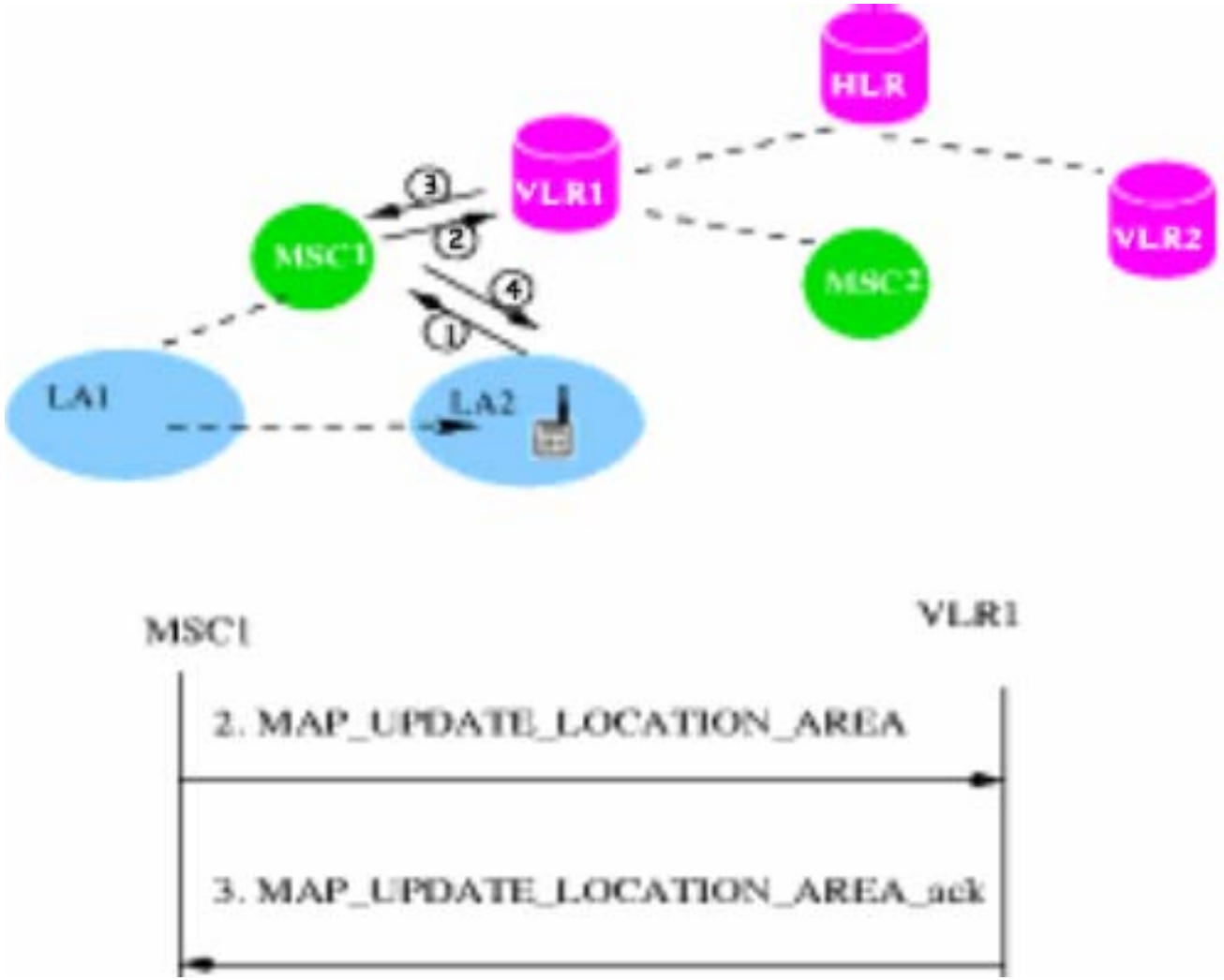


HLR : HOME Location Register
VLR : VISITOR Location Register
MSC : Mobile Switching Center
LA : Location Area
MS : Mobile Station

11.1.1.1 Inter-LA Movement

- The MS moves from LA1 to LA2, where both LAs are connected to the same MSC (Fig. 11.2)
- **Step 1.**
  - A location update request message is sent from the MS to the MSC through the BTS, include the address of the previously visited LA, MSC, and VLR
  - **TMSI** is used to avoid sending the **IMSI** on the radio path

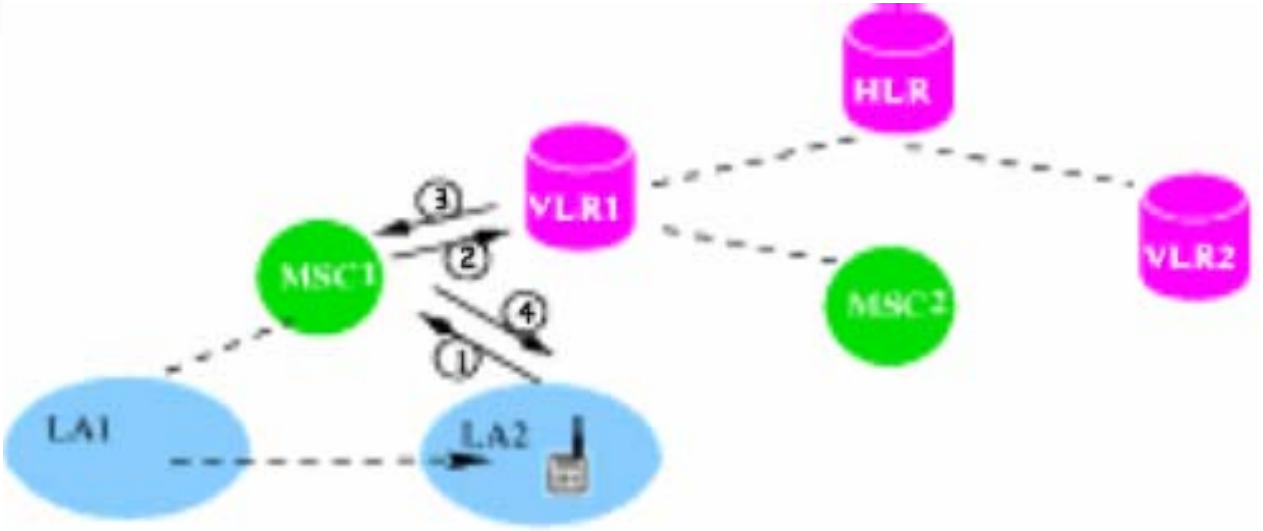
Fig. 11.2 Inter-LA registration message flow

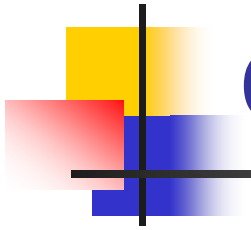


Cont.

- **Step 2.**
  - The MSC forwards the location update request to the VLR by a TCAP message, **MAP_UPDATE_LOCATION_AREA**
    - Address of the MSC
    - TMSI of the MS
    - Previous **location area identification** (LAI)
    - Target LAI
    - Other related information listed in Section 6.1.1 of GSM 09.02 and GSM 03.12

Fig. 11.2 Inter-LA registration message flow





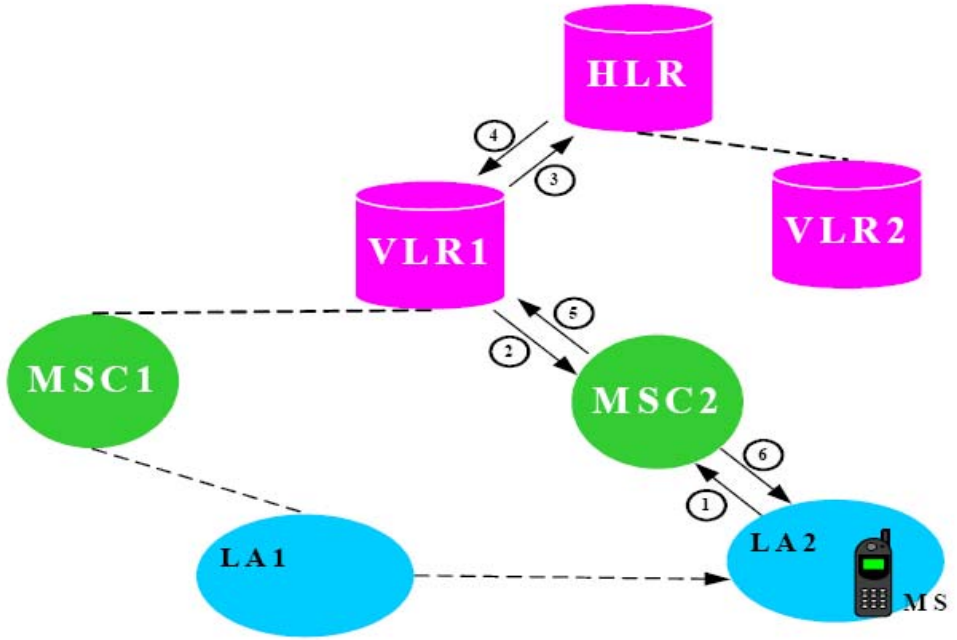
Cont.

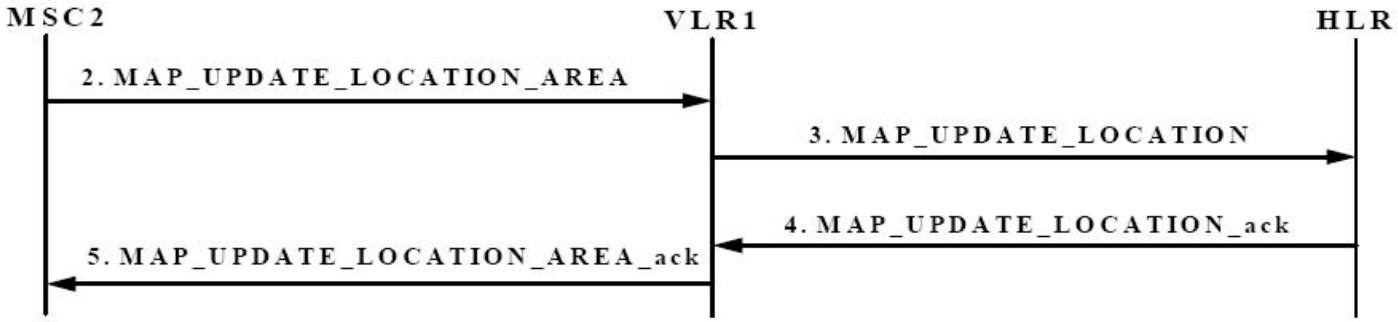
- **Step 3 and Step 4.**
  - MSC updates the LAI field of the VLR record, and replies with an acknowledgment to the MS through the MSC

11.1.1.2 Inter-MSC Movement

- Two LAs belong to different MSCs of the same VLR (Fig. 11.3)
- **Steps 1 and 2.**
  - The location update request is sent from the MS to the VLR

Fig. 11.3 Inter-MSC registration message flow

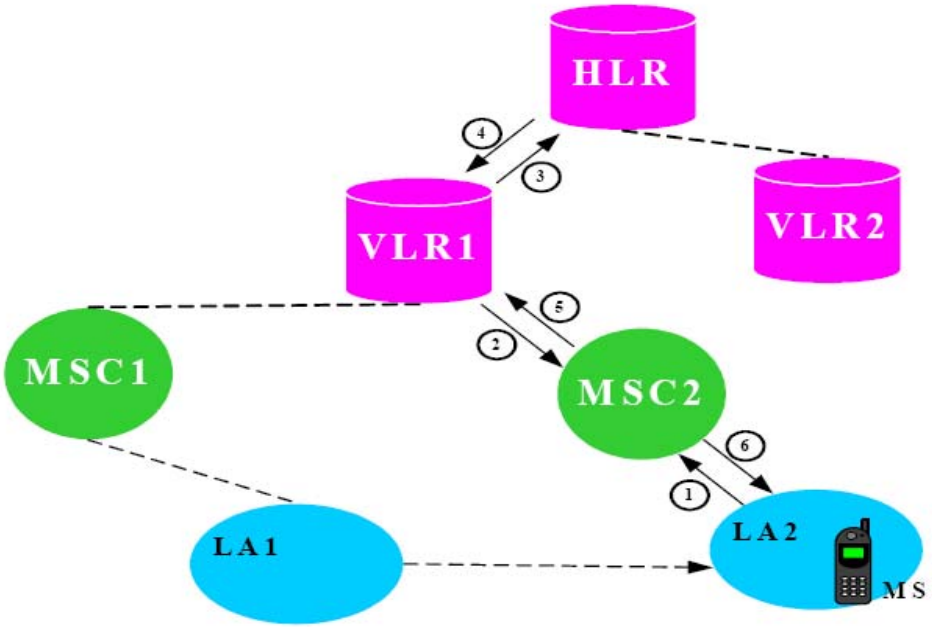


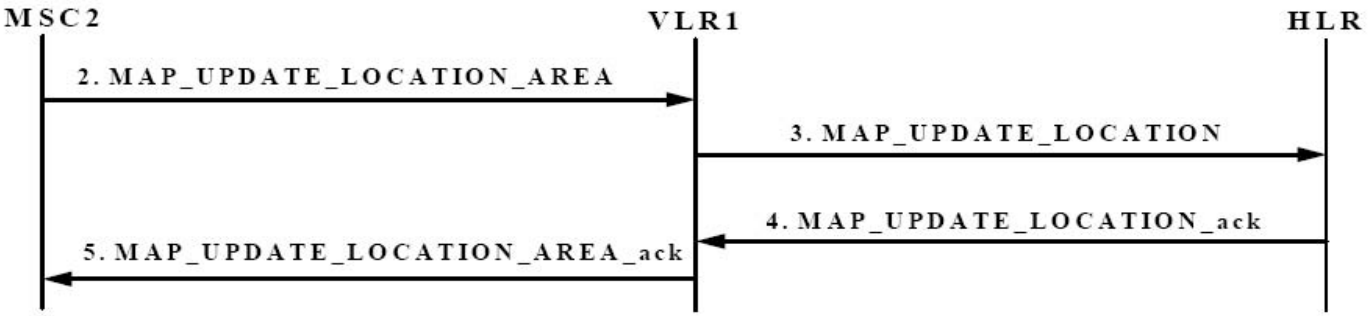


Cont.

- **Step 3.**
  - VLR updates the LAI and the MSC fields of VLR record, and derives the HLR address of the MS from the MS's IMSI
  - VLR sends the **MAP_UPDATE_LOCATION** message to the HLR
    - IMSI of the MS
    - Address of the target MSC (i.e., MSC2)
    - Address of the target VLR (i.e., VLR1)
    - Other related information, as listed in Section 6.1.2 of GSM 09.02

Fig. 11.3 Inter-MSC registration message flow





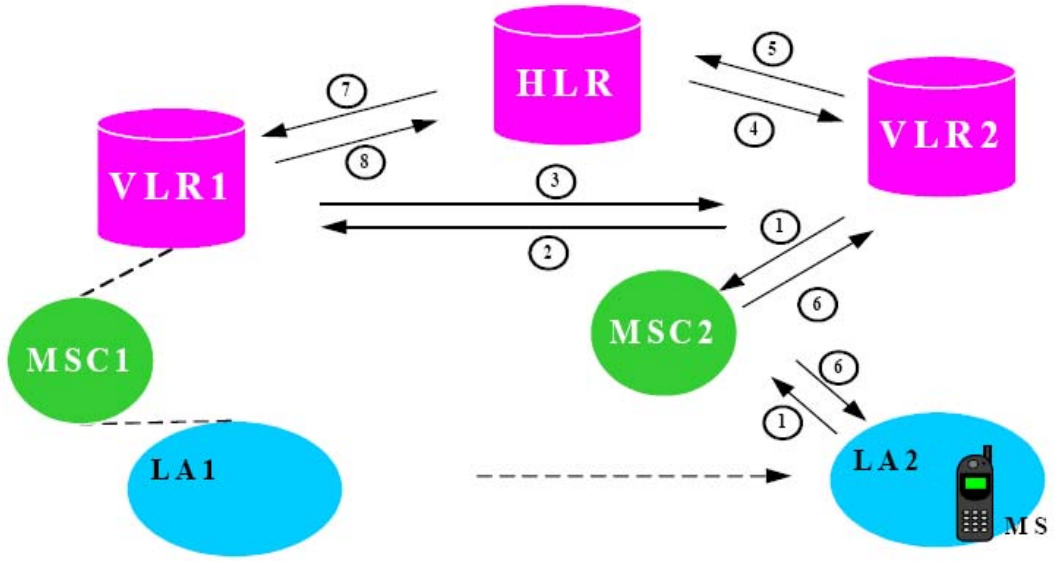
Cont.

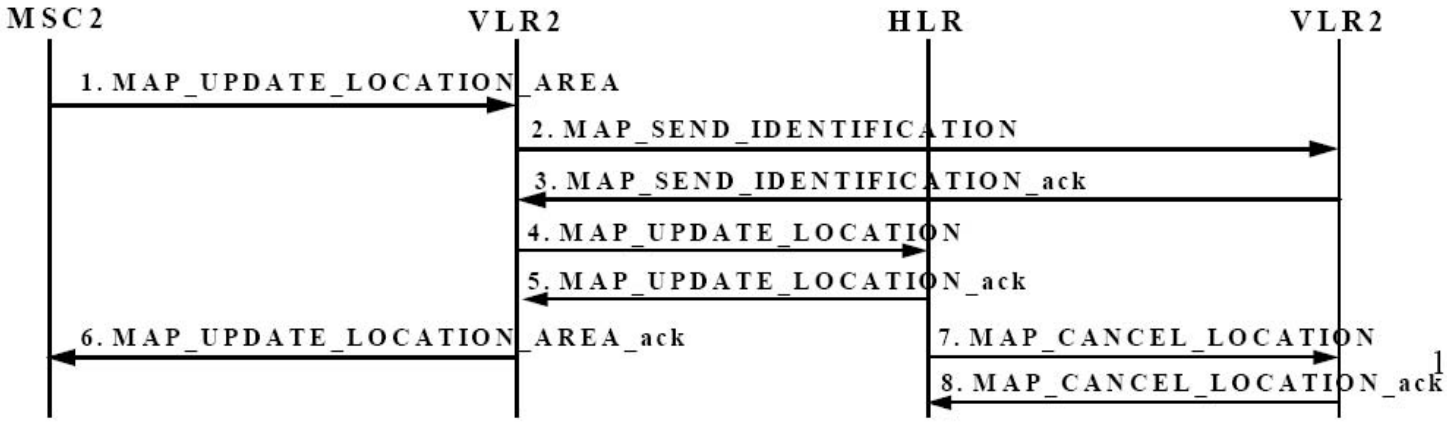
- **Step 4.**
  - HLR identifies the MS's record by using the received IMSI
  - MSC number field is updated
  - An acknowledgment is sent to the VLR
- **Step 5 and 6.** Similar to steps 3 and 4 in 11.1.1.1

11.1.1.3 Inter-VLR Movement

- Two LAs belong to MSCs connected to different VLRs (Fig 11.4)
- **Step 1.**
  - Location update request is sent from MS to VLR
- **Step 2 and 3.**
  - VLR2 identifies address of the previous VLR(VLR1), then sends the message **MAP_SEND_IDENTIFICATION** to VLR1
    - TMSI
  - VLR1 sends IMSI to VLR2

Fig. 11.4 Inter-VLR registration message flow

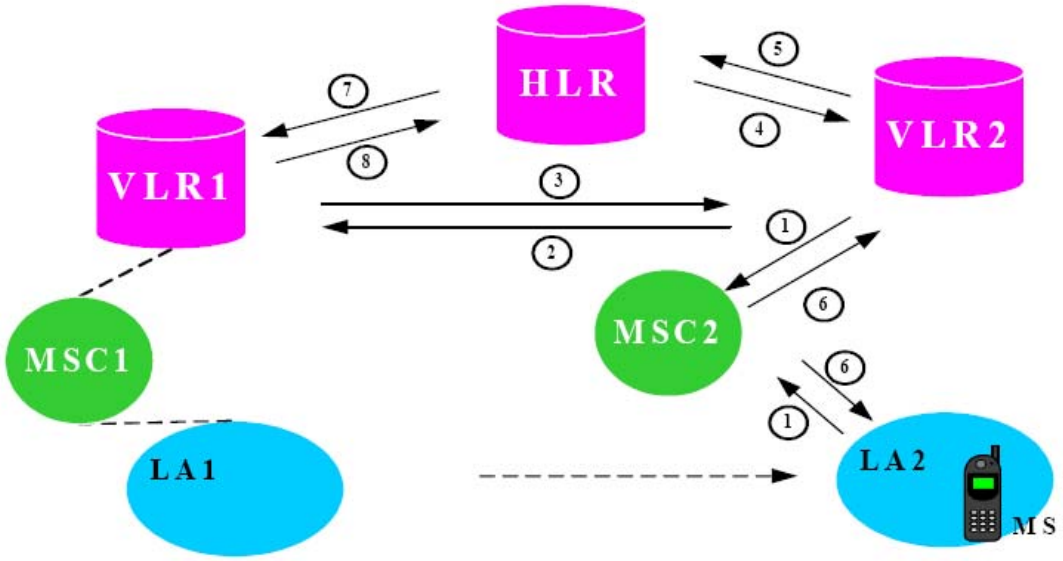


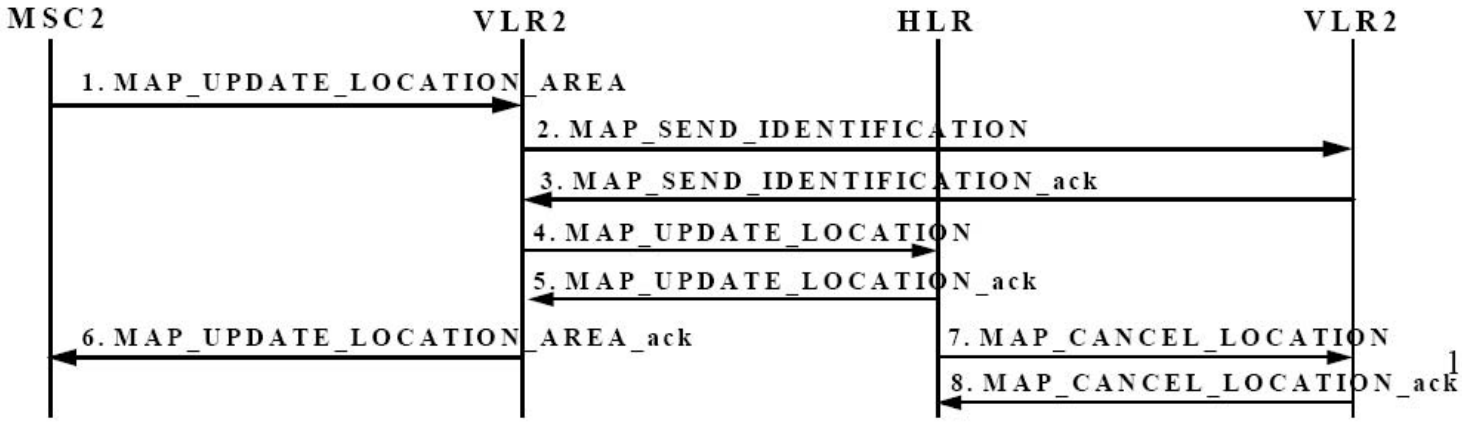


Cont.

- **Step 4 and 5.**
  - VLR2 creates a VLR record for the MS, and sends a registration message to update the HLR
  - HLR updates MSC and VLR address field of the record
  - An acknowledgment is sent back to VLR2
- **Step 6.**
  - VLR2 generates a new **TMSI** and sends it to the MS
- **Step 7 and 8.**
  - The obsolete record of the MS in VLR1 is delete

Fig. 11.4 Inter-VLR registration message flow





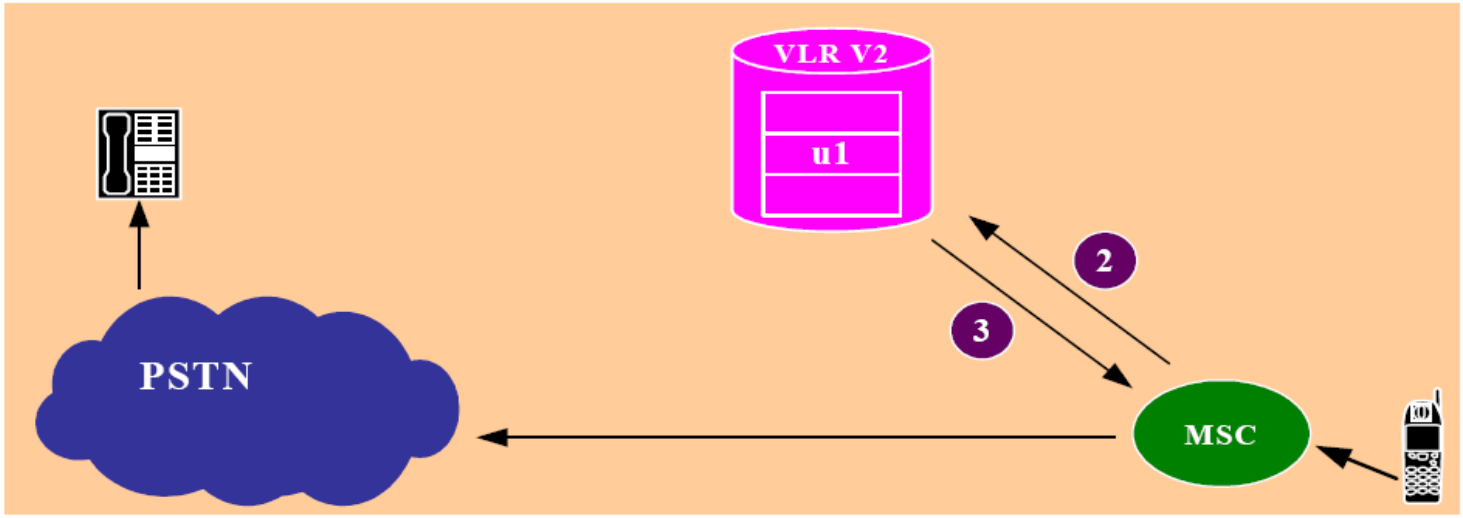
11.1.2 Basic call Origination and Termination Procedures

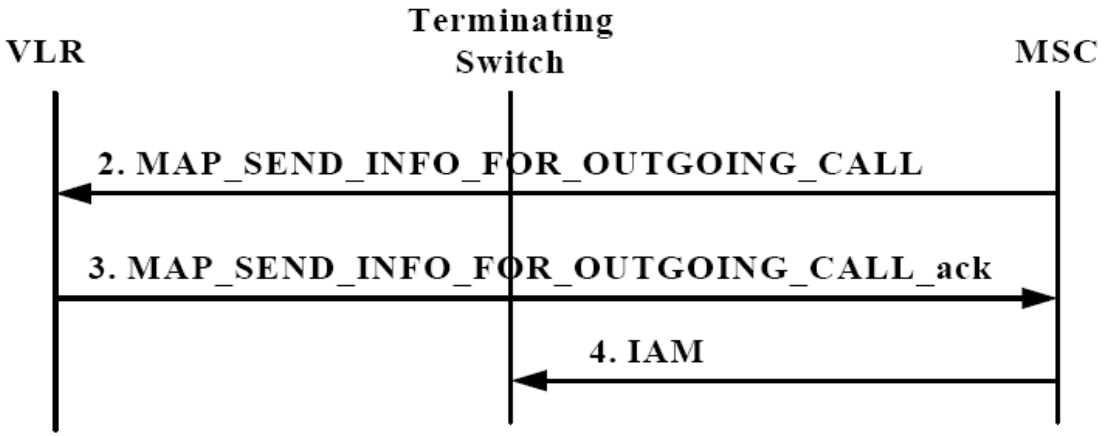
- Fig 11.5 illustrates the basic call origination procedure
- **Step 1.** MSu1 sends the call origination request to the MSC
- **Step 2.** MSC forwards the request to VLR by sending **MAP_SEND_INFO_FOR_OUTGOING_CALL**

Cont.

- **Step 3.** VLR checks u1's profile and sends **MAP_SEND_INFO_FOR_OUTGOING_CALL_ack** to MSC to grant the call request
- **Step 4.** MSC sets up the trunk according to the standard PSTN call setup procedure

Fig. 11.5


VLR V2
u1
2
3
PSTN
MSC


VLR
Terminating Switch
MSC
2. MAP_SEND_INFO_FOR_OUTGOING_CALL
3. MAP_SEND_INFO_FOR_OUTGOING_CALL_ack
4. IAM

Call Termination

- For call termination to a GSM subscriber, routing information must be obtained from the serving VLR (Fig. 11.6)
- **Step 1**. When **mobile station ISDN number** (MSISDN) is dialed by a PSTN user, the call is routed to a gateway MSC by SS7 ISUP IAM message.
- **Step 2.** GMSC or ISDN exchange sends **MAP_SEND_ROUTING_INFOMATION** to HLR to obtain routing information, include:
  - MSISDN
  - Other related information

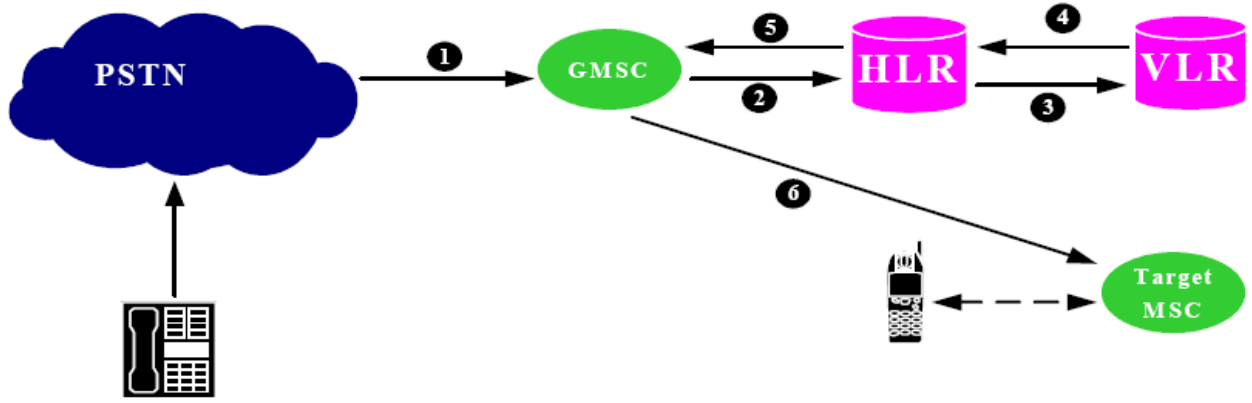
Cont.

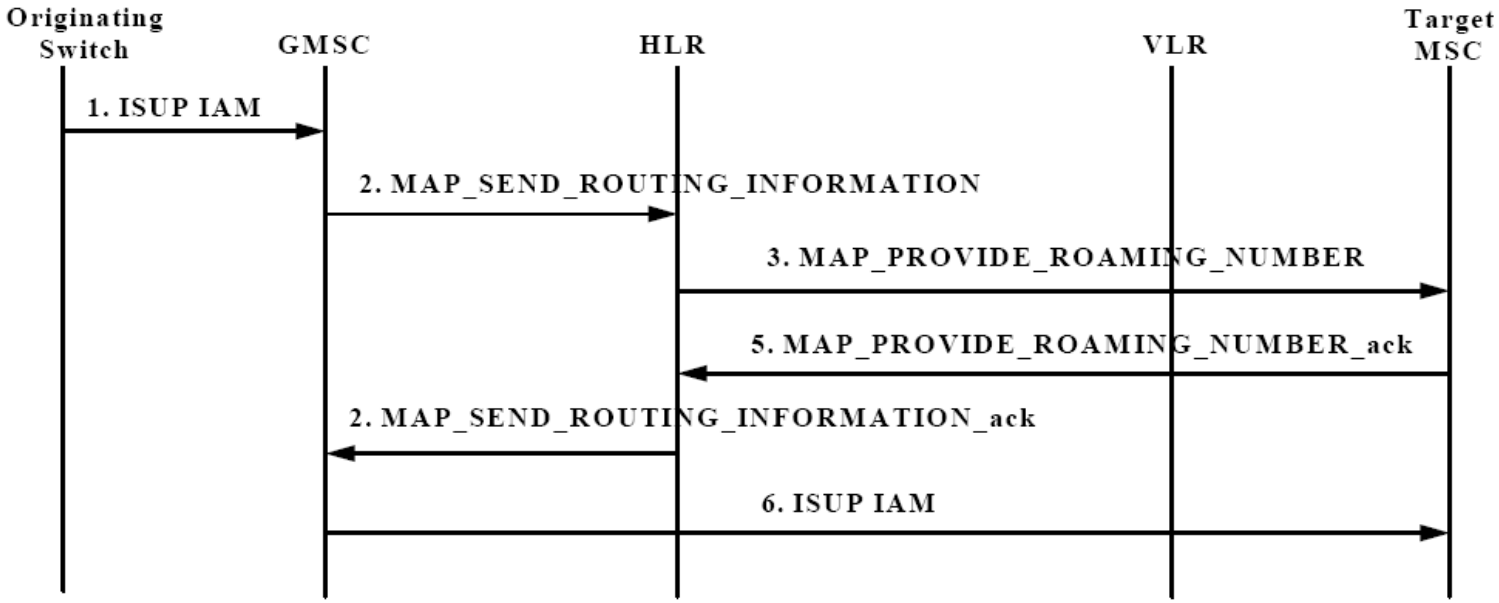
- **Step 3.** HLR sends **MAP_PROVIDE_ROAMING_NUMBER** message to VLR to obtain **mobile subscriber roaming number** (MSRN), include:
  - IMSI
  - MSC number

Cont.

- **Steps 4 and 5.** VLR creates MSRN by using MSC number storeed in the VLR record of the MS, and sends it back to GMSC through the HLR
- **Step 6.** An SS7 ISUP IAM message is directed from the GMSC to the target MSC to set up the voice trunk

Fig. 11.6 Call termination message flow



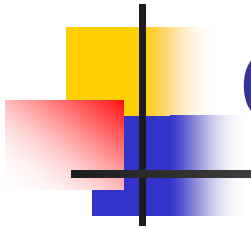


11.2 Mobility Databases

- **Home location register** (HLR) is a database used for mobile user information management. All permanent subscriber data are stored in this database.

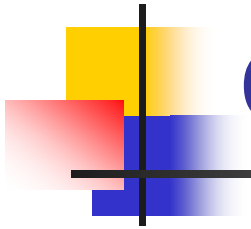
Cont.

- An HLR record consists of 3 types of information:
  - Mobile station information
    - IMSI used by MS to access network
    - MSISDN
  - Location information
    - ISDN number (address) of VLR and MSC where MS resides
  - Service information
    - Service subscription
    - Service restrictions
    - Supplementary services



Cont.

- **Visitor location register** (VLR) is a database of the service area visited by MS. All subscriber data of an MS required for call handling and other purpose are stored in VLR. VLR information consists of 3 parts:
  - Mobile station information
    - IMSI
    - MSISDN
    - TMSI



Cont.

- Location information
  - MSC number
  - **Location area ID** (LAI)
- Service information
  - Subset of the service information stored in the HLR

11.3 **Failure Restoration**
11.3.1 VLR Failure Restoration

- VLR failure restoration
  - Service information: recovered by first contact between VLR and HLR
  - Location information: recovered by first radio contact between VLR and MS
  - Mobile station information: recovered either by contact with HLR or MS

Cont.

- VLR record restoration is initiated by one of the three events
  - **MS registration**
  - **MS call origination**
  - **MS call termination**

Cont.

- **MS registration**
  - VLR considers the registration as inter-VLR movement because VLR record was erased by failure
  - VLR record is recovered from normal inter-VLR movement
    - MS is asked to send IMSI over the air because TMSI send from MS to the VLR cannot be recognized

Cont.

- **MS call origination**
  - VLR received the call origination request from MSC.
  - Because the VLR record for MS is not found, VLR considers the situation as a system error “unidentified subscriber”.
  - The request is rejected, and MS is asked to initiate location registration procedure

Cont.

- **MS call termination** (Fig. 11.7)
- **Steps 1-3.**
  - Similar to the first three steps of basic call termination procedure, VLR is queried to provide the MSRN.
  - Because searching for MS record by using IMSI fails, VLR creates a VLR record for MS
  - Neither service nor location information is available, Steps 4 and 5 are executed in parallel

Cont.

- **Steps 4 and 7.**
  - VLR create MSRN using MSC number provide by MAP_PROVIDE_ROAMING_NUMBER message. MSRN is sent back to GMSC to set up call in step 8
- **Steps 5 and 6.**
  - VLR recovers service information of VLR record by sending **MAP_RESTORE_DATA** message to HLR
  - HLR sends the service information to VLR using **MAP_INSERT_SUBSCRIBER_DATA** message
  - Location information, specially LAI number will be recovered at step 11

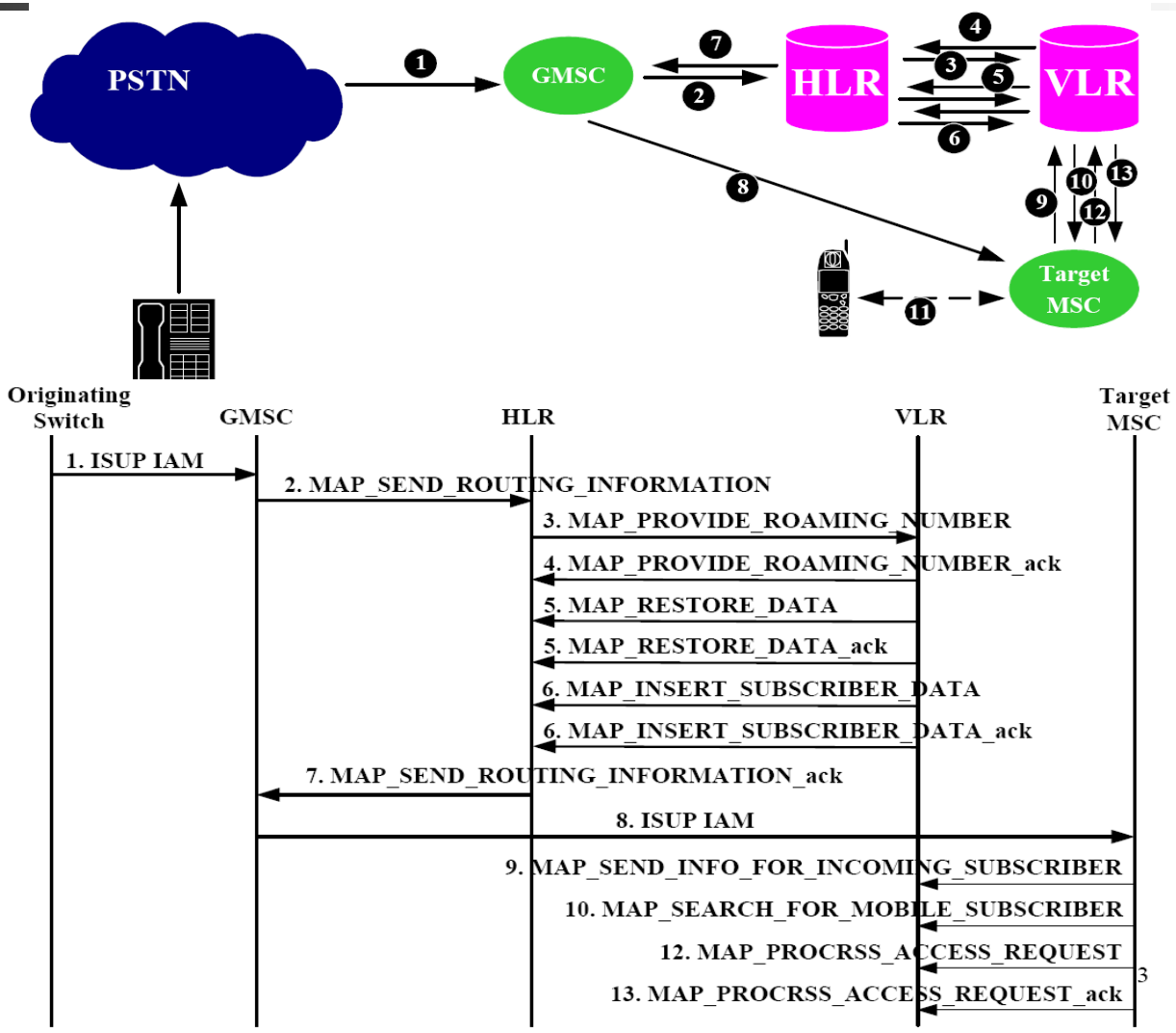
Cont.

- **Step 8.**
  - GMSC sends SS7 ISUP message IAM to target MSC
- **Steps 9-11.**
  - MSC sends message MAP_SEND_INFO_FOR_INCOMING_CALL to VLR to obtain LAI information
  - VLR does not have LAI information, and sends MAP_SEARCH_FOR_MOBILE_SUBSCRIBER to MSC to determine the LA of the MS
  - MSC initiates paging of the MS in all LAs

Cont.

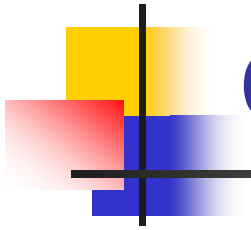
- **Steps 12 and 13.**
  - If paging is successful, the current LA address of the MS is sent back to VLR by MAP_PROCESS_ACCESS_REQUEST message
- **MAP_SEARCH_FOR_MOBILE_SUBSCRIBER is expensive because every BTS connected to the MSC must perform the paging operation**

Fig. 11.7 Call termination message flow (failure restoration)



11.3.2 **HLR Failure Restoration**

- HLR is mandatory to save updates into nonvolatile storage
  - Changes of service information are saved into backup storage device immediately after any update
  - Location information is periodically check-pointed (transferred into backup)
- After an HLR failure, the data in the backup are reloaded into the HLR



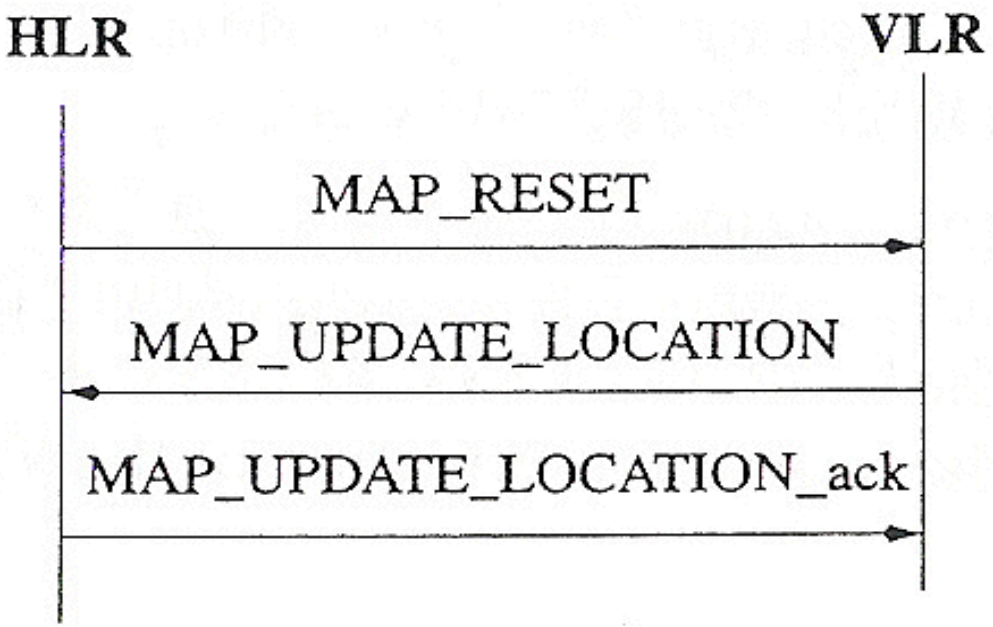
Cont.

- **Uncovered period**: time interval after the last backup operation and before the restart of the HLR
- Date that have been changed in the uncovered period cannot be recovered

Cont.

- HLR restoration procedure (Fig. 11.8)
- **Step 1.** HLR sends SS7 TCAP message MAP_RESET to VLRs
- **Step 2.** All the VLRs derive MSs of the HLR. Then MSs send SS7 TCAP message **MAP_UPDATE_LOCATION** to the HLR and HLR record is recovered
- HLR restoration procedure is not robust

Fig. 11.8 HLR restoration procedure



11.4 VLR Identification Algorithm

- **VLR Identification Algorithm** (VIA): an algorithm to identify the exact VLRs to be contacted by HLR after an HLR failure

Cont.

- Extra data structures required in the HLR (Fig 11.9)
  - ***VLR_List****: In the backup. A set of VLRs that have been modified during the uncovered period
  - ***ts field***: last time of location update
  - ***PVLR***: address of the VLR where the MS resided at the last check-pointing time. For any MS *p*:

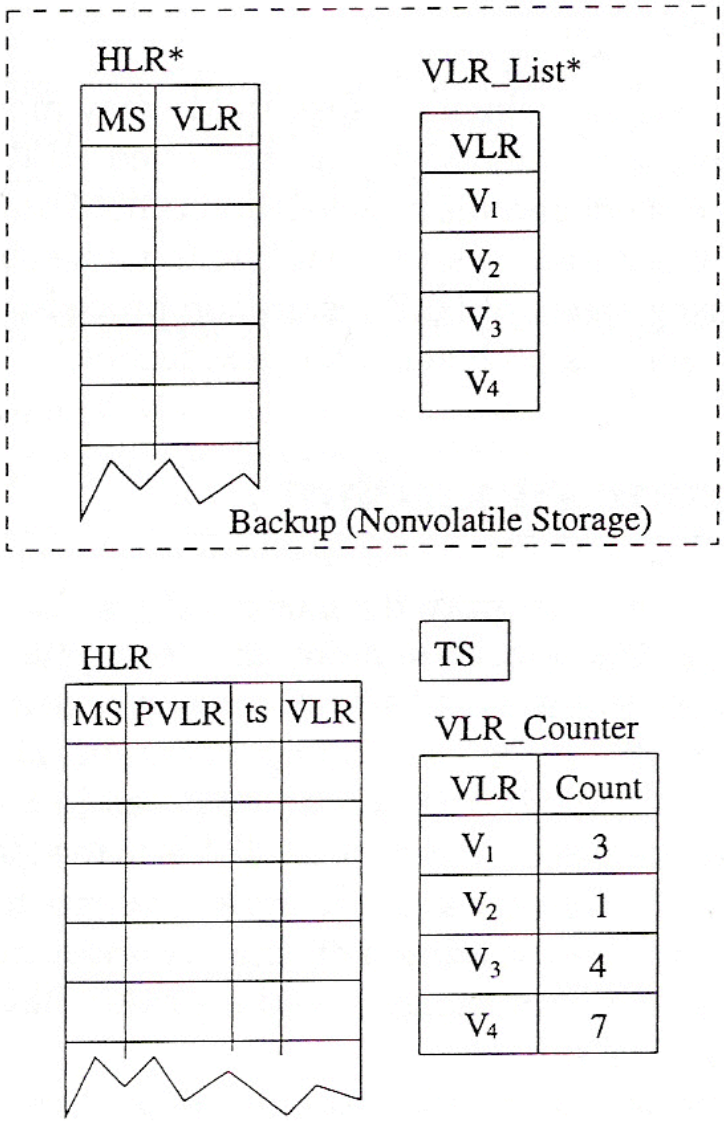
    $$HLR^*[p].VLR = HLR[p].\mathbf{PVLR}$$

  - ***TS***: last check-pointing time

Cont.

- ***VLR_Counter***: a set of (***VLR***, ***Count***) pairs
  - ***Count***: “effective number” of MSs entering the VLR ***VLR*** during uncovered period
  - VLRs recorded in ***VLR_Counter*** are the VLRs in ***VLR_List****
- An MS is not effective to a VLR if it entered the VLR area then left the area during the uncovered period

Fig. 11.9 HLR architecture



Cont.

- **VIA Procedure 1: Check-pointing**

  Step 1. For every location entry *p* in *HLR** **do**:

  HLR[p].VLR←HLR[p].PVLR*;

  Step 2. *TS* ← current time;

  Step 3. For every location entry *p* in *HLR* **do**:

  HLR[p].ts← TS; HLR[p].PVLR←HLR[p].VLR;

  Step 4. *VLR_Counter← null, VLR_List*← null*

- At step 4, both *VLR_Counter* and *VLR_List** are set to empty to indicate that no VLR has new roaming MS at TS

Cont.

- Suppose that MS *p* moves into VLR area *Vnew* at time t. The message **MAP_UPDATE_LOCATION** is sent from *Vnew* to the HLR. Procedure 2 at HLR is triggered to perform the registration operation

Cont.

- **VIA Procedure 2: Registration**
- **Step 1.** Update *HLR*:

$V_{old} \leftarrow HLR[p].VLR$;

Send message, MAP_CANCEL_LOCATION, to cancel the

VLR entry of *p* at V_{old}:

$HLR[p].VLR \leftarrow V_{new}$;

$t_{old} \leftarrow HLR[p].ts$

$HLR[p].ts \leftarrow t$

Cont.

- **Step 2.** Update the *Vnew Count* field in *VLR_Counter*:

  If *HLR[p].VLR != HLR[p].PVLR* **then**:

  Step 2.1 **If** *VLR_Counter[Vnew]* exists, **then**:

  VLR_Counter[Vnew] ← *VLR_Counter[Vnew]* + 1;

  Step 2.2 **Else** create *VLR_Counter[Vnew] and VLR_List*[Vnew]* ;

  VLR_Counter[Vnew] ←1

Cont.

- **Step 3.** Update the V_{old} counter entry: **If** $t_{old} > TS$ and $V_{old} != HLP[p].PVLR$ **then**:

  Step 3.1

  $VLR\_Counter[Vold] \leftarrow VLR\_Counter[Vold] - 1;$

  Step 3.2

  If *VLR_Counter[Vold] .Count* = 0 **then**:

  Step 3.2.1

  Delete *VLR_Counter[Vold] and VLR_List*[Vold]*

Cont.

- After an HLR failure, procedure 3 is executed to restore the HLR
- **VIA Procedure 3: Restore**

  Step 1. *TS* ← current time;

  Step 2. For every location entry *p* in *HLR* **do**:

  HLR[p].PVLR=*HLR[p].VLR* ←*HLR[p]*.VLR*;

  HLR[p].ts ← *TS*;

  Step 3. For every VLR entry *V* in *VLR_List*, send an SS7 TCAP

  MAP_RESET message to *V*;

11.5 VLR Overflow Control

- When a VLR is full, the incoming mobile users cannot receive cellular services
- To solve VLR overflow problem, overflow control algorithms O-I, O-II, O-III, and O-IV are presented
- An extra flag (1 bit) is required in the HLR records

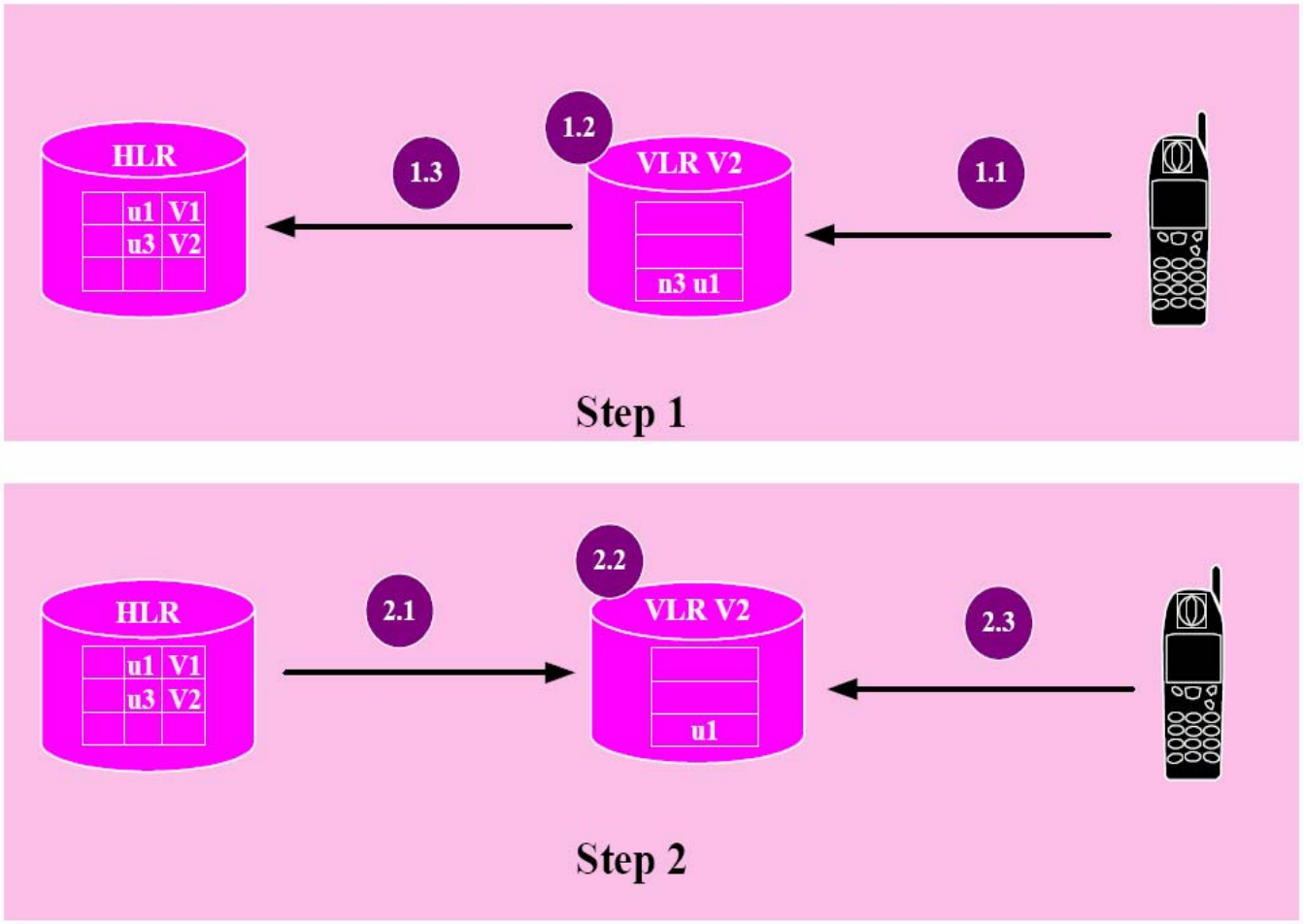
11.5.1 Algorithm O-I: Registration (Fig. 11.10)

- **Step 1.** Registration Request:
  - **Step 1.1** Same as step 1 of the normal registration procedure
  - **Step 1.2** *V2* is full. *V2* follows a replacement policy to select a record to be deleted (*u2* in Fig.11.10). The storage for the delete record is used to store *u1*'s information. The selected user (i.e., *u3*) is called overflow user. The replacement policy may be based on various heuristics
  - **Step 1.3** *V2* forwards the registration request to the HLR with indication that u3's record is delete due to database overflow

Cont.

- **Step 2.** Registration Response:
  - **Step 2.1** HLR update the location of *u1*, and sets the overflow flag in *u3*s record
  - **Step 2.2** HLR acknowledges the registration operation and sends *u1*'s profile to *V2*.
  - **Step 2.3** *V2* sends an acknowledgment to MS

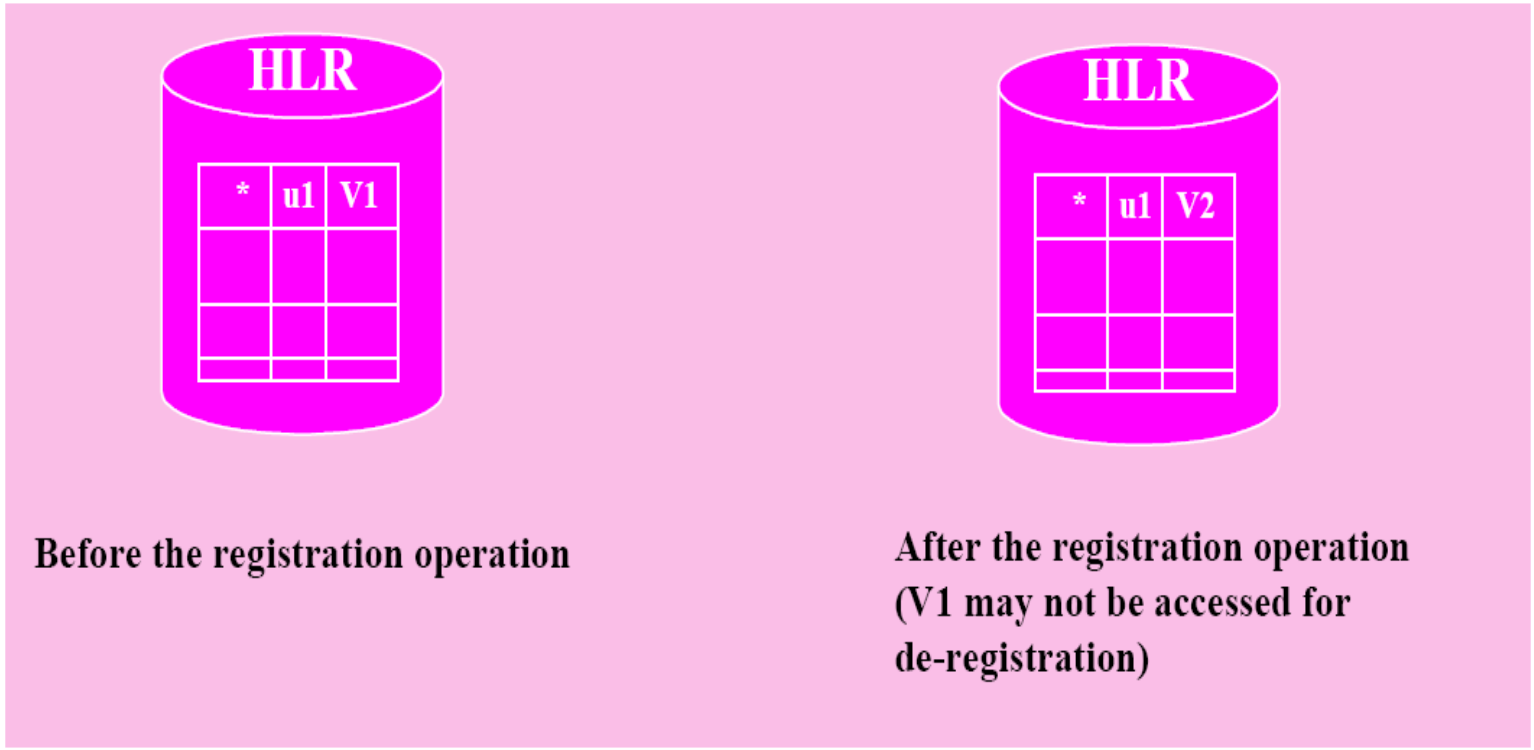
Fig. 11.10 Overflow registration operation



11.5.2 Algorithm O-II: Cancellation (Fig. 11.11)

- If *u1* is an overflow user at *V1*, then *u1* does not have a record in *V1*
- Cancellation operation simply resets the overflow flag of *u1*'s HLR record if *u1* is not an overflow user in *V2*

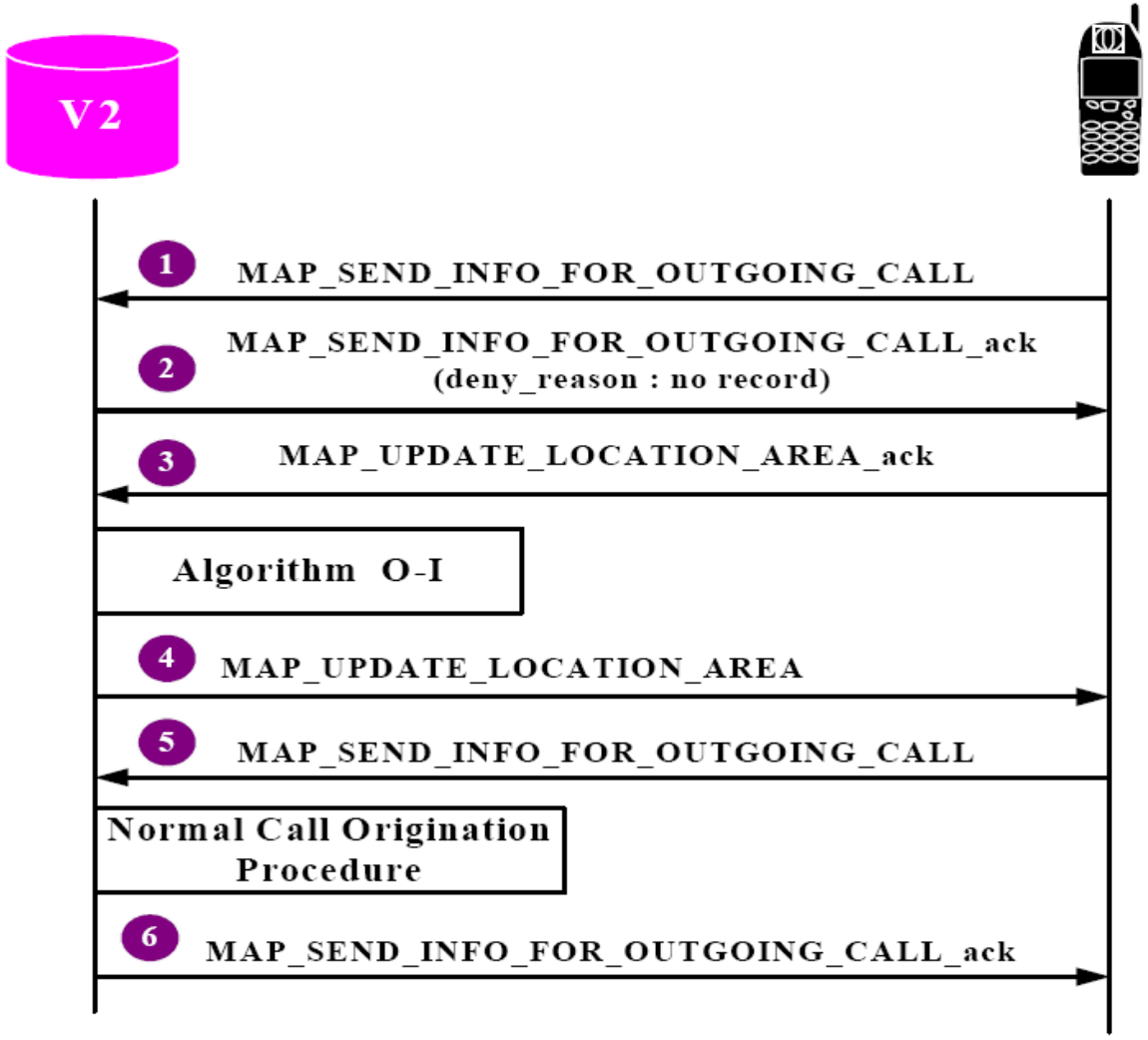
Fig. 11.11 Cancellation operation with overflow VLR



11.5.3 Algorithm O-III: Call Origination (Fig 11.12)

- **Step 1.** The MS sends the call origination request to *V2*
- **Step 2.** *V2* cannot fine *u1's* record, and denies the call request
- **Steps 3 and 4.** The MS initiates the registration procedure; Algorithm O-I is executed
- **Steps 5 and 6.** The MS reissues the call origination request, and the normal call origination procedure is executed

Fig. 11.12 Call origination with overflow VLR

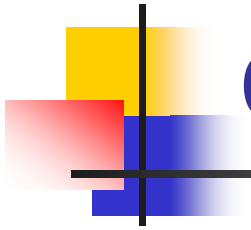


11.5.4 Algorithm O-IV: Call Termination (Fig. 11.13)

- **Step 1.** Location query:
  - **Step 1.1.** The calling party dials the phone number of *u1*. The request is sent to the origination switch in the PSTN
  - **Step 1.2.** The origination switch sends a location query message to the HLR
  - **Step 1.3.** The HLR determines that *u1* is an overflow user and sends a query message to obtain the routing information. The use profile information is attached in the message

Cont.

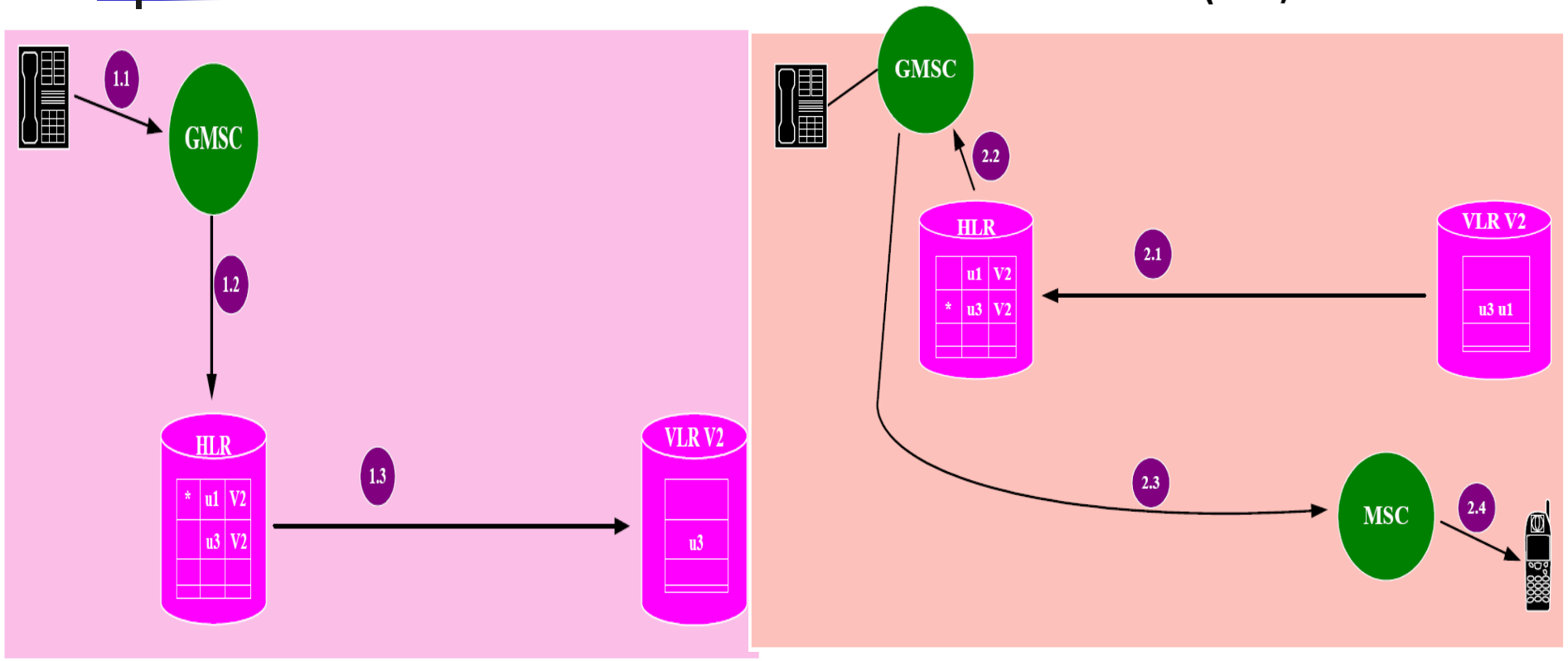
- **Step 2.** Location response:
  - **Step 2.1.** If V2 is not full, a record for u1 is created. If V2 is full, a user record is deleted and is used to store u1 and sends it back to HLR. V2 creates the routable address of u1 and sends it back to the HLR. If a record is replaced, the replacement information is included in the message
  - **Step 2.2.** HLR returns the routable address to the originating switch. If a record is replaced, the overflow flags are updated at the HLR
  - **Step 2.3.** The origination switch sets up the trunk to the MSC based on the routable address
  - **Step 2.4.** The MSC pages the mobile phone and the call path is established

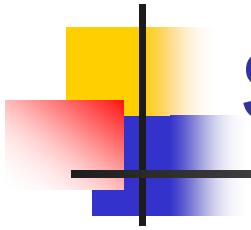


Cont.

- With Algorithms O-I through O-IV, an LA can accommodate an unlimited number of mobile users as long as the number of simultaneous phone calls to these users is no larger than the size of the database

Fig. 11.13 Call termination with overflow VLR





Summary

- MS registration procedure
- Call delivery procedure
- Location database failure restoration procedure
- VLR identification algorithm
- VLR overflow mechanism