Chapter 3: GSM Mobility Management

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

- **Addressing in GSM**

  - 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

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Call to Nr 085-123456

User (identifier: MSISDN)

SIM card (identifier: IMSI)

Terminal (identifier: IMEI)

SIM: Subscriber Identity Module
IMSI: International Mobile Subscriber Identity
IMEI: International Mobile Equipment Identity
MSISDN: Mobile Station ISDN Number

MSISDN 085-123456
IMSI 208347854033
• Fig. 11.1 GSM location area hierarchy

• In GSM, registration or location update occurs when an MS moves from one LA to another
• Basic Location Update Procedure
• **Inter- LA Movement**
• **Inter- MSC Movement**
• **Inter- VLR Movement**
• MS cannot distinguish the types of movement

• Inter-LA Movement

• **Step 1.** The MS moves from LA1 to LA2, where both LAs are connected to the same MSC (Fig. 11.2)
• 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
- **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

**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
- Fig. 11.2 Inter-LA registration message flow

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
- **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.

**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

Fig. 11.3 Inter-MSC registration message flow

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.

**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 deleted

- Fig. 11.4 Inter-VLR registration message flow

- Two Issues of GSM Mobility Databases
  - Mobility Databases: Home Location Register (HLR)
    - **Home location register** (HLR) is a database used for mobile user information management. All permanent subscriber data are stored in this database.
    - 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
• Visitor location register

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

• VLR Failure Restoration
  • Service Information of a VLR record recovered by – The first contact between the VLR and the HLR of the corresponding MS.
  • Location Information of a VLR record recovered by
  • First radio contact between the VLR and the MS
  • Mobile Station Information of a VLR record recovered by
  • Either by contact with the HLR or the MS
  • VLR record restoration is initiated by one of the three events
• MS registration
• MS call origination
• MS call termination

• VLR Record Restoration Initiation Event 1
• 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

• VLR Record Restoration Initiation Event 2
• 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

• Call Termination Message (Failure Restoration)
VLR Record Restoration Initiation Event 3 – MS Call Termination

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

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

VLR Record Restoration Initiation Event 3 – MS Call Termination

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

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.
- **HLR Failure Restoration**
- It is mandatory to save the updates into non volatile storage.
- Changes of the service information are saved into the backup storage device immediately after any update.
- The location information is periodically transferred from the HLR into the backup.
- After an HLR failure, the data in the backup are reloaded into the HLR.

- **HLR Restoration Procedure**
- After an HLR failure, the data in the backup are reloaded into the HLR.
- An Uncovered Period = the time interval after the last backup operation and before the restart of the HLR.
- Data that have been changed in the uncovered period can not be recovered.
- Step 1. The HLR sends an SS7 TCAP message MAP_RESET to the VLRs where its MSs are located.
- Step 2. All the VLRs derive all MSs of the HLR. For each MS, they send an SS7 TCAP message, MAP_UPDATE_LOCATION, to the HLR.
- The HLR restoration procedure is not robust. – An MS may move into a VLR (which does not have any other MSs from the given HLR residing) during the uncovered period. – The new location is not known to the HLR at the last checkpointing time.
- – If so, the HLR will not be locate the VLR of the MS during Step 1 of HLR restoration.
- VLR Identification Algorithm is to solve the problem.
- **Algorithm (VIA) (1/3)**

To simply the description, we assume that every VLR covers exactly one MSC.
To implement VIA, extra data structures are required.
In the backup, the extra data structure is a set VLR_List* of VLRs that have been modified during the uncovered period.

After an HLR failure, the HLR only needs to send the MAP_RESET messages to VLRs listed in VLR_List*.

- In HLR, every record includes two extra fields.
- The ts field = the last time of location update
- The PVLR field = the address of VLR where the resided at the last check-pointing time. Thus, for any MS p, we have
  \[ HLR^*[p].VLR = HLR[p].PVLR \]
- Two extra data structures are introduced in the HLR.
  - TS = the last check-pointing or backup time
  - VLR_Counter = \{(VLR1,Count), (VLR2,Count), \ldots, (VLRn,Count)\} where Count represents the “effective number” of MSs entering the VLR VLRn during the uncovered period.
  - An MS is not effective to a VLR if it entered the VLR area then left the area during uncovered period.
  - Note that the VLRs recorded in VLR_Counter are the VLRs in VLR_List*.

**VIA Procedure 1: Check-Pointing**

- In VIA, information of the HLR is periodically saved into the backup by this procedure.
  - **Step 1.** For every entry p in HLR* do:
    - \[ HLR[p]^*.VLR \leftarrow HLR[p].VLR; \]
  - **Step 2.** TS \leftarrow current time;
  - **Step 3.** For every location entry p in HLR do:
    - \[ HLR[p].ts \leftarrow TS; \quad HLR[p].PVLR \leftarrow HLR[p].VLR; \]
  - **Step 4.** VLR_Counter \leftarrow NULL; VLR_List* \leftarrow NULL;
• **VIA Procedure 2: Registration (1/3)**
  • **Step 1.** Update HLR:
    - \( \text{Vold} \leftarrow \text{HLR}[p].\text{VLR} \);
    - Send message, MAP\_CANCEL\_LOCATION, to cancel the VLR entry of \( p \) at \( \text{Vold} \);
    - \( \text{HLR}[p].\text{VLR} \leftarrow \text{Vnew} \);
    - \( \text{told} \leftarrow \text{HLR}[p].\text{ts} \);
    - \( \text{HLR}[p].\text{ts} \leftarrow t \);

• **VIA Procedure 2: Registration (2/3)**
  • **Step 2.** Update the Vnew Count field in VLR\_Counter:
    - If (\( \text{HLR}[p].\text{VLR} \neq \text{HLR}[p].\text{PVLR} \)){
      - If (VLR\_Counter[Vnew] exists){
        - VLR\_Counter[Vnew]\_Count \leftarrow VLR\_Counter[Vnew]\_Count + 1;
      }
      - } else{
        - create VLR\_Counter[Vnew] and VLR\_List*[Vnew];
        - VLR\_Counter[Vnew] \leftarrow 1;
      }

• **VIA Procedure 2: Registration (3/3)**
  **Step 3.** Update the Vold counter entry:
  - If (\( \text{told} > \text{TS} \) and \( \text{Vold} \neq \text{HLR}[p].\text{PVLR} \)){
    - VLR\_Counter[Vold]\_Count \leftarrow VLR\_Counter[Vold]\_Count – 1;
    - If (VLR\_Counter[Vold]\_Count = 0){
      - Delete VLR\_Counter[Vold] and VLR\_List*[Vold];
      }
  }

• **VIA Procedure 3: Restore**
  • **Step 1.** TS \leftarrow \text{current time};
  • **Step 2.**
    for (every location entry \( p \) in HLR){
      - \( \text{HLR}[p].\text{PLVR} = \text{HLR}[p].\text{VLR} \leftarrow \text{HLR}[p]\^*.\text{VLR} \);
      - \( \text{HLR}[p].\text{ts} \leftarrow \text{TS} \);
    }
  • **Step 3.**
    for (every VLR entry \( V \) in VLR\_List*){
      - Send an SS7 TCAP MAP\_RESET message to \( V \);
    }
- **VLR Overflow Control**
- The number of records in the VLR can change dynamically.
- It is possible that the number of the records in the corresponding VLR may be larger than that of the HLR, and the VLR may overflow if too many mobile users move into the LA in a short period.
- When a VLR is full, the incoming mobile users cannot register using the registration.
- To solve the 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

**Overflow Registration Operation**

11.5.1 Algorithm O-I: Registration

**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

**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

- **Cancellation Operation with Overflow VLR**

![Diagram](image)

- 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

- 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 find 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
• Call Origination with Overflow VLR Call

1. MAP_SEND_INFO_FOR_OUTGOING_CALL
2. MAP_SEND_INFO_FOR_OUTGOING_CALL_ack (deny_reason: no record)
3. MAP_UPDATE_LOCATION_AREA_ack

Algorithm 0-1
4. MAP_UPDATE_LOCATION_AREA_ack
5. MAP_SEND_INFO_FOR_OUTGOING_CALL

Normal Call Origination Procedure
6. MAP_SEND_INFO_FOR_OUTGOING_CALL_ack

• Termination 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

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

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

Termination with Overflow VLR

![Diagram of call termination process]
Questions

1. What is GSM Location update? When it is occurred? (4M S-15)
2. Describe step procedure for VLR failure Restoration. (4M S-15)
3. Write an algorithm for call termination of VLR overflow (4M S-15)
4. Write an algorithm for Registration of VLR overflow (6M S-15)
5. Explain Mobility Database. (HLR 2M, VLR 2M) Mobility (4M S-15)
7. Explain Location tracking and call setup in GSM. (6M S-15)
8. What is GSM Location update? When it is occurred? (4M S-15)
10. Describe situation when GSM Location update is performed
11. Describe the mobility of the database with respect to HLR and VLR
12. Describe the stepwise procedure for HLR Failure restoration.
13. Write an algorithm for Call origination of VLR overflow.
14. Write an algorithm for call Termination of VLR overflow
15. Describe GPRS network node in detail
16. Describe the registration process of Mobile system when it is moving from one VLR to another VLR.
18. With neat diagram describe steps for VLR failure restoration procedure(6M W-15).