Mobile Services (ST 2010)
Chapter 3: Mobility Management

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3 Mobility Management

3.1 Handover Management
3.2 Basics of Location Management
3.3 GSM Location Management
3.4 GPRS Location Management
3.5 UMTS Location Management
3 Mobility Management
Functions of Mobility Management

Handover Management
- Maintaining the traffic connection with a moving user when crossing cell boundaries
- Occurs when the quality or the strength of the radio signal falls below certain parameters (signal quality reason)
- Occurs when the traffic capacity of a cell has reached its maximum or is approaching (traffic reason)
- GSM standard identifies about 40 reasons for a handover
- Handover is initialized by the mobile or by the base station
- Other term: handoff (primarily used in the U.S.)

Location Management
- Mechanisms to localize users in case of incoming calls, short messages, or data
- Requires to partition an operator’s coverage area into location areas in order to efficiently perform location management
- Two basic operations: Location update and Paging
- Location Update (LU): operation initialized by the terminal to inform the network about the user’s location
- Paging: broadcast message initialized by the network to locate the current cell of a user
3.1 Handover Management
Overview of the Handover Process

Measurement
- Measurement criteria: signal strength (between mobile and current base station as well as between mobile and neighboring base stations), distance, quality (e.g., in terms of error rates), traffic volume,....
- Measurement reports exchanged between mobile and base station

Decision
- Decision parameters: thresholds and hysteresis margin
- Network-controlled, mobile-assisted, mobile-controlled handover

Execution
- Handover signaling
- Radio resource allocation
- Re-establishing connections in core and access networks
- Hard and soft handover
- Inter-cell and intra-cell handover
- Inter-frequency and intra-frequency handover
- Inter-system and intra-system handover
3.1 Handover Management
Measurement: Handover Parameters

- Primarily, RSS (relative signal strength) measurements from the serving point of attachment and neighboring points of attachment are used.

- Alternatively, or in conjunction, path loss, carrier-to-interference ratio, bit error rates, block error rates, symbol error rates, utilization have been employed as metrics in certain types of networks.
3.1 Handover Management

Decision: Relative Signal Strength

- Mobile terminal is handed off from BS A to BS B when the signal strength at B first exceeds that at A.
- If the signal strength at B first exceeds that at A, the mobile unit is handed back to A.
- In this figure, handover occurs at point $L_1$.

Because signal strength fluctuates due to multipath propagation effects, this method can lead to a ping-pong effect in which the unit is repeatedly passed back and forth between two base stations.
3.1 Handover Management

Decision: Relative Signal Strength with Threshold

- Handover only occurs if
  - the signal at the current BS is less than a predefined threshold, and
  - the signal from a neighboring base station is stronger
- Handover is avoided as long as the signal from the serving base station is strong enough

For a high threshold (e.g., $Th_1$), this scheme performs the same as the relative signal strength scheme.

If the threshold is set quite low (e.g., $Th_3$), the mobile may move far into the new cell.

Threshold should not be used alone because its effectiveness depends on prior knowledge of the crossover signal strength between the current and the candidate base stations.
3.1 Handover Management
Decision: Relative Signal Strength with Hysteresis

- Handover occurs only if the new base station is sufficiently stronger (by a margin $H$) than the current one.

- While the mobile is assigned to base station A, the scheme will generate a handover when the relative signal strength reaches or exceeds $H$.

- Once the mobile is assigned to B, it remains so until the relative signal strength falls below $-H$, at which point it is handed back to A.

- Prevents the ping-pong effect.

- Disadvantage: the first handover may still be unnecessary if base station A still has sufficient signal strength.
3.1 Handover Management

Decision: RSS with Threshold and Hysteresis

- Handover occurs only if
  - the current signal level drops below a threshold, **and**
  - the target base station is stronger than the current one by a hysteresis margin $H$

- Handover occurs at $L_4$, if the threshold is either $Th_1$ or $Th_2$
- Handover occurs at $L_3$ if the threshold is at $Th_3$

Scheme avoids the ping-pong effect and execution of handover if signal from the serving base station is still strong enough.
3.1 Handover Management

Execution: Hard versus Soft Handover

Hard handover
- "Break before make"
- Connection is released before making the new connection
- Causes a short cut in the connection
- The terminal is linked to no more than one base station at any given time
- Primarily used in FDMA and TDMA, where different frequency ranges are used in adjacent cells

Soft handover
- "Make before break"
- New connection is established before the old connection is released, avoiding a cut in the connection during handover
- After the successful handover, the old connection is released
- Used in CDMA, where adjacent cells use the same frequency range
3.1 Handover Management
Execution: Further Handover Types

Intra-frequency handover
- The new carrier frequency is the same as the previous carrier frequency
- Deployment: CDMA (as neighboring cells usually use the same frequency range)

Inter-frequency handover
- Carrier frequency of the new radio access is different from the old carrier frequency
- Deployment: GSM, handover between different UMTS operators

Inter-system handover
- Happens between two different radio access networks (e.g., GSM and UMTS)
- Special kind of inter-frequency handover
- Deployment: areas where GSM and UMTS coexist and overlay networks
3.1 Handover Management

Handover Control (I)

Network-controlled Handover (NCHO)
- Network measures the transmission quality via base stations and decides when handover should be executed
- Mobile terminal makes no measurements
- Intense signaling between the base stations and the node that decides on handover
- No handover signaling at the air interface
- Handover process (including data transmission, channel and network switching) takes 100-200ms

Mobile-assisted Handover (MAHO)
- Mobile terminal continuously measures signal strength from serving and neighboring base stations and sends the recorded values to the serving base station
- On the basis of these values, the network decides when handover should take place
- Unlike NCHO, the terminal’s situation is taken into account, as the terminal itself does the measuring
- Handover time between handover decision and execution is approximately 1 second
- Increased signaling across the air interface
3.1 Handover Management
Handover Control (II)

Mobile-controlled Handover (MCHO)
- Mobile terminal is completely in control of the handover process, i.e., it measures signal strength and decides on handover
- Very short reaction time (on the order of 0.1 seconds)

Overview

<table>
<thead>
<tr>
<th>Method</th>
<th>Measurem.</th>
<th>Decision</th>
<th>Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network-controlled handover (NCHO)</td>
<td>Network</td>
<td>Network</td>
<td>Analog systems</td>
</tr>
<tr>
<td>Mobile-assisted handover (MAHO)</td>
<td>Network and mobile</td>
<td>Network</td>
<td>GSM, UMTS</td>
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<tr>
<td>Mobile-controlled handover (MCHO)</td>
<td>Mobile</td>
<td>Mobile</td>
<td>DECT, 802.11</td>
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</tbody>
</table>
3.2 Basics of Location Management

Antagonism between Paging and Location Updating

Mobility Management based on pure Paging
- If a call arrives, terminal is paged in all cells of the mobile network
- Location update is not required
- As paging must be executed in all cells of the network for each arriving call/SMS/data-packet
  - high signaling overhead
  - high delay in call/SMS/data-packet delivery

Mobility Management based on pure Location Update
- Each time the user crosses cell boundaries a location update is triggered
- Paging is not required
- As location updates must be initialized whenever crossing cell boundaries
  - high signaling and database update overhead
  - high power consumption in the terminals
### 3.2 Basics of Location Management

#### Basics of Location Areas

**Location Areas**
- Several cells are combined to a location area (LA)
- Subscriber location is known if the system knows the LA in which the subscriber is located
- When the system must establish a communication with the mobile, the paging only occurs in the current LA where called user resides
- Resource consumption is limited to the respective LA: paging messages are only transmitted in the cells of this particular LA
- Location information are stored in databases (generally, a home database and several visitor location databases are included in the network architecture)

**Design of Location Areas**
- Size of LAs is determined in dependence on
  - the cell radius
  - the mean mobile velocity
  - the cost of LUs (in terms of the number of LU messages required to update the location of a mobile)
  - the cost of paging (in terms of the number of paging messages required to find a mobile)
- Goal: minimizing location management cost (LU+paging traffic and processing)
3.2 Basics of Location Management
Location Update Strategies

Periodic Location Updating
- Mobile periodically transmits its identity to the network
- Resource consumption is user-independent and can be unnecessary if the user does not move from a LA for a long time

Location Updating on LA Crossing
- BS periodically broadcasts the identity of its LA (Location Area Identifier, LAI)
- Mobile permanently listens to the broadcast and stores the current LAI
- If the received LAI differs from the stored one, a location update is triggered by the mobile
- Advantage: a highly mobile user generates a lot of LUs; a low mobility user only triggers a few

Hybrid Location Updating
- Combination of Periodic and Location Updating on LA Crossing
- Mobile generates its LUs each time it detects an LA crossing
- If no communication (related to an LU or a call) has occurred between mobile and network for a fixed period, the mobile generates a periodic LU
- Advantage: User location can be recovered in case of database failures
3.2 Basics of Location Management
Paging Strategies

LA-Splitting in Paging Areas
- Mobile registers only when entering the LA; it does not register when moving between PAs of one LA
- For an incoming call, paging messages are broadcast in the PAs according to a sequence determined by different strategies
- Example: Start paging in the PA where the terminal was last detected by the network

Multilayer Location Areas
- Problem: LU traffic is mainly concentrated in the cells of the LA border
- Introduction of multilayer LAs
- Each mobile is assigned to a given group, and each group is assigned one or several layers of LAs
- LU traffic load is distributed over all the cells

![Diagram of multilayer location areas showing different layers with varying traffic load distribution.]
3.3 GSM Location Management

Overview

- Different location management schemes for GSM circuit-switched and GPRS
- GSM circuit-switched: Hybrid location updating
- GPRS: introduction of new (smaller) location areas with adaptive paging/location update strategies

Hybrid location updating

- Periodic execution
  - Executed by the terminal if a timer has expired
  - Timer value is determined by operator:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Country</th>
<th>Periodic LU time constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telekom</td>
<td>Germany</td>
<td>6 hours</td>
</tr>
<tr>
<td>Vodafone</td>
<td>Germany</td>
<td>1 hour</td>
</tr>
<tr>
<td>Eplus</td>
<td>Germany</td>
<td>12 hours</td>
</tr>
<tr>
<td>O2</td>
<td>Germany</td>
<td>4 hours</td>
</tr>
<tr>
<td>Tele2</td>
<td>Estland</td>
<td>24 h</td>
</tr>
</tbody>
</table>

- Execution on location area crossing
  - Mobile station recognizes new location area by reading the LAI broadcast
  - If new location area is recognized, location update is triggered
3.3 GSM Location Management
Numbering Schemes for PSTN/ISDN

International Numbering Plan
- Enables that customers from different countries can call each other in a similar way, i.e., to use the same country code to make a call to a specific country
- Every country belonging to one of 9 different world areas starts with the same digit (e.g. Europe (3 or 4), Central and South America (5),...)
- International numbering plan is specified in the ITU-T recommendation E.164

National Numbering Plans
- Contains the rules of a specific country to follow when issuing telephone number
- Each country has autonomy about its numbering plan, but some countries use the same national numbering plan (e.g., USA and Canada)
- In Germany, the national numbering plan specifies the scheme for local numbers, carrier access numbers, service numbers,...
3.3 GSM Location Management

Example: National Numbering Plan for Germany

International telephone network

Intelligent Network (IN) services

Mobile services

Deutsche Telekom

Carrier access codes

01019

01013

0170, 0171, ...

0172, 0173, ...

0177, 0178, ...

0179, ...

00xx

0800 (0130)
0900 (0180, 0190)

Telekom

Vodafone

Eplus

O₂

freenet

Tele2

Arcor

Tele2

Arcor

0170, 0171, ...

0172, 0173, ...

0177, 0178, ...

0179, ...

00xx

0800 (0130)
0900 (0180, 0190)
3.3 GSM Location Management

Drawbacks of Conventional Numbering Schemes

Telephone numbers in the PSTN/ISDN...

- ...initially represented a geographic area where the associated device was located
- ...have been organized hierarchically in order to reflect the network topology
- ...contain routing information used to locate the destination device of a call

For GSM, this approach is not applicable, because...

- ...users want to be called via their personal telephone number independent of the used mobile device (personal mobility)
- ...are only temporarily attached to a local switch (i.e., MSC) due to terminal mobility
## 3.3 GSM Location Management

**Basics of Numbering in GSM**

<table>
<thead>
<tr>
<th><strong>Numbering of subscribers</strong></th>
<th><strong>Numbering of devices</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Permanent numbering</strong></td>
<td><strong>International Mobile Station Equipment Identity (IMEI)</strong></td>
</tr>
<tr>
<td>• International Mobile Subscriber Identity (IMSI)</td>
<td></td>
</tr>
<tr>
<td>• Mobile Subscriber ISDN Number (MISDN)</td>
<td></td>
</tr>
<tr>
<td><strong>Temporary numbering</strong></td>
<td></td>
</tr>
<tr>
<td>• Mobile Station Roaming Number (MSRN)</td>
<td></td>
</tr>
<tr>
<td>• Temporary Mobile Subscriber Identity (TMSI)</td>
<td></td>
</tr>
<tr>
<td>• Location Area Identifier (LAI)</td>
<td></td>
</tr>
<tr>
<td>• Cell Id (CI)</td>
<td></td>
</tr>
</tbody>
</table>

- Separation between subscriber and device numbering supports personal mobility
- Separation between permanent and temporary numbering supports mobility management
- Mapping between a user’s permanent/temporary and device/subscriber numbers is stored in the HLR and VLR for each user
3.3 GSM Location Management
Permanent Subscriber Addresses

International Mobile Subscriber Identity (IMSI)
- Uniquely identifies the subscriber and is stored in the SIM, HLR, and AuC
- Hierarchical addressing (example: MCN=262 for Germany, MNC=01,02,03,07 for Telekom, Vodafone, Eplus, O₂)
- Used, e.g., for billing

Mobile Subscriber ISDN Number (MSISDN)
- Real telephone number of a subscriber
- Subscriber can have several MSISDNs, e.g., to distinguish several services (voice, data, fax,...)
- Thus, automatic activation of service-specific resources is already possible during setup of connection
- Stored centrally in the HLR and in the SIM
3.3 GSM Location Management
Temporary Subscriber Addresses

Mobile Station Roaming Number (MSRN)
- Temporary location-dependent ISDN number
- Required to make routing decisions and to identify the responsible MSC
- Assigned by the locally responsible VLR to each mobile station in its area and passed to the HLR
- Generated at each registration or when the HLR requests it for call setup (on a call-by-call basis)

Temporary Mobile Subscriber Identity (TMSI)
- Used in place of the IMSI for the definite identification and addressing of the mobile station
- Avoids to determine the identity of the subscriber by listening to the radio channel
- Assigned during the mobile station’s presence in the area of one VLR (by that VLR) and can be changed during this period (ID hopping)
- Is stored by the mobile station on the SIM card
- Is stored on the network side only in the VLR, not in the HLR
- Is assigned in an operator specific way and consists of 4x8 Bits
- Subscriber can be uniquely identified; IMSI is replaced by (TMSI, LAI)
### 3.3 GSM Location Management

**Other Addresses**

### International Mobile Station Equipment Identity (IMEI)
- Uniquely identifies mobile stations internationally
- Allocated by the manufacturer, registered by the network operator and stored in the EIR
- Characterizes a mobile station and gives clues about the manufacturer and the date of manufacturing

### Location Area Identifier (LAI)
- Internationally unique identification of an LA
- Regularly broadcasted by the base station
- “Heard” by the mobile station in order to decide whether or not a new LA has been entered

### Cell Identifier (CI)
- Uniquely identification of cells within an LA
- Length of CI: 2x8 bits
- Internationally unique identification with the Global Cell Identity (LAI+CI)
3.3 GSM Location Management
Overview of Addresses

Cell Identifier
International Mobile Station Equipment Identity
International Mobile Subscriber Identity
Kc - Cipher/Decipher Key
Ki - Subscriber Authentication Key
Mobile Subscriber ISDN Number

Mobile Station Roaming Number
Location Area Identifier
Random Number
SRES – Session Key
Temporary Mobile Subscriber Identity

IMSI, MSISDN, TMSI

IMSI, MSISDN, TMSI

IMSI

MSISDN

MSRN

HLR

MSC

VLR

AuC

EiR

IMEI

BTS

CI, LAI

CI, LAI

CI, LAI
3.3 GSM Location Management
Delivery of a Mobile-Terminated Call (I)

1. Forwarding to responsible GMSC (based on CC and NDC of MSISDN)
2. Request of Mobile Station Roaming Number, which addresses the subscriber at her/his current MSC
3. Delivery of MSRN
4. Forwarding of call to MSC
5. Request of LAI and TMSI for paging
6. Delivery of TMSI
7. Paging request to all BTSs that belong to the LA referenced by the LAI
8. Paging execution through broadcast of TMSI at the paging channel
9. Paging response
3.3 GSM Location Management

Delivery of a Mobile-Terminated Call (II)

Initial Address Message

Process Access Request

Access Request Accepted

Auth. Info

(msi, Kc, RAND, SRES)

Connection through Auth. Par. Request (IMS)

Auth. Info

VLR

MSC

BSC

UE

Paging Resp.

Paging Request (TMSI)

Send info for setup

Page MS (TMSI, LAI)

Setup

Call Conf.

Assign comnd.

Assign compl.

Alert

Connect

Connect ack.

Answer, i.e., switch connection through

Call Conf.

Assign comnd.

Assign compl.

Alert

Connect

Connect ack.

Answer, i.e., switch connection through
### 3.3 GSM Location Management

#### Location Registration versus Update

**Location Registration**
- Must be executed in order to get access to a GSM network, i.e., to receive or to initiate calls
- Registration with home network or a foreign network (roaming; provided there is a roaming agreement between home and foreign network)
- Steps:
  - Sending IMSI and LAI to the network
  - Authentication
  - Start of ciphering
  - Generation of a TMSI (stored in the associated VLR) and an MSRN (stored in the central HLR)
  - MS receives TMSI and saves it in the SIM storage

**Location Update**
- Purpose: Tracking the mobile user in order to deliver calls or SMS
- Hybrid location updating
  - **Execution on LA crossing**: mobile station recognizes that it is in a new LA by regularly reading the LAI broadcasted in each cell
  - **Periodic execution**: Periodic execution of location updates (independent of “Execution on LA crossing”)
- Difference between location registration and location update: location update is based on TMSI (which is only unique in connection with an LAI) instead of the IMSI
3.3 GSM Location Management

Location Update (I)

1. Crossing the border of a new LA
2. Location Update request
3. Update Location (contains old TMSI as well as old and new LAI)
4. Request parameters from old VLR (only required if VLR changes)
5. Deliver parameters from old VLR
6. Update location in HLR (only required if VLR changes)
7. Update confirmation
8. Remove parameters in old VLR
9. Remove acknowledgement
10. Location update confirmation and delivery of a new TMSI
### 3.3 GSM Location Management

#### Location Update (II)

- **Figure shows the location update sequence for subscribers moving within a VLR area and MSC area**
- **If the location area change incorporates change of the MSC or/and the VLR, location update procedure requires interactions with the central HLR (see previous slide)**

- **Location Update Request** ($LAI_{new}, LAI_{old}, TMSI_{old}$)
3.3 GSM Location Management
Number Portability

- MSISDNs are operator-specific and initially could not be kept by the user when changing the operator (number portability)
- Regulatory Authority for Telecommunications and Posts imposed operators to support number portability

- GSM TS 23.066: introduction of an additional Number Portability Database (NPDB)
- NPDB: operational database (used in real time at call set-up) which provides portability information

Diagram:
- Incoming call
- MSISDN
- Number range holder network (initial operator of target subscriber)
- Home network
- Visited network

Detection that MSISDN is ported
- NPDB
- HLR
- Unknown Subscriber error
- Routing Number, MSISDN
- GMSC
- GMSC
- MSC
- VLR
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
3.4 GPRS Location Management

Introduction of Routing Areas

- Like terminals must be located for incoming calls in circuit-switched GSM, in GPRS localization is necessary for the delivery of data packets in the downlink:
  - High overhead, which may exceed amount of user data to be transferred
  - High delay for packet delivery
  - Not used

- Instead: Introduction of
  - Routing areas and
  - State model for adaptive location management

Routing Areas

- A routing area comprises several cells
- Routing areas are significantly smaller than location areas
- Depending on the GPRS state model, location updates and paging are related
  - to routing instead of location areas or
  - to cells
### 3.4 GPRS Location Management

#### Circuit versus Packet-Switched Traffic

- Frequency of data bursts (i.e., packets) exchanged in the packet-switched mode may be much higher than that of calls in the circuit-switched mode.
- Interarrival-time of data bursts is on average much smaller than the inter-arrival time of calls.
- Packet switched traffic may result in an increased number of paging requests, i.e., each time a data burst is to be transferred in the downlink.
3.4 GPRS Location Management

LA/RA Size versus Signaling Overhead

- Optimal LA/RA size is determined in dependence on the margin between location update and paging costs.
- As paging costs are much higher for packet-switched traffic, routing areas have a smaller number of cells than location areas.
3.4 GPRS Location Management

GPRS Location Management State Model

- **States:** IDLE, READY, STANDBY
- **Timers:** READY, STANDBY

- State transitions are executed by timers, data packet transfer, or user activity
- No paging and low delay of packet delivery in the READY state, but increased location-update overhead
- Decreased location-update overhead and power consumption in the STANDBY state, but increased paging overhead if downlink transmission starts
- Timers are operator-specific and are broadcasted on a dedicated signaling channel to the terminals

### IDLE
- Terminal is not reachable in GPRS mode
- Location management according to GSM circuit-switched

### READY
- Terminal performs location updates whenever entering a new cell

### STANDBY
- Terminal performs location updates whenever entering a new routing area
3.5 UMTS Location Management
Introduction of UTRAN Registration Areas

Experiences from GPRS
- Location management is exclusively controlled in the core network (e.g., by SGSNs)
- Procedures (paging and location/cell updates) must pass the interface between access and core network
- High load and large delays

New approach for UMTS PS domain
- Track subscribers on the basis of routing areas in the core network
- Track subscribers on the basis of UTRAN Registration Areas (URAs) and cells in the access networks
3.5 UMTS Location Management

UMTS Location Management State Models

- Location updates on crossing of routing areas
- Corresponds to CELL CONNECTED or URA CONNECTED state in the access network

(a) State model for the core network

- PMM DETACHED
- PMM CONNECTED
- PMM IDLE

- Location updates on crossing of routing areas
- No location management in the PS domain

(b) State model for the access network

- IDLE
- CELL CONNECTED
- URA CONNECTED

- Location updates on crossing of cells
- Location updates on crossing of URAs
- Corresponds to PMM CONNECTED state in the core network

- No location management in the access network

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3.5 UMTS Location Management

Overview of Components Storing Location Data

- Location of a terminal in idle mode is not always known to the network with the granularity of radio cells
- In circuit-switched mode the network tracks an idle terminal only in terms of location areas
- In packet-switched mode the granularity of tracking depends on the idle terminal’s state with regard to the GPRS/UMTS state model, i.e., on the time the last packet transfer has occurred between terminal and network (or vice versa)

<table>
<thead>
<tr>
<th>Components that store location data and the granularity of location:</th>
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<tbody>
<tr>
<td>GSM</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>Cell</td>
</tr>
<tr>
<td>URA</td>
</tr>
<tr>
<td>Routing area</td>
</tr>
<tr>
<td>Location area</td>
</tr>
</tbody>
</table>