Lecture 2
Mobility management & handovers

Network architecture

Node B  Base station (UMTS)
BSS  Base station (GSM)
BSC  Base station Controller (GSM)
RNC  Radio Network Controller (UMTS)
MSC  Mobile Switching Center
SGSN  Serving GPRS Support Node
GGSN  Gateway GPRS Support Node
GMSC  Gateway MSC
VLR  Visitor Location Register
HLR  Home Location Register
UE  User Equipment
Mobility management

- Mobility management MM is handled by MSC (circuit switched CS domain) or SGSN (packet switched PS domain) and UE.
- The location register should keep track of the user location area. The mobility management protocol is utilized to updates this information.
- Base stations are grouped into Location Areas and they broadcast the Location Area Identifier (LAI).
- When mobiles are switched on and off attach/detach messages are transmitted.
- Mobiles need to detect the LAI and make location update.
  - Normal location update:
    - UE detects its location area based on the LAI (Location Area Identifier) value broadcasted by the network and informs connection management CN entity. If LAI changes due to Mobility, UE informs CN using normal location update procedure.
    - The procedure is also started if the network indicates that UE is unknown in VLR as a response to service request.
    - UE is required to maintain a list of forbidden location areas based on failed location updates.
  - Periodic location update: UE informs its availability and location to CN periodically.
- The size of the LAI affects the system performance.
  - If LAI is large (in terms of base stations), the mobile does not have to transmit location area updates often. On the other hand, multiple paging messages are needed in case of incoming call to the mobile.
  - If LAI is small, the UE must make location area updates often which consumes radio resources in the uplink.
  - The mobile needs to periodically listen for the LAI broadcast by the base stations which consumes mobile power. If the LAI update rate is too low, mobile may move out of paging coverage before next update is made.
  - There is a tradeoff between efficient paging and radio resource and energy consumption.
Handovers

- While MSC or SGSN keeps track of the mobility on higher layer, the task of handover control is to hand a on-going call from cell to another without breaking the end-to-end connectivity.
- Handover control is done by the radio resource control protocol running at the UE and RNC.
- The handover procedure can be divided into three phases
  1. Handover decision
  2. Handover resource assignment
  3. Handover execution

Handover types

- Soft(er) handover (SHO) / Macro diversity handover
  - Mobile is connected to multiple base stations at the same time.
- Hard handover (HHO)
  - Mobile can be connected to a single base station
  - Old radio link is released before new one is made.
    - This can cause a short time during which data transfer is disconnected.
- Inter-frequency handover (IF-HO)
  - Single operator can have multiple frequency bands available.
  - Handover between macro, micro and pico cells
- Inter-radio access technology handover (IRATHO)
  - Handover between different systems controlled by the same mobile switching center (e.g. handover between UTRAN and GRAN)
- Vertical handover
  - Handover between different networks (e.g. handover between UTRAN and WLAN)
Handover types

- UTRAN
- Interfrequency handover
- Vertical handover
- WLAN/WiMAX
- Other networks
- RAN controlled by single MSC

Handover decision

- UE classifies the base stations into the following sets
  - Neighboring set / monitored set / candidate set
    - Defines the set of base stations that UE monitors which are currently not included into active set
  - Active set
    - If soft handover is possible, the UE can be connected to more than one base station at the time.
    - The active set defines the set of cells that the UE is currently connected
Handover decision

- The handover decision is made by measuring the pilot signal quality received by the UE from the different cells.
- The handover procedure can be controlled either by the network or the user terminal
  - MAHO Mobile assisted handover:
    - Mobiles periodically measures and reports the signal strengths of the pilots transmitted by the base stations.
    - To limit the number of channels that the mobile needs to track, the network can provide the mobile neighbor lists.
    - The decision to initiate the handover is done by the radio network / base station controller.
    - Most of the cellular radio systems use MAHO.
  - Mobile controlled handover: The mobile initiates the handover procedure. Such a system is used e.g. in DECT.

Handover decision

- The measurement of the pilot signal quality affects handover performance.
  - The pilot signal contains both fast fading and shadow fading.
  - To avoid frequent handovers, the pilot signal must be filtered before decision is made.
    - The time the signal needs to be filtered depends on the mobile speed. If the filtering time is too long, then a fast mobile can penetrate deep into the neighboring cell before it is handed over. This can cause high interference.
  - The choice of pilot signal quality measure has an impact on the system performance.
  - **Pilot pollution** occurs when the due to interference the number of (almost) equally strong pilots in a cell becomes large
Handover decision

- Consider a simple 1D handover model where mobile is moving from base station 1 to 2 on a straight line with speed $v$

  $\begin{align*}
  A_1(n) &= C - K \log_{10}(v n T) + X_1(n) \\
  A_2(n) &= C - K \log_{10}(D - v n T) + X_2(n)
  \end{align*}$

  $D$ denotes the distance between base stations
  $K$ is a parameter related to the pathloss exponent
  $X_i(n)$ denotes the shadow fading

Handover decision

- The pilot signals transmitted by the base stations are subject to correlated shadow fading
  - Two points in the line separated by distance $d$ have correlation $\epsilon_d$
  - As the mobile moves we sample the pilots with sampling interval $T$
  - The shadow fading sample $X_i(n)$ is Gaussian random variable with correlation structure
    $E\{X_i(n)X_i(n+k)\} = \sigma^2 a^{|k|}$
    $a = \epsilon_d^{vT/d}$ Pilot signal strength from base 1
Handover decision

- Handover decision
  \[ b(n) = F(B_1(n), B_2(n)) \]
  selected base station
  \[ B_i(n) \] decision variable calculated from past pilot signal
  samples \( A_i(0), A_i(1), \ldots A_i(n) \).

- Examples for handoff criteria
  - **Instantaneous handoff**: \( B_i(n) = A_i(n) \)
  - **Averaging**: \( B_i(n) = 1/W \sum_{k=n-W+1}^{n} A_i(k) \)
  - **Optimal (ideal prediction)**: \( B_i(n) = A_i(n+1) \)
  - **Prediction**: \( B_i(n) = E\{A_i(n+1)|n\} \)

- Filtering is needed, since in practice the estimates are
  noisy.

Handover decision

- Handover performance metrics
  - **Outage probability**: \( G_1 = \text{Pr}\{A_{b(n)}(n+1) < \beta\} \)
    handover is not done even if the signal level drops
    below the threshold value \( \beta \)
  - **Probability of unnecessary handover**:
    \( G_2 = \text{Pr}\{A_{b(n)}(n+1) > \beta, A_{b(n-1)}(n+1) > \beta, b(n) \neq b(n+1)\} \)
    handover is done even if the signal level from the old
    cell would have been large enough to support
    communication
  - **Handover probability**:
    \( G_3 = \text{Pr}\{b(n) \neq b(n+1)\} \)
    Average number of handovers during the call
Handover decision

- $C=115$, $K=35$, $\sigma=5$ dB, $D=1000$ m
- $\Delta$ denotes the protection margin on the cell edge

**Figure 3**: Probability of handover as a function of $\sigma$.

**Figure 4**: Probability of lost call as a function of $\Delta$.

Handover decision

- Instantaneous handoff leads to frequent handovers which causes large signaling load.
- Filtering reduces the number of handovers, but makes the system slow to react to sudden changes in the signal strength (e.g. in Manhattan grid environment)
Handover decision

• Besides mobility management, handovers are also used as a tool for load control (and load balancing).
• In hierarchical cell layouts, the system can relieve congestion on a given band by making inter-frequency (IF-HO) or inter-radio access network (IRATHO) handovers.
• If the loading among the neighboring base stations are very uneven, then the quality of service for the users in the loaded cell could be increased by handing some of the users on the cell edge to a lightly loaded neighboring cell.

Handover decision in UMTS

• UE measures the strength of pilot signals (CPICH channels) of the neighboring base stations.
• In addition, UE needs to listen to the SCH channels to find out the timing differences between the base stations.
• SRNC keeps track of the pilot signals. If the power of certain pilot exceeds a given threshold, the corresponding base station is added to the Active set. Similarly, if the pilot strength deteriorates below some lower limit, the corresponding base station is removed from the active set.
• All the base stations in the active set take part in the communication.
• 30...40% of the users will be in handover state

CPICH  Common Pilot Channel
SCH    Synchronization Channel
SRNC   Serving Radio Network Controller
Soft(er) Handover

- If $\text{Pilot}_\text{SIR} > \text{Best}_\text{pilot}_\text{SIR} - \text{reporting}_\text{range} + \text{Hysteresis}_\text{event}_1A$ for $\Delta T$ (sec) and the active set is not full, base station is added to the set.

- If $\text{Pilot}_\text{SIR} < \text{Best}_\text{pilot}_\text{SIR} - \text{reporting}_\text{range} - \text{Hysteresis}_\text{event}_1B$ for $\Delta T$ (sec), then the base station is removed from the active set.

- If $\text{Best}_\text{candidate}_\text{PILOT}_\text{SIR} > \text{Worst}_\text{Old}_\text{Pilot}_\text{SIR} + \text{Hysteresis}_\text{event}_1C$ for $\Delta T$ (sec), then the best candidate base station replaces the base station corresponding to the weakest pilot signal.

Soft(er) Handover in UMTS

- 1A: Add cell 2
- 1B: Remove cell 3
- 1C: Replace cell 1 by cell 3

Management of active set

<table>
<thead>
<tr>
<th>Event</th>
<th>Hysteresis</th>
<th>Time to trigger</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>0.5 dB</td>
<td>0 s</td>
</tr>
<tr>
<td>1B</td>
<td>0.5 dB</td>
<td>250 ms</td>
</tr>
<tr>
<td>1C</td>
<td>1.5 dB</td>
<td>500 ms</td>
</tr>
</tbody>
</table>
Soft(er) Handover in UMTS

- Handover should be based on mean CIR of the pilot signal. Fast fading must be filtered out to prevent the ping-pong phenomenon.
  - If the mobile speed is high (say 50 km/h or more) then it is relatively easy to average out the fast fading. Filtering time constant of 100ms is enough.
  - If the mobile speed is low (e.g. pedestrian), then averaging out the fast fading requires a filter with a time constant of the magnitude of 1 s.
  - Filtering causes sluggishness to the handover: If the filter time constant is long, then the mobile can penetrate deep into the neighboring cell before it is handed over to that cell. This causes a lot of interference to the other users.
  - Hence, there is a trade off between minimizing the signaling load and interference.
  - In 3GPP standard, the measurement time for SIR is set to 200 ms.

- The choice of pilot quality measure has an impact on the system performance.
- In UMTS, we could measure e.g. the pilot E_c/I_0 (chip-energy-to-interference power density) or the pilot SIR.
  - Wideband criterion CPICH Ec/I0 = CPICH RSCP/RSSI
  - Narrowband criterion CPICH SIR = CPICH RSCP/ISCP
- RSCP is the received code power measured on the Primary CPICH. RSSI is the wide-band received power within the relevant channel bandwidth.
- ISCP is the measured interference after despreading on a reserved orthogonal code, which has the same spreading factor as the Primary CPICH.
- If the narrowband criterion is used for handover evaluation, the mobile station tends to propose that a handover is made to higher loaded cell due to orthogonality.
- Ideally narrowband criterion minimizes locally the required downlink power for an individual radio link if secondary effects are not taken into account. Thus, theoretically narrowband criterion could minimize the total downlink interference and thereby maximize downlink capacity.
- If realistic measurement performance is considered, the wideband criterion gives 1.4 to 3.7 times better capacity than the narrowband criterion, assuming 2–4 dB measurement error for wideband measurement and 7–10 dB measurement error for narrowband measurement.

Soft(er) Handover in UMTS

- System level simulation results su

![Graphs showing uplink and downlink capacity as a function of measurement error.](image)


Handover resource assignment

- Practical handover quality measures include
  - *Active set update success rate*: Fraction of active set updates that were successful
  - *Soft handover overhead*: Average number of radio links per connection
  - *Handover success ratio*: Fraction of handover attempts that were successful. Handover failure does not necessarily imply call drop, if the call can be replaced back to the original cell
  - *Call drop rate*: Fraction of handoff calls that were dropped due to handover failure.
Handover resource management

- Once a handoff decision has been made, a receiving base station needs to allocate resources for the call.
- Handover resource management is closely related to admission control which controls the allocation of resources to new calls.
- Typically dropping an ongoing handoff call is considered more undesirable than blocking and incoming new call. Consequently, handoff calls are typically prioritized over incoming new calls. This is done by resource reservation.
- *Grade of service* GoS = Blocking probability + K \cdot Handoff failure (dropping probability), K>1

Priority handoff

- Priority given to handoff calls before new calls
- State dependent rejection scheme (SRS)
  - When \( i \) channels are occupied a newly originated call is given the channel with probability \( p_i \)
  - If there are still free channels, a handover call is given channel with probability 1.

Handover resource assignment

- A queued handoff call will be dropped if a channel cannot be assigned to it during the time it dwells in the handover region. This time is modeled as exponential distributed r.v. with mean $1/\delta$.
- The system can be modeled as a Markov chain.

Define

\[ A = \frac{\lambda}{\mu} \]
\[ \lambda_i = \lambda (p_i + \alpha), 0 \leq i < C \]
\[ \lambda_i = \lambda \mu, i \geq C \]
\[ \mu_i = \mu, 0 \leq i < C \]
\[ \mu_i = \mu + (i-C)\mu, C \geq i \]
\[ p'_i = (\alpha + p_i)/(\alpha + 1) \]
\[ \alpha' = \alpha/(\alpha + 1) \]
\[ \gamma' = \delta/\mu \]

Steady state probabilities:

\[ P_0 = \left[ 1 + \sum_{i=1}^{C} \frac{\lambda \mu p_i \ldots \lambda_{i+C} p_{i+C-1}}{\mu \mu_2 \ldots \mu_{i+C-1}} \right]^{-1} \]
\[ P_i = P_0 \frac{A_i}{i} \prod_{j=0}^{i-1} \mu'_{i-j-1}, \quad \text{for } 1 \leq i \leq C \]
\[ P_i = P_0 \frac{A_i^C}{C!} \frac{\lambda'_{i+C-1}}{\lambda'_{i+C-1}} \frac{\mu'_{i+C-1}}{\mu'_{i+C-1}} \frac{\lambda'_{i+C-1}}{\mu'_{i+C-1}} \prod_{j=1}^{C} \left( \frac{\alpha' \gamma' - j}{\lambda'_{i+C-1}(i+j-1)} \right), \quad \text{for } C < i \]
Handover resource assignment

- Probability that new call is blocked

\[ PB = \frac{\text{number of blocked calls}}{\text{total number of call attempts}} \]

\[ = \frac{\lambda \sum_{i=0}^{C-1} (1 - p_i) P_i}{\lambda \sum_{i=0}^{\infty} P_i} + \frac{\lambda}{\lambda \sum_{i=0}^{\infty} P_i} \sum_{i=0}^{C-1} P_i \]

\[ = \sum_{i=0}^{C-1} (1 - p_i) P_i + \sum_{i=C}^{\infty} P_i = 1 - \sum_{i=0}^{C-1} p_i P_i \]

**Handover resource assignment**

- Probability that handoff call fails. That is, the call departs the handoff region before it can be assigned a channel. (Departures due to call ending are not counted as failures)

\[ PD = \frac{\text{number of dropped calls}}{\text{total number of handoff attempts}} \]

\[ = \frac{\sum_{i=C}^{\infty} \delta(i-C)P_i}{\sum_{i=0}^{\infty} \alpha_i \lambda P_i} = \frac{1}{\alpha' A' \gamma} \sum_{i=C}^{\infty} (i-C)P_i \]

- In multi-cellular case, a call on average experiences \( \alpha \) handovers, so the overall handoff failure probability \( PF \) is

\[ PF = 1 - (1 - PD)^\alpha \approx \alpha \cdot PD \]
Handover resource assignment

- Guard channel scheme
  GCS:
  - C-G channels are reserved for handoff calls
    \[ p_i = 1, \ i < G, \ p_i = 0, \ i \geq G \]
  - No queuing is allowed
    \[ \delta \to \infty \]
  - Guard channel scheme with queuing GCQ:
    - Queuing is allowed
      \[ \delta < \infty \]

- Handoff queuing scheme HQS:
  - There is no prioritization, but only handoff calls are allowed to queue
    \[ p_i = 1, \ i \leq C \]

- Modified Handoff queuing scheme HQS2:
  - A fraction \(1-p\) of the new call attempts are rejected
    \[ p_i = p \] for all \( i \leq C \)

- Dynamic channel reservation scheme (DCRS)
  - Fractional channel reservation
    \[ p_i = 1, \ i < G, \ 0 < p_i < 1, \ i \geq G \]
  - Handoff attempts do not queue \( \delta \to \infty \)

- Dynamic channel reservation scheme (DCRQ)
  - Handoff attempts are queued \( \delta < \infty \)
Handover resource assignment

- **EB**: A modification of DCRQ, but the probabilities $p_i$ are set to $1 - EB_{C_i}(\rho)$ that corresponds to the blocking probability in case of $C_i$ channels

\[
EB_{C_i}(A) = \frac{A^e}{C!} \sum_{k=0}^{\frac{A^e}{A}} \frac{A^e}{A}
\]

- **EC**: As EB, but Erlang-C formula is used instead $1 - p_i = EC_{C_i}(\rho)$

\[
EC_{C_i}(\rho) = \frac{(CA)^{i}}{C! \cdot 1 - \rho} \sum_{k=0}^{\frac{(CA)^{i}}{C}} \frac{(CA)^{i}}{k!} \cdot \frac{1}{C! \cdot 1 - \rho}
\]

- **Linear**: SRS with linearly decreasing probability ($p_0 = 1$ and $p_C = 0$)

Handover resource assignment

- **Numerical examples**
  - Channel holding time $1/\mu = 41$ s
  - Average number cells of visited cells during a call $\alpha = 2.78$
  - Average time in the degradation area 10% - 20% of the channel holding time
Handover resource assignment

- PB Blocking Probability, PF Handoff Failure Probability, Carried Traffic (CT), GoS Grade of Service

<table>
<thead>
<tr>
<th>Method</th>
<th>PB (%)</th>
<th>PF (%)</th>
<th>CT (%)</th>
<th>GoS</th>
<th>Good</th>
<th>Bad</th>
</tr>
</thead>
<tbody>
<tr>
<td>H266</td>
<td>0.65</td>
<td>0.27</td>
<td>8.96</td>
<td>4.7</td>
<td>PB CT</td>
<td>PF</td>
</tr>
<tr>
<td>H267</td>
<td>0.5</td>
<td>0.26</td>
<td>8.91</td>
<td>5.5</td>
<td>PB, GoS</td>
<td>PF</td>
</tr>
<tr>
<td>GCS</td>
<td>G=13</td>
<td>2.8</td>
<td>0.14</td>
<td>8.87</td>
<td>4.9</td>
<td>PP</td>
</tr>
<tr>
<td>GCO</td>
<td>G=14</td>
<td>1.4</td>
<td>0.15</td>
<td>8.93</td>
<td>3.4</td>
<td>PP, GAS</td>
</tr>
<tr>
<td>DCAR</td>
<td>G=11</td>
<td>2.7</td>
<td>0.24</td>
<td>8.87</td>
<td>6.3</td>
<td>PP, GoS, CT</td>
</tr>
<tr>
<td>DCBIQ</td>
<td>G=12</td>
<td>1.7</td>
<td>0.15</td>
<td>8.92</td>
<td>4.6</td>
<td>GoS</td>
</tr>
<tr>
<td>EB</td>
<td>G=10</td>
<td>0.9</td>
<td>0.22</td>
<td>8.95</td>
<td>4.2</td>
<td>PF</td>
</tr>
<tr>
<td>ES</td>
<td>G=16</td>
<td>1.8</td>
<td>0.20</td>
<td>8.84</td>
<td>4.1</td>
<td></td>
</tr>
</tbody>
</table>

S-72.3260 Radio Resource Management Methods 3 op | TKK Communications Laboratory | 35

Handover resource assignment
Handover resource assignment

- Simulation results in 7x7 cell hexagonal layout for DECT system (mobile speed 36 km/h)

- HQC obtains highest resource utilization (CT) however this comes with the cost of high handoff failure probability (high GoS)
- The performance of GCS and DCRS can be improved by allowing queuing.
- The higher the mobility, the larger portion of the resources should be allocated to handoff calls in order to keep handoff failure probability small.
- The lower the handoff failure rate the higher the blocking probability