Handover algorithms and parameter estimations

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S-72.333 Post-Graduate course in
Radio Communications
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REFERENCES

• Stüber: ”Principles of mobile communication”, 2001
• Lee: ”CDMA systems engineering handbook”, 1998
• Laiho, Wacker, Novosad: ”Radio network planning and optimisation for UMTS”, 2002
• 3GPP specifications
• Selected VTC 99-00 conference proceedings

• Other material and experiences of practical networks
1. Introduction and motivation

- Handovers are needed in cellular systems to maintain mobility and acceptable link quality without causing unnecessary co-channel and adjacent channel interference.
- Handover decisions are based on the measurement results reported by the MS / BTS, parameter sets for each cell and algorithms.
- Handovers are made on the basis of algorithms, which are used for comparisons. Different handovers make use of different algorithms to be successful in different situations.
- Target cell evaluation is a big part of the handover process. This can be performed by measuring e.g. C/I, BER, signal strength, distance, traffic load etc.
- Handovers are triggered off by threshold comparison or by periodic comparison fullfilling different reasons and priorities.
Different ways to control handover

- There exists basically three (3) different ways to control handovers in cellular networks. Based on these the handover algorithms are characterized to:

<table>
<thead>
<tr>
<th>Network controlled</th>
<th>Mobile assisted – Network controlled</th>
<th>Mobile controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used widely in 1st generation systems</td>
<td>Used widely in 2nd gen. systems (GSM).</td>
<td>Used for example in DECT</td>
</tr>
<tr>
<td>Link quality is only monitored by serving BTS and surrounding ones</td>
<td>Both serving BTS and mobile measure link quality.</td>
<td>Both serving BTS and mobile measure link quality.</td>
</tr>
<tr>
<td>Handover decisions are made centrally in ”MSC”</td>
<td>Surrounding BTS measurements obtained only by the mobile and reported to the network.</td>
<td>Surrounding BTS measurements obtained only by the mobile and reported to the network.</td>
</tr>
<tr>
<td>Typically support only intercell handovers and have massive delays (several secs..)</td>
<td>Handover decisions made by serving BTS and MSC.</td>
<td>Link measurements at the serving BTS are relayed to the mobile.</td>
</tr>
<tr>
<td></td>
<td>Both inter- and intracell handovers supported and typically 1-2 sec delays.</td>
<td>Mobile makes the handover decision</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Very low delays</td>
</tr>
</tbody>
</table>
2. Signal strength based hard handover algorithms

- In hard handover the mobile can connect to only one BTS at a time (the connection is interrupted for a short moment).
- Basic hard handover is very simple and inexpensive to implement (no diversity gain possibility, based on imposed hysteresis)

- Most hard handover algorithms are basically optimised via two main parameters;
  - Hysteresis (or handover margin) and
  - Temporal window length (over which the measurements are averaged)
- The optimal window length can be estimated e.g. through theory of analog averaging (Lee)
- Stüber shows that the rule of thumb for number of samples to average within a window is \( N = \frac{20...40\lambda_c}{S} \), where S is the spatial sampling period.
Signal strengh based hard handover algorithms

There are many more controlling parameters in practice, e.g. **individual offset** can be given to cells.
Basic handover situations from GSM

Practical Examples

1. Adjacent Channel in Adjacent Cell
   - $C/I_a = -9 \text{ dB}$
   - In practice after -6 dB -> interferences + quality goes down to 4-5
   - $\text{hoMarginLev} < -6 \text{ dB} \rightarrow \text{Ping-Pong}!!$

2. Cell with Very Large Coverage Area
   - MS switched off in cell A and transferred to area of cell X
   - MS switched on in new place
     -> MS tries first old channel + neighbours
   - MS camped on cell A which is not in neighbour list of cell X
     -> do not listen BCCH of cell X -> no HOs to cell X !!!

Handover algorithm parameter optimisation is needed in practical networks
Example of how a list of candidate cells for handover is provided to the mobile

If previous entities are present, penalty list is provided.

Measurement results:

Two urgency conditions are evaluated: bad signal quality and excessive timing advance. The signal quality is evaluated in the UL as well as in the DL.

The criteria for e.g. Hierarchical Cell Structures, Intra-cell Handover, and Cell Load Sharing are evaluated.

The candidate list is sent for further processing to be used for channel allocation.

Penalty list:

Initiations

Filtering

Urgency conditions

Basic ranking

Auxiliary radio network functions evaluations

List organizing

List sending

Allocation reply

Connection entity is created

Measured values (for signal strength, quality and timing advance) are filtered by performing an averaging of a number of consecutive measurements.

A basic ranking list of cell candidates is prepared. Algorithms can take both signal strength and path loss into account.

All cells are organized into one final candidate list according to rules that are defined by the outcome of the urgency conditions.

The outcome of the channel allocation determines the action. At success, the connection is transferred to another channel and the process is transferred to a new connection entity. At congestion or signalling failure, the connection remains.
Quality and signal level based handover algorithm

- If the handover threshold comparison indicates that a handover due to uplink or downlink quality or level is required, the radio link properties of the adjacent cells are evaluated in order to find a target cell. For example, next equations can be used in case of uplink or downlink quality or level (for quality, parameters with level are replaced):

\[ AV_{RXLEV\_NCELL}(n) > rxLevMin\_Cell(n) + \text{Max}(0, A) \]
\[ A = msTxPwr\_Max(n) - msTxPwr\_Max \]
\[ AV_{RXLEV\_NCELL}(n) > AV_{RXLEV\_DL\_HO + hoMargin\_Lev}(n) \]

- The averaged measurement values of signal quality or level are compared against the set threshold values to trigger the handover.
  E.g. \( AV_{RXQUAL\_UL/DL\_HO} \) vs \( \text{HoThresholdsQualUL} \)

- Parameters such as total number of averages to be taken into account and a number of averages which have to be worse/better than threshold value are often used.
Power budget based handovers

- Power budget handover procedure ensures that the mobile is always handed over to the cell with the minimum path loss, even though the quality and the level thresholds may not have been exceeded.

Example (Power Budget HO)

Serving Cell:
- AV_RXLEV_DL_HO = -90 dBm
- msTxPwrMax = 33 dBm (= 2W)
- btsTxPwrMax = 42 dBm (= 16 W)
- BTS_TX_PWR = 42 dBm (= 16 W)
- hoMarginPBGT(n) = 6 dB

Best Adjacent Cell:
- AV_RXLEV_NCELL(n) = -80 dBm
- rxLevMinCell(n) = -99 dBm
- msTxPwrMax(n) = 33 dBm (= 2W)
- btsTxPwrMax = 42 dBm (= 16 W)
- BTS_TX_PWR = 42 dBm (= 16 W)

1. **-80 dBm > -99 dBm + (33 dBm - 33 dBm) = -99 dBm**

2. **PBGT = (33 dBm - -90 dBm - (42 dBm - 42 dBm)) - (33 dBm - -80 dBm) = 10 dB**

**10 dB > 6 dB**

OK !!!!
Umbrella handover algorithm

- The umbrella handovers are utilised in order to make handovers between different network layers or cell sizes possible when needed. For example between GSM 900/1800 or macro/micro cells.

- The measurement results of the adjacent cell must satisfy the equations

\[ AV\_RXLEV\_NCELL(n) > hoLevelUmbrella(n) \]
\[ AV\_RXLEV\_NCELL(n) > AV\_RXLEV\_DL\_HO + hoMarginLev(n) \]

before the umbrella handover is possible.

- In order to be effective, the umbrella HO algorithm should take into account also the power class of the mobile. For example so that selected cells are macrocells for vehicle mobiles and microcells for handhelds.
Other handover algorithm types

• The handover can be considered imperative if the cause is for example one of the following two events:

• 1. MS - BTS distance
   - The mobile can be ordered to wait for a certain time or try level/quality handover at once when certain distance is reached

• 2. Rapid field drop
   - When a mobile experiences rapid drop in signal strength, the handover must be performed as fast as possible.
   - The basic idea of the faster target cell evaluation is to make the handover rapidly to the better adjacent cell by using smaller averaging windows thus speeding up the handover process.

• Traffic based handover

   In order to share the load between cells, a specified number of handovers from one specified cell can be performed. It is usually possible to make traffic reason handovers to cells with better, equal or even worse radiolink conditions
3. Velocity adaptive handover algorithms

- Temporal based handover algorithms can give poor performance in diverse propagation environments and with wide range of mobile speeds. This situation is difficult to improve with algorithm parameter optimisation...

- Temporal averaging of received signal measurements with short fixed window length gives optimal handover performance for only a single velocity.

- A method for estimating mobile speed is needed in order to keep handover delays acceptable.

- Crossing rate algorithm is based on counting the rate with which the signal level crosses the averaged signal level due to fast fading.

- The estimations are based on using LCR or ZCR functions

- Velocity can be estimated also e.g. by estimating the autocovariance between faded samples (covariance method)
Velocity adaptive handover algorithms

- A velocity adaptive handover algorithm must **adapt the temporal window** over which the mean signal strength estimates are taken by either **keeping the sampling period constant and adjusting the number of samples per window**, or vice versa.

- In principle, **high-speed mobile should use shorter average window size, and low-speed MS should use longer average window size**. Therefore, all averaging-processes should have two sets of window parameters, one set for high speed mobiles and one set for low speed mobiles.

- By applying various window size, fast-moving MSs have shorter window size and they may handover to target cell faster. For a slow-moving MS, a longer window size is applied in order to prevent it from unnecessary oscillation.

- Velocity adaptive handovers are used to increase the capacity of a cellular network, areas of high traffic density may be covered with a multi-layer network consisting of different sized cells. If a high speed mobile is located in such an area it should be located in a macrocell to decrease the amount of handovers. In other words a high speed mobile locating in a microcell would result in increased signalling load and potentially high amount of dropped calls in the network.
Velocity adaptive handover algorithms – Example usage in GSM

- Macrocell with RF hopping
- Fast MSs
- Slow MSs
- Microcell(s), no RF hopping
- BSS6/MS speed
- BSS5/Fast MS
- Adjacent cell measurements
- Meas_res
- HO&PC algorithm
- Crossing rate algorithm
4. Pilot-to-interference based handover algorithms

- In **CDMA** based systems the mobiles use the pilot signals from different base stations to initiate and complete handovers. Each pilot signal is measured in terms of $E_c/I_0$ (energy per chip/interference):

$$E_c = \frac{E_b \cdot R}{I_0 \cdot N_0 \cdot W \cdot (1-\eta)}$$

- **Soft handover** is utilised, where the mobile can be connected to several base stations simultaneously (in practice $\leq 3$)

- **Parameters to estimate in soft handover:**
  - Window-add
  - Window-drop
  - Window-replace
  - Time-to-trigger
  - active set size (AS)
  - Individual offsets

SHO algorithm performance can be monitored by e.g.:
- Rate of AS updates
- Mean size of AS
- Average signal quality
Example WCDMA soft handover algorithm

<table>
<thead>
<tr>
<th>Measurement Quantity</th>
<th>CPICH 1</th>
<th>CPICH 2</th>
<th>CPICH 3</th>
<th>ΔT</th>
<th>ΔT</th>
<th>ΔT</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>AS_Th – AS_Th_Hyst</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>As_Th + As_Th_Hyst</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>As_Rep_Hyst</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Event 1A ➔ Add Cell 2
Event 1C ➔ Replace Cell 1 with Cell 3
Event 1B ➔ Remove Cell 3

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Example wcdma soft handover algorithm

- If Meas_Sign is greater than (Best_Ss - As_Th + As_Th_Hyst) for a period of \( \Delta T \) and the Active Set is not full add **Best cell outside the Active Set in the Active Set.**

- If Active Set is full and Best_Cand_Ss is greater than (Worst_Old_Ss + As_Rep_Hyst) for a period of \( \Delta T \) **add Best cell outside Active Set and Remove Worst cell in the Active Set.**

- If Meas_Sign is below (Best_Ss - As_Th - As_Th_Hyst) for a period of \( \Delta T \) **remove Worst cell in the Active Set.**

Where:
- Best_Ss: the best measured cell present in the Active Set;
- Worst_Old_Ss: the worst measured cell present in the Active Set;
- Best_Cand_Set: the best measured cell present in the monitored set.
- Meas_Sign: the measured and filtered quantity.
Parameter estimations for wcdma soft handover

- Increasing the margin for SHO, will allow more SHOs to occur
- Pilot channel power optimisation important
Parameter estimations for WCDMA soft handover – individual offset
Parameter estimations for WCDMA soft handover – Time to trigger

![Diagram showing parameter estimations for WCDMA soft handover.](image)

- Measurement Quantity
- P_CPICH best cell
- P_CPICH 2
- Reporting range
- Event 1b: not reported
- Event 1b: reported
- Time to trigger

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Parameter effects for WCDMA soft handover window add
Parameter effects for WCDMA soft handover-window drop

- Too high: Unnecessary branches stay in AS
- Too low: Frequent HOs
- Too low: Relevant cells removed from AS

Degraded performance due to too high level difference of the signals in AS

Increased soft HO overhead

Too large SHO area

Increased BS Tx power

Reduced UL capacity

Increased MS Tx power

Reduced DL capacity

Increased signalling overhead

Increased Tx powers

Reduced UL/DL capacity
Parameter effects for WCDMA soft handover - active set size

- Too big: Possible unnecessary branch addition
  - Degraded performance due to too high level difference of the signals in AS
    - Increased MS Tx power
      - Reduced UL capacity
- Too small: Prevent necessary soft HO branch addition
  - Increased SHO overhead
    - Increased BS Tx power
      - Reduced DL capacity
  - Require higher Tx power to a MS
    - Degraded DL BLER performance
      - Increased Call Drop/Block Rate
  - Require higher Tx power from a MS
    - Degraded UL BLER performance

Max AS size

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