UTRAN Radio Resource Management

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  - Congestion Control
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  - Packet Data Control
  - Dynamic Scheduling
References


3GPP standards:
◆ TS 25.214: “Physical Layer Procedures” (esp. power control)
◆ TR 25.942: “RF System Scenarios”
RRM – High-Level Requirements

- Efficient use of limited radio resources (spectrum, power, code space)
- Minimizing interference
- Flexibility regarding services (Quality of Service, user behaviour)
- Simple algorithms requiring small signalling overhead only
- Stability and overload protection
- Self adaptive in varying environments
- Allow interoperability in multi-vendor environments

Radio Resource Management algorithms control the efficient use of resources with respect to interdependent objectives:
- cell coverage
- cell capacity
- quality of service
RRM – Components

Radio Resource Management

Core Network/ other RNCs

Handover Control

Load Control

Packet Data Control

Power Control

Medium Access Control

Physical layer

typically in RNC

typically in NodeB
Handover Control: Basics

**General:** mechanism of changing a cell or base station during a call or session

**Handover in UMTS:**
- UE may have active radio links to more than one Node B
- Mobile-assisted & network-based handover in UMTS:
  - UE reports measurements to UTRAN if reporting criteria (which are set by the UTRAN) are met
  - UTRAN then decides to dynamically add or delete radio links depending on the measurement results

**Types of Handover:**
- Soft/Softer Handover (dedicated channels)
- Hard Handover (shared channels)
- Inter Frequency (Hard) Handover
- Inter System Handover (e.g. UMTS-GSM)
- Cell selection/re-selection (inactive or idle)

All handover types require heavy support from the UMTS network infrastructure!
Macro Diversity & Soft Handover (Wrap-Up)

Downlink: combining in the mobile station
Uplink: combining in the base station and/or radio network controller
Soft/ Softer Handover

- In soft/softer handover the UE maintains active radio links to more than one Node B
- Combination of the signals from multiple active radio links is necessary

**Soft Handover**
- The mobile is connected to (at least) two cells belonging to different NodeBs
- In uplink, the signals are combined in the RNC, e.g. by means of *selection combining* using CRC

**Softer Handover**
- The mobile is connected to two sectors within one NodeB
- More efficient combining in the uplink is possible like *maximum ratio combining* (MRC) in the NodeB instead of RNC

**Note:**
- In uplink no additional signal is transmitted, while in downlink each new link causes interference to other users, therefore:
  - **Uplink**: HO general increase performance
  - **Downlink**: Trade-off
Soft and Softer Handover in Practice
Soft Handover Control

- Measurement quantity, e.g. $E_C/I_0$ on CPICH
- Relative thresholds $\delta_{\text{add}}$ & $\delta_{\text{drop}}$ for adding & dropping
- Preservation time $T_{\text{link}}$ to avoid “ping-pong” effects
- Event triggered measurement reporting to decrease signalling load
Soft Handover – Simulation Results

Soft handover significantly improves the performance, but ...

Outage Probability (Blocking and Dropping)

Offered Traffic [Erlang per site]
... the overhead due to simultaneous connections becomes higher!
Inter-Frequency Handover

Hierarchical cell structure (HCS)

```
Macro               Micro       Macro
f_1          f_2        f_1
```

Handover $f_1 \leftrightarrow f_2$ always needed between layers

- Hard handover
- Inter-frequency measurements of target cell needed in both scenarios
- Mobile-assisted handover (MAHO)
  - slotted (compressed) mode for inter-frequency measurements to find suitable target cell
  - also supports GSM system measurements
- Database assisted handover (DAHO)
  - no measurements performed on other frequencies or systems
  - use cell mapping information stored in database to identify the target cell

Hot-spot

```
Macro               Micro       Macro
f_1          f_2        f_1
```

Handover $f_1 \leftrightarrow f_2$ needed sometimes at hot spot
Cell Selection/Re-selection

- “Handover” when UE is idle or there is no active connection between UE and UTRAN
- Goal: find a suitable cell to camp on
- The cell to camp on is chosen by the UE on measured link quality $Q$, e.g. $E_c/I_0$ on CPICH (after cell-search)
- Cell re-selection with hysteresis $H$ to avoid “ping-pong” effects
- Additional offsets for $Q$ on different frequencies, e.g. to support hierarchical cells
- Mapping functions for $Q$ between UMTS and GSM to support priorities
- Cell selection and re-selection mainly performed internally in UE, but controlled by UTRAN with broadcast of neighbour cell frequencies and control parameters (hysteresis, mapping, etc.)
**Power Control: Basics**

Controls the setting of the transmit power in order to:
- Keep the QoS within the required limits, e.g. data rate, delay and BER
- Minimise interference, i.e. the overall power consumption

Power control handles:
- Path Loss (Near-Far-Problem), Shadowing (Log-Normal-Fading) and Fast Fading (Rayleigh-, Ricean-Fading)
- Environment (delay spread, UE speed, ...) which implies different performance of the de-interleaver and decoder

Uplink: per mobile  
Downlink: per physical channel

Three types of power control:
- Inner loop power control
- Outer loop power control (SIR-target adjustment)
- Open loop power control (power allocation)

Downlink power overload control to protect amplifier
- Gain Clipping (GC)
- Aggregated Overload Control (AOC)
Near-Far Problem:  
- Spreading sequences are not orthogonal (multi-user interference)  
- Near mobile dominate  
- Signal to interference ratio is lower for far mobiles and performance degrades  

The problem can be resolved through dynamic power control to equalize all received power levels  

AND/OR  

By means of joint multi-user detection
Closed Loop Power Control

- Closed loop power control is used on channels, which are established in both directions, such as DCH.
- There are two parts:
  - Inner Loop Power Control (ILPC): receiver generates up/down commands to incrementally adjust the sender’s transmit power.
  - Outer Loop Power Control (OLPC): readjusts the target settings of the ILPC to cope with different fading performance.

Example: Uplink Closed Loop Power Control

\[
\text{SIR} > \text{SIR}_{\text{target}}? \\
\text{control command: Up/Down} \\
\text{Inner Loop (1500 Hz)} \\
\text{NodeB} \\
\text{Outer Loop (≤ 100Hz)} \\
\text{target adjustment} \\
\text{BLER}_{\text{target}} \\
\text{RNC} \\
\text{Example: Uplink Closed Loop Power Control}
\]
Impact of Power Control

Example: UMTS Closed Loop Power Control in the slow fading channel
SIR requirement strongly depends on the environment (due to different fast fading conditions – Jakes models)
⇒ outer loop power control needed to adapt SIR
Open Loop Power Control

- Open loop power control is used on channels that cannot apply closed loop power control, e.g. RACH, FACH
- The transmitter power is determined on the basis of a path loss estimate from the received power measure of the opposite direction
- To avoid excessive interference, probes with incremental power steps until a response is obtained: “power ramping”
CDMA Overload

- CDMA systems tend to become unstable
  - More traffic increases the interference
  - More interference requires higher power
  - More power increases the interference …

- Methods are required to limit the system load
  - Restrict the access to the system
  - Overcome overload situations
Interference in CDMA Networks

<table>
<thead>
<tr>
<th>Interference</th>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter-Symbol Interference (ISI)</td>
<td>Delayed components from the same user signal interfere due to multipath propagation</td>
</tr>
<tr>
<td>Multiple Access Interference – MAI</td>
<td>Different user signals interfere dependent on the access scheme</td>
</tr>
<tr>
<td>Intra-Cell Interference</td>
<td>Interference caused by the users belonging to same cell</td>
</tr>
<tr>
<td>Inter-Cell Interference</td>
<td>Interference caused by the users belonging to neighbor cells.</td>
</tr>
</tbody>
</table>

- Frequency reuse factor is one
- CDMA is subject to high multiple access interference
- Soft capacity: CDMA capacity (e.g. number of users) determined by the interference is soft
- Handling of interference is the main challenge in designing CDMA networks
Cell Breathing

- CDMA systems: cell size depends on the actual loading
  - Additional traffic will cause more interference
  - If the interference becomes too strong, users at the cell edge can no more communicate with the basestation
- CDMA interference management
  - Restriction of the users access necessary
  - Cell breathing makes network planning difficult

Example: cell breathing with increasing traffic
Cell Breathing (contd.)

Coverage depending on load: load causes interference, which reduces the area where a SIR sufficient for communication can be provided.

coverage
low load

coverage
medium load

coverage
high load

shadowed area: connection maybe lost
Coverage vs. Capacity

- **Capacity depends on:**
  - QoS of the users (data rate, error performance (bit-error-rate))
  - User behaviour (activity)
  - Interference (out of cell)
  - Number of carriers/sectors

- **Coverage (service area) depends on:**
  - Interference (intra- & inter-cell) + noise
  - Pathloss (propagation conditions)
  - QoS of the users (data rate, error performance (bit-error-rate))

- Thus, trade-off between capacity and coverage
Coverage vs. Capacity

- Downlink limits capacity while uplink limits coverage
- Downlink depends more on the load (users share total transmit BS power)
Example of Coverage and Best Server Map

Application: RF engineering (cell layout)
Legend: violet indicates high signal level, yellow indicates low level

Application: HO decision
Legend: color indicates cell with best CPICH in area
**Load Control: Basics**

- **Main objective:**
  - Avoid overload situations by controlling system load
  - Monitor and controls radio resources of users
- **Call Admission Control (CAC)**
  - Admit or deny *new users*, new radio access bearers or new radio links
  - Avoid overload situations, *e.g.* by means of **blocking** the request
  - Decisions are based on interference and resource measurements
- **Congestion Control (ConC)**
  - Monitor, detect and handle overload situations with the already connected users
  - Bring the system back to a stable state, *e.g.* by means of **dropping** an existing call
Resource Consumption

- Service/BLER-dependent resource consumption

- Uplink example:
  - Service I: Voice
    \[ R_b = 12.2 \text{kbps}, \frac{E_b}{N_t} = 5\text{dB} \]
    \[ \alpha_I = 0.99\% \]
  - Service II: Data
    \[ R_b = 144\text{kbps}, \frac{E_b}{N_t} = 3.1\text{dB} \]
    \[ \alpha_{II} = 7.11\% \]

- In downlink there is additional dependency on the location of the user
  - Cell center → low consumption
  - Cell edge → high consumption
Admission/ Congestion Control

Basic algorithm
- Admission control is triggered when load $\geq \text{thr\_CAC}$
  - New users are blocked
  - Existing users are not affected as long as load < $\text{thr\_ConC}$
- Congestion Control is triggered when load $\geq \text{thr\_ConC}$
  - Reduce consumption of one or several users
  - Simple action: drop the user
  - Repeat until load < $\text{thr\_ConC}$
Tradeoff between blocking and dropping

Example: 64k per user, urban
Cell load depending on CAC threshold

Example: 64k per user, urban

Call Admission Control: Simulation Results II

Cell Loading

Offered Traffic [Erlang per site]

- thr_CAC = 50%
- thr_CAC = 75%
- thr_CAC = 90%
Packet Data Control: Channel Switching

- **Flexibility of packet services**
  - Asymmetrical data rates
  - Very low to very high data rates
  - Control information/user information

- **Efficient transmission making good use of CDMA characteristics**
  - Dedicated channel (DCH)
    - Minimise transmission power by closed-loop power control
    - Independence between uplink and downlink capacity
  - Common channel
    - Random access in the uplink (RACH)
    - Dynamic scheduling in the downlink (FACH)
  - Adaptive channel usage depending on traffic characteristics
    - Infrequent or short packets ⇒ Common channel (Cell_FACH)
    - Frequent or large packets ⇒ Dedicated channel (Cell_DCH)
    - No packet transmission ⇒ UE “stand by” modus (URA_PCH)
Channel Switching – Example

- Example: Web service
- Chatty apps.: keep alive message, stock tickers, etc. (e.g. 100 bytes every 15 sec)
- Second stage: when no activity in CELL_FACH then switch to URA_PCH
Power Control vs. Rate Adaptation

- **Power Control:**
  - Balances user received quality (BLER, SIR)
  - Users at cell center get less share of BTS transmit power assigned than at cell edge
  - Occurrence of power overload

- **Rate Adaptation:**
  - Transmit power ~ data rate
  - Users at cell edge get lower data rate assigned than at cell center
  - Reduces also power overload

- **On DCH combination of power control and rate adaptation**
  - Rate assignment at begin of a transmission based on load and user location
  - Rate adaptation when ongoing transmission according to power consumption and overload
  - Based on RRC-signaling (time horizon: 100msec ... 10sec)
Rate adaptation significantly improves the RRM performance on DCH.
Dynamic Scheduling

- "Statistical multiplexing" of data packets from different data flows on one shared medium, e.g. on DSCH or HSDPA
- Scheduling with time-horizon of 2msec ... 1sec
- Optimised usage of radio resources
- Exploitation of the short-term variations on the radio channels (opportunistic scheduling)
- Can provide certain degree of QoS