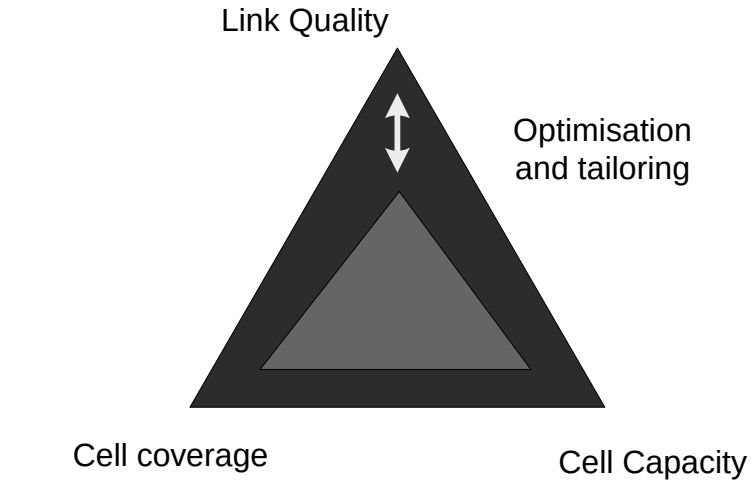
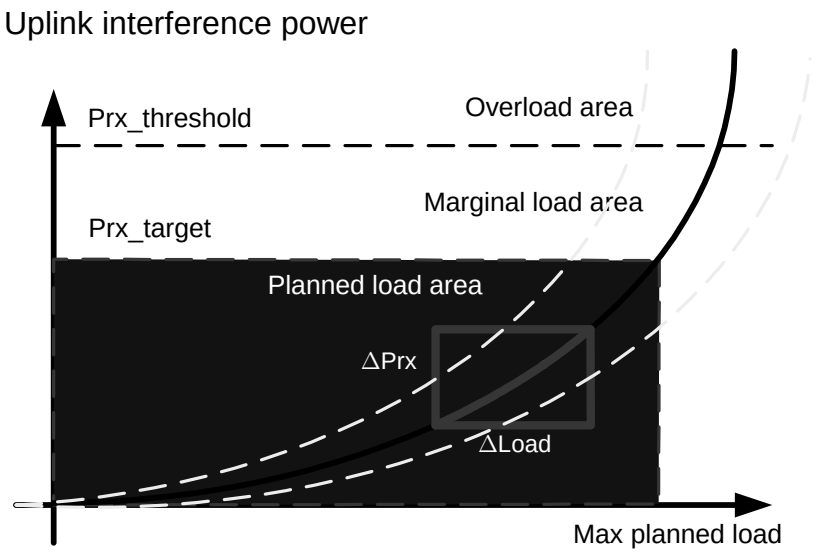
Radio Resource Management

Content of the lecture

- Changing capacity.
- Admission control.
- Packet scheduling.
- Load Control.
- Resource management.
- Power control.
- Handover control.

Changing Capacity





RRM purpose.

- Ensure planned coverage for each service.
- Ensure required connection quality.
- Ensure planned (low) blocking.
- Optimise the system usage in run time.

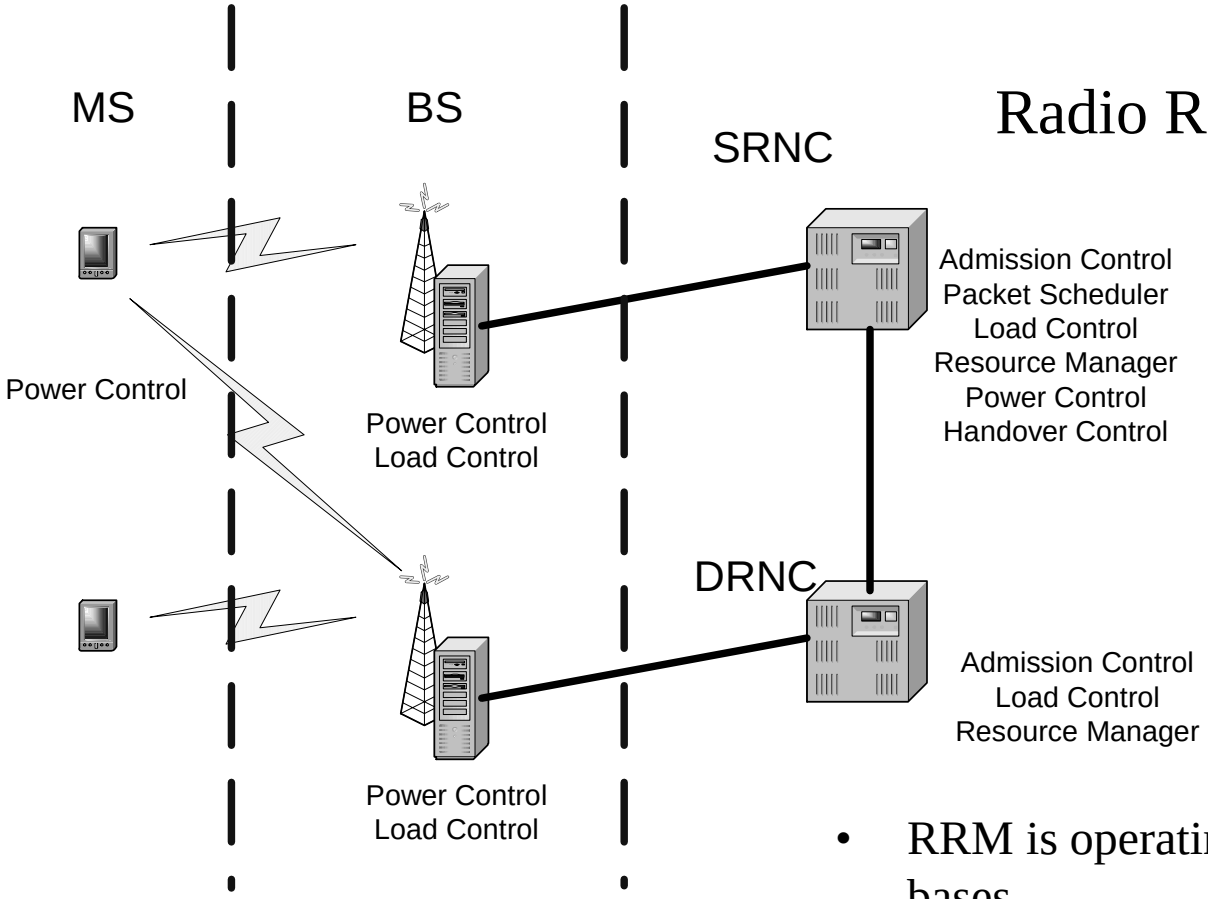
Real time RRM and Optimisation functions.

- Interference measurements.
- Soft capacity utilisation.
- Scheduling in radio interface.
- Actions to load change.
- Real time interference minimisation:
  - Handover control.
  - Service prioritisation.
  - Connection parameter settings.
  - Admission control.

WCDMA radio network control

In WCDMA QoS will be controlled by:

- Radio Network Planning. (Network Parameters.)
- Real time RRM (Radio Resource Management) operations in RNC BS.
- Real time power control.



Radio Resource Management.

RRM functionality is a set of algorithms used for optimal utilisation of air interface and HW resources.

- RRM is operating on connection and cell bases.
- System load is measured in run time.

RRM methods

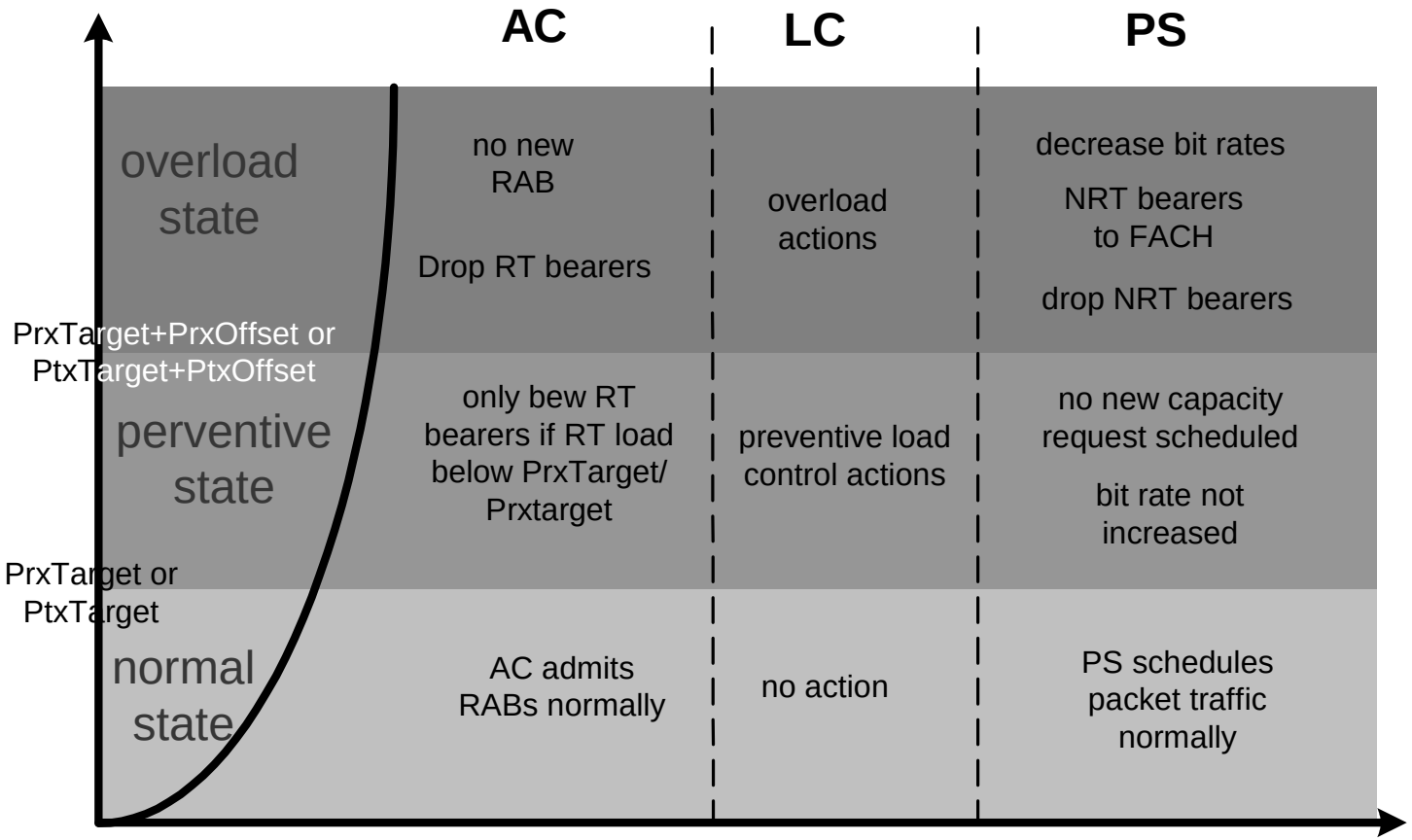
Network based functions.

- Admission control (AC).
  - Handles all new incoming traffic. Check whether new connection can be admitted to the system and generates parameters for it.
  - Occurs when new connection is set up as well during handovers and bearer modification.
- Load control (LC).
  - Manages situation when system load exceeds the threshold and some counter measures have to be taken to get system back to a feasible load.
- Packet scheduler (PS).
  - Handles all non real time traffic, (packet data users). It decides when a packet transmission is initiated and the bit rate to be used.
- Resource Manager (RM).
  - Controller over logical resources in BTS and RNC and reserves resources in terrestrial network.

Connection based functions.

- Handover Control (HC).
  - Handles and makes the handover decisions.
  - Controls the active set of BS of MS.
- Power Control (PC).
  - Maintains radio link quality.
  - Minimise and control the power used in radio interface.

Interworking actions of AC, PS, and LC



In uplink.

- $\boldsymbol{PrxTarget}$, the optimal average $PrxTotal$.
- $\boldsymbol{PrxOffset}$, the maximum margin by which $PrxTarget$ can be exceeded.

In downlink.

- $\boldsymbol{PtxTarget}$, the optimal average for $PtxTotal$.
- $\boldsymbol{PtxOffset}$, the maximum margin by which $PtxTarget$ can be exceeded.

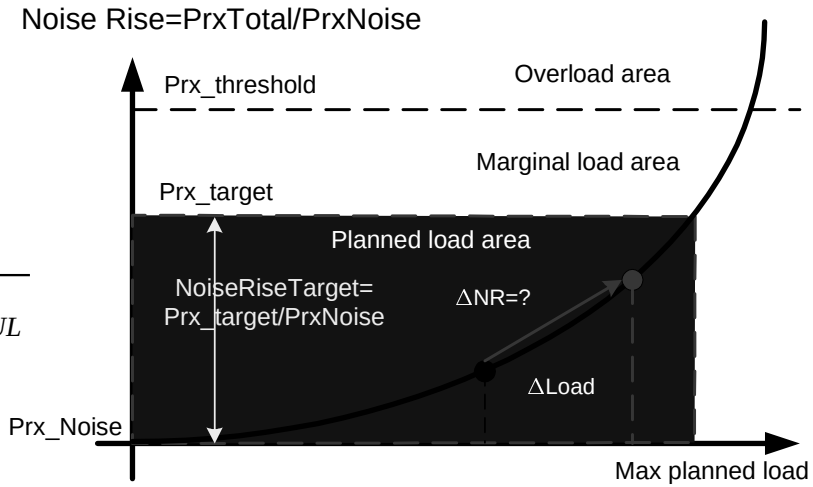
Air Interface Load: Uplink

Wideband power based uplink loading.

- The BS measures the total received power
- The Uplink loading can be described by

$$P_{rxTotal} = I_{own} + I_{oth} + P_n$$

  - Load factor $\eta_{UL} = \frac{I_{own} + I_{oth}}{P_{rxTotal}}$
  - Noise rise $Noise\_Rise_{UL} = \frac{P_{rxTotal}}{P_N} = \frac{1}{1-\eta_{UL}}$



Throughput based uplink loading

- The UL loading is calculated based on the individual load factor of each individual user.

$$\eta_{UL} = \sum_k \frac{1}{1 + \frac{W}{\rho_k \cdot R_k \cdot \nu_k} \cdot (1+i)}$$

Air Interface Load: Downlink

Wideband power-based downlink loading.

- The load can be estimated by dividing the total currently allocated transmit power at the BS by the maximum transmitted power capability of the cell:

$$\eta_{DL} = \frac{P_{txTotal}}{P_{txmax}}$$

Throughput based downlink loading.

- The loading is the sum of the bit rates of all currently active connections divided by the maximum throughput of the cell:

$$\eta_{DL} = \frac{\sum_{k=1}^{N} R_k}{R_{max}}$$

- Alternatively. Loading is calculated by using concepts of orthogonality other-to-own cell interference:

$$\eta_{DL} = \left[(1 - \bar{\alpha}) + i_{DL} \right] \sum_{k=1}^{N} \left(\frac{W}{\rho_k \cdot R_k \cdot \nu_k} \right)$$

Admission control

- Decides whether new RAB is admitted or not.
  - Real-Time traffic admission to the network is decided.
  - Non-Real-Time traffic after RAB has been admitted the optimum scheduling is determined. Co-operation with PC.
- Used when the bearer is
  - Set up.
  - Modified
  - During the handover.
    - Only downlink is considered in UL the BS is already measuring a MS as and other to own cell interferecnce.
      - In new branch the AC is needed for initial power allocation.
    - In inter-frequency handovers the UL is also considered.
- Estimates the load and fills the system up to the limit.
- Used to guarantee the stability of the network and to achieve high network capacity.
- Separate admission for UL and DL.
  - Load change estimation is done in the own and neighbouring cells.
  - RAB admitted if the resources in both links can be guaranteed.
  - In decision procedure AC will use thresholds set during radio network planning.
- The functionality located in the RRM of the RNC.

Power based admission control

Uplink

- The bearer is admitted if RT load fulfils: $P_{rxNC} + \Delta I \le P_{rxTraget}$ and total received wideband power fulfils $P_{rxTotal} \le P_{rxTarget} + P_{rxOffset}$.
- For NRT only the latter condition is applied.
- The increase of wideband power is estimated as
  - $\Delta I \approx \frac{P_{rxTotal}}{1-\eta} \cdot \Delta L$
  - $\Delta I \approx \frac{P_{rxTotal}}{1-\eta-\Delta L} \cdot \Delta L$.
- The fractional load for the new user can be calculated $\Delta L = \frac{1}{1+\frac{W}{\rho \cdot R \cdot \nu}}$.

Downlink

- RT bearer will be admitted if non-controllable downlink load fulfils equation $P_{txNC} + \Delta P \le P_{txTarget}$ and total transmitted power fulfils $P_{txTotal} \le P_{txTarget} + P_{txOffset}$.

Throughput based admission control

- A new bearer is admitted only if the load after admittance stays below the threshold defined by RNP.

Uplink

$$\eta_{oldUL} + \Delta L \leq \eta_{thresholdUL}$$

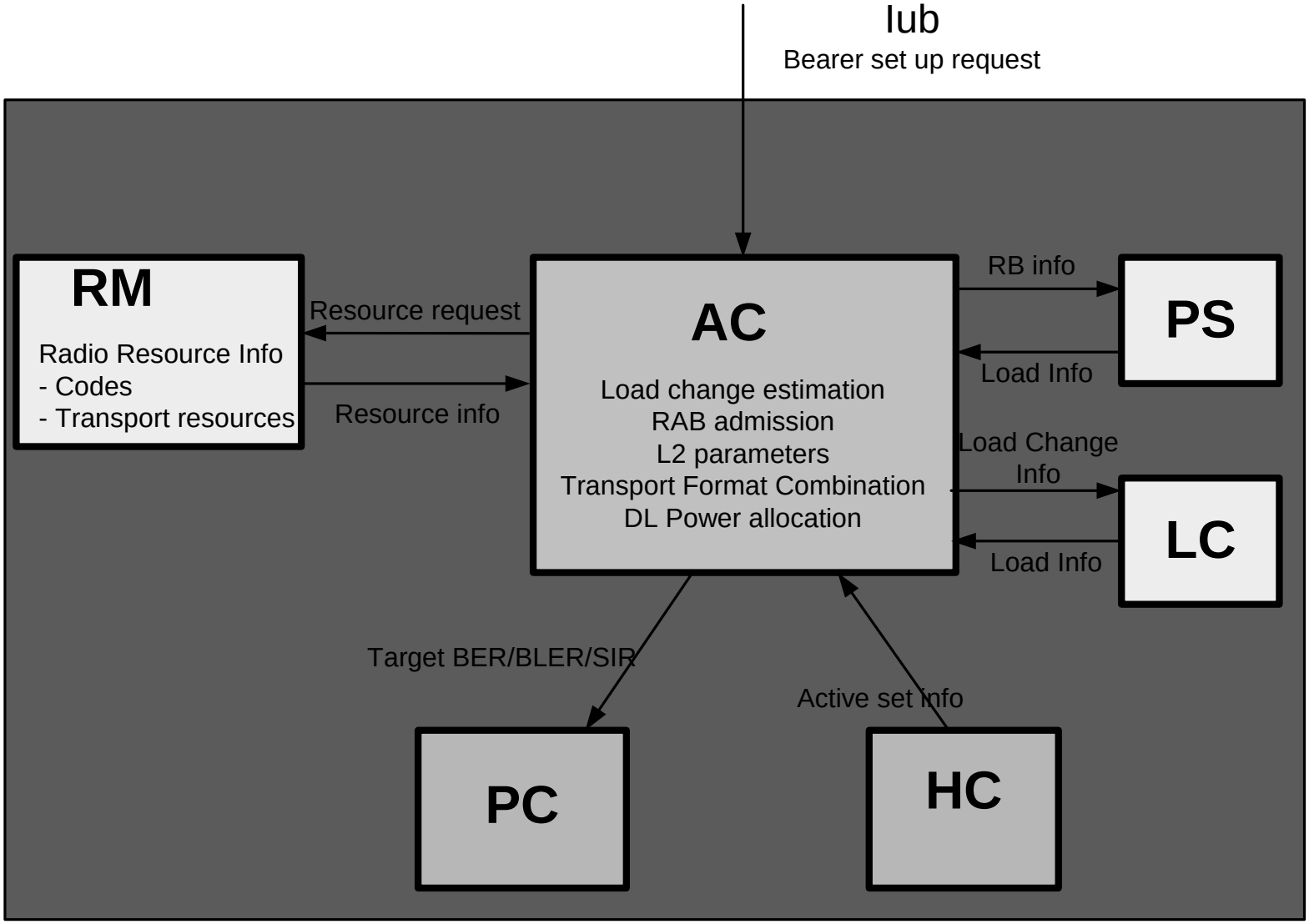
Downlink

$$\eta_{oldDL} + \Delta L \leq \eta_{thresholdDL}$$

Admission control

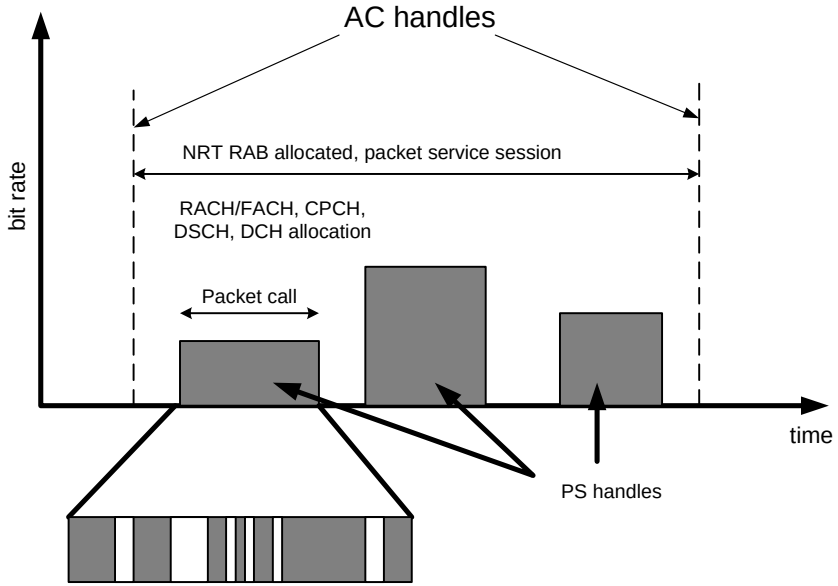
- In the decision procedure AC will use threshold form network planning and from interference measurements.
- The new connection should not impact the planned coverage and quality of existing connections. (During the whole connection time.)
- AC estimates the UL and DL load increase which new connection would produce. AC uses load information from LC and PC.
- Load change depends on attributes of RAB: traffic and quality parameters.
- If UL or DL limit threshold is exceeded the RAB is not admitted.
- AC derives the transmitted bit rate, processing gain, Radio link initial quality parameters, target BER, BLER, Eb/No, SIR target.
- AC manages the bearer mapping
  - The L1 parameters to be used during the call.
- AC initiates the forced call release, forced inter-frequency or intersystem handover.

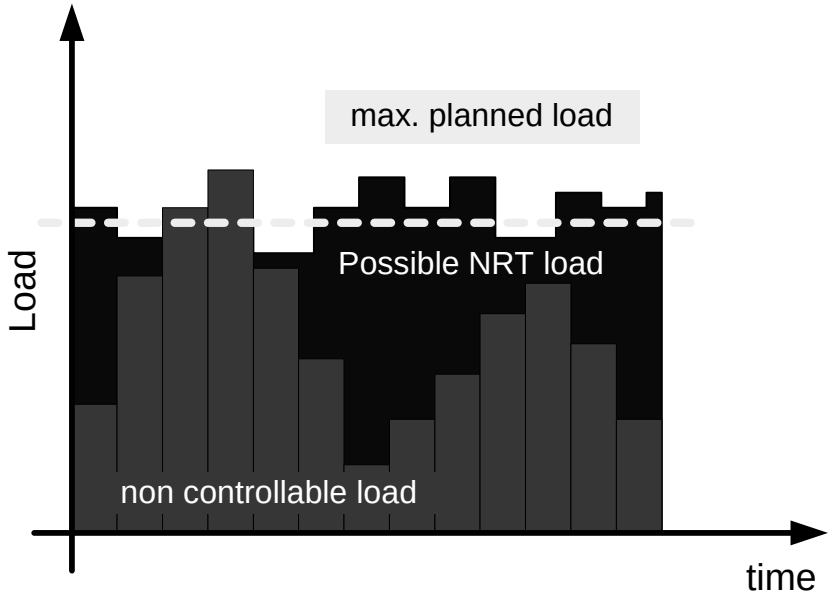
Logical dependencies of AC



Packet scheduling

- To determine the available radio interface resources for non real time radio bearer.
- To share the available radio interface resources between non real time radio bearers.
- to monitor the allocations for non real time radio bearers.
- To initiate transport channel type switching between common, shared and dedicated channels when necessary.
- To monitor the system loading.
- To perform load control actions for the non-real-time radio bearers when necessary.





Properties of WCDMA transport channels applicable for packet data transfer

TrCh	DCH	RACH	FACH	CPCH	DSCH
TrCH type	Dedicated	Common	Common	Common	Shared
Applicable UE state	CELL_DCH	CELL_FACH	CELL_FACH	CELL_FACH	CELL_FACH
Direction	Both	Uplink	Downlink	Uplink	Downlink
Code Usage	Accordingly to maximum bit rate	Fixed code allocations in a cell	Fixed code allocations in a cell	Fixed code allocations in a cell	Fixed code allocations in a cell
Power control	Fast closed-loop	Open-loop	Open-loop	Fast closed-loop	Fast closed-loop
SHO support	Yes	No	No	No	No
Target data traffic volume	Medium or high	Small	Small	Small or medium	Medium or high
Suitability for bursty data	Poor	Good	Good	Good	Good
Setup time	High	Low	Low	Low	Low
Relative radio performance	High	Low	Low	Medium	Medium or high

Configurations for transport channel

- AC determines the Transport Channel parameters (RNC, BS, MS).
- Transport format (RNC, BS, MS).
- AC/PS determine a Transport Format Combination in DCN multiplexing (RNC, BS, MS).
- Service multiplexing and rate matching are controlled (RNC)
- AC/PS determine a Gain factor for the uplink DPCCH/DPDCH power difference. (MS RNC)

Load Control

Purpose: optimise the capacity of a cell and prevent overload

- The interference main resource criteria.
- LC measures continuously UL and DL interference.
- RRM acts based on the measurements and parameters from planning

Preventive load control.

- In normal conditions LC takes care that the network is not overloaded and remains stable.

Overload condition.

- LC is responsible for reducing the load and bringing the network back into operating area.

- Fast LC actions in BTS:
  - deny (DL) or overwrite (uplink) TPC ‘up’ commands.
  - Lower SIR target for the uplink inner-loop PC.
- LC actions located in the RNC.
  - Interact with PS and throttle back packet data traffic.
  - Lower bit rates of RT users.(speech service or CS data).
  - WCDMA interfrequency or GSM intersystem handover.
  - Drop single calls in a controlled manner.

Traffic types and load

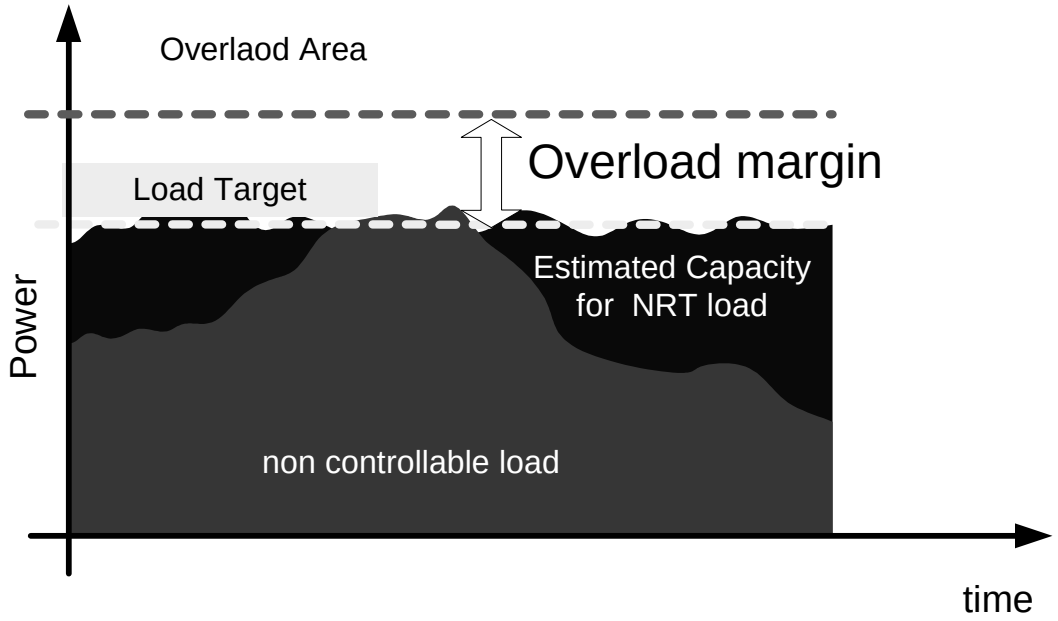
- Non controllable traffic
  - Real-time (RT) users (traffic).
  - Users in other cells.
  - Noise.
  - NRT users with minimum bit rate.
- Controllable traffic.
  - Non-real-time users (traffic).

- Uplink received power.

$$P_{rxTotal} = P_{rxOwn} + P_{rxOth} + P_n = P_{rxNc} + P_{rxNRT}$$

- Downlink received power.

$$P_{txTotal} = P_{txNc} + P_{txNRT}$$



Some slice of capacity must be allocated to the non controllable traffic for mobility purposes all the time. The proportion between controllable and non-controllable traffic varies all the time.

Description of LC

- LC consists of AC, PS algorithms and LC, updating load status based on the measurements and estimations from AC and PS.

LC algorithm

- BTS measures the total received power.
- BTS reports measurements to the Controlling-RNC. (periodically).
- RRM in RNC updates cell load status for each controlled cell.
- AC and PS work based on the current load status in the cell.

- The load is estimated based on received noise power. PrxNoise.
  - Overestimation -> under estimation of cell load, can lead to overload situation.
  - Underestiamtion -> overestimation of the cell load, causes low system utilisation (unnecessary call blocking).

Resource management

- Purpose: to allocate physical radio resources when requested by the RRC layer.
- Knows radio network configuration and state data.
- Sees only logical radio resources.
  - Allocation is a reservation of proportion of the available radio resources according to the channel request from RRC layer for each radio connection.
- Input comes from AC/PS.
- RM informs PS about network conditions.
- Allocates scrambling codes in UL.
- Allocates the spreading codes in downlink direction.
  - Able to switch codes and code types
    - During soft handover.
    - defragmentation of code tree.

Power control

- Uplink open loop power control.
- Downlink open loop power control.
- Power in downlink common channels.
- Uplink inner (closed) loop power control.
- Downlink inner (closed) loop power control.
- Outer loop power control.
- Power control in compressed mode.

Uplink open loop PC

- Setting the initial transmission power.
- The terminal sets the initial power for the first PRACH preamble and for the DPCCH before starting inner loop PC.

$$Preamble\_Initial\_Power = CPICH\_Tx\_Power - CPICH\_RSCP + UL\_interference + UL\_required\_CI$$

$UL\_interference$ is measured at the BS and broadcast on the BCH.

- First DPCCH power level for the uplink inner-loop PC is started as.

$$DPCCH\_Initial\_Power = DPCCH\_Power\_Offset - CPICH\_RSCP$$

$CPICH\_RSCP$ is measured bye the terminal.

$DPCCH\_Power\_Offset$ is calculated by AC in the RNC and provided to MS during a radio bearer or physical channel reconfiguration.

$$DPCCH\_Power\_Offset = CPICH\_Tx\_Power + UL\_interference + SIR_{DPCCH} - 10 \cdot \log_{10}(SF_{DPDCH})$$

SIR_{DPCCH} is the initial target SIR produced by the AC for the particular connection.

SF_{DPDCH} is the spreading factor of the corresponding DPDCH.

Downlink Open loop PC

- The open loop PC is used to the the initial power of the downlink channelsbased on downlink measurement reports.
- The function is in UTRAN and MS.
- A possible algorithm for initial power calculations is

$$P_{Tx}^{Initial} = \frac{R \cdot \left(E_b / N_0\right)_{DL}}{W} \left(\frac{CPICH\_Tx\_power}{\left(E_b / N_0\right)_{CPICH}} - \alpha \cdot PtxTotal \right)$$

R	user bit rate
$\left(E_b / N_0\right)_{DL}$	dwonlink planned Eb/No set by RNP for particular bearer service.
W	the chip rate.
$\left(E_b / N_0\right)_{CPICH}$	reported by MS.
α	the downlink orthogonality factor.
$PtxTotal$	carrier power measured at the BS an reported to the RNC.

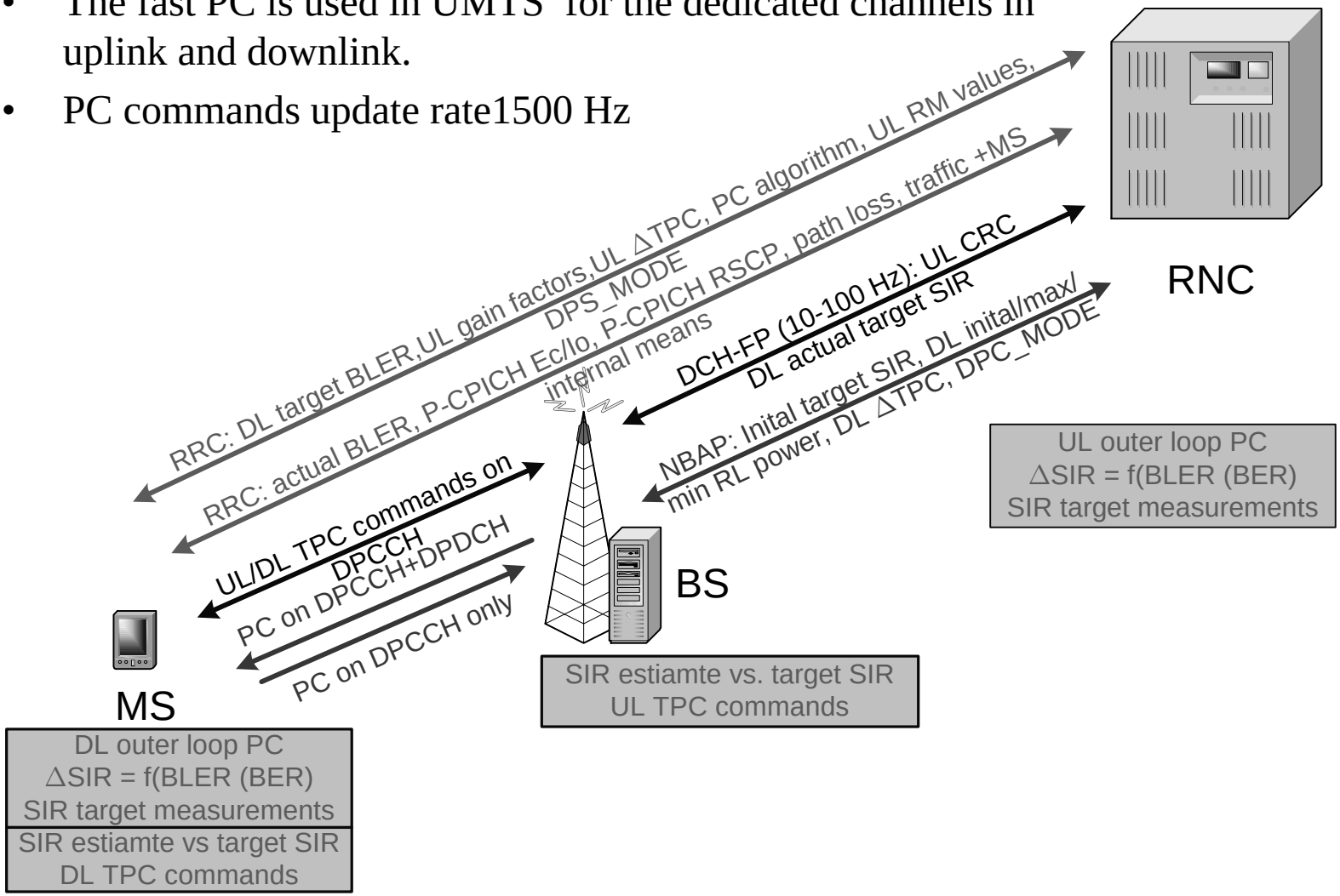
PC in downlink common channels

- Determined by the network.
- The ratio of the transmit powers between different downlink common channels not specified in recommendations.

DL common channels	Typical power level	Note
P-CPICH	**30-33 dBm**	**5-10% of maximum cell Tx power (20 W). Set during Network planning.**
P-SCH S-SCH	**-3 dB**	**Relative to P-CPICH power.**
P-CCPCH	**-5 dB**	**Relative to P-CPICH power.**
PICH	**-8 dB**	**Relative to P-CPICH power and Number of paging indicators per frame Np = 72.**
AICH	**-8 dB**	**Power of one Aquisation Indicator (AI) compared to P-CPICH power.**
S-CCPCH	**-5 dB**	**Relative to P-CPICH and SF=256 (15 ksps). The configuration covers FACH power, max FACH power, PCH power.** **FACH slow PC can be applied.**
PDSCH	**Inner loop PC**	**TPC commands from user. A proprietary protocol for slow PC can be used.**

UL/DL inner and Outer loop PC

- Inner loop PC relies on the feedback information at Layer 1.
- The fast PC is used in UMTS for the dedicated channels in uplink and downlink.
- PC commands update rate1500 Hz



Uplink closed loop PC

- Received signal power is compared to the CIRtarget and depending on the result transmission power is asked to increase to decrease.
  - CIRtarget is got from uplink outer loop PC.
- Performance depends on users speed
  - v < 30 km/h step size 1 dB. (Algorithm 1).
  - 30< v <80 km/h step size 2 dB. (Algorithm 1).
  - 80 < v PC can not follow the channel changes and generates only noise (Algorithm 2).
- Before starting the communication a DPCCH PC preamble could be send.
  - For convergence of the uplink Tr power. 0-7 frames (the number set during RNP).

Fast PC algorithm: 1

- The PC command is received and that can be +1 or -1 dB

PC during handover

- Commands know to be same are combined into one command that is combined further with other TPC commands
- commands not known to be the same
  - soft symbol decision on each of the PC commands TPCi where i=1…N
  - to each symbol is assigned a realiability figure Wi
  - The TPC commands are combined as function of γ of all N power control commands TPCi and reliability estimates Wi:

    $TPC\_cmd=\gamma(W1,W2,..,WN,TPC1,TPC2,\ldots,TPCN)$, where $TPC\_cmd \in -1,1$

Fast PC algorithm: 2

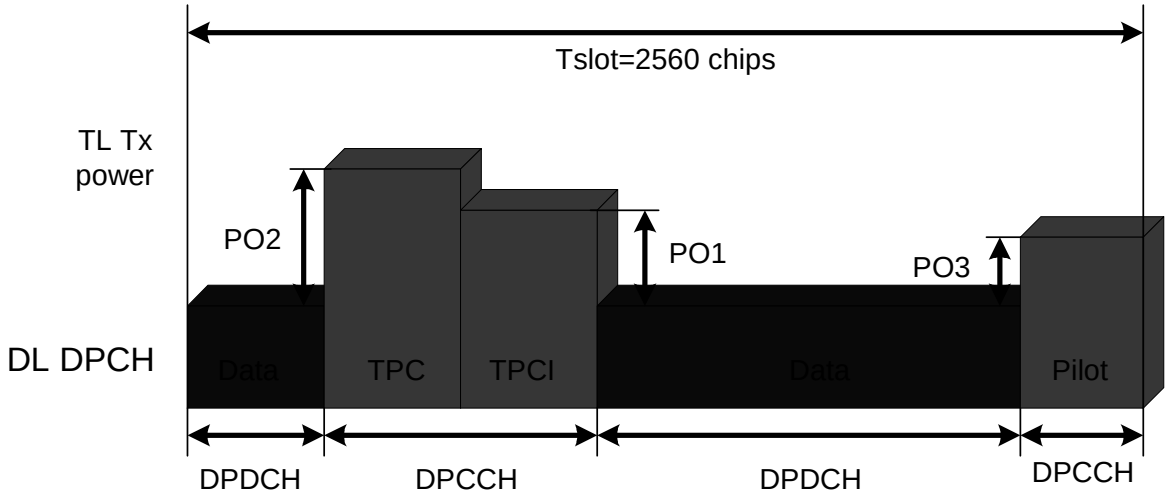
- Allows:
  - To emulate smaller step sizes for PC.
  - To turn off uplink PC.
- PC commands processed in non overlap 5 slot cycle.
- TPC_cmd
  - for the first 4 slots of a set TPC_cmd = 0
  - for the fifth slot is used hard decision
    - all hard decisions 1 TPC_cmd = 1.
    - all hard decisions 0 TPC_cmd = 0.
    - Otherwise TPC_cmd = 0.

Algorithm 2 during handover.

- Combining TPC_cmd known to be same. The commands are combined into one command
- Combining TPC_cmd not known to be same
  - MS makes PC decision over 3 slots
  - sums all the decisions that are not known to be same in a slot
  - the TPC_cmd for two first slots is 0 and for the third slot it is either - 1, 0, + 1 depending on the value of the normalised sum of PC bits
- Example: TPC_cmd set accordingly
  - +1 if $1/N\sum i$ TPC_cmdi > 0.5
  - -1 if $1/N\sum i$ TPC_cmdi < 0.5
  - otherwise 0

DL fast closed loop PC

- MS estimates the received SIR and compares it with required SIR target.
  - SIR is estimated from the pilot symbols of the DL-DPCH
- MS transmits the TPC command in first available TPC field.
- Two downlink PC modes:
  - DPC_MODE = 0: power command in every slot.
  - DPC_MODE = 0: power command once in every third slot.
- Power difference for different channels is estimated from given power offset values.
- Changes of power are multiplies of the minimum step size
  - it is mandatory for BS to support 0.5 and 1 dB step size



DL power during handover

Softer handover (diversity transmission).

- Only one TPC is send.
- Signals from different antennas are combined in the symbol level.

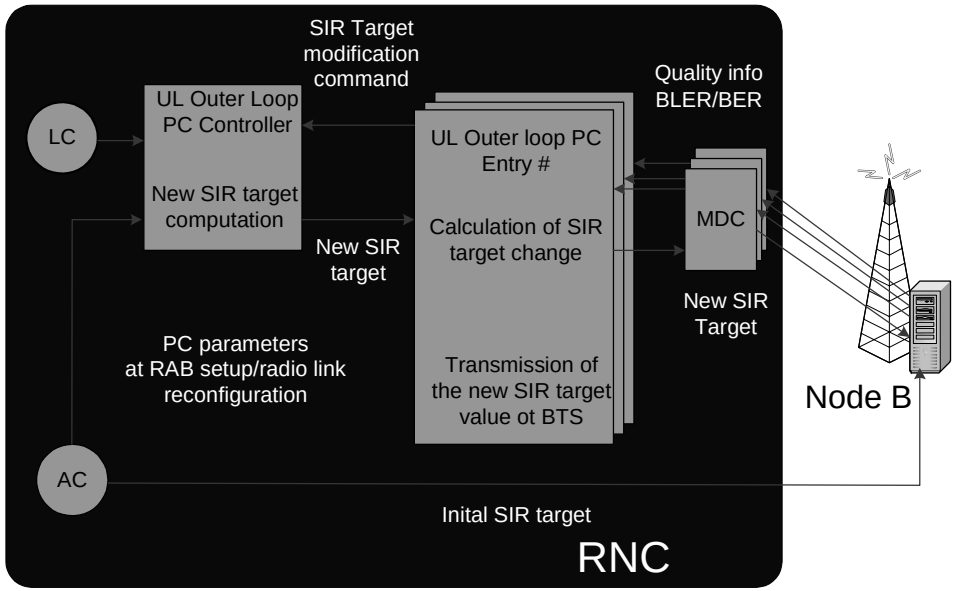
Soft handover.

- The signals are combined in MS.
- Power drifting?

- In Soft handover mode only one single TPC is send in uplink.
- Each cell detects TPC command independently.
  - Possible errors. Some BS may lower the Tx power when others increase -> the Tx powers are drifting apart.
- The transmission code power levels of athe connecions from the cell in SHO are forwarded, after averaging, to RNC.
  - Averaging for example 750 TPC commands (500 ms).
- RNC derives a reference power values and send to the cells.

Outer loop PC

- Outer loop power control produces an adequate target CIR for inner loop PC.
- Done for each DCH belonging to the same RRC connection.
- Frequency typically 10-100 Hz.
- During Soft HO.
  - The UL quality is observed after the MDC. The SIR target is generated for all cells in SHO.
    - The reliability of the blocks is provided to RNC. The quality is estimated based on CRC codes.



- DL the outer loop PC implemented in MS.
  - In CPCH a quality target is DPCCH BER.
  - DPCCH BLER quality taret otherwise.
- The value of the DL otuer loop PC is controlled by the AC in RNC.
  - The value of the target is send to MS in a RRC message.

PC in compressed mode

- Aim to recover a SIR close to the target SIR after each transmission gap
- In downlink compressed mode no PC is applied during transmission gap
- In simultaneous DL/UL compressed mode transmission is stopped
- The initial tr power of each UL after the tr gap is equal to the power before the gap, but with an offset Δresume
- Δresume may be
  - 0
  - Δresume = Int[σlast / ΔTPCmin] ΔTPCmin

    σlast =09375 σlast-1 -096875 TPCcmdlast ΔTPC
- PC modes are fixed and signalled with the other parameters during the downlink compressed mode
  - ordinary PC is applied
  - ordinary PC is applied with step size ΔRP-TPC during RPL slots after transmission gap.
- ΔRP-TPC is recovery PC step size in dB
  - if algorithm 1 used is is equal to the minimum value of 3 dB and 2 ΔTPC
  - if algorithm 2 is used ΔRP-TPC is equal to 1 dB
- RPL is recovery period length and is expressed in number of slots

Handovers

- Intrasystem HO.
  - Intrafrequency HO.
  - Interfrequency HO.
- Intersystem HO.

- Hard HO (HHO).
  - All the old radio links of an MS are released before the new radio links are established.
    - Real time bearers: short disconnection in transmission.
    - Non real time bearers HHO is lossless.
- Soft HO (SHO).
  - MS always keeps at least one radio link to UTRAN.
  - *Soft* HO: MS is simultaneously controlled by two or more cells belonging to diffetrent BTS of the same RNC or to different RNC.
  - *Softer* HO. MS is controlled by at least two cells under one BTS.
- Mobile evaluated handover (MEHO).
  - The UE mainly prepares the handover decision. The final decision is made by SRNC.
- Network evaluated handover (NEHO).
  - The SRNC makes the handover decision.

Intrasystem intra-frequency HO

Objectives of *soft*/*softer* HO.

- Optimum fast closed loop PC as the terminal is always linked with the strongest cells.
- Seamless handover with no disconnection of the radio access bearer.
- Diversity gain by combining the received signals from different cells. Better coverage. Less transmission power.

- MEHO: MS continuously measures serving and neighbouring cells on the current carrier.
- The RAN can perform *soft* and *softer* HO simultaneously.

General HO activities.

- Reporting of the MS measurements.
  - Compares measurement results with the HO threshold.
  - MS sends reports to BTS when the criteria is met.
    - Threshold is provided by the RNC.
    - Comparison result is transmitted to RNC.
- HO decision.
  - SRNC orders MS to add or remove cells from/to Active set.
- Measurement reporting criteria.
  - Definition of event that triggers the measurement report.
  - Parameters are defined on cell bases.

RRM functions in HO process

RRM functions

HC: processes the measurements made by terminal and makes decisions. Updates reference transmission powers.

AC: DL admission decision: acceptance and queuing. DL power allocation. May initiate a forced call release of IF-HO IS-HO.

RM: Activates/deactivates HO brances. Allocates/releases DL spreading codes.

LC: Updates DL load information when new HO link is admitted.

PS: Releases codes for HO brances of NRT. Schedules HO additions requests for NRT

- DL channelisation codes are allocated separately for each soft(er) HO branch.
- UL channelisation code is the same for each soft(er) HO branch.

Measurements reporting

- The measurements based on Eb/Io.
- The MS constantly monitors the CPICH Eb/Io of the cells defined by the neighbouring list.
- If the reporting criteria is fulfilled MS sends a event triggered measurement report
- The CPICH Eb/Io is the received energy per chip divided by the power density in the band.
- The accuracy of pilot Eb/Io important for HO performance.
  - The accuracy depends on the filtering length and mobile speed.

HO measurements reporting can be divided as:

- Neighbouring cell definitions.
- Measurement reporting criteria.
- Reporting of measurement results.

Neighbouring cells

For each cell in the radio network configuration database are defined a list of neighbouring cells.

- Intrafrequency neighbouring list. The UE must be able to monitor at least 32 cells on the same WCDMA carrier frequency as the serving cell.
- Interfrequency neighbouring list. The UE must be able to monitor at least 32 cells on the two other WCDMA carrier frequencies compared to the serving cell.
- Intersystem neighbouring list. For each neighbouring PLMN a separate list is maintained.

Measurement reporting criteria

Depending on the hondover type (MEHO, NEHO) different measurement reporting criteria can be used.

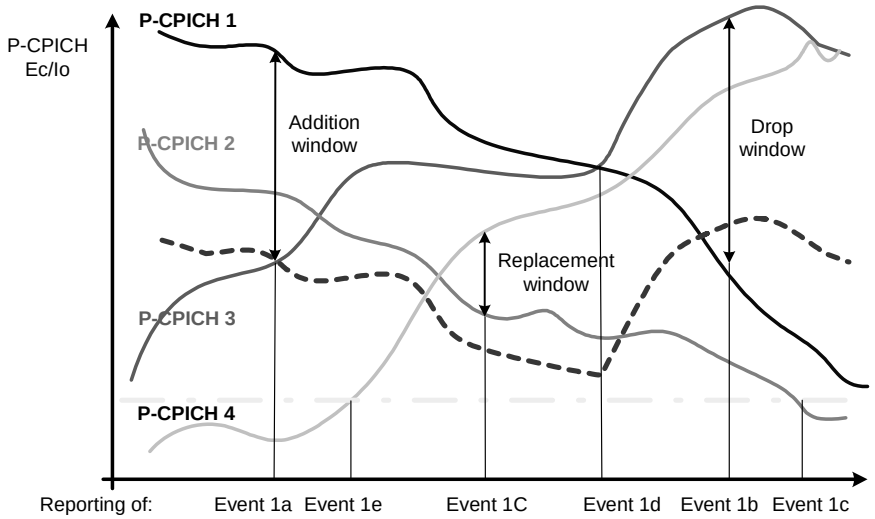
- Intrafrequency measurements.(MEHO).
  - HO measurements. The RAN broadcast the measurements reporting criteria (measuremetns parameters on the BCCH.
- Interfrequency and Intersystem measurements.
  - Made only when requested by RNC.
  - When once initiated MS periodically reports the measurement results to RNC
- UE internal measurements.
  - Controlled cell by cell bases. Info transmitted to MS in DCCH.

Reporting Intrafrequency measurments

Can be either event-triggered or periodic.

Reporting criteria for intrafrequency measurements are:

- Event 1a: A p-CPICH enters the reporting range.
- Event 1b: A P-CPICH leaves the reporting range.
- Event 1c: A non-active P-CPICH becomes better than an active one.
- Event 1d: Change of best cell. Reporting event is triggered when any P-CPICH in the reporting range becomes better than thet current best one plus an optional hysteresis value.



- Event 1e: A P-CPICH becomes better than an absolute threshold plus an optional hysteresis value.
- Event 1f: A P-CPICH becomes worse than an absolute minus an optional hysteresis value.

Intrafrequency measurements (2)

- Event 1a. $10 \cdot \log_{10}(M_{new}) \geq W \cdot 10 \cdot \log_{10}\left(\sum_{i=1}^{N_A} M_i\right) + (1-W) \cdot M_{Best} - (R_{1a} - H_{1a}/2)$
- Event 1b. $10 \cdot \log_{10}(M_{Old}) \leq W \cdot 10 \cdot \log_{10}\left(\sum_{i=1}^{N_A} M_i\right) + (1-W) \cdot M_{Best} - (R_{1b} + H_{1b}/2)$

M_{new}	the measurement result of the cell entering the reporting range.
M_i	a measurement result of a cell in the active set.
N_A	the number of cells in the current active set.
M_{Best}	the measurement result of the strongest cell in the active set.
W	a weighting parameter sent from RNC to UE.
R_{1a}	the reporting range for Event 1a sent from RNC to UE.
H_{1a}	the hysteresis parameter for Event 1a.
R_{1b}	the reporting range constant for Event 1b sent from RNC.
M_{Old}	the measurement result of the cell leaving the reporting range.
H_{1b}	the hysteresis parameter for Event 1B.

Time to trigger mechanism.

- To protect the network from excessive signalling in case of frequent reports.
  - The reporting events could have a timer.
    - If the measuring criteria is fulfilled during the whole period the event is reported.

Periodic Reporting.

- If the operation (AS update) can not occur because lack of HW the MS continues to send periodic reports.