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Cellular Network Planning and Optimization
Part VII: WCDMA RRM

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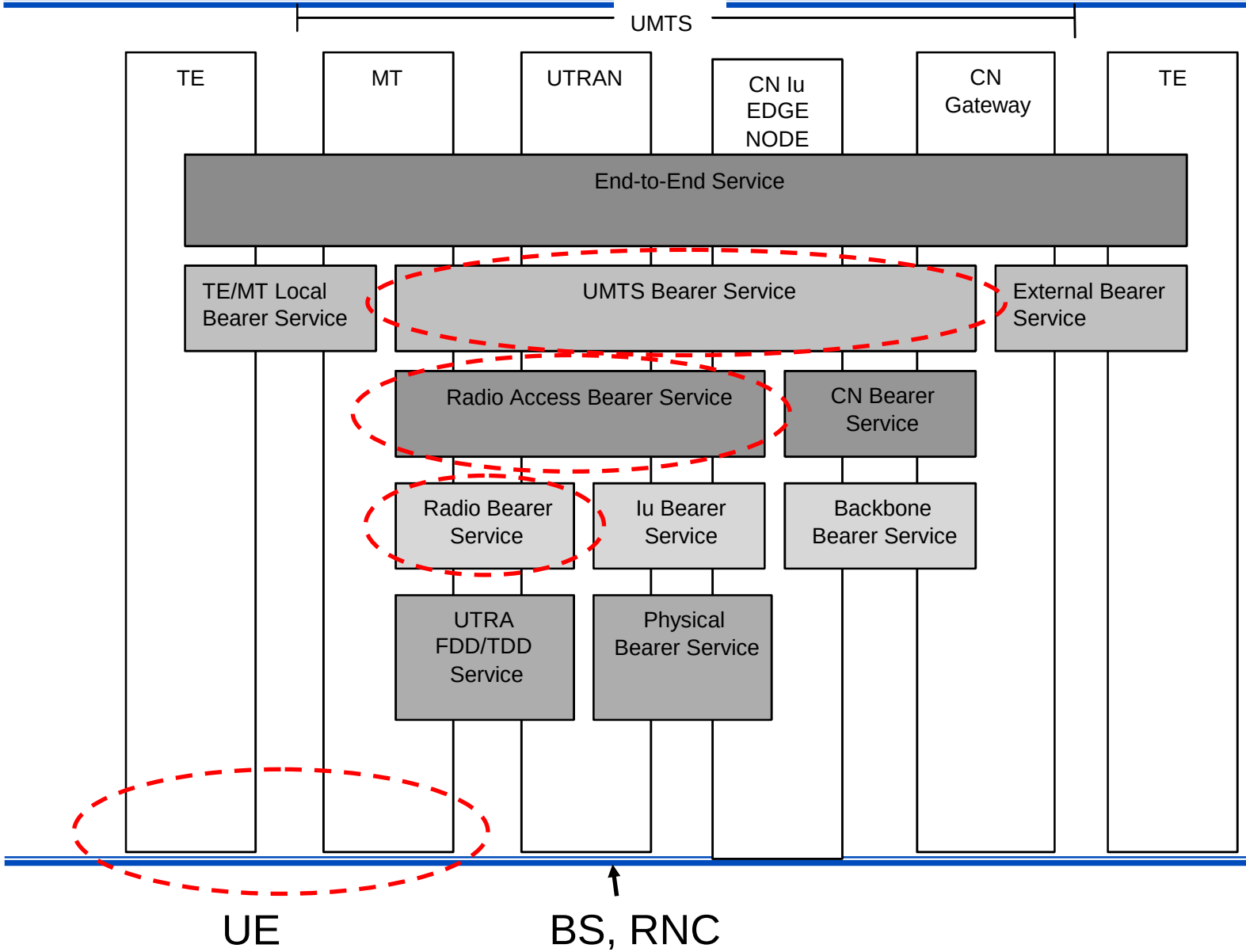
Quality of Service (QoS)

Radio Access Bearer



Radio Access Bearer

- Main task of the UTRAN is to create and maintain RAB for communication between UE and CN.
- *RAB is build up in order to give for CN elements an illusion about fixed communication path to UE.*
- The network builds up the end-to-end QoS connection from small pieces, which compose a complete chain without bottlenecks
- These pieces are called Bearers
- When the connection is set up, the network elements negotiate the QoS requirements of the bearers set up between them
- The result is a compromise, in which the QoS requirements and network's capacity is taken into account

UMTS QoS Classes

Traffic Class	Example application
Conversational class	Speech and video calls
Streaming class	Real-time streaming video
Interactive class	Web surfing
Background class	File downloading, e-mails

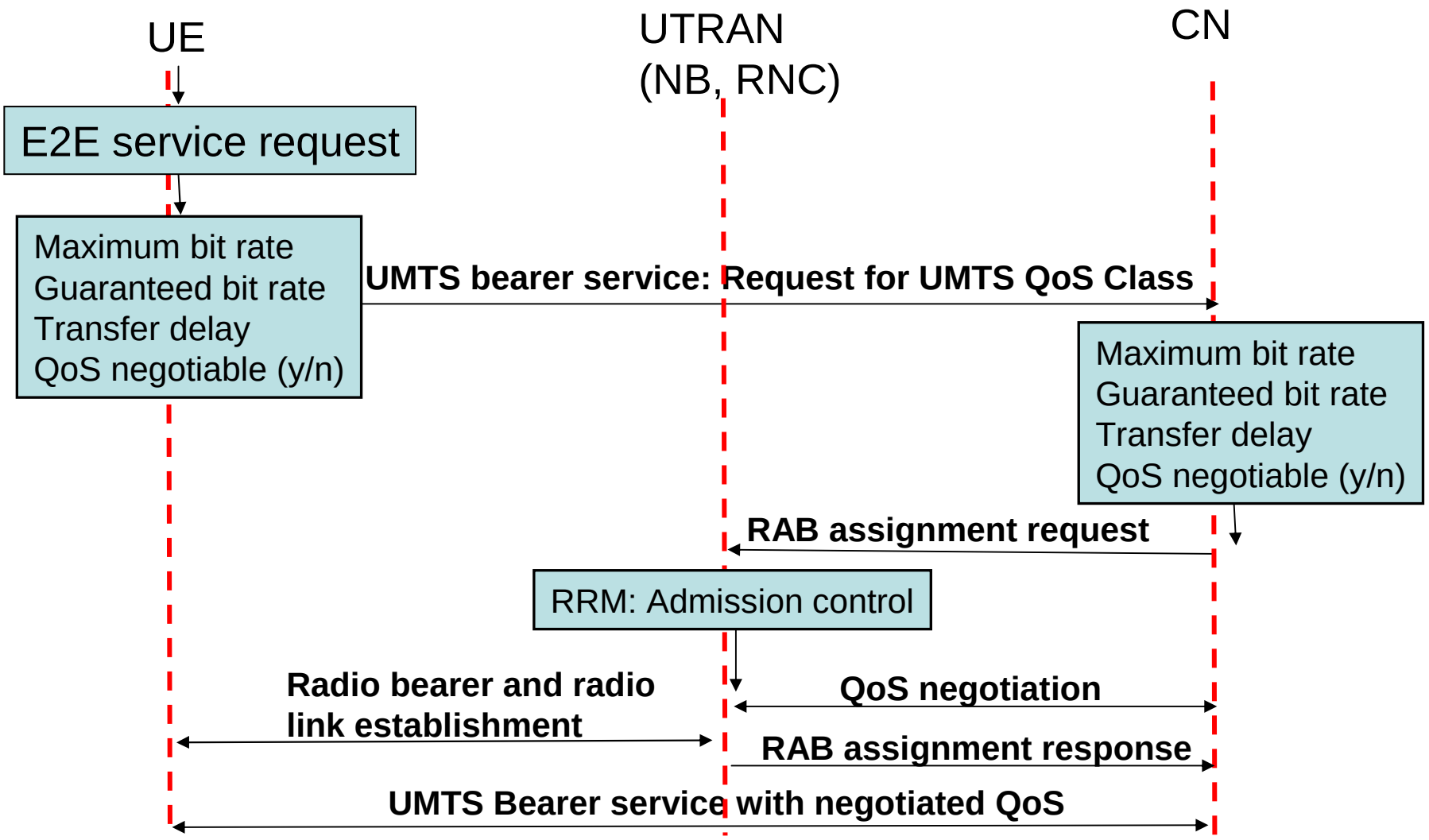
UMTS QoS Classes

Traffic Class	Properties
Conversational class	Minimum fixed delay, no buffering, symmetric traffic, guaranteed bit rate
Streaming class	Minimum variable delay, buffering allowed, asymmetric traffic, guaranteed bit rate
Interactive class	Moderate variable delay, buffering allowed, asymmetric traffic, no guaranteed bit rate
Background class	Big variable delay, buffering allowed, asymmetric traffic, no guaranteed bit rate

UMTS QoS Parameters

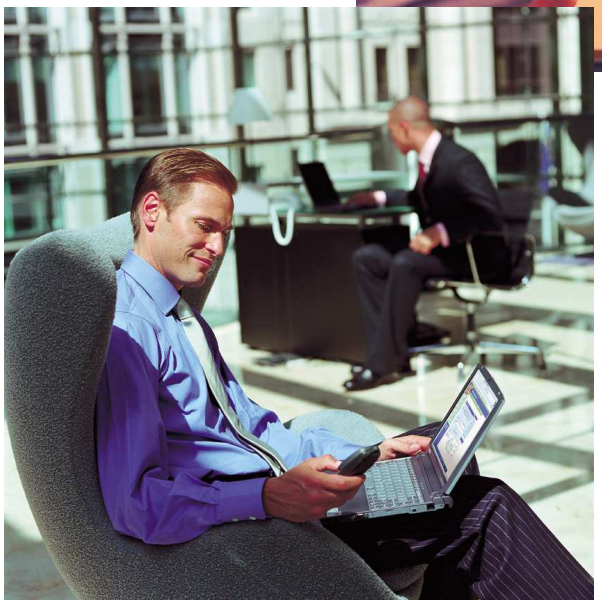
Parameter	Explanation
Maximum bit rate	Defines the maximum bit rate when delivering information between end points of UMTS bearer (<2Mbps)
Guaranteed bit rate	Defines the bit rate that the UMTS bearer must carry between its end points
Allowed transfer delay	Set the limits for delay (>80ms)
QoS negotiable	QoS of some services are not negotiable (speech), packet data services admit various QoS classes

QoS Negotiation



QoS in UMTS

- In early UMTS Release 99 all conversational and streaming class traffic were offered over the CS bearer
  - Voice
  - RT multimedia (e.g videotelephony)
- In early Release 99 only Interactive and background class traffic utilisises the PS bearer
- Release 4 capable networks introduce some streaming class traffic on PS bearer as well
- Release 5 brings along a full portfolio of PS bearers also utilised for conversational traffic



QoS in UMTS

- The QoS over the air interface is implemented by matching each radio bearer with a transport channel whose format set defines the QoS parameters
- The mapping is performed during the establishment of the RAB
- RNC performs the mapping of RAB characteristics to actual resource requirements (vendor dependent)
- Example of mapping for web service, which belongs to the interactive class

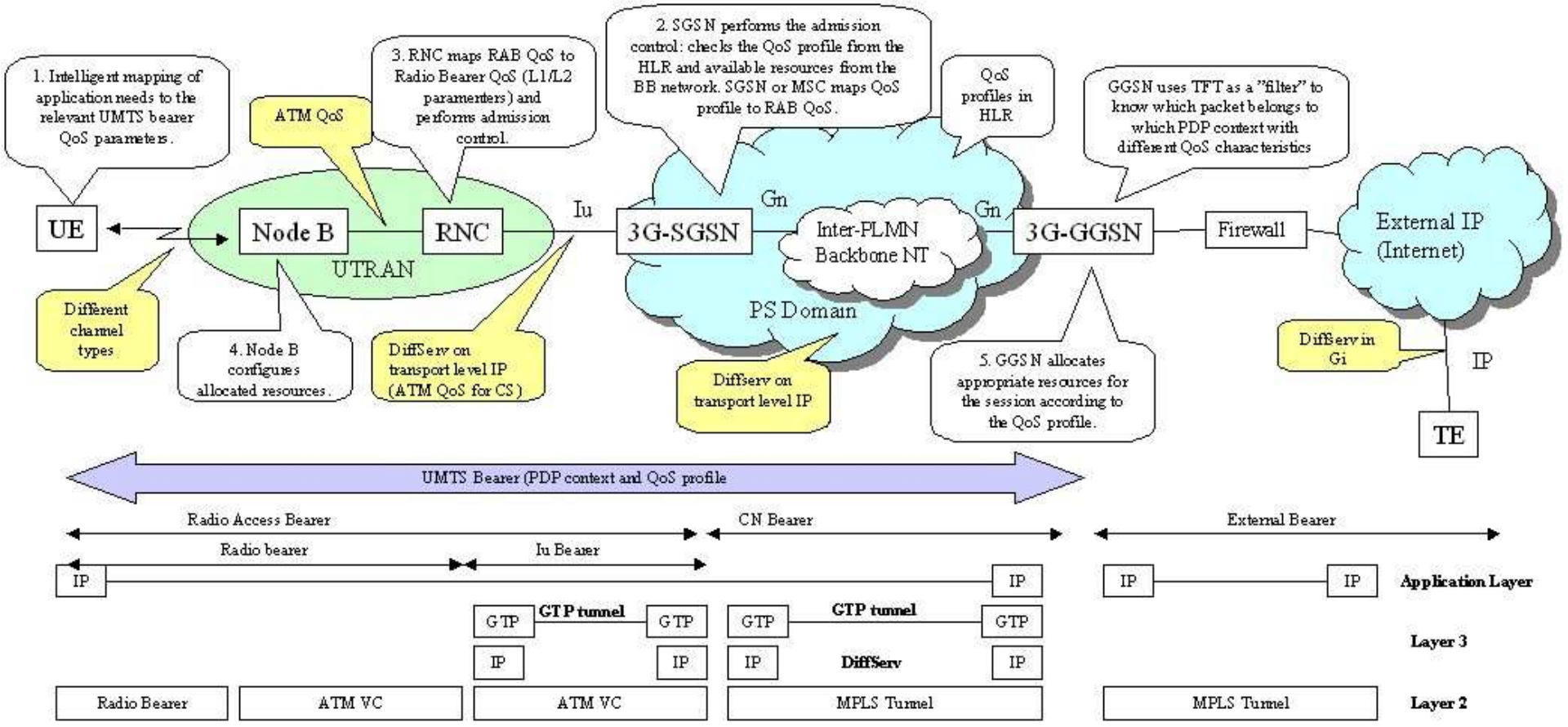
Parameters	Interactive Class	Radio Resource mapping
Maximum bit rate	128 kbps	SF=16
Maximum SDU size	1500	Map to Transport formats
Residual BER	10^-6	1/3 turbo encoder
Transfer Delay	NA	Interleaver = 40 or 80 msec
Guaranteed bit rate	64 kbps	SF=16
Delivery order	yes	Use Acknowledged RLC
SDU Error Ratio	1 %	Set appropriate threshold for outer loop power control
Delivery of erroneous SDU	No	Use Acknowledged RLC

QoS in UMTS

- Operators can define the wanted QoS profile (in HLR) per subscriber
- Users can be categorised (QoS differentiation) for various tariffing schemes
- Traffic handling priorities can be set (THP)

	Business	**Remote office**	**Basic free time**
Traffic class	All four allowed	All four allowed	Only converational (voice calls) and background
Max bit rate	400 kbps	800 kbps	64 kbps
Guaranteed bit rate	384 kbps	64 kbps	12 kbps
Allowed THPs	THP 1 (e.g. for e-mail downloads)	THP 2 (e.g. for file transfer)	THP 3

QoS in UMTS


1. Intelligent mapping of application needs to the relevant UMTS bearer QoS parameters.
ATM QoS
3. RNC maps RAB QoS to Radio Bearer QoS (L1/L2 parameters) and performs admission control.
2. SGSN performs the admission control: checks the QoS profile from the HLR and available resources from the BB network. SGSN or MSC maps QoS profile to RAB QoS.
QoS profiles in HLR
GGSN uses TFT as a "filter" to know which packet belongs to which PDP context with different QoS characteristics
UE
Node B
RNC
UTRAN
Iu
Gn
3G-SGSN
Inter-PLMN Backbone NT
Gn
3G-GGSN
Firewall
External IP (Internet)
PS Domain
Different channel types
4. Node B configures allocated resources.
DiffServ on transport level IP (ATM QoS for CS)
Diffserv on transport level IP
5. GGSN allocates appropriate resources for the session according to the QoS profile.
Diffserv in Gi
IP
TE
UMTS Bearer (PDP context and QoS profile
Radio Access Bearer
CN Bearer
External Bearer
Radio bearer
Iu Bearer
IP
IP
IP
IP
Application Layer
GTP
GTP tunnel
GTP
GTP
GTP tunnel
GTP
IP
IP
IP
DiffServ
IP
Layer 3
Radio Bearer
ATM VC
ATM VC
MPLS Tunnel
MPLS Tunnel
Layer 2

Radio resource management

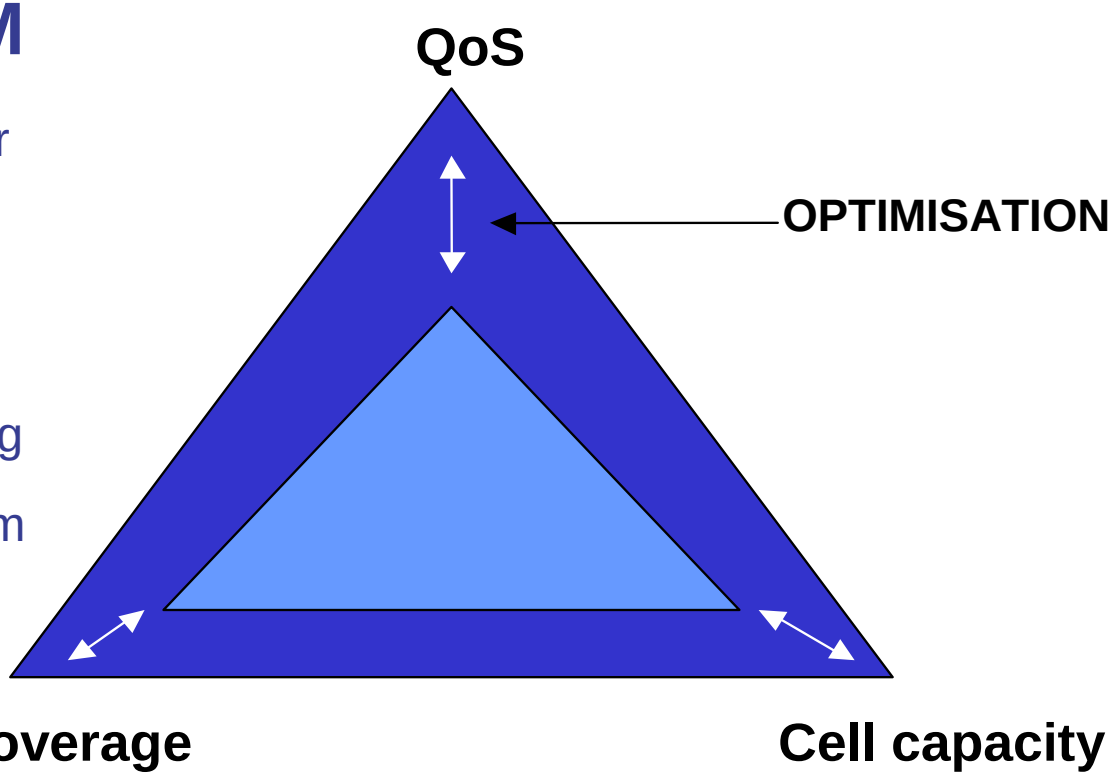
General

- Radio Resource Management (RRM) is elementary part of WCDMA.
- RRM is responsible for efficient utilization of the air interface resources it is needed to
  - Guarantee Quality of Service (QoS)
  - Maintain the planned coverage area
  - Optimize the cell capacity
- The importance of RRM is mostly due to the features of the UMTS system; interference limited nature and adaptive services

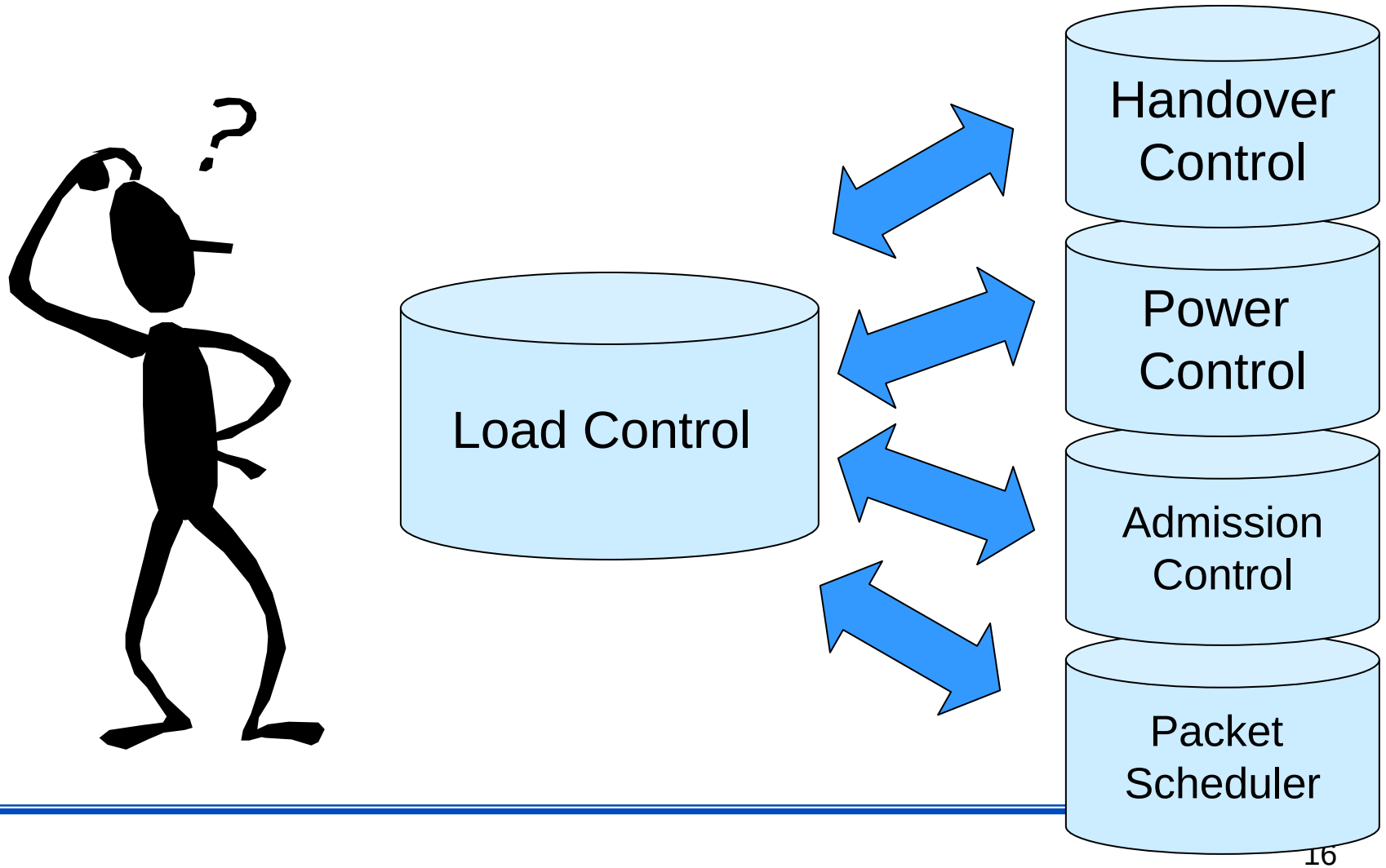
Introduction to RRM/objectives

Objectives of RRM

- Ensure planned coverage for each service
- Ensure required connection quality
- Ensure planned max blocking
- Optimise the usage of system capacity resources

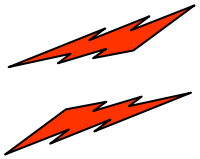


Introduction to RRM/Functions



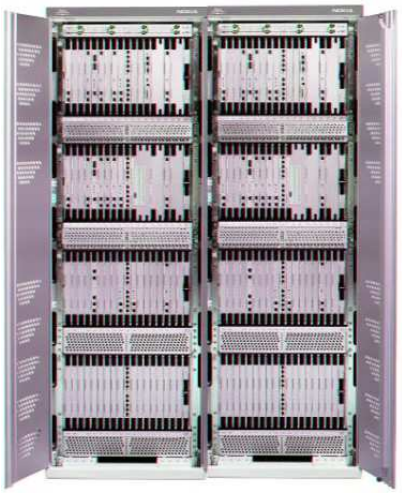
Introduction to RRM/Logical model

MS



Node B

RNC



- **Power Control**

- **Power Control**
- **Load Control**

- **Power Control**
- **Load Control**
- **Handover Control**
- **Admission Control (also in SGSN)**
- **Packet Scheduler**

RRM algorithms

- Family of RRM algorithms:
  - Power control
    - Fast power control (Node B, UE)
    - Outer loop power control (RNC)
  - Handover control (RNC)
  - Admission control (RNC)
  - Load control (RNC)
    - Fast load control (Node B)
  - Packet scheduling (RNC)

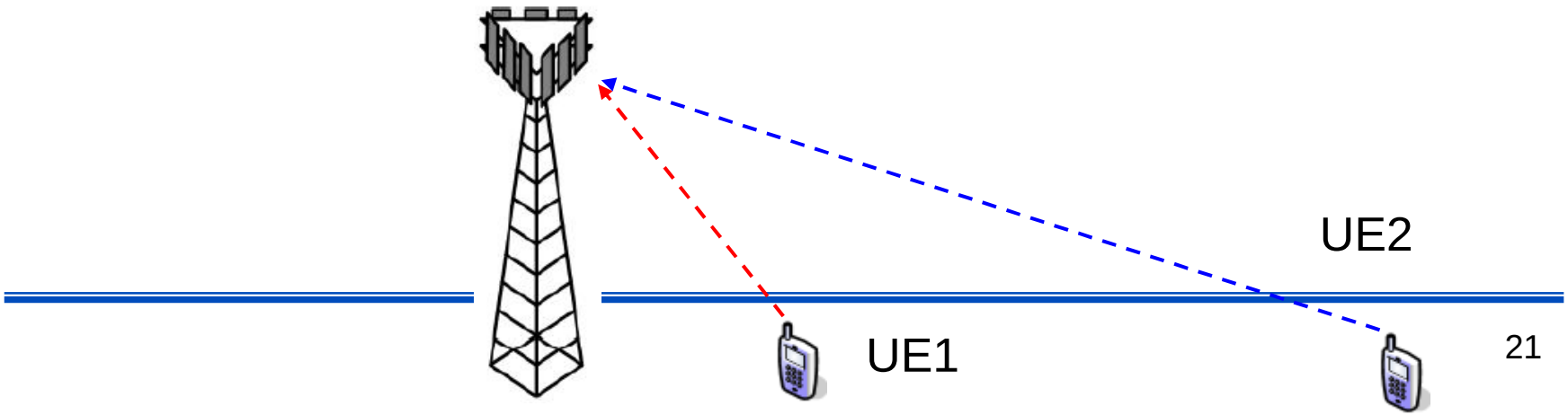
Power control

Power control

- Objectives
  - Maintain the link quality in uplink and in downlink by controlling the transmission powers
  - Prevents near-far effect
  - Minimise effects of fast and slow fading
  - Minimises interference in network
- Accuracy of the power control is important
  - No time-frequency separation of users, all use the same bandwidth
  - Inaccuracy in power control immediately lifts the network's interference level, which correspondingly lowers the capacity
  - Due to users mobility the speed of power control is also a critical issue

Near-far problem in uplink

- There can large path loss difference between UE1 (cell centre) and UE2 (cell edge)
- If both UEs are transmitting with the same power then UE1 will block UE2 (and other cell edge users too)
- Power control will drive transmission powers of UE1 and UE2 to the minimum level that is required to meet QoS
- In Node B received powers from UE1 and UE2 will be the same for same services



Power control

- Power Control on the **common channels** ensures that their coverage is sufficient both to set up UE-originating and UE-terminating calls.
- Power Control on the **dedicated channels** ensures an agreed quality of connection in terms of Block Error Rate (BLER), while minimizing the impact on other UEs.
- **Uplink Power Control** increases the maximum number of connections that can be served with the required Quality of Service (QoS), while reducing both the interference and the total amount of radiated power in the network.
- **Downlink Power Control** minimizes the transmission power of the NodeB and compensates for channel fading. Minimizing transmitted power maximizes the downlink capacity.

Power control

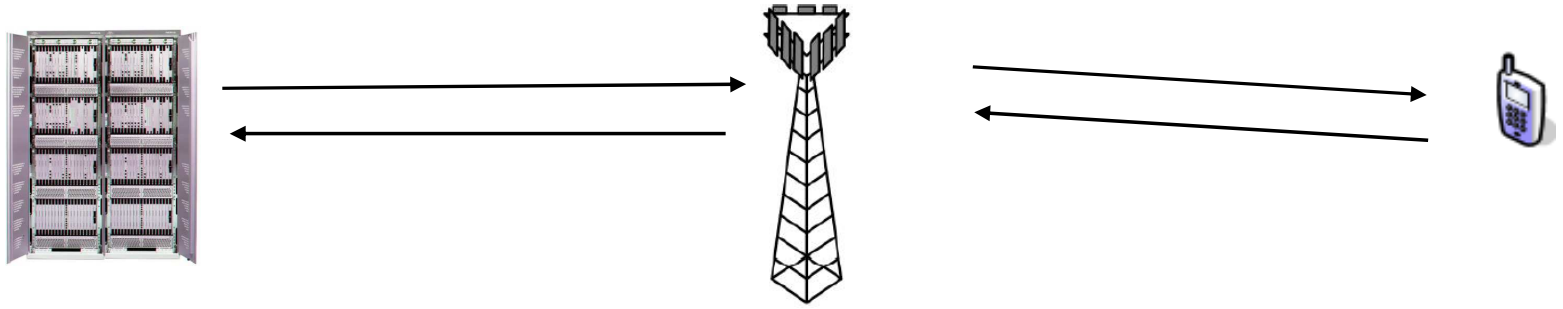
- Main power control approaches
  - Fast power control:
    - Aim is to compensate the effect of fast fading
    - Gain from fast power control is largest for slowly moving UEs and when fading is flat, i.e. there is multi-path diversity
    - Fast power control drives the received power to a target SIR. This value is discussed more closely in connection with dimensioning.
  - Outer loop power control
    - Adjust the target SIR according to service QoS.

PC mechanism

Outer loop PC: RNC adjust the target SIR in order to meet target BLER

Fast PC: Node B command terminal to change transmit power in order to meet target SIR

Received SIR



Outer loop power control

Fast power control

Uplink outer loop PC

- The goal is to control the target SIR in order to sustain the wanted QoS with minimum transmit power
- The target BLER is defined with the admission control algorithm
- The uplink algorithm is controlled in RNC
- Update frequency from 10 Hz up to 100 Hz
- Outer loop power control will raise or lower the target SIR according to step size, which is defined by radio network planning.
- The equipments' performance defines the minimum value for target SIR

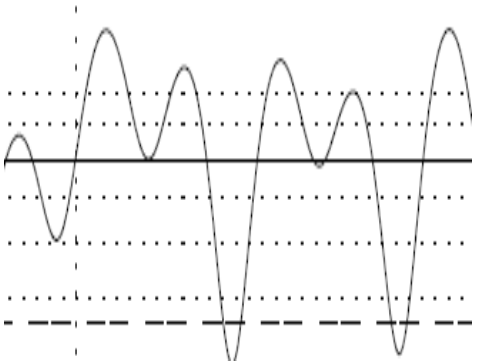
Downlink outer loop PC

- Implemented in UE to set SIR target on DL traffic channels
- Quality target: BLER of each transport channel as set by RNC
- Admission control determines the value of DL BLER.
- No SIR target change if NodeB power reaches maximum or network congestion occurs.

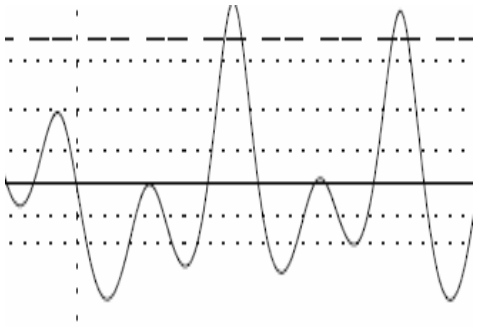
Transmit Power Control (TPC)

- Ideal fast power control invert the channel
  - In practice power control accuracy is reduced by feedback errors,
  - Better figure, PC headroom etc

Fast fading channel



Transmitted power



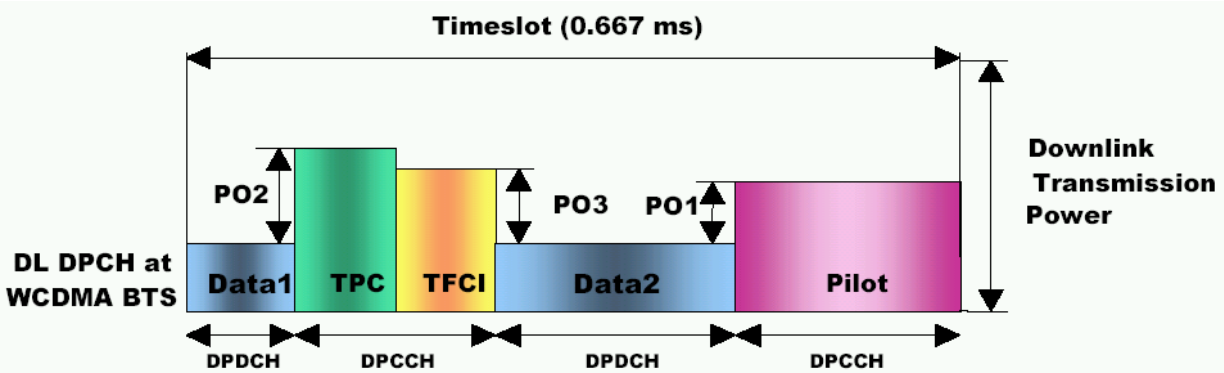
Note: It is usual to talk about ‘fast power control’ when power control is build up to mitigate fast fading. Transmit power control is WCDMA specific term

Uplink TPC

- Update rate 1.5 kHz => fast enough to track and compensate fast fading up to x km/h mobile speed
- If received SIR > target SIR in Node B => UE is commanded to decrease its transmit power. Similarly UE is commanded to increase its transmission power if received SIR < target SIR
- Network planning defines the step size. Usual step size values are between 0.5dB and 2dB.
- Soft handover:
  - UE can receive contradictory PC commands from different node Bs
  - UE transmission power will be increased if all node B's ask for it and decreased if at least one node B demands it

Downlink TPC

- Similar as UL TPC:
  - UE measures SIR on DL DPCCH during the pilot period (or use CPICH)
  - UE maintains the QoS by sending fast power control commands (TPC bits) requesting power adjustment
- Power offsets can be used in DL in order to improve control reliability. Offsets are network parameters that can be set in planning phase



TPC characters

- Main interference migitation means in UMTS
- TPC (1500Hz) is able to follow fast fading up to ~50km/h MS speed, after that the fading dips are averaged out
- In high MS speeds TPC can have even negative impact
- TPC lowers the required Eb/No, not so much tx-powers directly

• Concerns in practise:

•In SHO, DL powers can drift apart due to the inaccurate reception of uplink PC commands → Degraded SHO performance in case drift prevention not working

•In SHO, DL PC commands cannot be combined in RAKE (because they contain different information). Data bits however can be combined → Worse reability for PC commands.

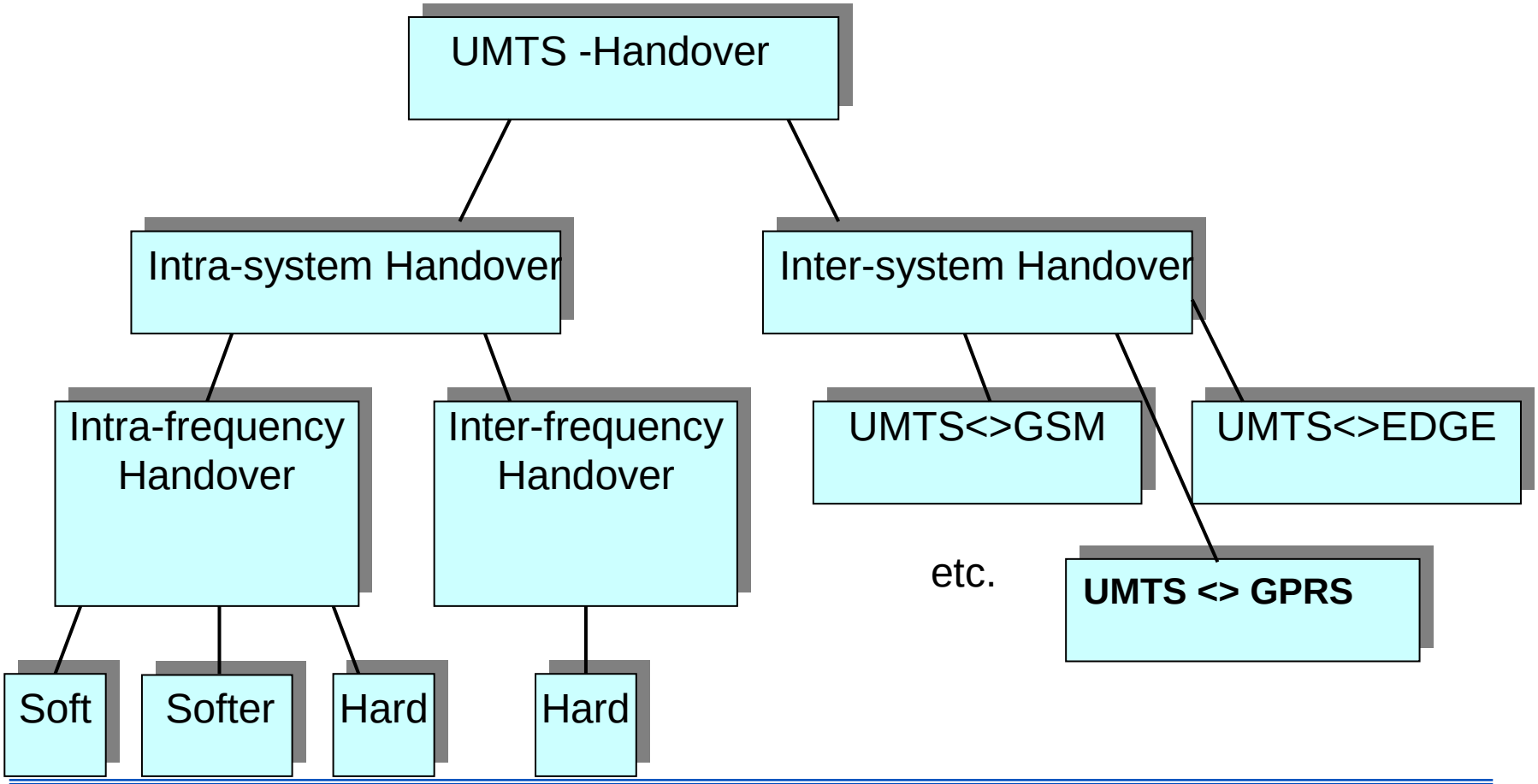
=> Can be improved by allocating more power to CCHs

•Building corners in the urban areas

• Average TPC headroom (4dB) must be assumed to pathloss.

Handover control

Handover types in WCDMA



WCDMA Handover control

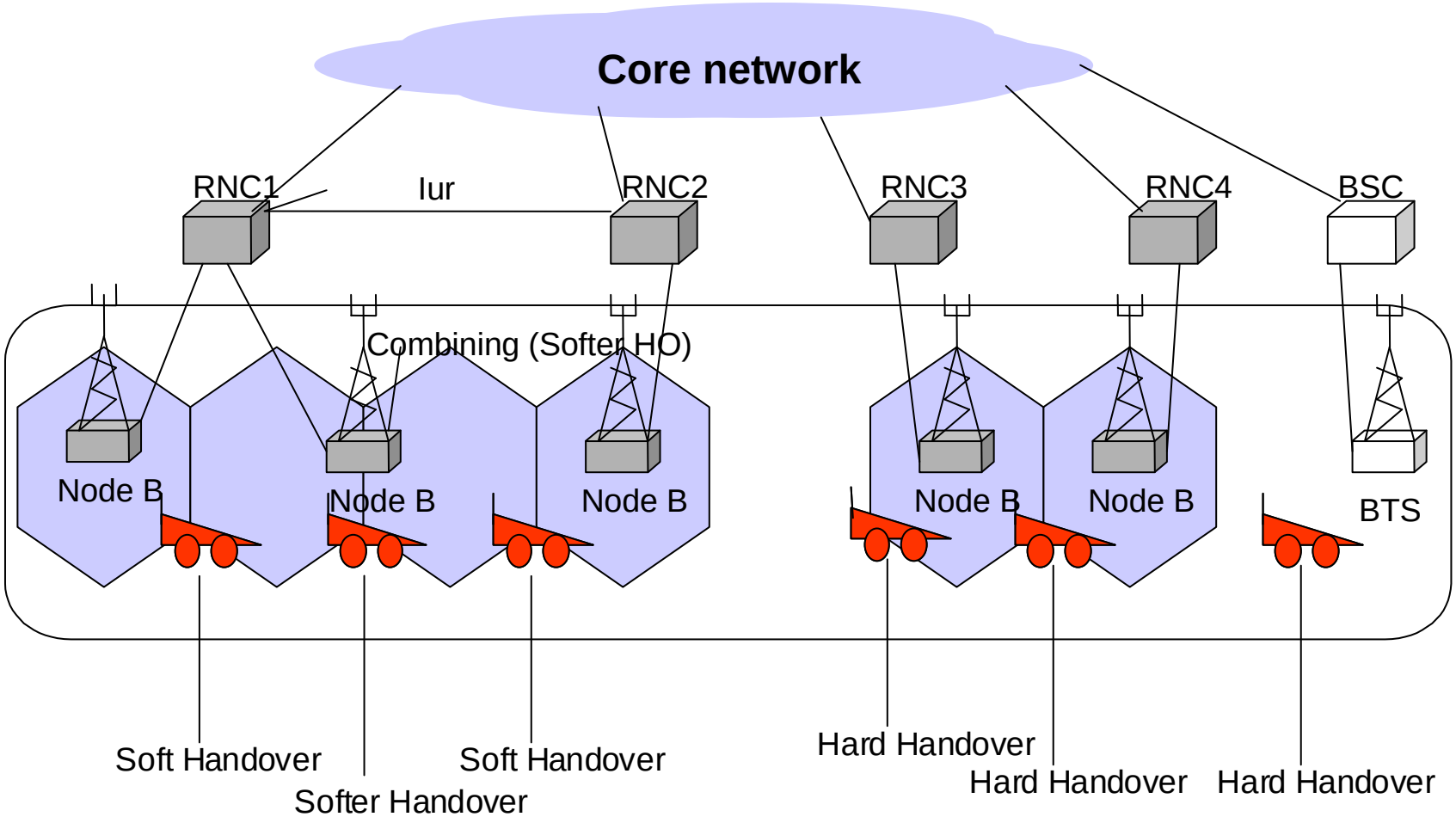
Hard HO (HHO)

- All the old radio links of an UE are released before the new radio links are established.
- Real time bearers: short disconnection in transmission.
- Non real time bearers: HHO is lossless.
- Shared & common channels used for hard handover (cell reselection)

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.
  - Dedicated channels (Cell_DCH state) used for SHO
- Handover can be either network or UE initiated
  - Serving RNC makes the decisions in both cases

WCDMA Handover control



Hard handovers

- Intra & Inter-frequency HHO's
- Usually triggered to maintain mobility
- Not recommended in WCDMA unless there is an urgent need, because
  - Hard HO increases interference easily, since the real-time user is disconnected temporarily and the used power must be re-evalueted
  - This decreases the capacity in heavy traffic situations and can worsen the near-far effect
- Absence of Iur (connection between RNC's) will cause hard HOs
- Compressed mode used in HOs between carriers and systems
  - In compressed mode UE stop UL transmission for few milliseconds within a radio frame (10ms) in order to enable measurements of different carriers/systems

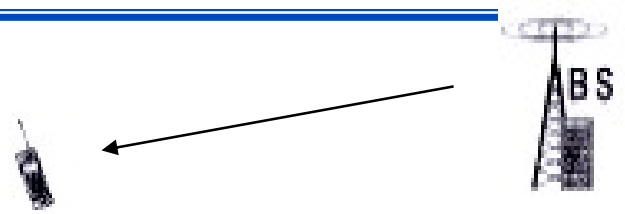
Inter frequency handover

- IFHO can be used in planning to
  - provide coverage (micro ↦ macro cell)
  - provide capacity (reduce cell loading)
- 2nd carrier can be enabled on cell basis
- Not so straightforward to perform in UE due to need of compressed mode
- Most Network vendors' equipment supports IFHO
- IFHO is generally seen as a means of optimisation as the traffic evolves, but can be used also e.g. to provide indoor coverage

Soft Handover (SHO)

- SHO helps avoid near-far effect for real-time connection
- For high mobility users shadow fading + (slow) hard handovers would create near-far situations
- SHO is an essential interference mitigation tool in WCDMA

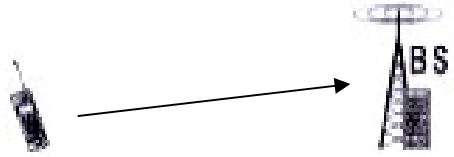
Soft Handover



DOWNLINK:

- SHO utilises two separate codes in DL (RAKE fingers in UE are assigned for reception)
- Maximum ratio combining done in UE for the signals
- Produced gain 1-3 dB, however...
  - Gain depends on the difference of the signals' strength
  - Gain depends on channel conditions and accuracy of the received channel estimate → In some circumstanses the gain can be lost!
- The more multipath diversity is available the less SHO gain is achived

Softer/Soft Handover



UPLINK:

- More complex situation than in DL
- During softer HO, same procedure in node B's RAKE than in DL case
  - Produced gain 1-3 dB
  - Better performance in terms of strenght differences, since the signals come from the same source
- During Soft HO, the combining of signals is done in the RNC
  - Selection combining performed for baseband signal
  - Based on selecting the frame with better FER or BER
  - Better frame send to be used in open loop PC (target SIR estimation)
  - Gain achieved through more stable UE tx-powers (1-2dB)

  → No actual gain to the radio link

Soft Handover

The cells in a WCDMA RAN are, from UE point of view, divided in different mutual excluding sets defined by 3GPP:

- **Active Set**
  - The cells involved in soft handover and measured by the UE
- **Monitored Set**
  - The cells only measured by the UE and not part of the Active Set. The monitored set can consist of intra-frequency, Inter-Frequency and Inter-RAT cells
- The cells measured by the UE are the sum of the Active Set and the Monitored Set.
- The number of Intra-frequency cells in the Monitored Set + the Active Set cells is limited by 3GPP to 32.
- The number of Inter-Frequency cells in the Monitored set is limited to 32.
- The number of Inter-RAT cells in the Monitored set is limited to 32.

Soft Handover

Active Set

- As UE moves, node Bs are continuously added to and removed from the active set. When added, they are also updated to the neighbor cell list.
- UE measures the *monitored set* of cells and Handover Control evaluates if any node B should be added to, removed from or replaced in the active set
- Maximum Active Set Size parameter
  - is used to determine the maximum allowed number of SHO connections (varies between 1-5, typical default 3)
    - Too high value decreases capacity (signalling increases and multiple connections occur too often)
    - Too low value degreases the SHO performance (best candidate cells may be excluded in some situations)

Soft Handover

- The handover measurements for Intra-Frequency HO are based on P-CPICH Ec/Io
- Ec/Io is the received signal code power divided by the total received power. It is calculated from signal *before* the signal de-spreading operation while Eb/No is calculated *after* de-spreading.
  - Ec/Io can be be determined for the signal ”in the air”
- *Eb/No depends* on the service (bit rate, CS/PS, receiving end) and *Ec/Io is service independent*
- The accuracy of the Ec/Io measurements is essential for HO performance
  - Depends on filtering lenght and mobile speed
    - Filter length for slowly moving & stationary UE’s should be just long enough to avoid Fast Fading errors
    - Too long filter length for will cause HO delays to fast moving UE

Soft Handover

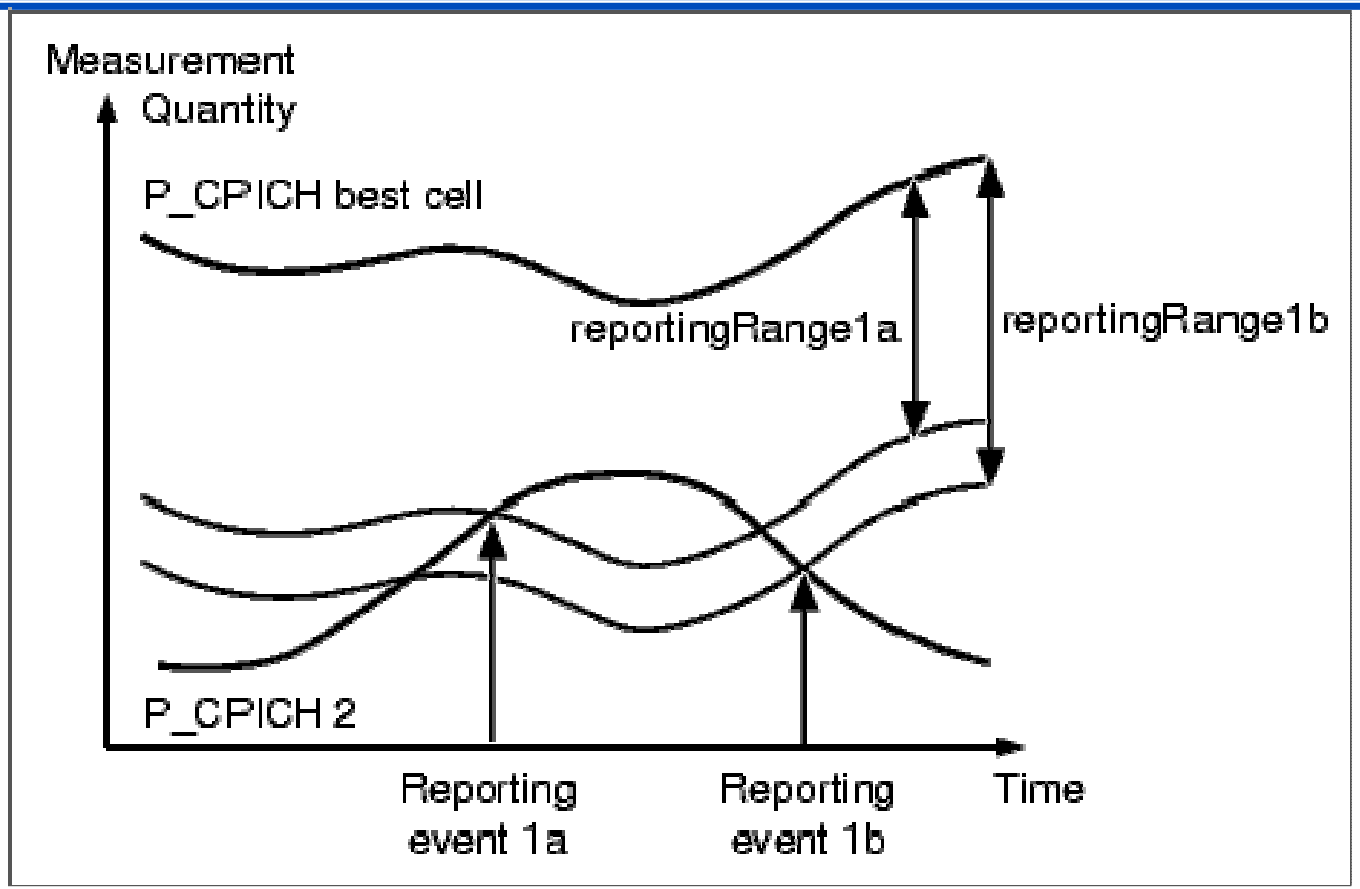
Event based triggered measurements and reporting

- Basic reporting events 1A, 1B and 1C (Ref. 3GPP)
  - 1A: Primary CPICH enters the reporting range
  - 1B: P-CPICH leaves the reporting range
  - 1C: Non-active P-CPICH becomes better than an active P-CPICH
  - 1D: Change of current best cell with new P-CPICH

Handover decision

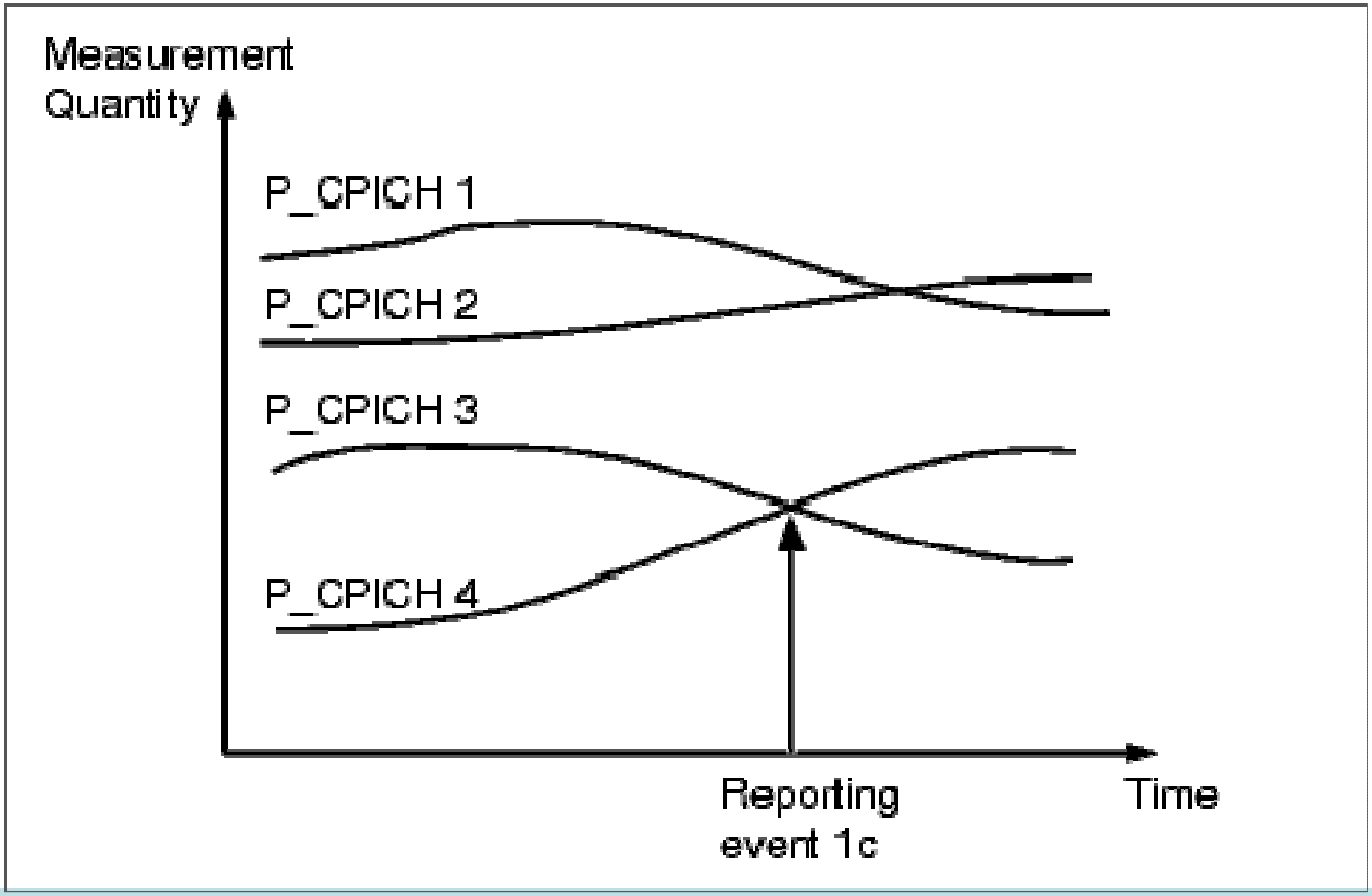
- Done by RNC based on measurements and available resources

Soft Handover



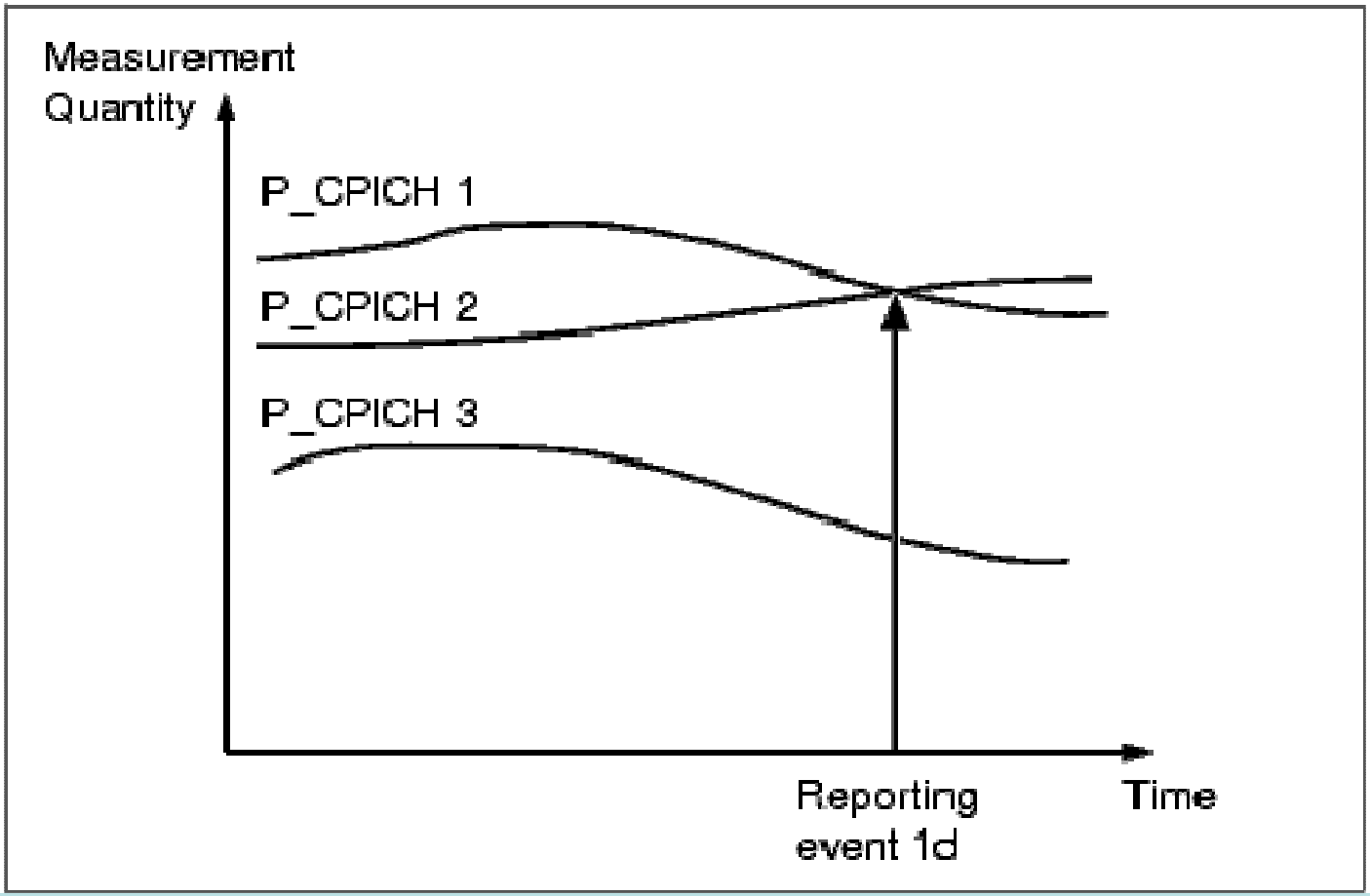
- **Picture of events 1A and 1B. Example: The terminal sends an event 1A report to the RNC, if the new cell belongs to the monitored cells list and Active Set is not full. Then new cell is proposed to be added to the Active Set. If the Active Set is full, the cell is proposed as a replacement of the worst cell in the Active Set (1C)**

Soft Handover



- **Picture of event 1C. Example: The terminal sends an event 1C report to the RNC if the new cell belongs to the monitored cells list and Active Set is not full. Then new cell is proposed to be added to the Active Set. If the Active Set is full, theen new cell is proposed as a replacement of the worst cell in the Active Set**

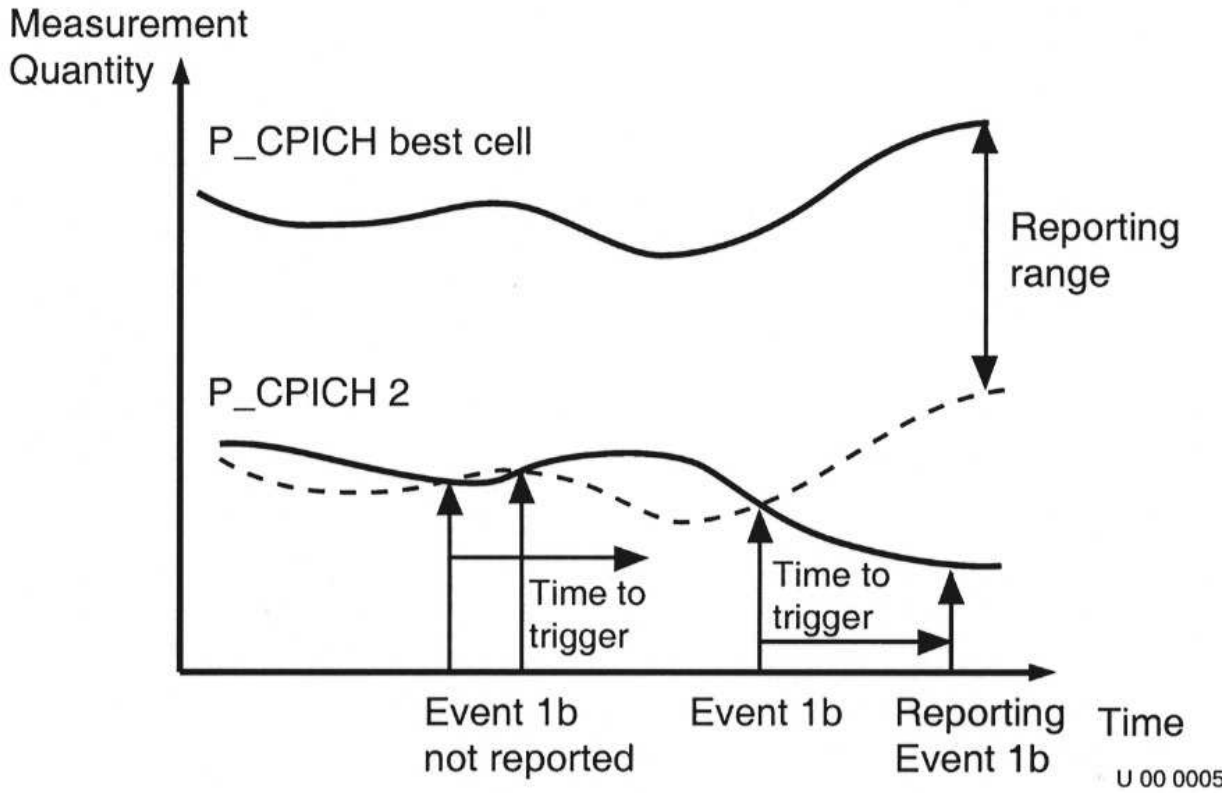
Soft Handover



- **Picture of event 1D. Example: The terminal sends an event 1D report to the RNC if the cell belongs to the monitored cells list and Active Set is not full. Then cell is proposed to be added to the Active Set. If the Active Set is full, the cell is proposed as a replacement of the strongest cell in the Active Set**

Soft Handover

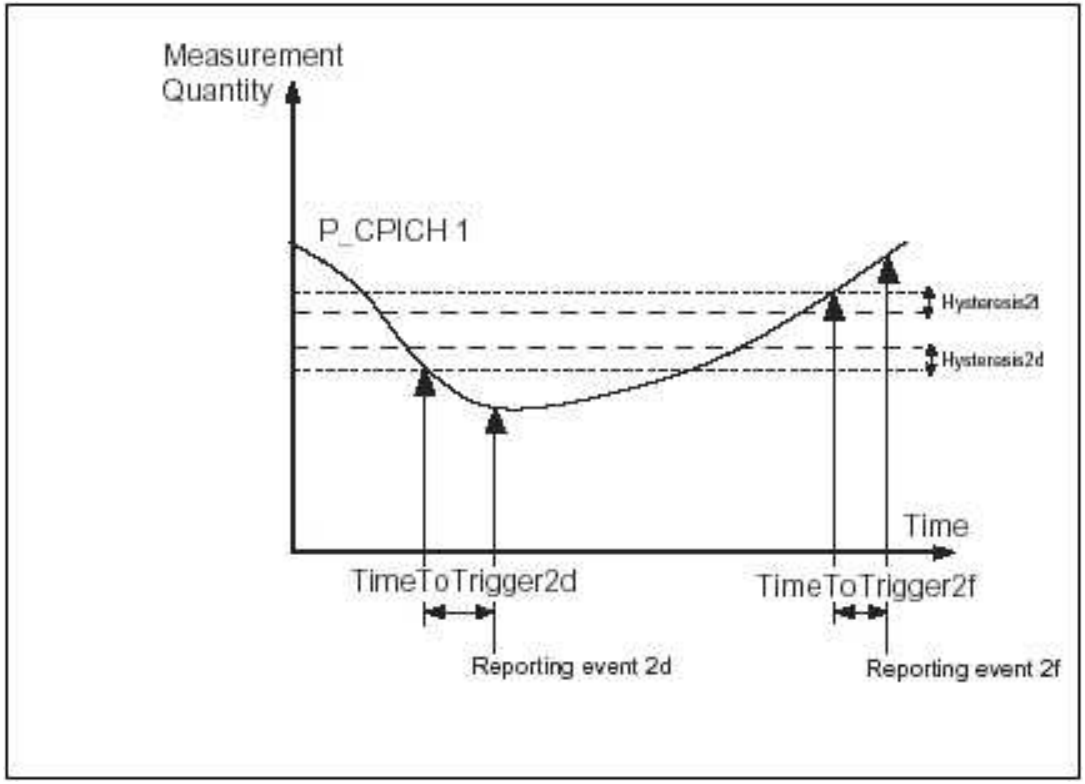
- Time-to-trigger



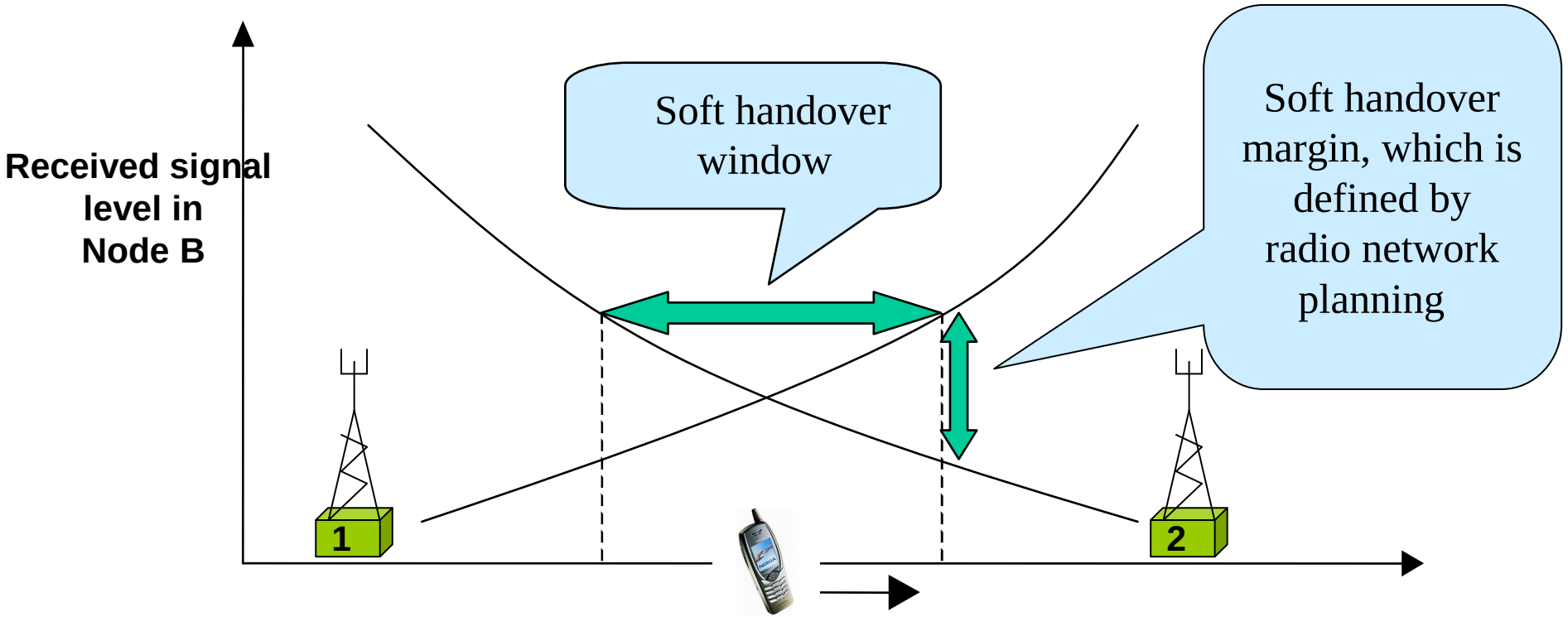
Inter-Frequency HO (IFHO)

- Inter-Frequency Handover is a hard handover where the UE is ordered by the network to tune to another frequency.
- This means that there will be small interuptions in the data flow to and from the UE

- When Inter-Frequency HO is considered, first the UE measures the conditions to start Compressed Mode
  - Usually Ec/Io of current carrier
  - Events 2d and 2f defined for IFHO
  - Time to trigger used



SHO margin in planning tools



- Some 3G planning tools use one single SHO planning parameter (=SHO margin/SHO gain)
- Default Value varies between 2 and 6 dB
- Value for this parameter should be defined as:

$$\text{Handover margin} = \frac{\text{Reporting range1a} + \text{Reporting range1b}}{2}$$

HO related topics in network planning

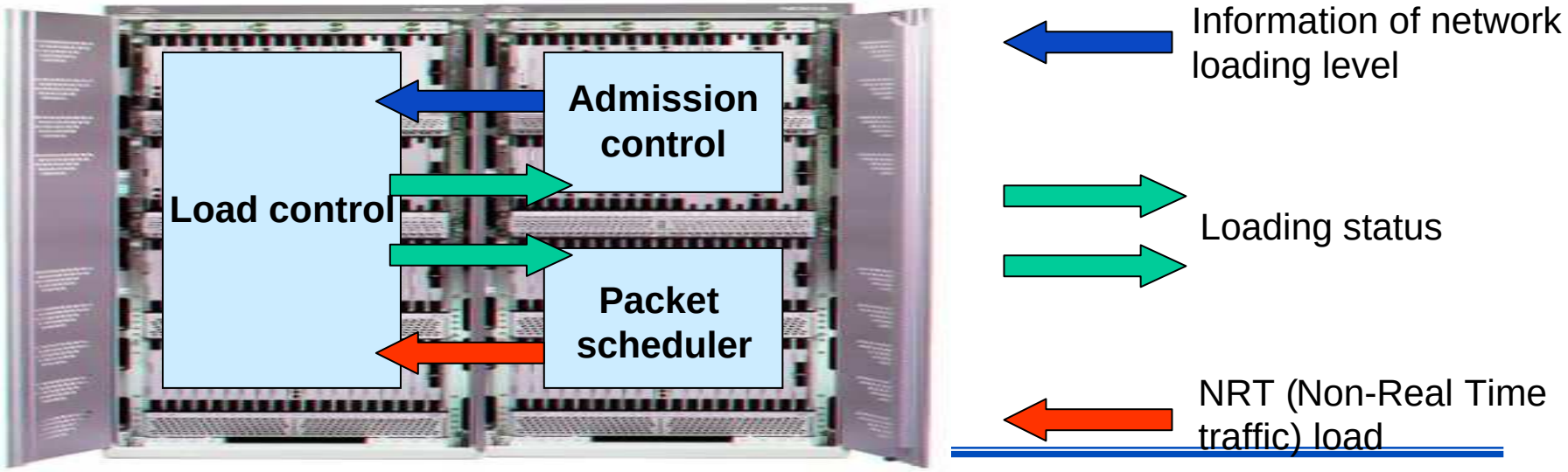
- Network topology: How sites are located relative to each other, how many sectors/site
- Node B antenna radiation patterns
  - Overlapping patterns => more softer HOs
  - Antenna tilt => Number of potential Node B's in Active Set
- Path loss and shadow fading characteristics
- The average number of Node B's that a UE can synchronise to
- HO parameter adjustments is part of the network optimization

Admission and Congestion control

Congestion and Admission Control

- Congestion/Load Control's general responsibility is to remain the network in a stable state and prevent overloading
- Congestion/Load control is in close co-operation with functions of admission control and packet scheduler

Load control operates in RNC:

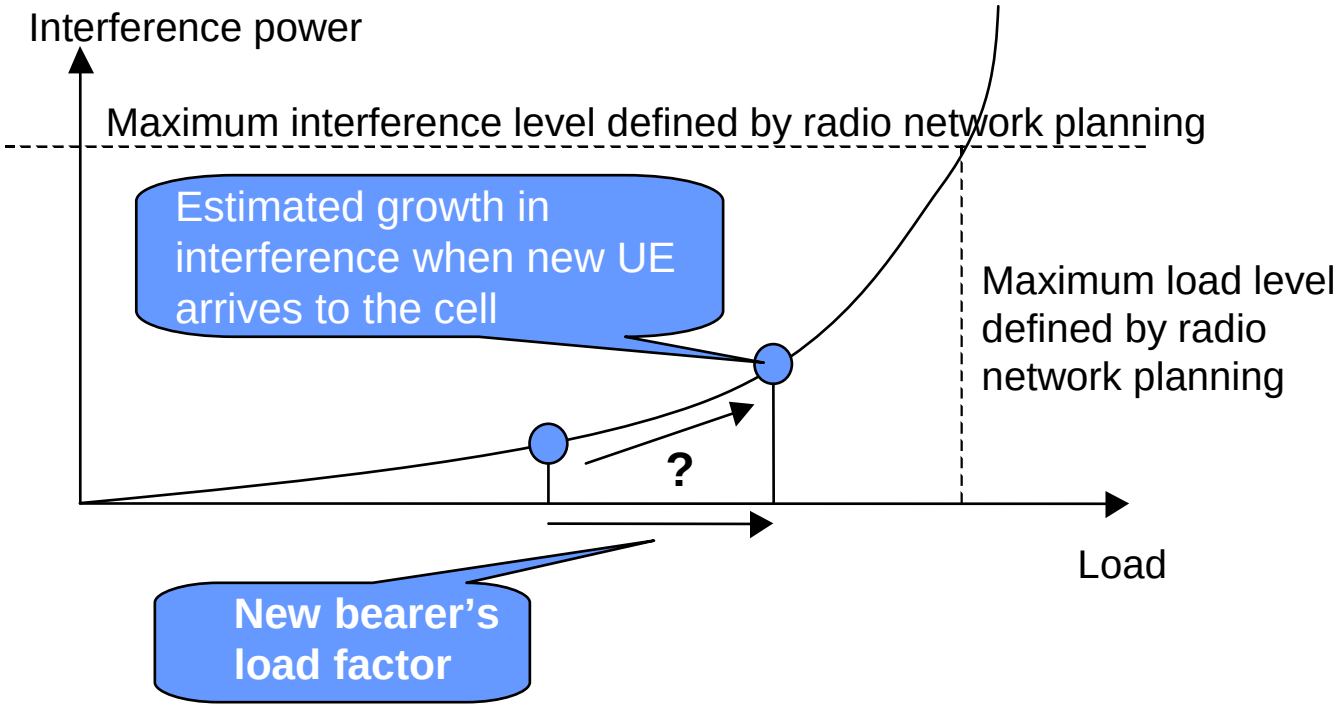


Admission and Congestion Control

- Admission control
  - If air interface loading is allowed to increase too much the coverage of the cell will be reduced below the planned value.
  - Admission control decides whether to accept the terminal's request for new radio access bearer by calculating how much interference new bearer would create to the cell in both UL and DL
- Congestion control
  - Responsible of returning the network back into desired target load in case of overload
  - Target load is set in network planning and overload should be an exceptional situation

Admission Control

- There are predefined UL and DL thresholds for interference power. Thresholds are set in network planning.
- If either UL or DL threshold is exceeded the RAB is not admitted.
- For decision AC may derive the transmitted bit rate, processing gain, radio link initial quality parameters, target BER, BLER, Eb/No, SIR target.



Congestion control

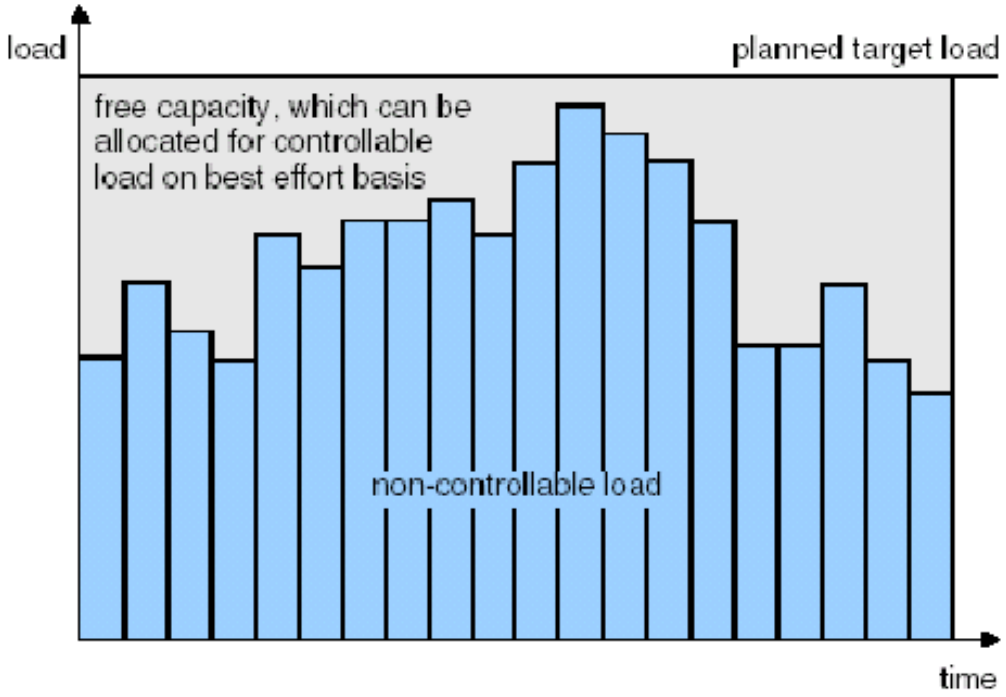
- In case of congestion the use of resources are scaled down to reach normal loading status
- The priorisation and order of congestion control actions is based on vendor algorithms.
- Actions that can be carried out in order to decrease the load
  - Deny power control commands received from UE
  - Reduce the UL Eb/No target used in UL fast power control
  - Reduce the throughput of packet data traffic
  - Handover to other WCDMA carrier or to GSM
  - Decrease bit rates in real time services
  - Drop low priority data calls

Packet scheduler

- Determines the available radio resources for NRT radio bearers
- Share the available radio resources between NRT radio bearers.
- Monitor the allocations for NRT radio bearers.
- Initiate the switching between common, shared and dedicated channels when necessary.
- Monitor the system loading.
- Perform load control actions for the NRT radio bearers when necessary.

Packet Scheduler

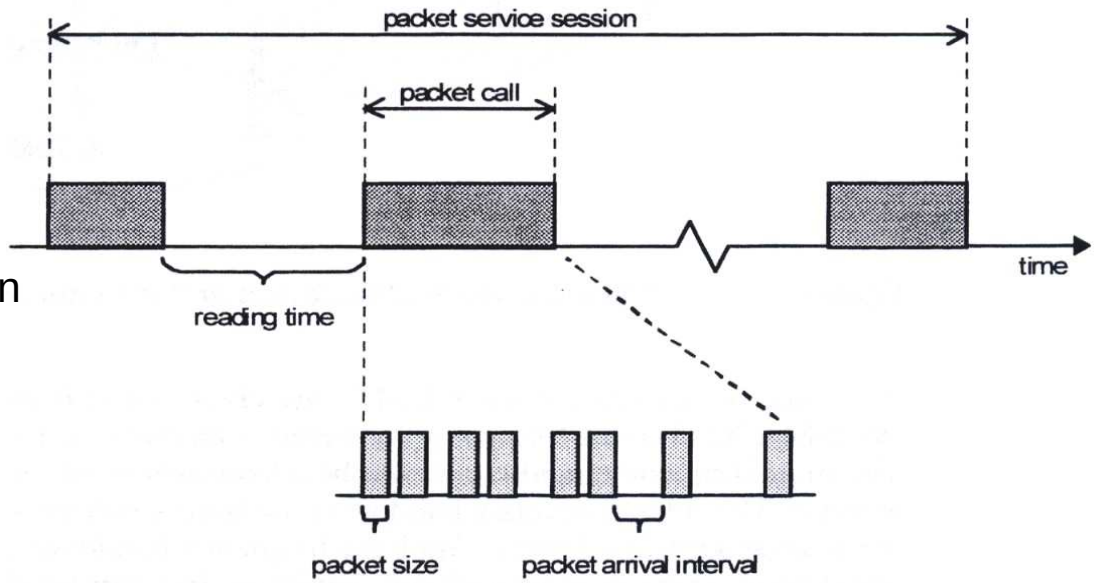
- Capacity can be divided between non-controllable and controllable traffic
- Load caused by real time traffic, interference from other cell users and noise together is called non-controllable load
- The part of the available capacity that is not used for non-controllable load can be used for NRT radio bearers on best effort basis (= controllable load).
- PS is implemented for dedicated (DCH) as well as common control transport channels (RACH/FACH).
- PS takes care of filling the controllable capacity with NRT traffic



- The amount of scheduled capacity depends on:
  - UE and BTS capabilities,
  - the current load in the cell,
  - the availability of physical resources.

Packet Scheduler

- For dimensioning purposes radio network planning can define packet access features per service, e.g.by next parameters:
- Amount of packet bursts per session
- Reading time between bursts
- Size of packets
- Arrival rate packets
- Amount of packets per burst
- Number of retransmission



Control summary

Admission control	Congestion control	Packet Scheduler
	Overload actions	Decrease bit rates and NRT Bearers are dropped
No new bearers are admitted	Preventive load control actions	Decrease bit rates
No new bearers are admitted	No actions	NRT load is not increased, but bit rate changes are allowed
New RT bearers are admitted normally	No actions	NRT bearers are increased