AAiT

Wideband Code Division Multiple Access (WCDMA)

Beneyam Berehanu Haile (PhD)
April 2019

Contents

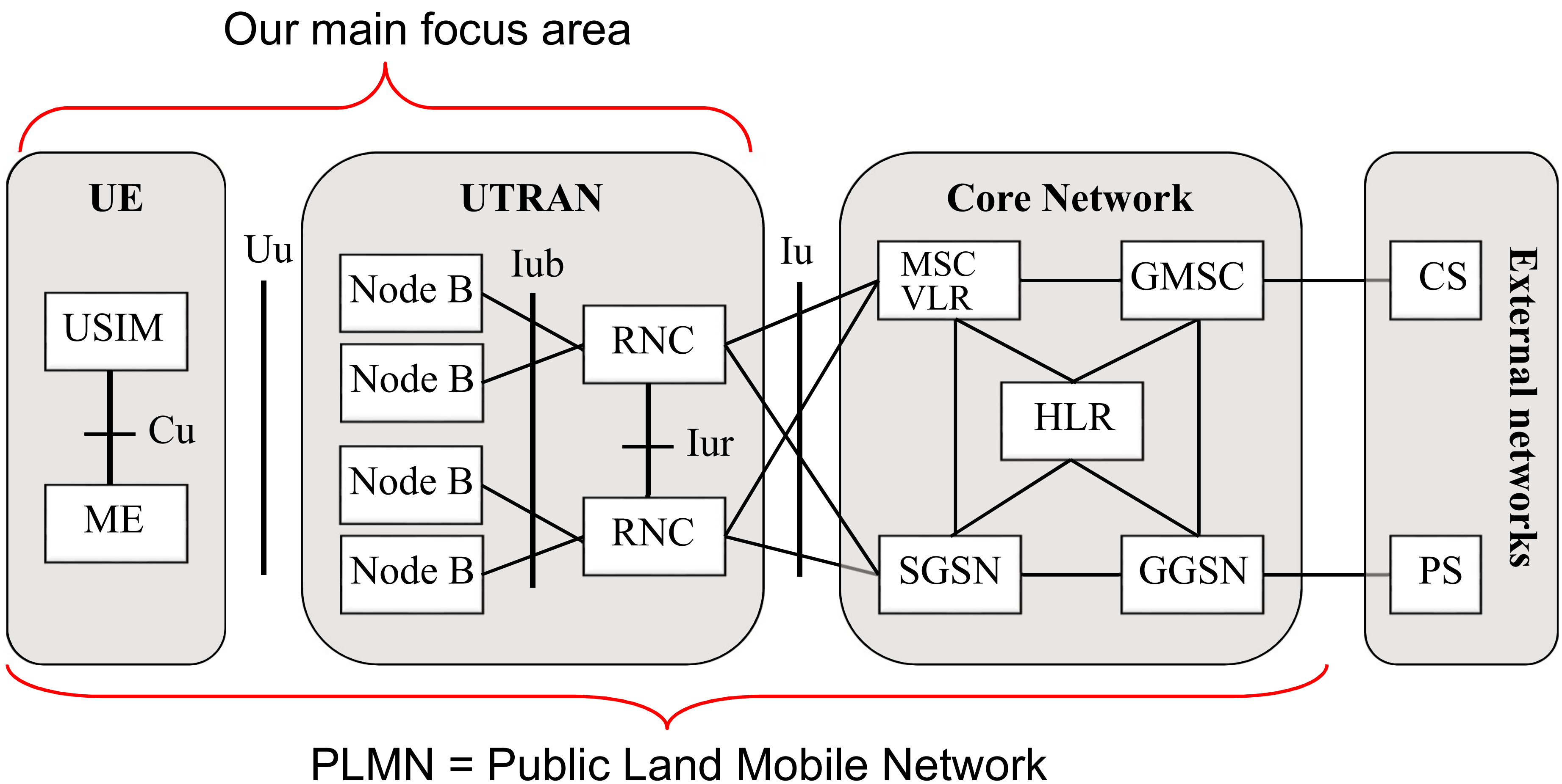
1. *UMTS radio access network architecture*
2. *Physical layer: CDMA principles*
3. *Physical layer: WCDMA spreading and scrambling*
4. WCDMA channel concepts
5. Physical layer procedures
6. Radio Resource Management (RRM)
7. UMTS Radio Access Bearer concept, QoS and radio interface protocols

AAiT

Contents

AAiT

Network elements in WCDMA based PLMN



AAiT

Network elements

- Functionally the network elements are grouped into the
  - ***Radio Access Network*** **(RAN/UTRAN)** that handles radio-related functionalities
  - ***Core Network*** **(CN),** which is responsible for switching and routing calls and data connections to external networks.
  - ***User Equipment*** **(UE)** that interfaces with the user.
- From standardization point of view, both UE and UTRAN are fully different from GSM.
- Part of the definition of Core Network (CN) is adopted from GSM.
  - This supports, for example, cost effective introduction of new radio technologies and global roaming.

UTRAN = UMTS Terrestrial Radio Access Network

AAiT

Network elements: UE

❖ User Equipment (UE) contains

- **Mobile equipment (ME):** Radio communication over Uu interface
- **UMTS Subscriber Identity Module (USIM):**
  - ✓ The subscriber identity,
  - ✓ execution of authentication algorithms,
  - ✓ storing of authentication and encryption keys and some subscription information that is needed at the terminal

Network elements: UTRAN

- **UTRAN consists of Node B's and RNC's**
- **Node B (Base Station):** Handles/manages the traffic between Uu and Iub interfaces. Basic tasks like coding, interleaving, rate adaptation, modulation, spreading etc. Handles also some mobility management tasks.
- **Radio Network Controller (RNC):** Control radio resources of Node B's in its operation area. Provide services for Core Network (CN). Load and congestion control, admission control, code allocation, radio resource management tasks. In addition
  - RNC terminates the RRC (Radio Resource Control) protocol that defines the messages and procedures between the UE and UTRAN.
  - The RNC controlling one Node B (i.e. terminating the Iub interface towards the Node B) is indicated as the *Controlling RNC* (CRNC) of the Node B. The Controlling RNC is responsible for the load and congestion control of its own cells, and also executes the admission control and code allocation for new radio links to be established in those cells.

Task: find pictures of 3G base stations and RNC's from internet.

Network elements: CN

- **HLR (Home Location Register):** Database that is located in the user's home system. Stores the master copy of the user's service profile.
  - The service profile consists of, for example, information on allowed services and forbidden roaming areas. It is created when a new user subscribes to the system, and remains stored as long as the subscription is active.
- **MSC/VLR (Mobile Services Switching Centre/Visitor Location Register):** The switch (MSC) and database (VLR) that serves the UE for Circuit Switched (CS) services.
  - The MSC function is used to switch the CS transactions
  - The VLR function holds a copy of the visiting user's service profile, as well as more precise information on the UE's location within the serving system.
  - The part of the network that is accessed via the MSC/VLR is often referred to as the CS domain.

AAiT

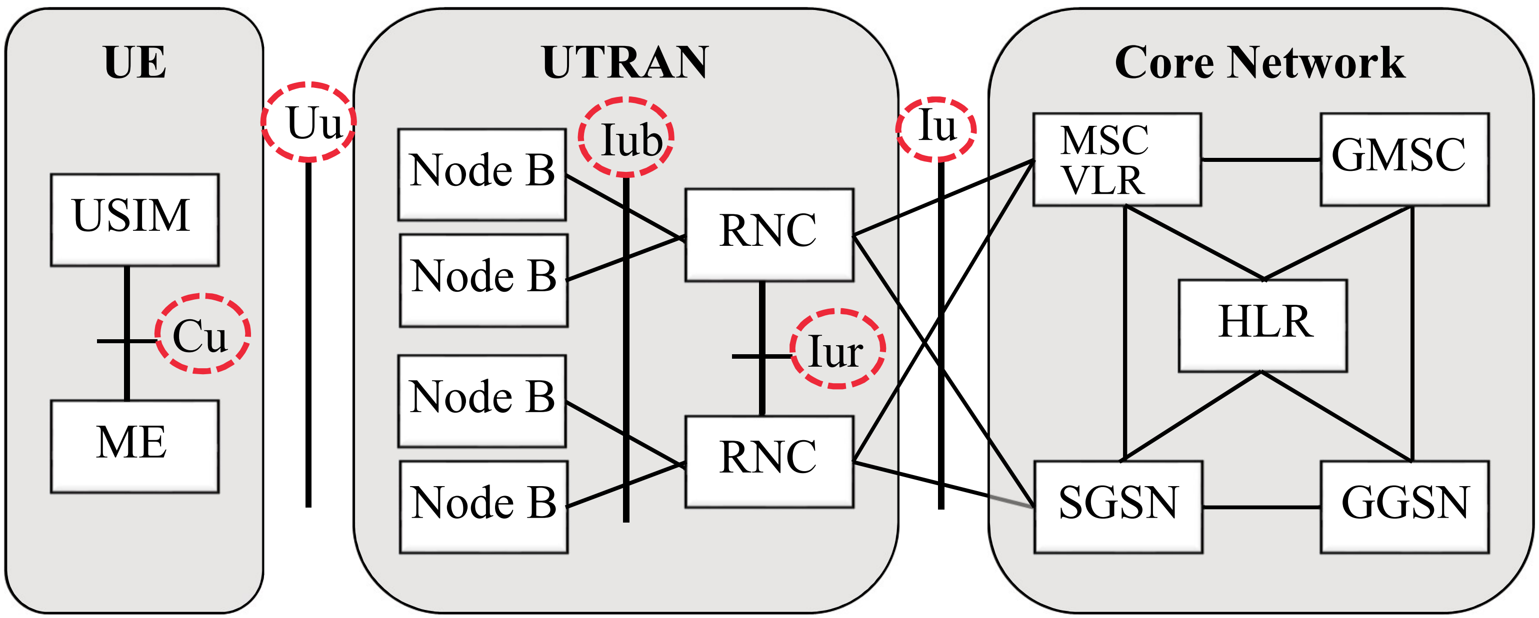
Network elements: CN

- **GMSC (Gateway MSC):** The switch at the point where UMTS PLMN is connected to external CS networks. All incoming and outgoing CS connections go through GMSC.
- **SGSN (Serving GPRS (General Packet Radio Service) Support Node):** Functionality is similar to that of MSC/VLR but is used for Packet Switched (PS) services.
  - The part of the network that is accessed via the SGSN is often referred to as the PS domain.
  - Similar to MSC, SGSN support is needed for the early UE handling operation.
- **GGSN (Gateway GPRS Support Node):** Functionality is close to that of GMSC but is in relation to PS services.

AAiT

UTRAN Architecture: Open interfaces

- The UMTS standards are structured so that *internal functionality of the network elements is not specified in detail.*
- Instead, *the interfaces between the logical network elements have been defined.* Few important <u>open interfaces</u> are indicated below:



AAiT

UTRAN Architecture: Open interfaces

- **Cu interface**. This is the interface between the USIM smartcard and the ME. The interface follows a standard format for smartcards.
- **Uu interface**. *This is the WCDMA radio interface*. The Uu is the interface through which the UE accesses the fixed part of the system.
  - It is important that radio interface standards are very precise since there are many UE manufacturers and all UE's should work in all WCDMA networks.
  - Uu is also called as 'Air Interface'.
- **Iub interface**. The Iub connects a Node B and an RNC. Like the other open interfaces, open Iub is expected to further motivate competition between manufacturers in this area.
  - However, in practice there have been incompatibility problems if Node B's and RNC are from different manufacturers.
  - RNC controls Node B's through Iub interface.

UTRAN Architecture: Open interfaces

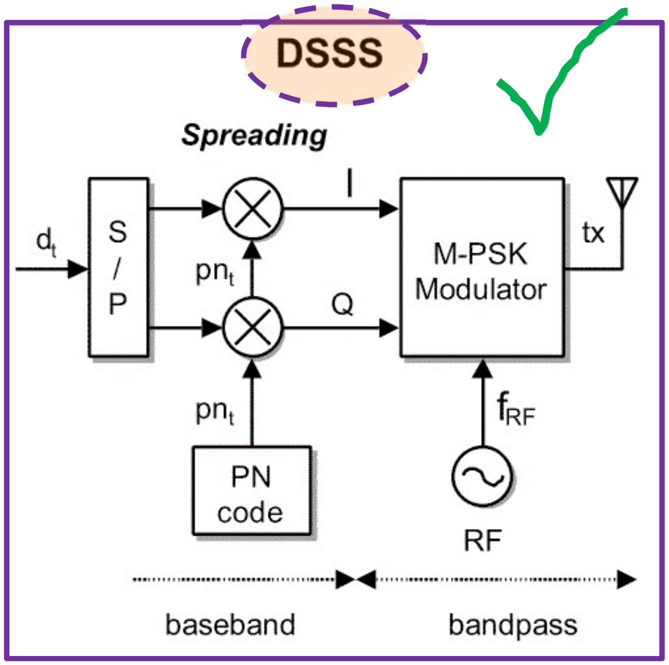
- **Iu interface**. This connects UTRAN to the CN. The open Iu interface gives UMTS operators the possibility of buying UTRAN and CN from different manufacturers. The enabled competition in this area has been one of the success factors of mobile networks.
- **Iur interface**. The open Iur interface allows soft handover between Node B's connected to different RNCs.

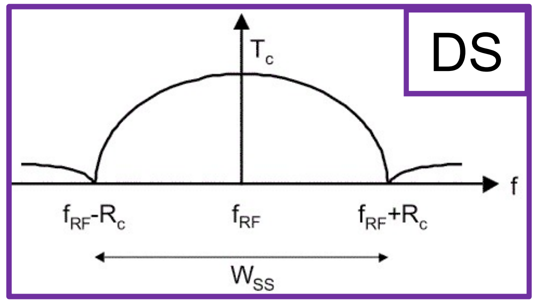
Contents

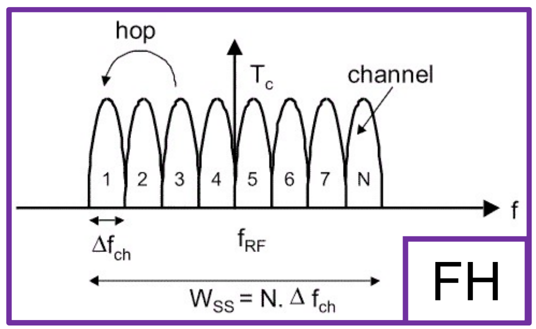
AAiT

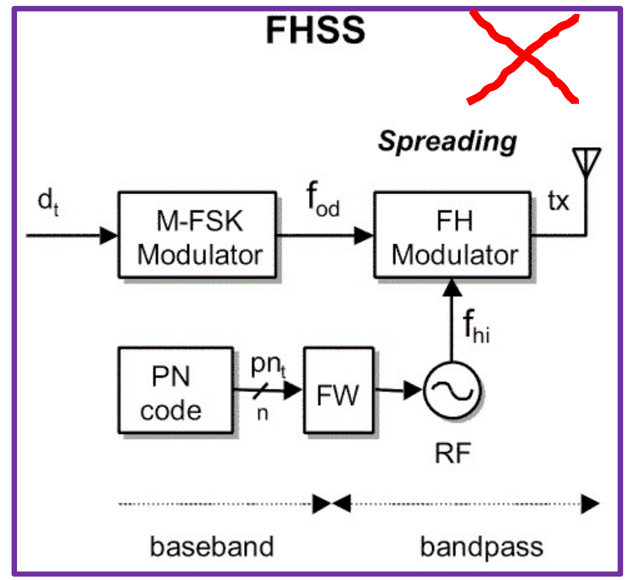
Code division multiple access (1)

- In CDMA, each transmission is spread **over the entire bandwidth** and separation between transmissions is done using the Code Division Multiplexing (CDM)







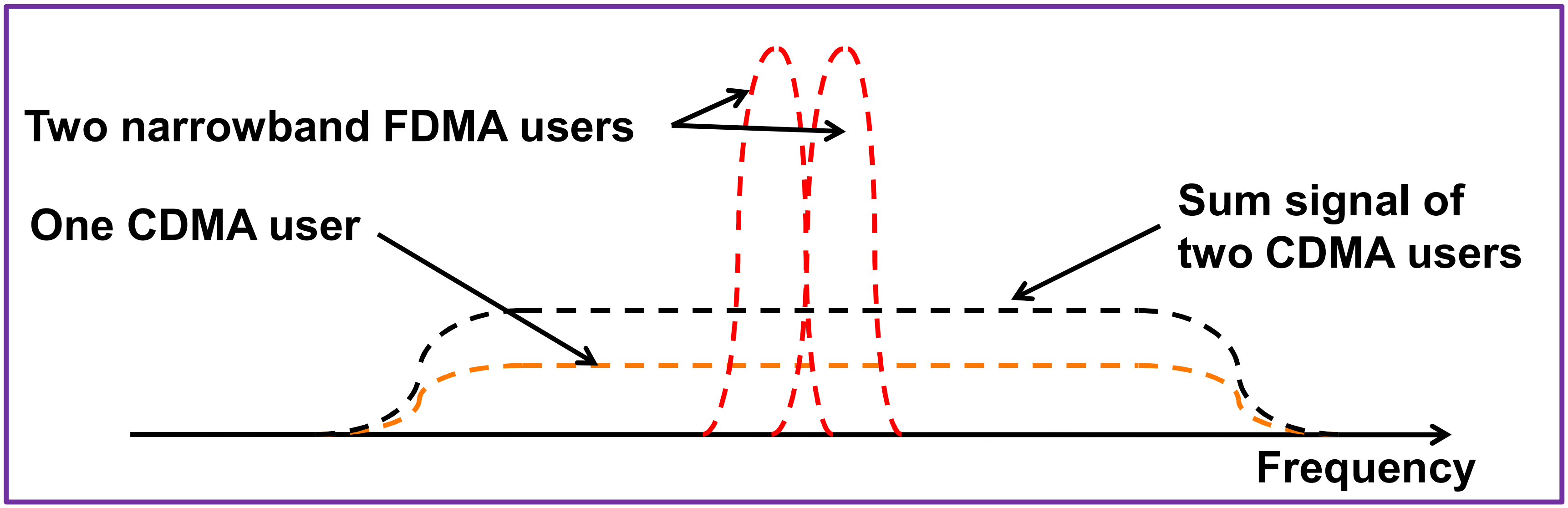


DS = direct sequence

FH = frequency hopping

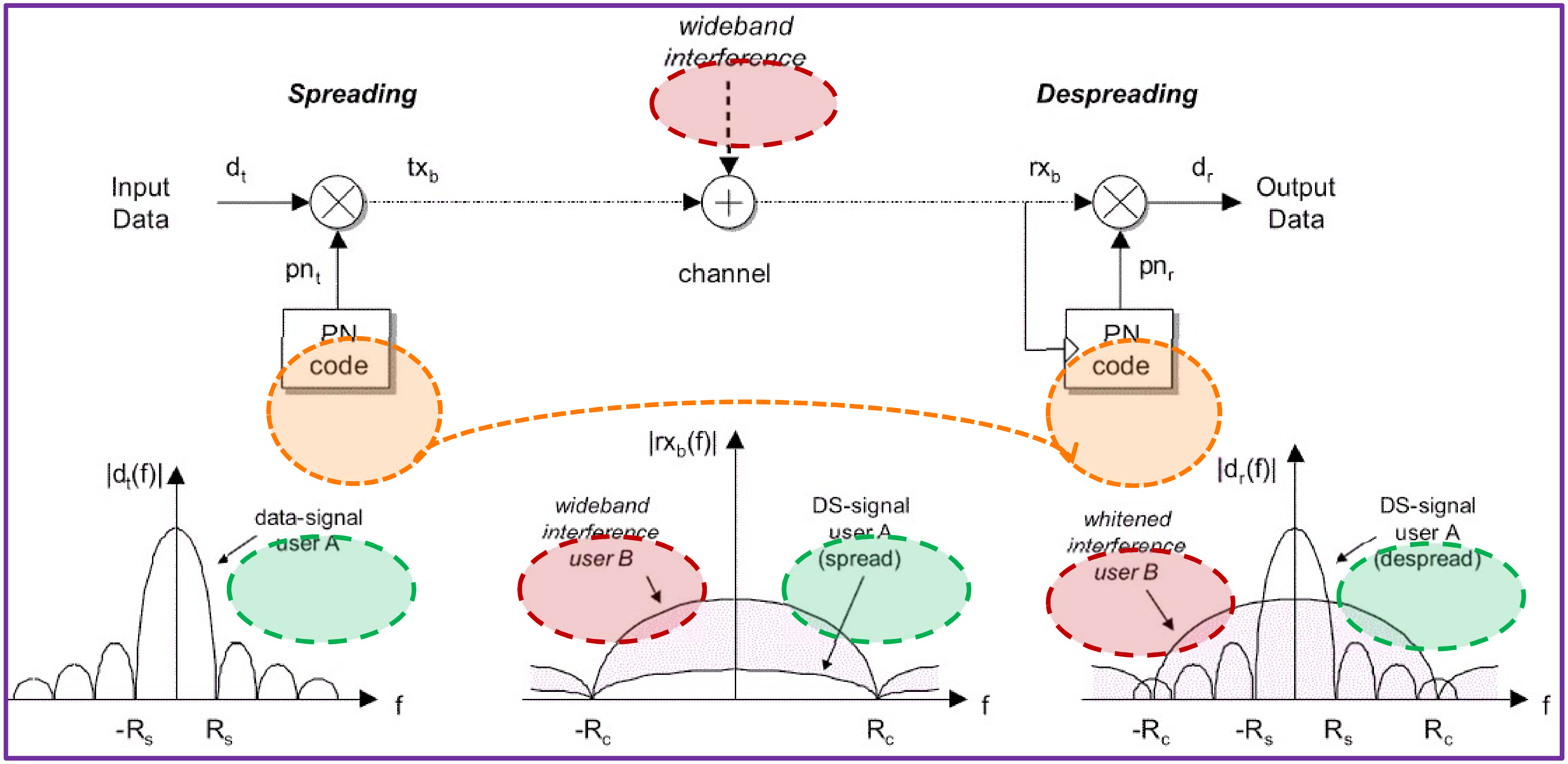
Code division multiple access (2)

- In the so-called Direct-Sequence Spread-Spectrum (DS-SS), the low rate stream of information bits from user is modulated by pseudo-noise sequence
- So, inter-cell interference occurs evenly over the **whole bandwidth**, and it is looking like white noise



AAiT

Code division multiple access (3)



Despreading in presence of wideband interference

AAiT

CDMA Downlink (1)

- In the Downlink (DL) of a CDMA system, transmissions to different users are **synchronized by nature**
  - Transmission is emerging from a single point (i.e., the BS)
- Therefore, in DL users in the single cell can be separated using **orthogonal** channelization codes

$$\sum_{k=0}^{N-1} h_{ik} \cdot h_{jk} = 0$$

$$H_N = \begin{bmatrix} H_{N/2} & H_{N/2} \\ H_{N/2} & -H_{N/2} \end{bmatrix} \quad \text{with} \quad H_0 = [1]$$

Hadamard-Walsh codes

$$H_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \qquad H_4 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}$$

Row "i"

Row "j"

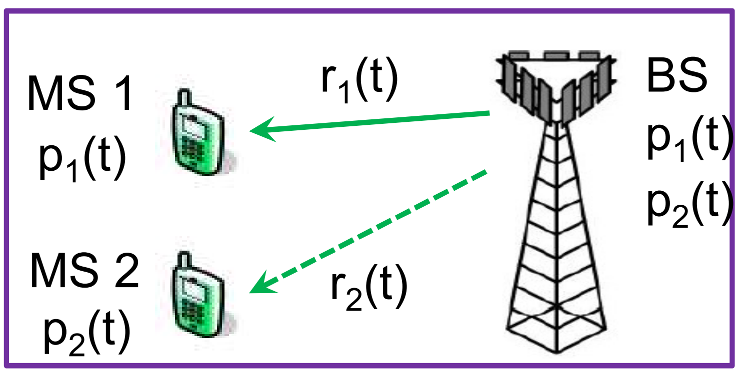
$$H_8 = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix}$$

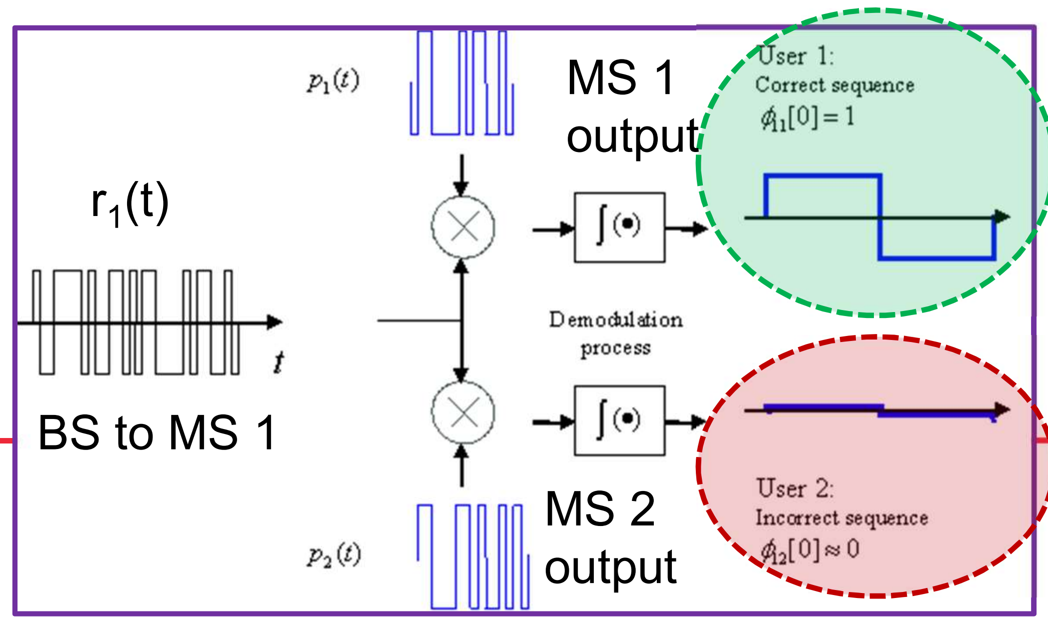
Hadamard-Walsh codes

AAiT

CDMA Downlink (2)

- Thus, each user is assigned a channelization code
- Then, if reception in terminal receiver is perfect, signals from base station to other users of the same cell may be **completely removed**
- Yet, the co-channel interference from adjacent cells cannot be removed, but for mobile terminal it is seen as an additional component of Gaussian white noise

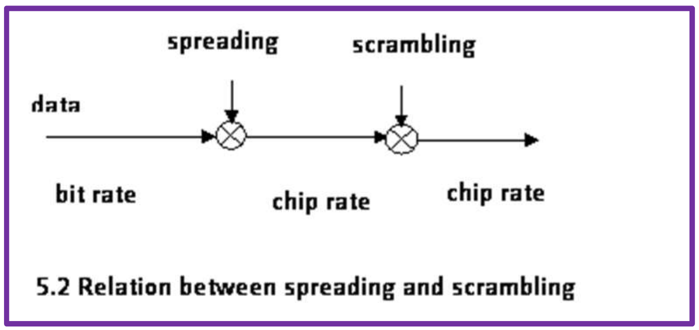




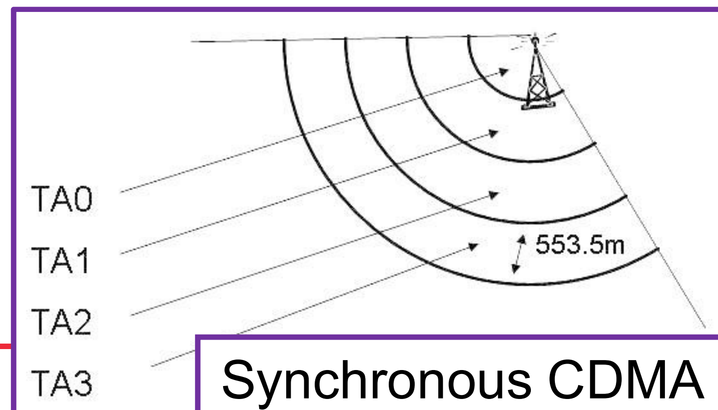
AAiT

Asynchronous vs synchronous CDMA uplink

- In the Uplink (UL) of CDMA systems, users are **asynchronous** in nature
  - I.e., each one has its local oscillator that runs independently
  - Cross correlation properties of the spreading codes change
- Then, there are two options to separate users in a proper way (i.e., keep co-channel interference low)
  - (a) Use scrambling codes (make interference look like AWGN)
  - (b) Estimate the timing advance, and synchronize to the local oscillator to the oscillator of the base station



Asynchronous CDMA



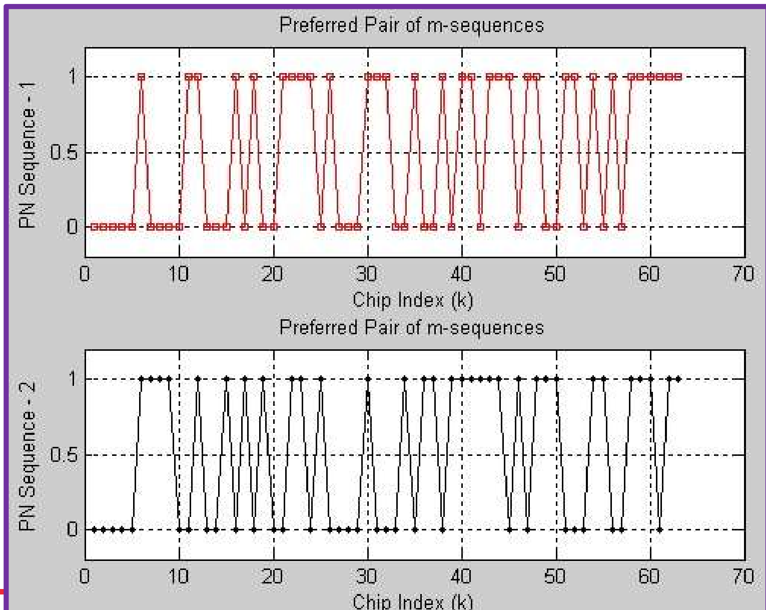
Synchronous CDMA

Baseline approach in WCDMA

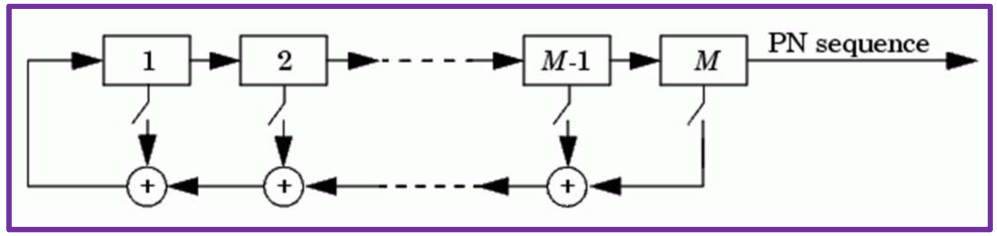
Asynchronous CDMA uplink

(a) **Scrambling codes** are assigned to users to randomize different users wideband signals with respect to each other.

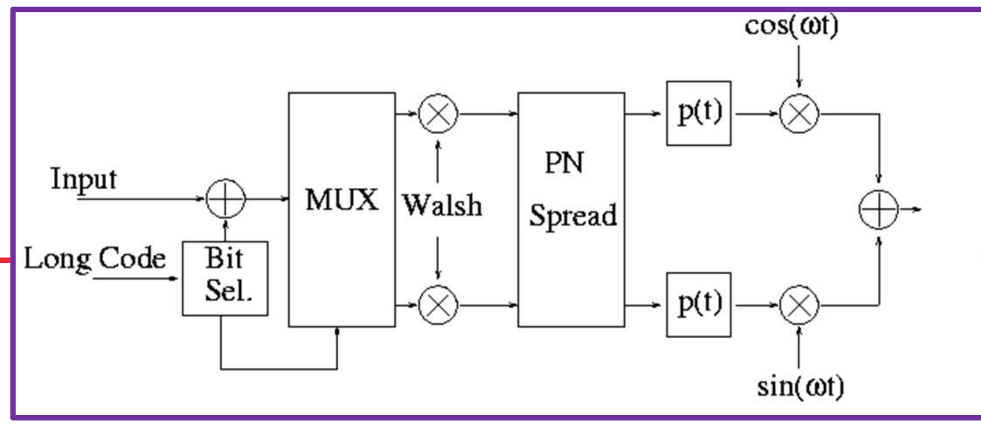
- When base station receiver detects the signal from a certain user, the sum signal from other users is seen as AWGN
- Advanced receiver structures can be used at the base station to improve the performance in this situation



The use of scrambling does not affect the chip rate of CDMA system



PN Sequence Generator



Some CDMA design aspects (1)

(1) In general, the interference in CDMA should be **"white noise like"**

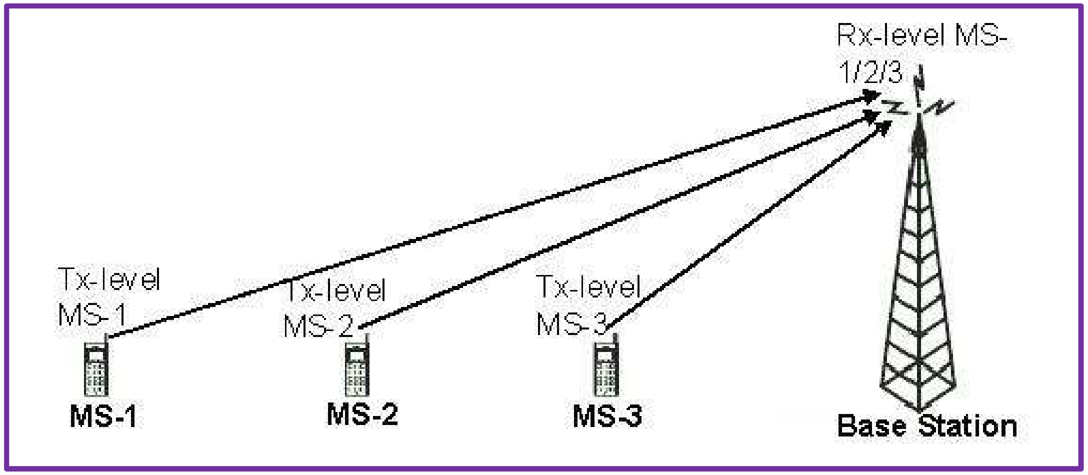
- If interference rejection methods are not used, then it is very important to make interference as similar as AWGN as possible

(2) Since interference is spread over the entire bandwidth, the interference should be kept as low as possible

- ❖ Aspect (2) may lead to the implementation of **tight power control** mechanisms specially in UL, where large differences in received powers from different users may make detection of weak signals very difficult
- ❖ This phenomenon is called **"near-far problem"**

Some CDMA design aspects (2)

- In the DL, base station transmitter can centrally control the signal differences
- However, UL power control requires the assistance of the base station (feedback information is required)
- The best performance is obtained when received power is just on the level that is needed for reliable detection

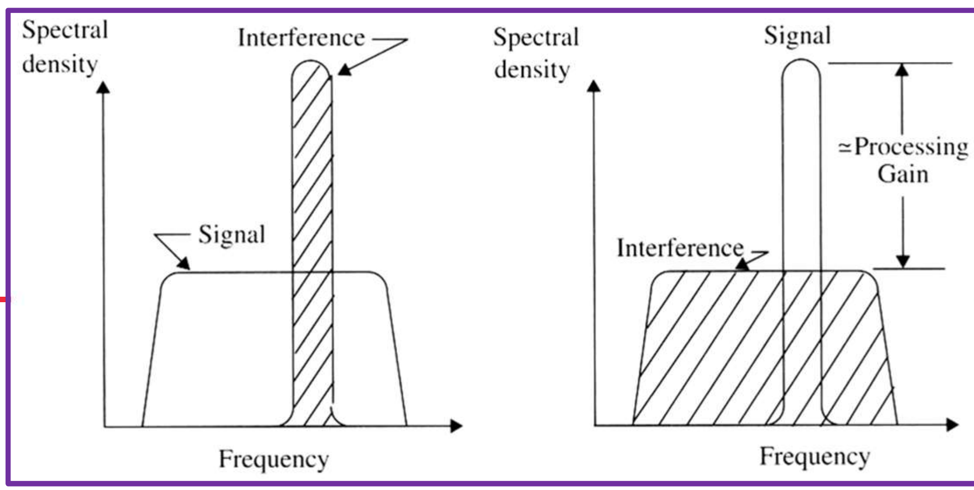


The near-far problem (CDMA UL)

AAiT

Advantages of CDMA

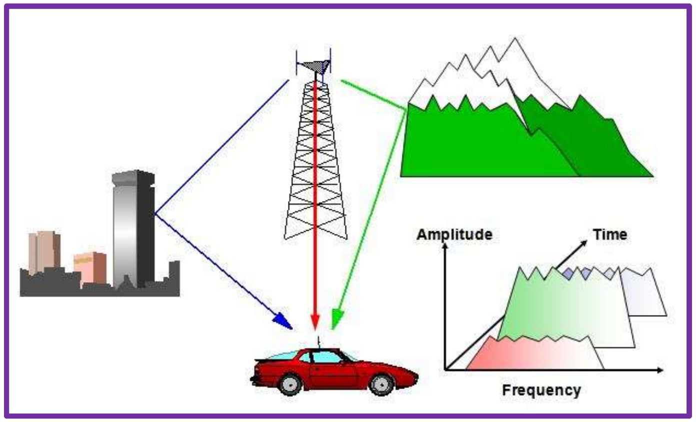
- All frequency resources can be used in all cells (i.e., universal frequency reuse)
- The implementation of CDMA provides relatively high system capacity, especially when the data rates of users are low
  - Thus, CDMA is relatively good multiple access method when system is characterized by a **large number of low rate users**
- Different channels can be multiplexed easily in the code domain
  - I.e., separation of control and data channels is quite easy
- Narrowband interference is spread in the receiver, which leads to good protection against narrowband interference (Jamming)



Narrowband jamming in CDMA systems

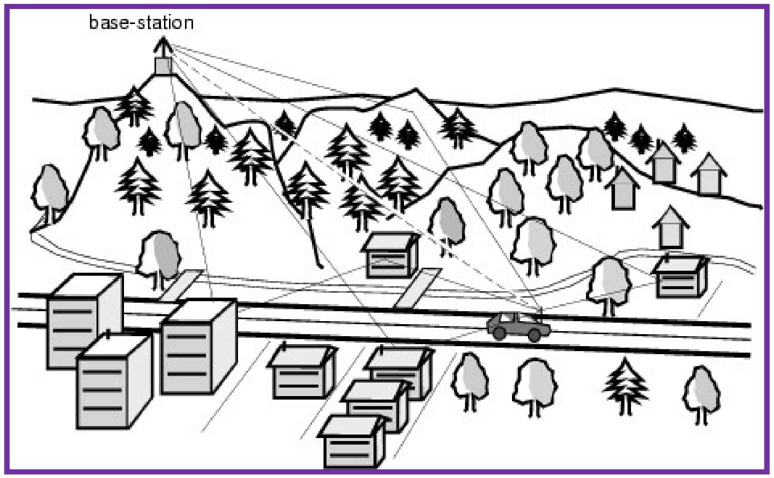
Disadvantages of CDMA (1)

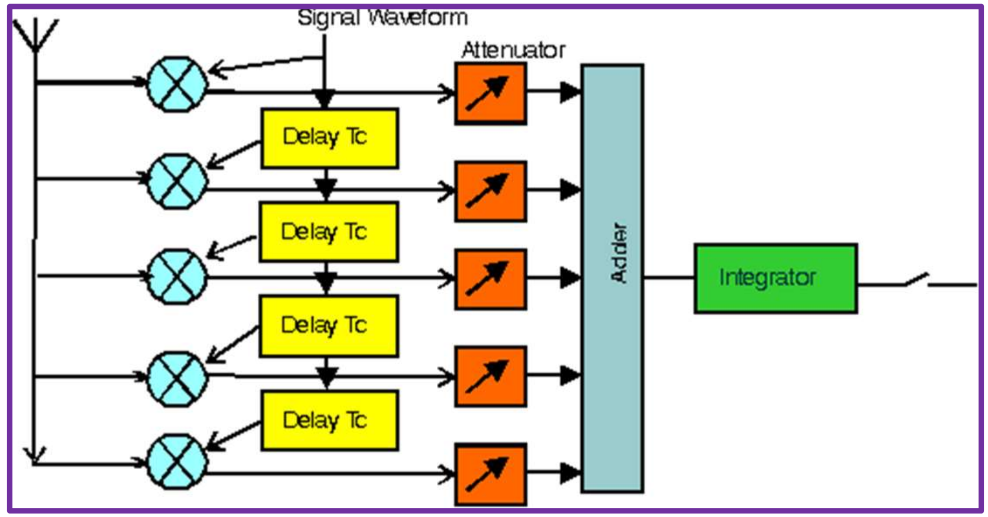
- ❖ Accurate power control is needed, to avoid near-far problem in both links
  - – This statement becomes especially true in the uplink direction
- ❖ The use of CDMA is a better choice when dealing with a **large number of low-rate users**, rather than few users that demand high data rates
  - ➢ Code orthogonality can be partially lost in presence of strong multipath propagation conditions
    - – Then, interference between code channels takes place, and orthogonality on same cell users is partially lost (i.e., **intra-cell interference** is generated)



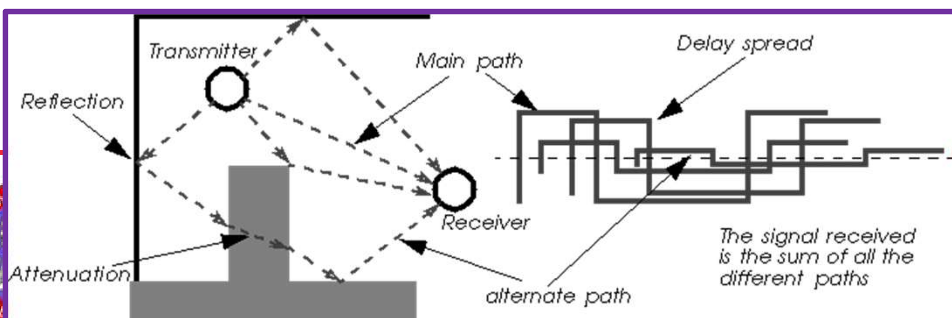
Disadvantages of CDMA (2)

- Inter-cell interference is similar to white noise, making the interference mitigation difficult
- Very accurate synchronization is needed, since chip duration is short in time





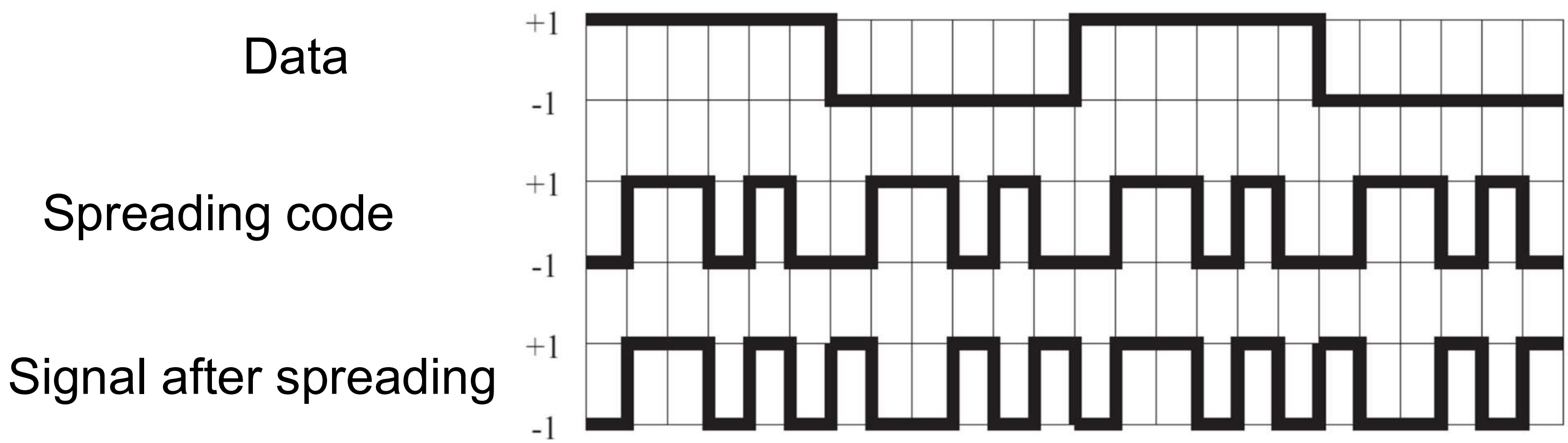
Rake receiver concept



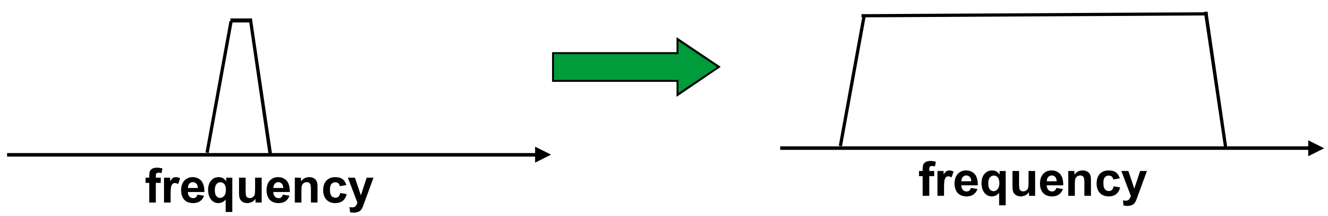
Contents

AAiT

Spreading



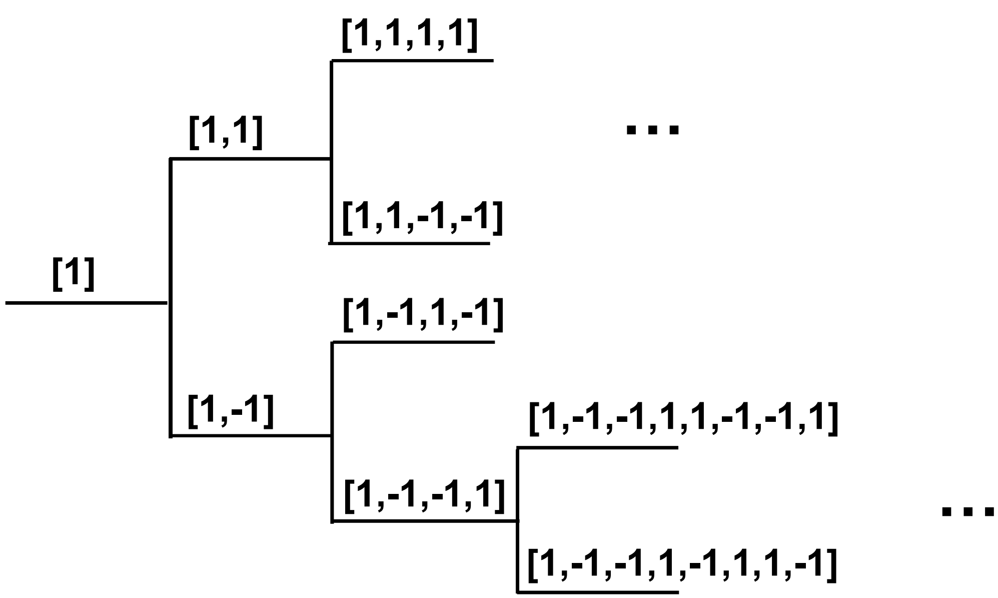
Spreading expands the signal to wide band



Spreading Factor (SF) defines how many chips are used to represent one data symbol

Spreading

❖ Spreading is done using orthogonal codes
  – Codes remain orthogonal only if synchronization is perfect
  – Multi-path fading will reduce the orthogonality



Spreading

- Spreading provides processing gain. Let us denote
  - W = system chip rate
  - R = user bit rate

  Then processing gain is defined by

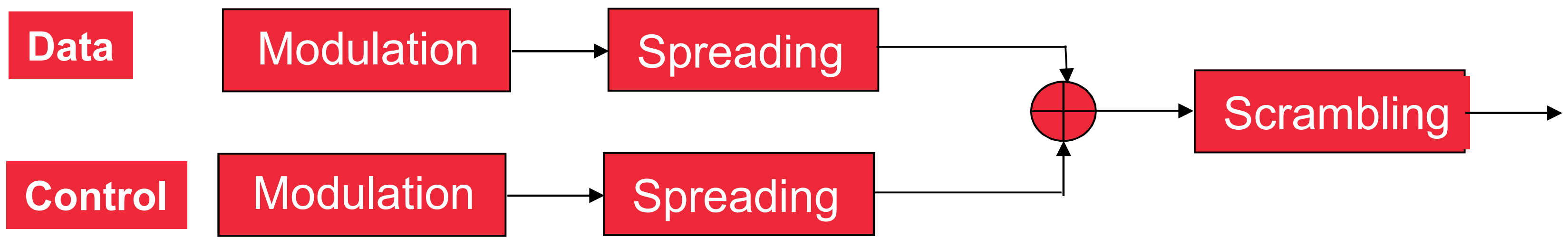
$$PG = 10\log_{10}\left(\frac{W}{R}\right)$$

- While user data rate increases, the processing gain decreases as well as the spreading factor. Hence, it is harder for the receiver to detect the signal correctly.
- Sometimes we also use term spreading gain. It refers to value

$$\text{Spreading gain} = 10\log_{10}(SF)$$

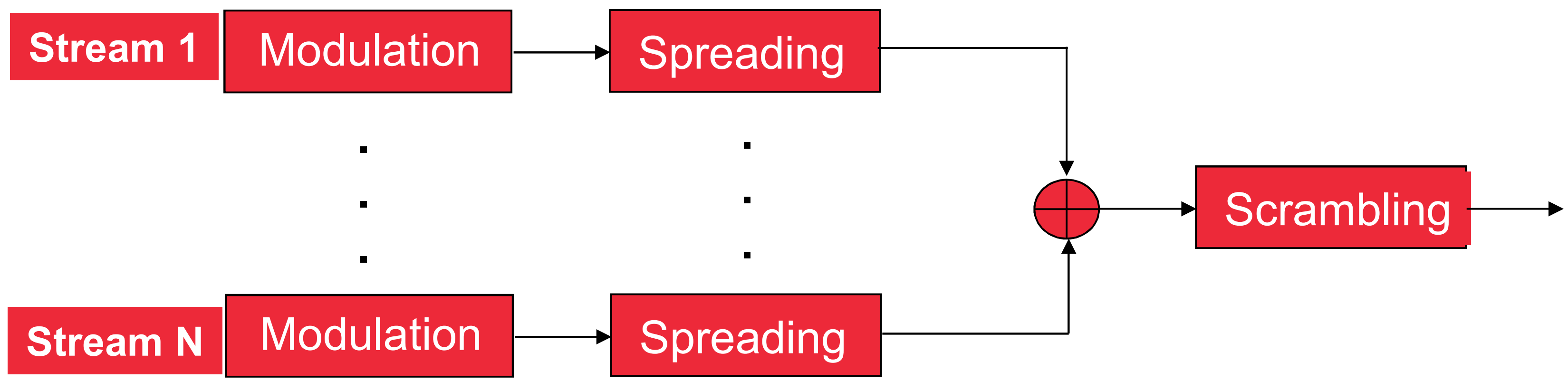
AAiT

WCDMA uplink transmission path



- Spreading codes are used to separate data and control of a user.
- Scrambling codes are used to separate different users.
- Dual channel QPSK modulation (data and control into different I/Q branches)

WCDMA downlink transmission path



- Users within a cell (sector) are separated by orthogonal spreading codes (sometimes also called as channelization codes)
- Cells (sectors) are separated by scrambling codes
- QPSK modulation (in HSDPA higher order modulations introduced).

Despreading: Separation of channels (users) in DL

- Assume flat fading and N users with different spreading codes. Then, (after descrambling) the receiver *d* sees the sum signal

$$\mathbf{r_d} = \sum_{i=1}^{N} h_i s_i \mathbf{c_i} + \mathbf{n},$$

where

s_i user *i* data symbol

$\mathbf{c_i}$ user *i* chip code (vector)

h_i channel response for user *i*

- Vector ***n*** contains the noise

AAiT

Despreading: Separation of channels (users) in DL

- In the despreading procedure of user *d* the signal stream is correlated with the chip code $\mathbf{c}_\mathrm{d}$

$$
\begin{aligned}
z_d &= \mathbf{c}_\mathrm{d}^\mathrm{T} \cdot \mathbf{r}_\mathrm{d} \\
&= h_d s_d \mathbf{c}_\mathrm{d}^\mathrm{T} \cdot \mathbf{c}_\mathrm{d} + \sum_{i=1}^{N, i \neq d} h_i s_i \mathbf{c}_\mathrm{d}^\mathrm{T} \cdot \mathbf{c}_\mathrm{i} + \mathbf{c}_\mathrm{d}^\mathrm{T} \cdot \mathbf{n} \\
&= \underbrace{h_d s_d x_d}_{\text{Desired signal}} + \underbrace{\sum_{i=1}^{N, i \neq d} h_i s_i x_i}_{\text{Interference from other users in the own cell}} + \underbrace{\mathbf{c}_\mathrm{d}^\mathrm{T} \cdot \mathbf{n}}_{\text{Other noise/interference}},
\end{aligned}
$$

Desired signal

Interference from other users in the own cell

Other noise/interference

Despreading: Separation of channels (users) in DL

- The code autocorrelation and cross correlation are denoted by

$$x_d = \mathbf{c}_{\mathrm{d}}^{\mathrm{T}} \cdot \mathbf{c}_{\mathrm{d}},$$

$$x_i = \mathbf{c}_{\mathrm{d}}^{\mathrm{T}} \cdot \mathbf{c}_{\mathrm{i}}.$$

- Value of the autocorrelation depends on the length of the spreading code and other autocorrelation properties.
- If orthogonal codes are used (like in WCDMA) then cross-correlation is zero in ideal case.

AAiT

Despreading: Separation of channels (users) in DL

- The (post-processing) signal-to-interference plus noise ratio (SINR) after despreading at receiver *d* is now of the form

$$(E_b/N_0)_d = \frac{|h_d|^2|s_d|^2|x_d|^2}{\sum_{i=1}^{N,i\neq d}|h_i|^2|s_i|^2|x_i|^2 + \mathbb{E}\{\mathbf{c}_\mathbf{d}^\mathrm{T}\mathbf{n}\mathbf{n}^\mathrm{H}\mathbf{c}_\mathbf{d}\}}$$

- Note that we have taken expectations of the power of the desired part of the signal and divided it by the expectation of the interference + noise power.

AAiT

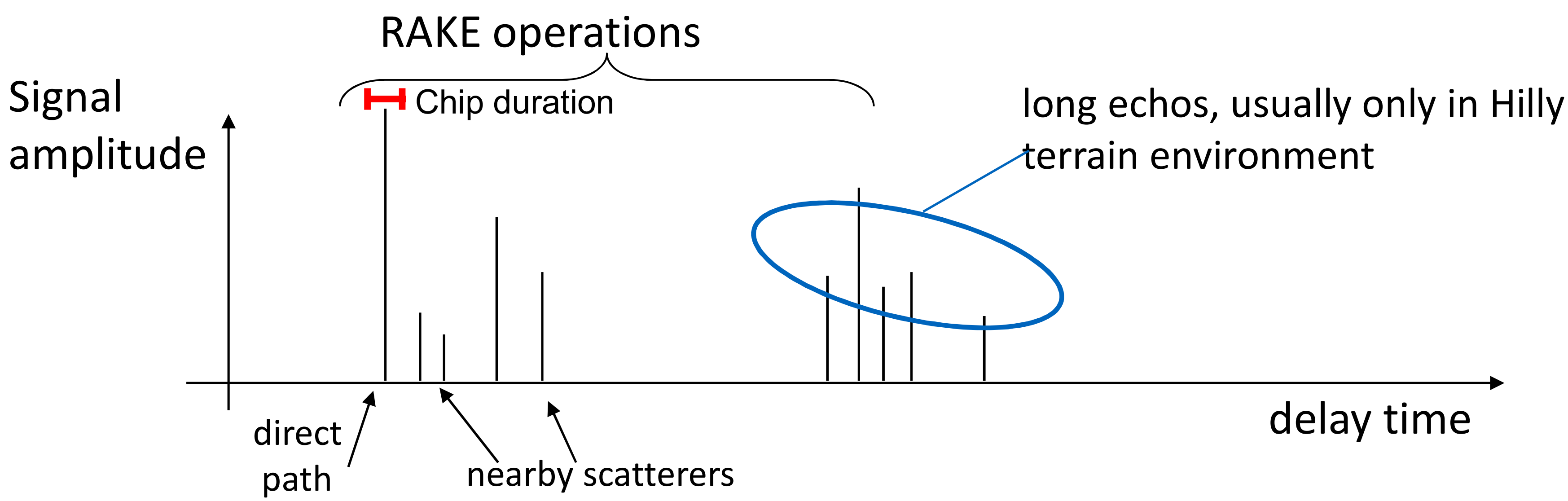
Performance measures

- Some measures that are used in WCDMA receiver investigations
  - CINR = Carrier to interference and noise ratio, also term Signal to interference and Noise Ratio (SINR) is used. Definitions of these measures may vary in different books.
  - CIR = Carrier to interference ratio, also SIR is used
  - SNR = Signal to noise ratio
  - *E* = Energy per user bit divided by the noise spectral density = processing gain * power that is needed to overcome the noise+interference from other users.
  - Notation E_b / N_0 is commonly used for *E*

AAiT

Spreading and multipath propagation

- In WCDMA chip rate is 3.84 Mcps.
  - Temporal duration of the chip is 1/3.84*10^6 = 260.4ns.
  - Signal travels 78.125 meters during the chip duration
  - This distance defines the maximum accuracy by which receiver can resolve different signal paths.



AAiT

RAKE receiver

- A basic receiver that is used in WCDMA is called as RAKE
  - The multipath channel through which a radio wave propagates can be viewed as a sum of many delayed copies of the original transmitted wave, each with a different magnitude and time-of-arrival at the receiver.
  - Each multipath component contains the original information => if the magnitude and time-of-arrival of each multipath component is known (through channel estimation), then all the multipath components can be added coherently
  - RAKE is designed to counter the effects of multipath fading. It does this by using several fingers, each delayed (by order of some chips) in order to catch the individual multipath components.
  - Component signals from fingers are combined coherently for the sum signal that is used in decoding.

RAKE: separation of multipaths

❖ Assume that there are M signal paths after despreading. Then ideal RAKE receiver can combine signals from different paths:

$$z_{d,1} = h_{d,1} s_d x_d + n_{d,1}$$

$$\vdots$$

$$z_{d,M} = h_{d,M} s_d x_d + n_{d,M}$$

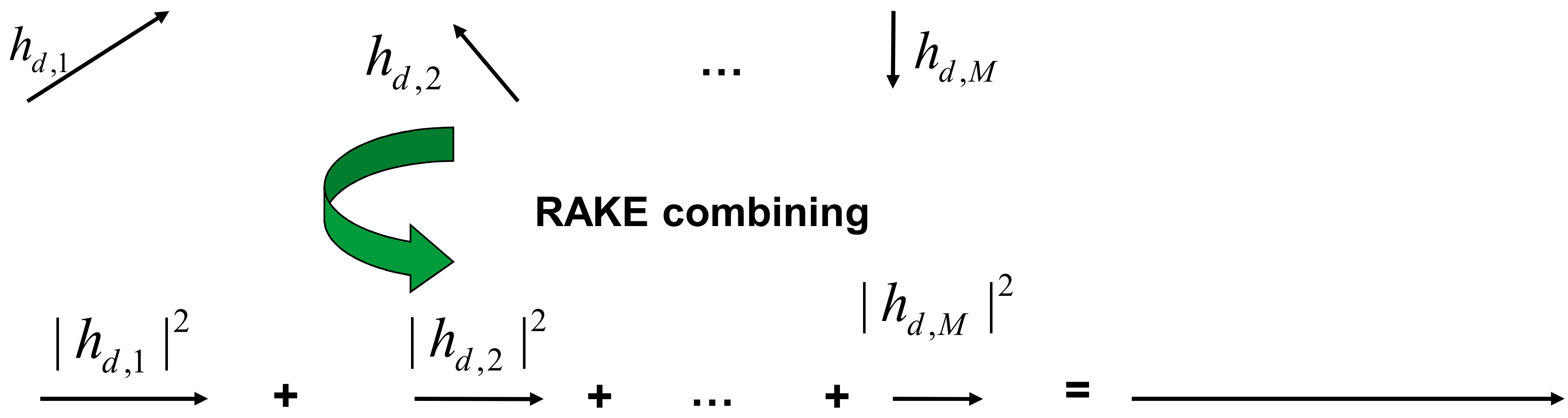
$$\Rightarrow$$

$$Z_d = \sum_{m=1}^{M} h^*_{d,m} z_{d,m} = \sum_{m=1}^{M} |h_{d,m}|^2 s_d x_d + N_d$$

AAiT

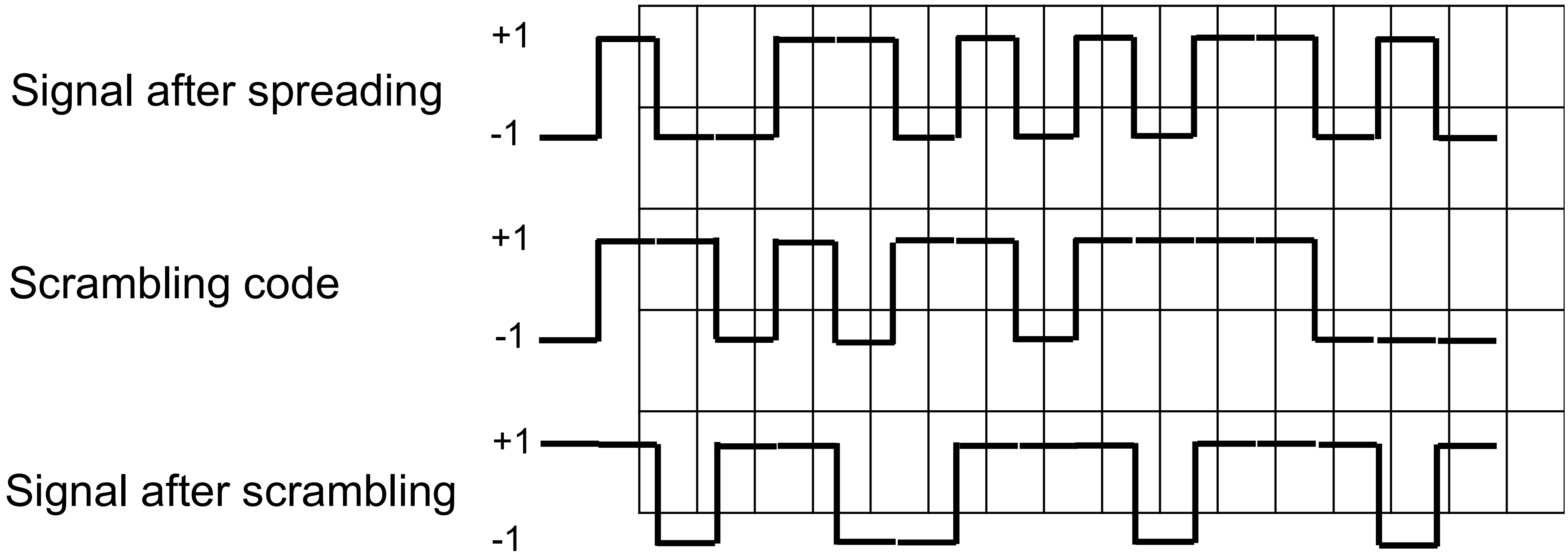
RAKE: separation of multipaths

❖ Coherent combining of complex channels:



AAiT

Scrambling



AAiT

Scrambling

- ❖ Scrambling codes are used to separate users in uplink and cells in downlink
- ❖ Scrambling is used on top of spreading
- ❖ Scrambling is not changing the signal bandwidth
- ❖ In downlink scrambling codes are allocated to the cells (sectors) in network planning phase
  - – Number of scrambling codes is high => code planning is almost a trivial task and can be automated

Spreading and scrambling summary

	Spreading codes	Scrambling codes
Usage	UL: Separation of control and data from the same user DL: Separation of connections within a cell	UL: Separation of users DL: Separation of cells
Length	UL: 4-256 chips DL: 4-512 chips Code length defines symbol rate	UL: 38400 chips = 10ms = frame length DL: 38400 chips = 10ms = frame length
Bandwidth	Increases transmission bandwidth	No impact to transmission bandwidth

AAiT

Contents

AAiT

Channel concepts

- Three separate channel concepts in the UTRA: *logical*, *transport*, and *physical channels*.
- Concept of logical channels is omitted in this presentation.
- Transport channels define how and with which type of characteristics the data is transferred by the physical layer.
- Physical channels define the exact physical characteristics of the radio channel. There exists
  - physical channels that carry transport channel data
  - physical channels used only for *signaling* purposes to carry information between network and the terminals.

Mapping between (most important) transport and physical channels

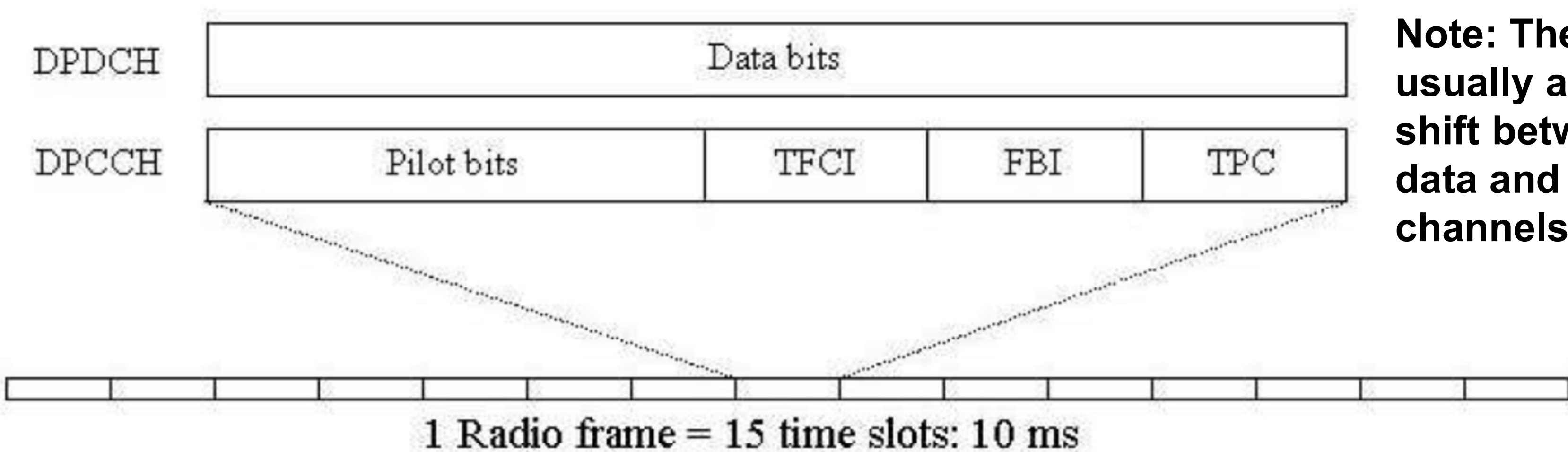
Transport channels	Physical channels	
DCH	DPDCH	Dedicated Physical Data CHannel
DCH	DPCCH	Dedicated Physical Control CHannel
BCH	PCCPCH	Primary Common Control Physical CHannel
RACH	PRACH	Physical Random Access CHannel
PCH	SCCPCH	Secondary Common Control Physical CHannel
FACH	SCCPCH	

Physical channels for signaling purposes (not associated to transport channels):

Physical channels	
CPICH	Common Pilot CHannel
SCH	Synchronization CHannel
AICH	Acquisition Indication CHannel
PICH	Paging Indication CHannel

Uplink dedicated channel

- Physical layer control information in Dedicated Physical Control Channel (DPCCH), spreading factor =256
- Data is carried in Dedicated Physical Data Channels (DPDCH). Variable spreading factor
- There can be multiple DPDCHs but only one DPCCH.



Note: There is usually a power shift between data and control channels

AAiT

Control information in DPCCH

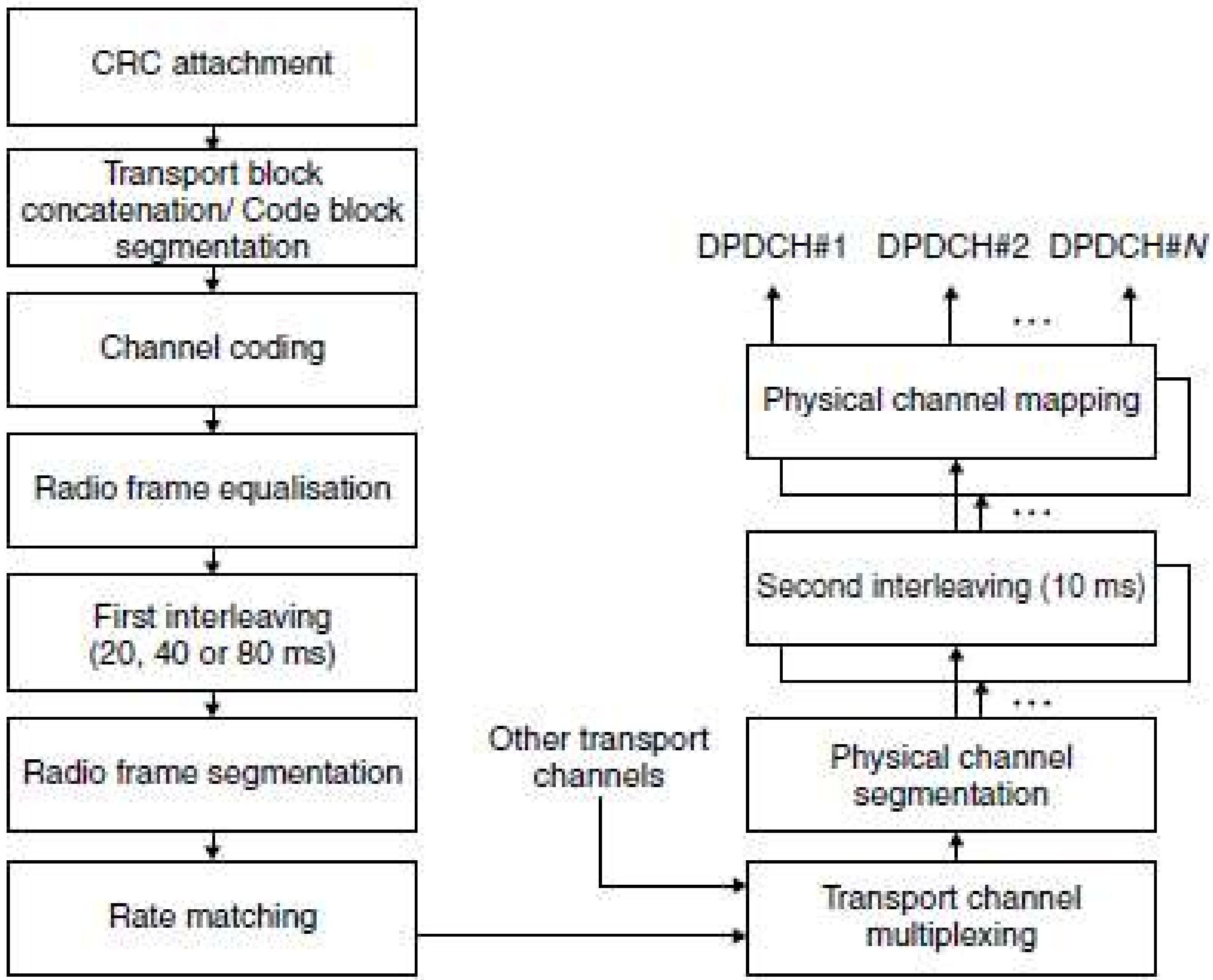
- Pilot (reference) bits for channel estimation
  - Always present
- Transmit Power Control (TPC) bits for downlink power control
  - Always present
- Transport Format Combination Indicator (TFCI)
  - Inform receiver about active transport channels
- Feedback Bit Information (FBI)
  - Present only when downlink two-antenna closed loop transmit diversity method is applied

Uplink DPDCH data rates

- Data rates in the table achieved with ½ rate coding
- Parallel codes not used in practice due to reduced power amplifier efficiency
- Maximum rate below 500 kbps.
- **Note:** In uplink each user have all spreading codes in its use
- **Note:** Higher rates can be achieved through HSUPA, this will be discussed in the next course in more details.

Spreading factor	User data rate
256	7.5 kbps
128	15 kbps
64	30 kbps
32	60 kbps
16	120 kbps
8	240 kbps
4	480 kbps
4, 6 parallel codes	2.8 Mbps

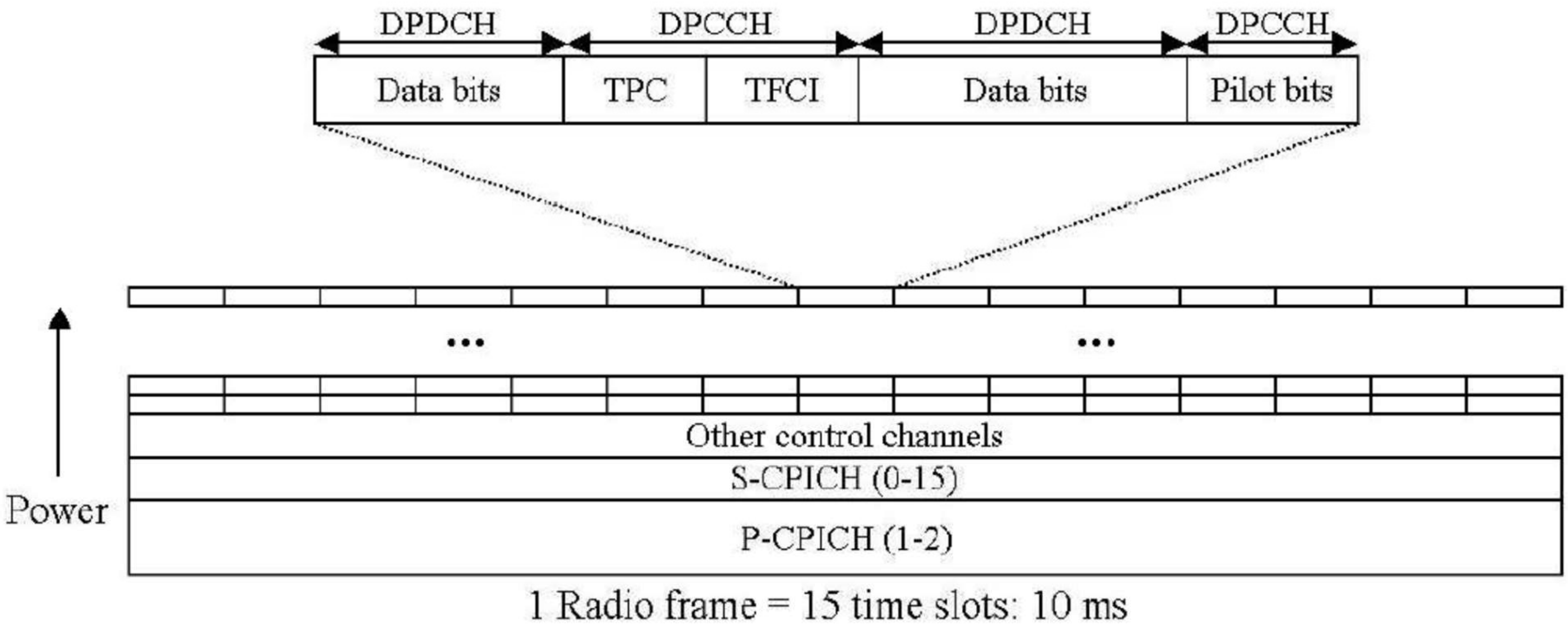
Uplink multiplexing



AAiT

Downlink dedicated channel

- ❖ Downlink control information is carried in Dedicated Physical Control Channel (DPCCH)
- ❖ Downlink data is carried in Dedicated Physical Data Channel (DPDCH)
- ❖ Spreading factor depends on the service



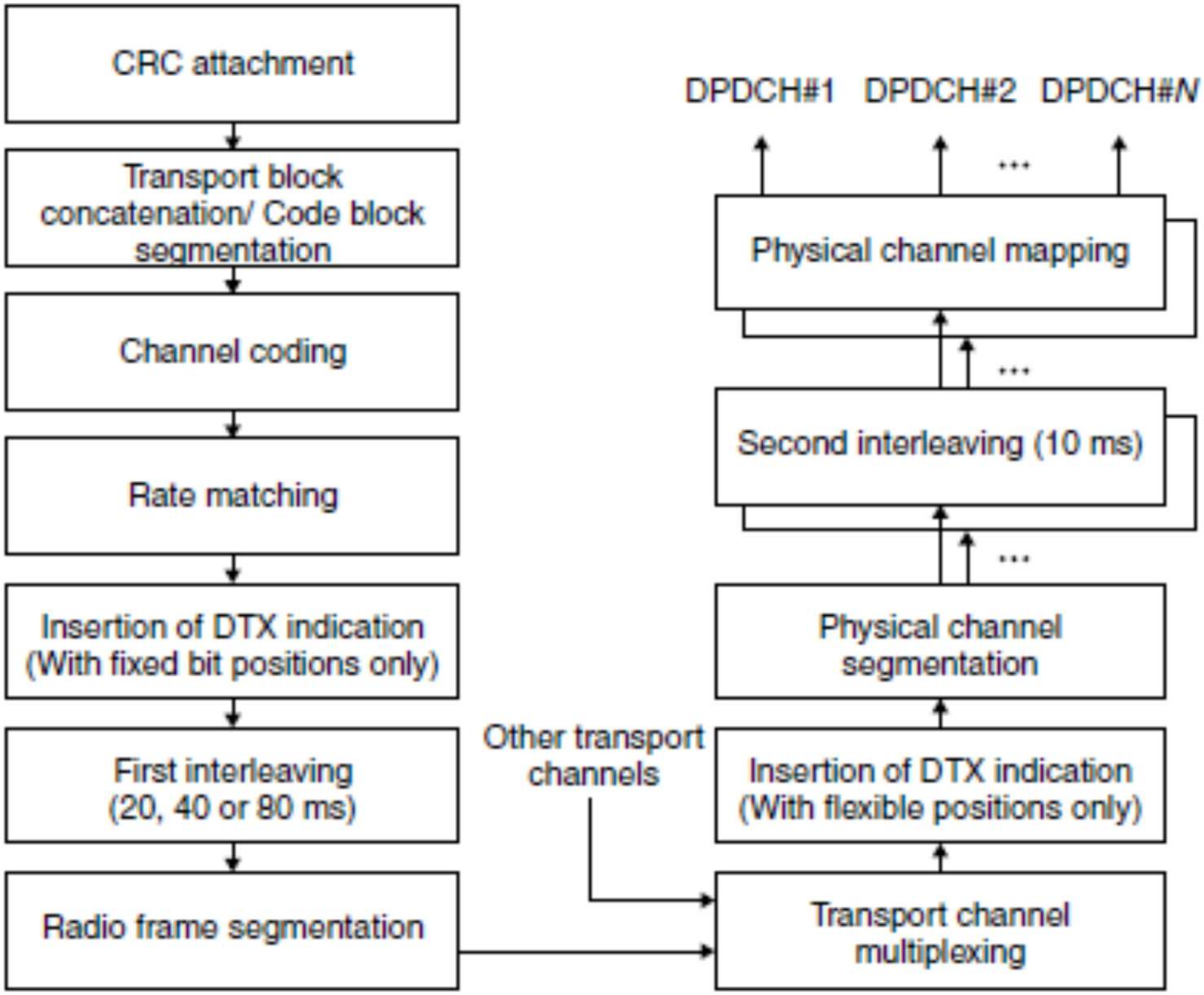
AAiT

Downlink DPDCH data rates

- Data rates in the table achieved with ½ rate coding
- In downlink all users share the spreading codes => number of orthogonal codes defines a hard limit for cell capacity
- Part of the spreading codes are reserved for control channels
- **Note:** Higher rates can be achieved through HSDPA, this will be discussed in the next course in more details.

Spreading factor	User data rate
512	1-3 kbps
256	6-12 kbps
128	20-24 kbps
64	45 kbps
32	105 kbps
16	215 kbps
8	456 kbps
4	936 kbps
4, 3 parallel codes	2.8 Mbps

Downlink multiplexing



AAiT

Signalling: Common PIlot CHannel (CPICH)

- The *function of the CPICH is to aid the channel estimation* at the terminal for the dedicated channel and to provide the channel estimation reference for the common channels when they are not associated with the dedicated channels.
- UTRA has two types of common pilot channel, primary (P-CPICH) and secondary (S-CPICH). The difference is that the Primary CPICH is always under the primary scrambling code with a fixed chanelisation code allocation and there is only one such channel for a cell or sector.
- The typical area of Secondary CPICH usage would be operations with narrow antenna beams intended for service provision at specific 'hot spots' or places with high traffic density.
- An important area for the primary common pilot channel is the measurements for the handover and cell selection/reselection.

Signalling: Common PIlot CHannel (CPICH)

- CPICH defines the reference reception level at the terminal for handover measurements => by adjusting the CPICH power level, the cell load can be balanced between different cells. Reducing the CPICH power causes part of the terminals to hand over to other cells, while increasing it invites more terminals to hand over to the cell, as well as to make their initial access to the network in that cell.
- The CPICH does not carry any higher layer information, neither is there any transport channel mapped to it. The CPICH uses the spreading factor of 256.
- CPICH may be sent from two antennas in case transmission diversity methods are used in the base station.

Signalling: Synchronization CHannel (SCH)

- *SCH is needed for the cell search*. It consists of two channels, the primary and secondary synchronization channels.
- The Primary SCH uses a 256-chip spreading sequence identical in every cell.
- The Secondary SCH uses sequences with different code word combination possibilities representing different code groups. Once the terminal has identified the secondary synchronization channel, it has obtained frame and slot synchronization as well as information on the group the cell belongs to.

See also cell search

Signalling: Synchronization CHannel (SCH)

- There are 64 different code groups in use, pointed out by the 256 chip sequences sent on the secondary SCHs. Such a full cell search process with a need to search for all groups is needed only at the initial search upon terminal power-on or when entering a coverage area, otherwise a terminal has more information available on the neighboring cells and not all the steps are always necessary.
- No transport channel is mapped on the SCH, as the code words are transmitted for cell search purposes only.

See also cell search

Signalling: Primary Common Control Physical CHannel (P-CCPCH)

- P-CCPCH is the *physical channel carrying the Broadcast Channel (BCH).*
- P-CCPCH needs to be demodulated correctly by a terminal. If parameters with respect to, for example, channel coding and spreading code are not correctly received, the connection fails.
- Primary CCPCH needs to be available over the whole cell area and does not use specific antenna techniques but is sent with the same antenna radiation pattern as the common pilot channel.
- The channel bit rate is 30 kbps with spreading factor 256 of the permanently allocated channelisation code.

Signalling: Secondary Common Control Physical CHannel (S-CCPCH)

- S-CCPCH carries two different common transport channels: the Forward Access Channel (FACH) and the Paging Channel (PCH). The two channels can share a single Secondary CCPCH or can use different physical channels.
- There must be at least one S-CCPCH in each cell
- The spreading factor used in a Secondary CCPCH is fixed and determined according to the maximum data rate.

Signalling: Random Access CHannel (RACH)

- *RACH is typically used to register the terminal to the network or to perform location update after moving from one location area to another or to initiate a call*.
- In addition to signaling purposes the physical RACH can be used for user data transmission (in small scale)
- When used for signaling the RACH data rate needs to be kept relatively low, otherwise the range achievable with RACH signaling starts to limit the system coverage.
- RACH coverage optimization is important in network planning.

Signalling: Acquisition Indicator CHannel (AICH)

- In connection with the Random Access Channel, the *AICH is used to indicate from the base station the reception of the random access channel signature sequence*.
- The AICH uses an identical signature sequence as the RACH on one of the downlink channelization codes of the base station.
- Once the base station has detected the preamble with the random access attempt, then the same signature sequence will be echoed back on AICH.
- The AICH also needs to be heard by all terminals and needs to be sent typically at high power level without power control.
- The AICH is not visible to higher layers but is controlled directly by the physical layer in the base station

Signalling: Paging Indicator CHannel (PICH)

- The Paging Channel (PCH) is operated together with the PICH to provide terminals with efficient sleep mode operation.
- The paging indicators use a channelization code of length 256.
- PICH needs to be heard by all terminals in the cell and thus needs to be sent at high power level without power control
- The paging indicators occur once per slot on the corresponding physical channel, the Paging Indicator Channel (PICH).
- Depending on the paging indicator repetition ratio, there can be 18, 36, 72 or 144 paging indicators per PICH frame. How often a terminal needs to listen to the PICH is parameterized.

Contents

AAiT

Physical layer procedures

- In the physical layer of a WCDMA system there are many procedures essential for system operation:
  - Power control procedure
  - Paging procedure
  - Random Access procedure
  - Cell search procedure
  - Multiantenna procedures (discussed in HSPA part)
  - Measurement procedures (omitted)
  - Compressed mode procedure (omitted)
- In the following we go through briefly paging, random access and cell search while power control is discussed in connection with Radio Resource Management.

Paging procedure

- In the Paging Channel (PCH) operation a terminal, once registered to a network, is allocated a paging group.
- For the paging group there are Paging Indicators (PI) which appear periodically on the Paging Indicator Channel (PICH) when there are paging messages for any of the terminals belonging to that paging group.
- Once a PI has been detected, the terminal decodes the next PCH frame transmitted on the Secondary CCPCH to see whether there was a paging message intended for it.
- The less often the PIs appear, the less often the terminal needs to wake up from the sleep mode and the longer the battery life becomes. The trade-off is the response time to the network-originated call.

Random Access procedure

Phases in WCDMA Random Access procedure:

1. UE decodes the BCH to find out the available RACH sub-channels and their scrambling codes and signatures.
2. UE selects randomly one of the RACH sub-channels and signature from among the available signatures.
3. The downlink power level is measured and the initial RACH power level is set with the proper margin.
4. 1 ms RACH preamble is sent with the selected signature.
5. UE decodes AICH from Node B to see whether its preamble has been detected.
6. In case no AICH is detected, the terminal increases the preamble transmission power by a step given by the Node B (1 dB step). The preamble is retransmitted in the next available access slot.
7. When an AICH transmission is detected from the base station, the terminal transmits the 10 ms or 20 ms message part of the RACH transmission.

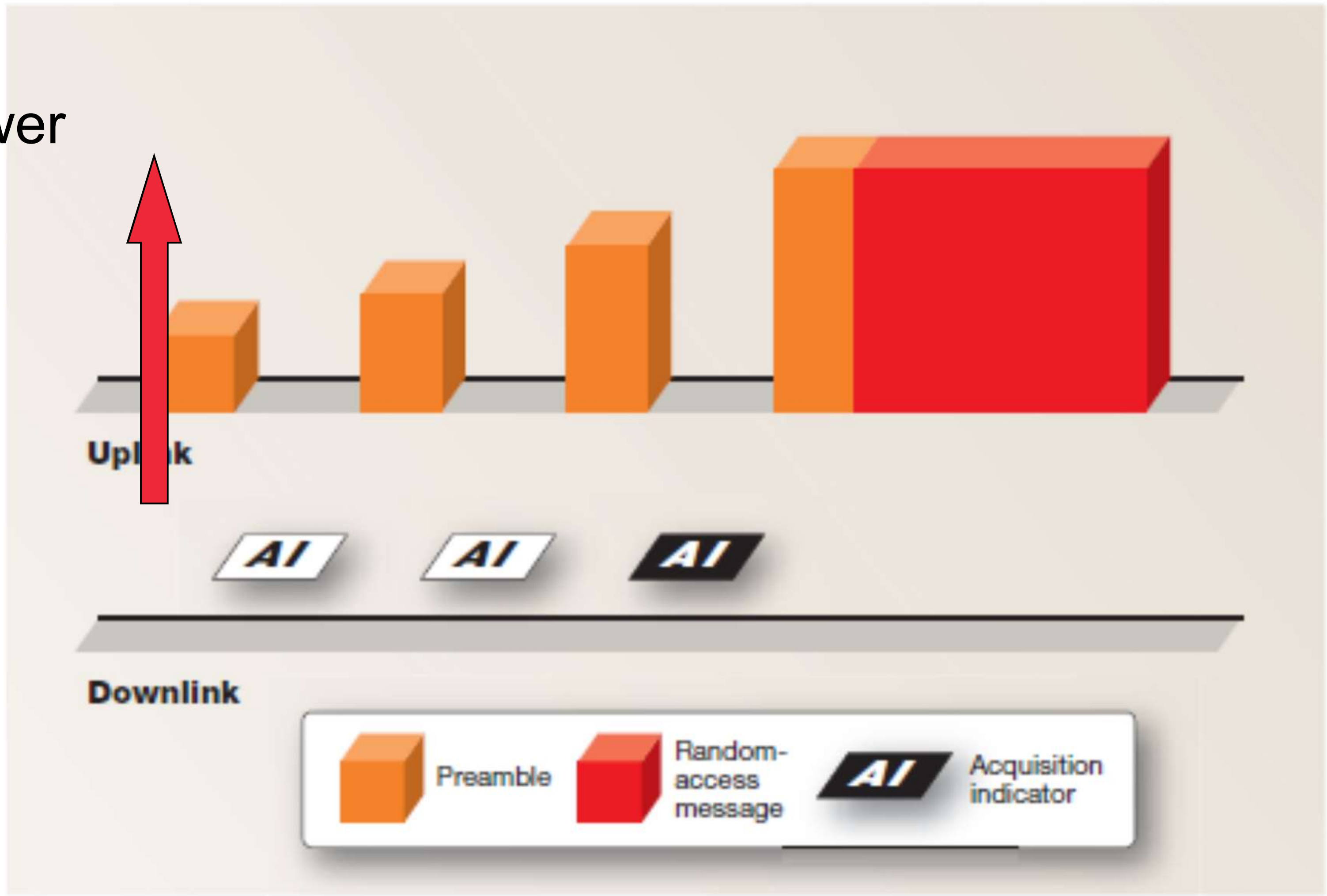
Random Access procedure

- The Random Access procedure in a WCDMA system has to cope with the near–far problem: when initiating the RACH procedure there is no exact knowledge of the required transmission power.
- The initial transmission power selection based on downlink CPICH measurements has a large uncertainty because fast fading in uplink and downlink are uncorrelated.
- As a result the explained power ramping needs to be used. Power ramping is illustrated in the next slide.
- In the case of data transmission on RACH, the spreading factor and thus the data rate may vary; this is indicated with the TFCI on the DPCCH on PRACH.

AAiT

Power ramping in RACH procedure

TX power in UE



AAiT

Cell Search Procedure

The initial cell search procedure has basically three steps:

1. The terminal searches the primary synchronization code that is identical for all cells. As the primary synchronization code is the same in every slot, the detected peak indicates the slot boundary.
2. Based on the detected peaks on the primary synchronization code, the UE seeks the largest peak from the Secondary SCH code word. The UE needs to check all 15 slots in frame since the frame boundary is not known before Secondary SCH code word is detected.
3. Once the Secondary SCH code word has been detected, the frame timing is known. Then UE seeks the primary scrambling codes that belong to code group defined by secondary SCH. Each group consists of eight primary scrambling codes.

Contents

1. *UMTS radio access network architecture*
2. *Physical layer: CDMA principles*
3. *Physical layer: WCDMA spreading and scrambling*
4. WCDMA channel concepts
5. Physical layer procedures
6. Radio Resource Management (RRM)
7. UMTS Radio Access Bearer concept, QoS and radio interface protocols (optional)

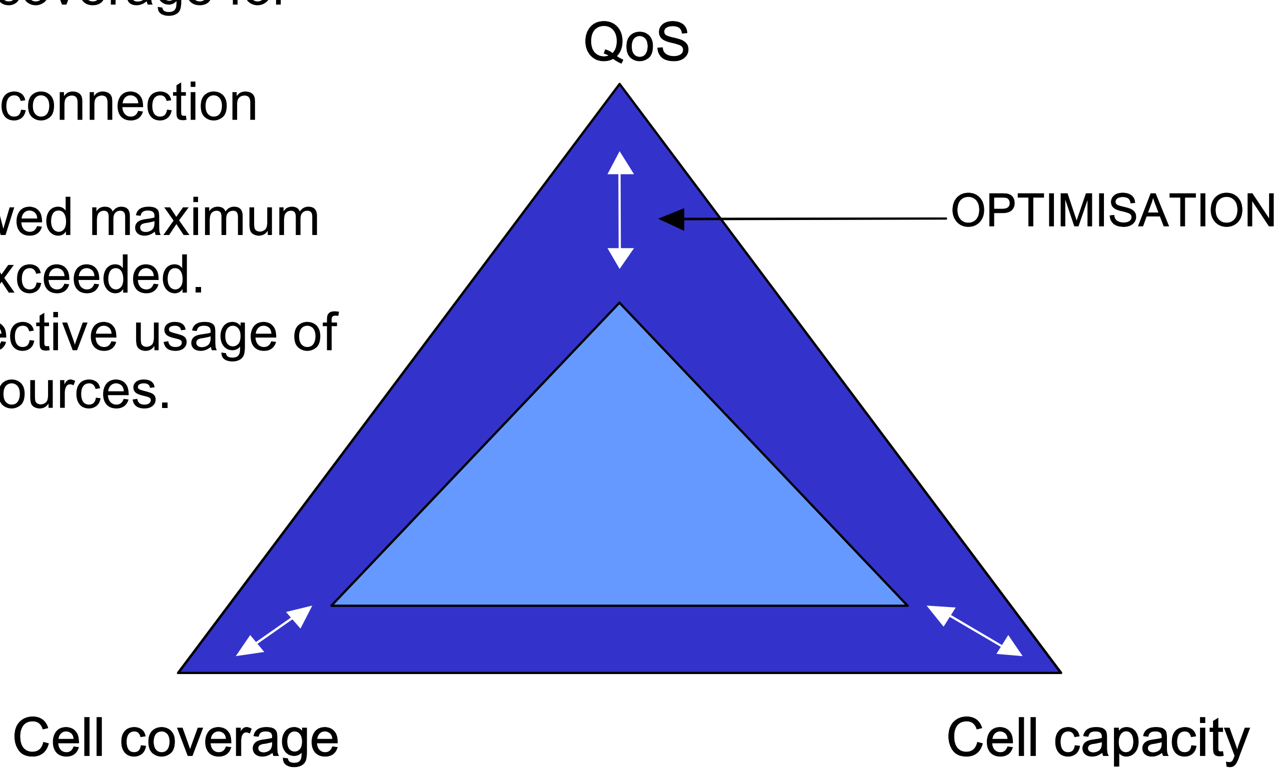
AAiT

General

- ❖ Radio Resource Management (RRM) is elementary part of a mobile system.
- ❖ 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 radio resource usage in the network

Objectives of RRM

- Ensure planned coverage for services.
- Ensure required connection quality
- Ensure that allowed maximum blocking is not exceeded.
- Optimise the effective usage of system radio resources.

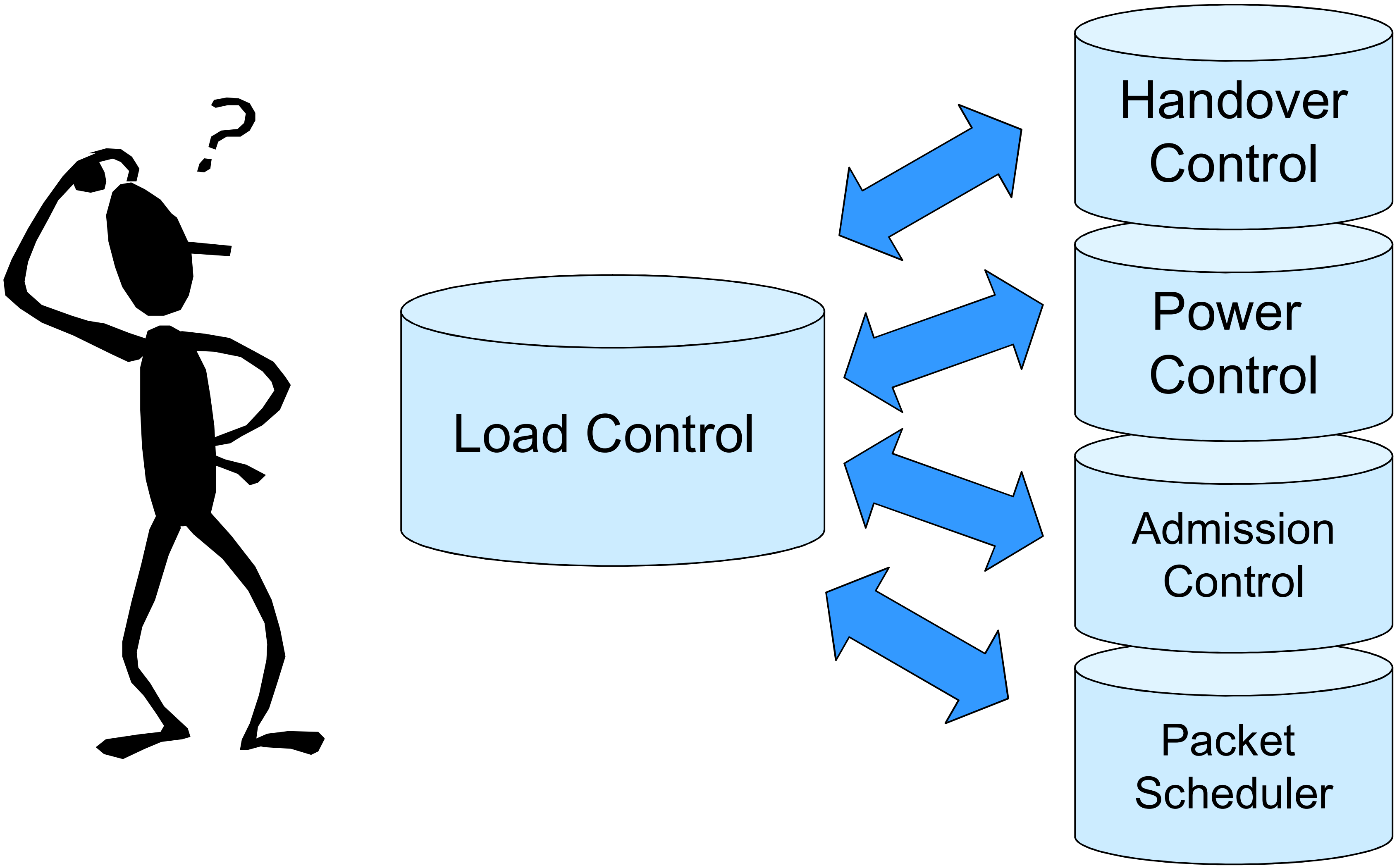


RRM algorithms

- Power control
  - Transmit (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, Note: HSPA PS is in Node B)

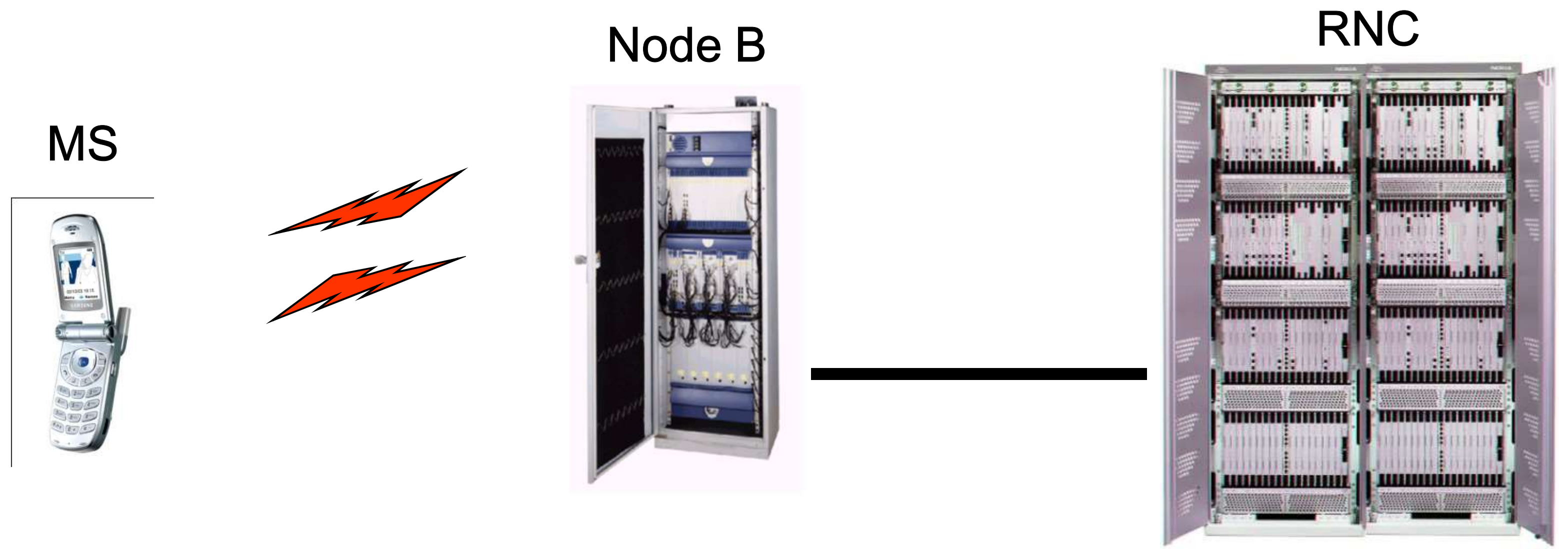
AAiT

Introduction to RRM/Functions



AAiT

RRM algorithm execution in different elements



MS
- Power Control

Node B
- Power Control
- Load Control
- HSPA packet scheduling

RNC
- Power Control
- Load Control
- Handover Control
- Admission Control (also in SGSN)
- WCDMA packet scheduler

AAiT

Shotrtcut: Node B figures

NSN Flexi multimode BTS

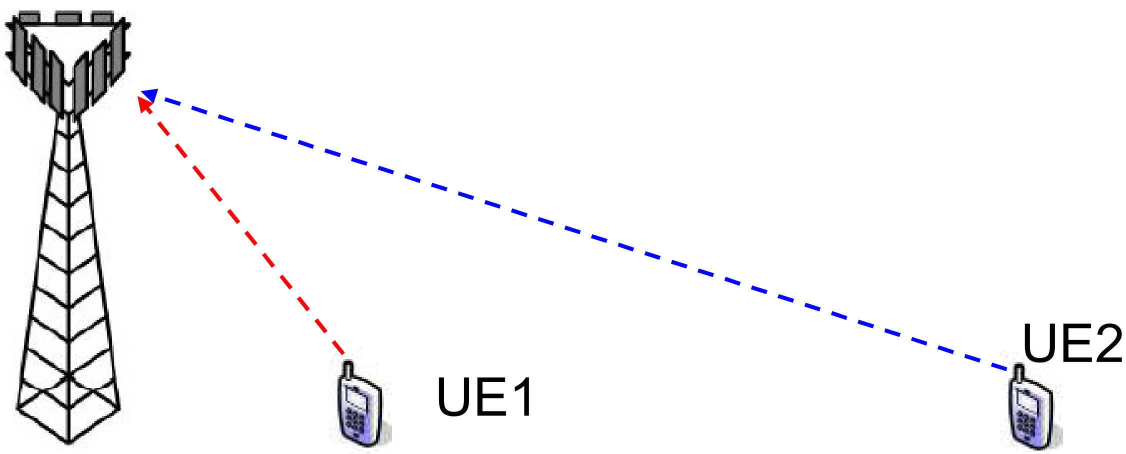
WCDMA Power Control

Power control

- Objectives:
  - Maintain the link quality in uplink and in downlink by controlling the transmission powers
  - Prevents the near-far effect
  - Minimize effects of fast and slow fading
  - Minimizes the interference in the network
- Accuracy of the power control is important in CDMA
  - 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 be 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
- After power control the Node B received powers from UE1 and UE2 will be the same for the same services



AAiT

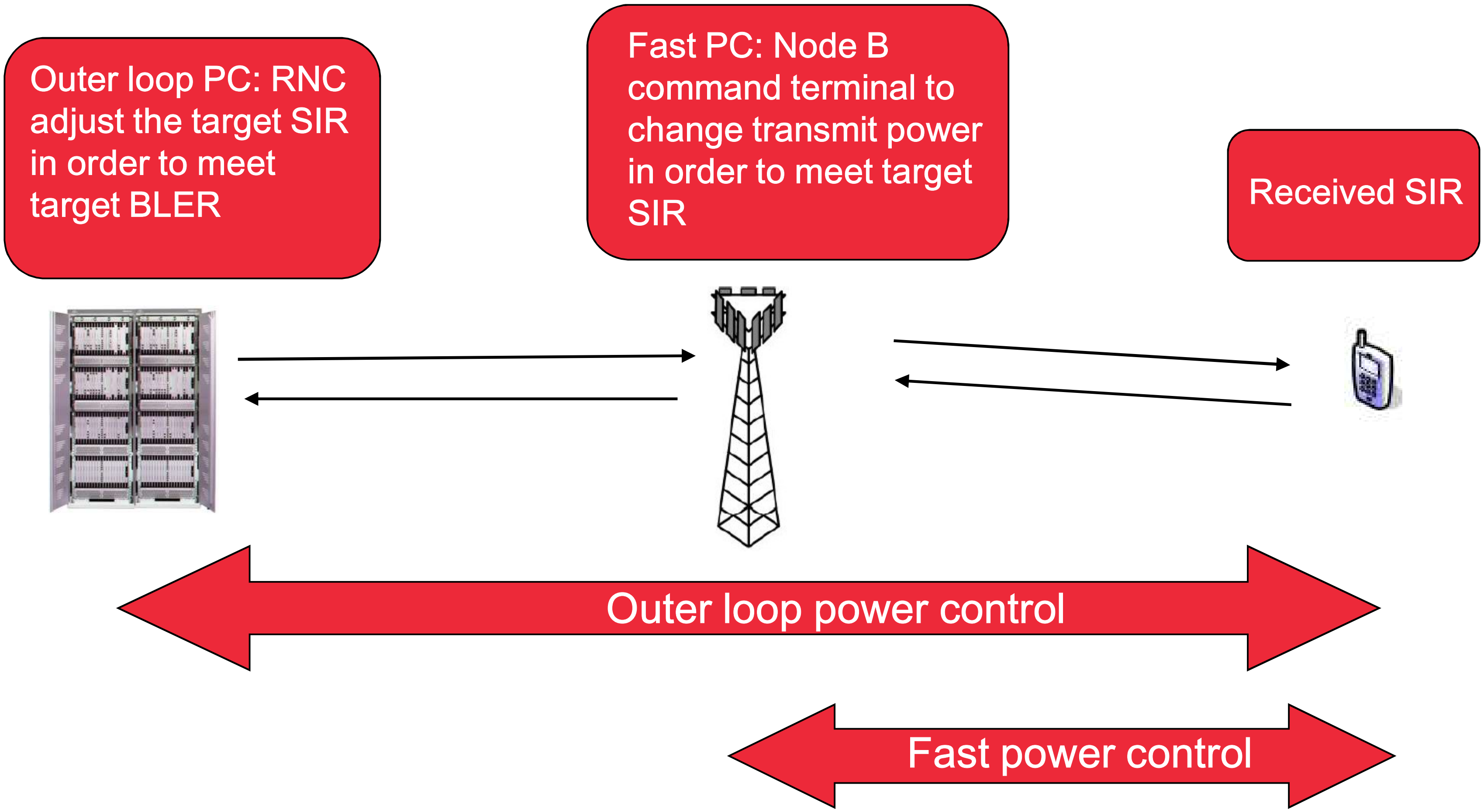
Power control

- Power control on the **common channels** ensures that their coverage is sufficient (common channel reception critical for UEs)
- Power control on the **dedicated channels** ensures an agreed quality of connection in terms of Block Error Rate (BLER)
- **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 Node B and compensates the impact of channel fading. Minimizing transmitted power improves the downlink capacity.

Main PC approaches in WCDMA

- 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 no multi-path diversity
  - Fast power control drives the received power to a *target SIR*.
- Outer loop power control:
  - Adjust the target SIR according to service QoS.

PC mechanism



AAiT

Uplink outer loop PC

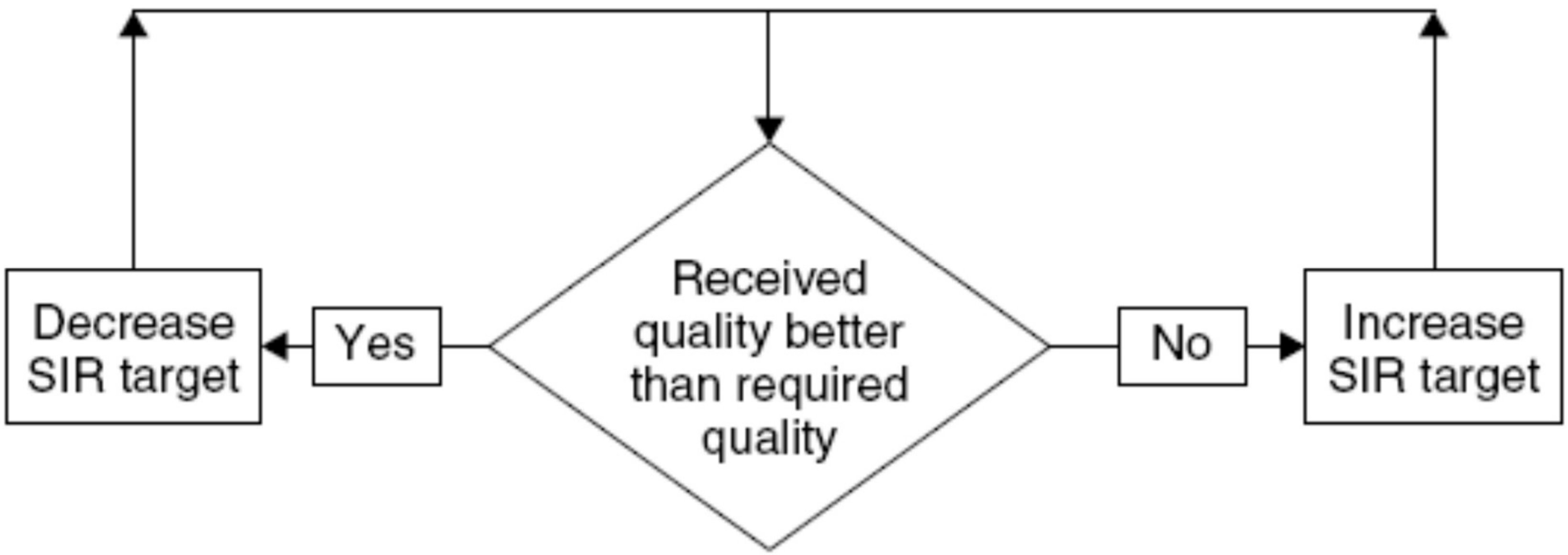
- The goal is to control the target SIR in order to sustain the wanted QoS with minimum transmit power
- The target BLER is defined by the admission control algorithm
- The outer loop algorithm is controlled in RNC
- Update frequency from 10 Hz up to 100 Hz
- Outer loop power control will raise or lower the target SIR according to step size, which is defined during radio network planning and optimization. Typical step size is 0.5dB.

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 target value of DL BLER.
- No SIR target change if Node B power reaches maximum or network congestion occurs.

AAiT

General Outer loop PC algorithm



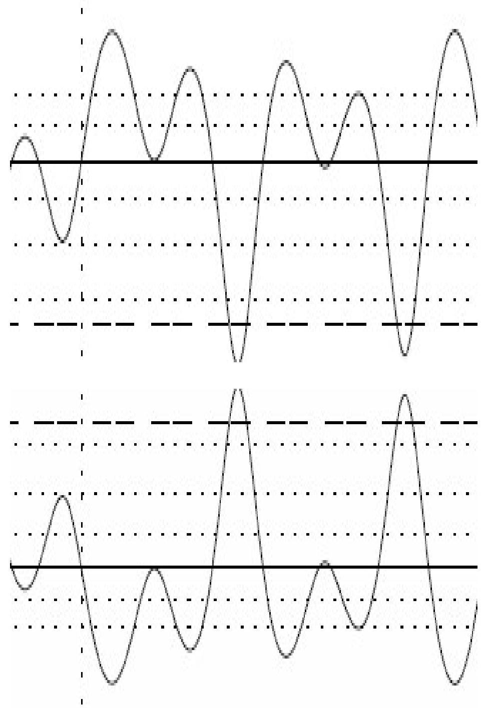
AAiT

Transmit Power Control (TPC)

- ❖ Ideal fast power control invert the channel
  - – In practice power control accuracy is reduced by feedback errors,

Fast fading channel

Transmitted power



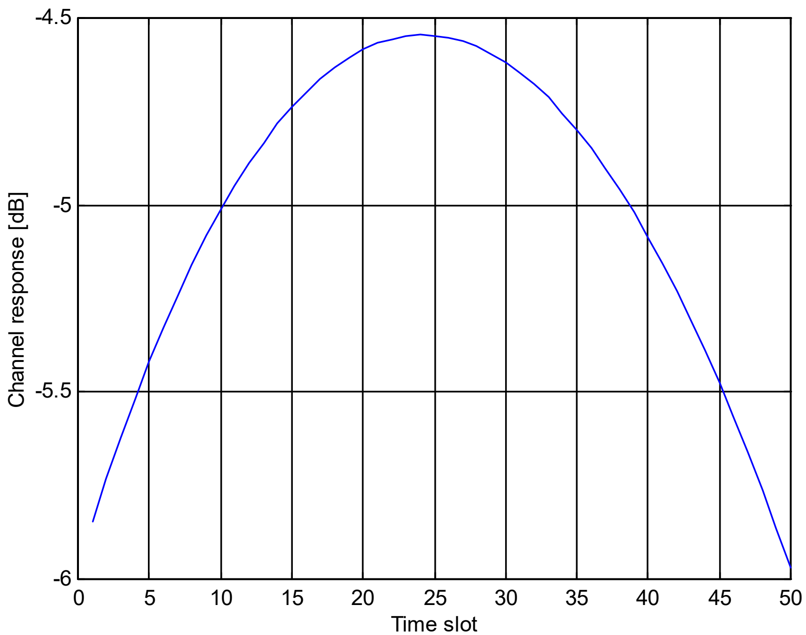
Note: It is usual to talk about 'fast power control' when power control is build up to mitigate fast fading. Transmit power control is a WCDMA specific term

AAiT

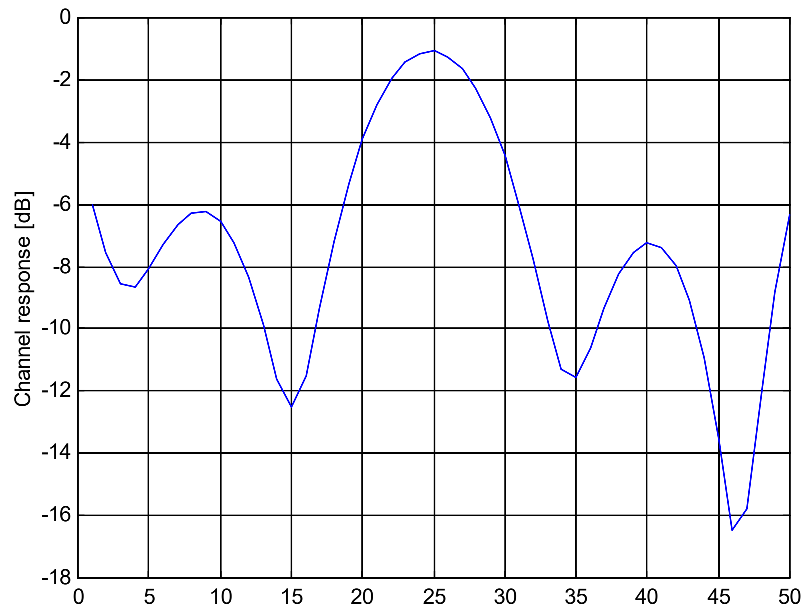
Uplink TPC

- ❖ Update rate 1.5 kHz => fast enough to track and compensate fast fading up to 30-50 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.
- ❖ UL 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

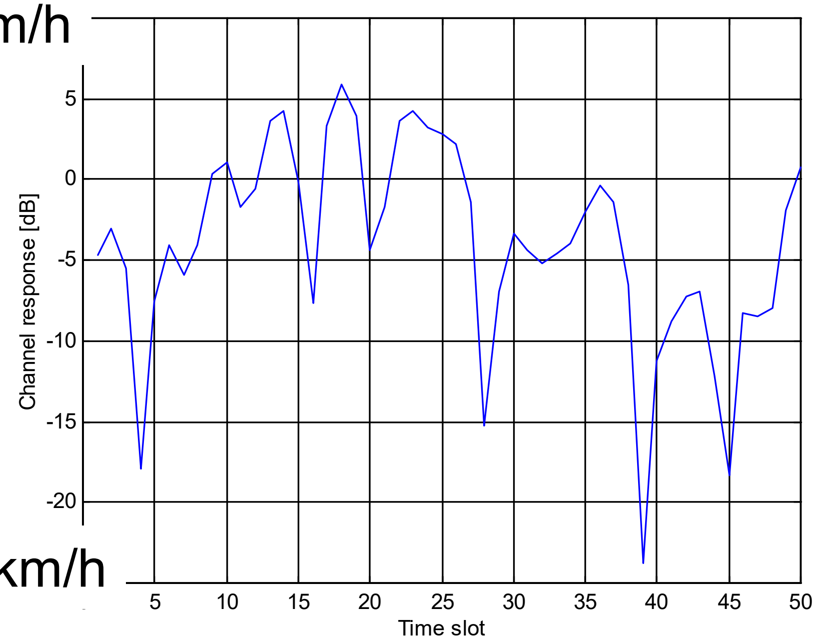
Uplink TPC: Impact of mobile speed



3km/h



25km/h

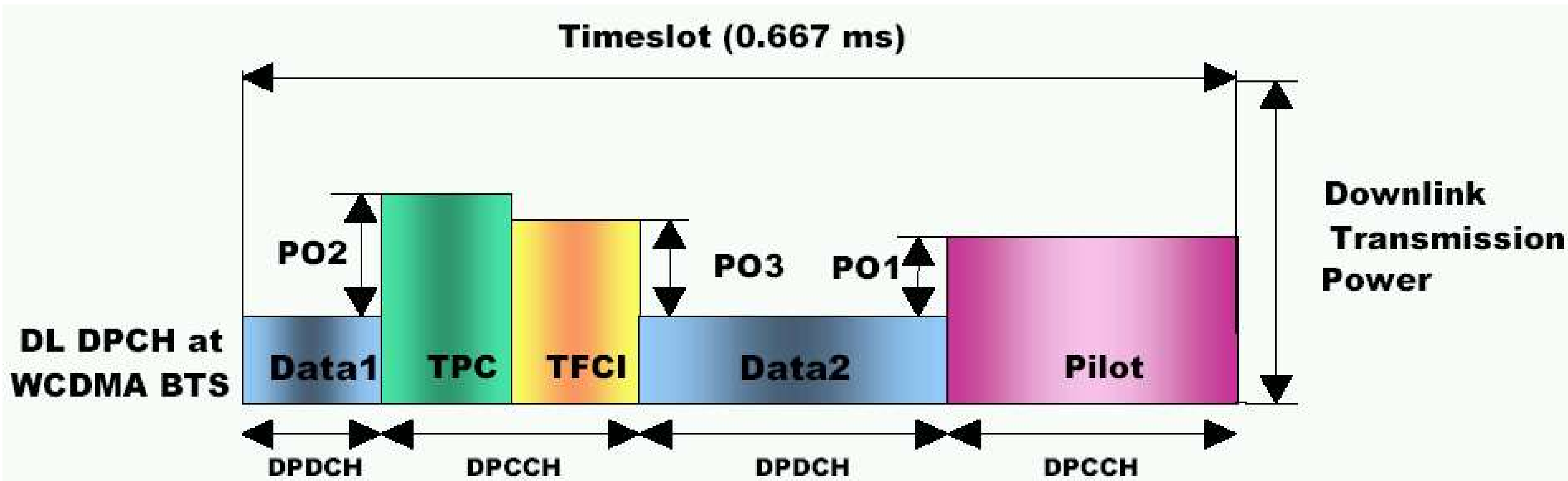


120km/h

3 km/h TPC work well
25 km/h TPC still works
120 km/h TPC is not working well

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



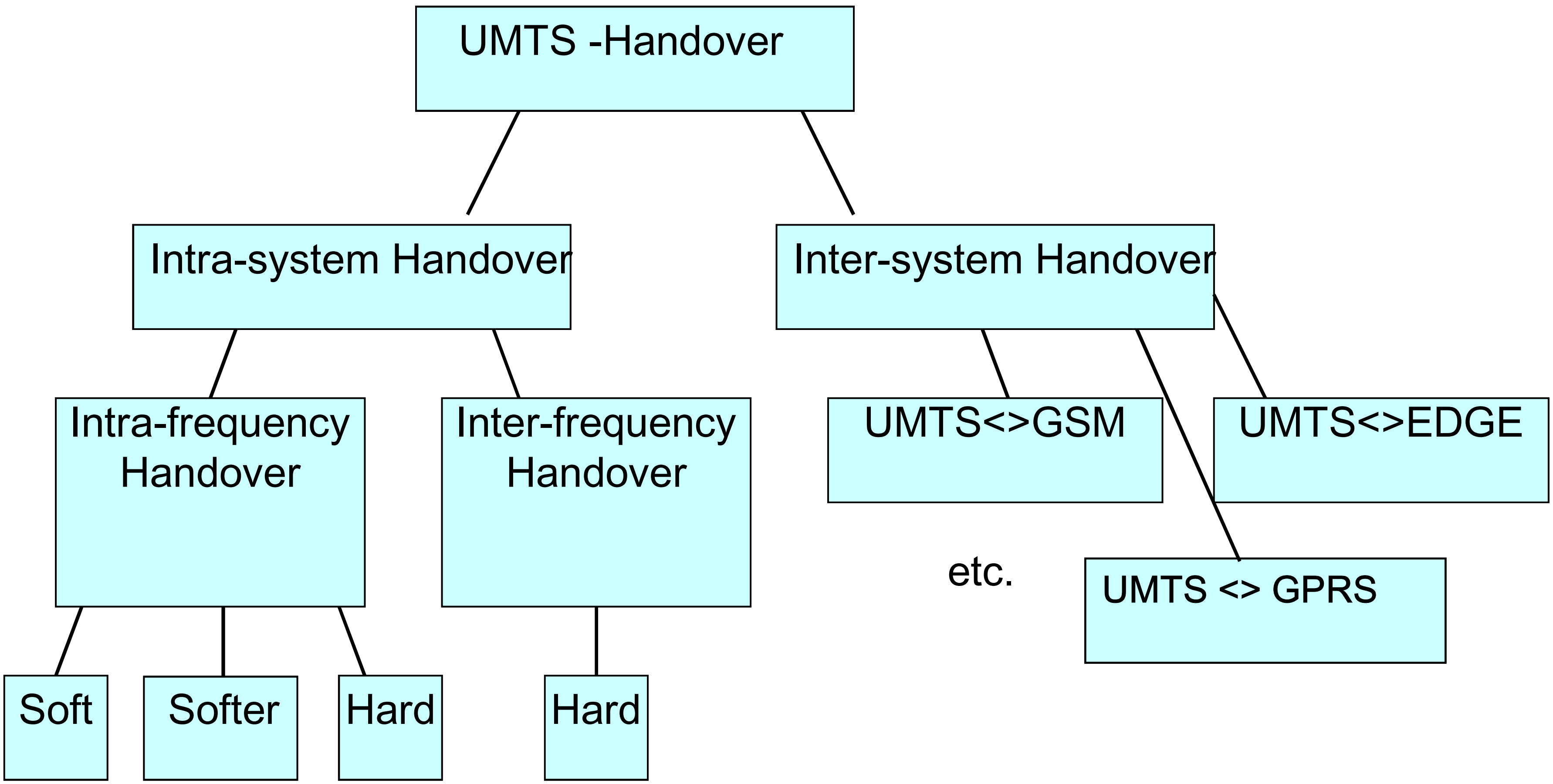
AAiT

TPC characters

- PC concerns in practise:
  - In SHO, DL powers may drift apart due to the inaccurate reception of uplink PC commands → Degraded SHO performance
  - In SHO, DL PC commands cannot be combined in RAKE (because they contain different information). Data bits however can be combined → decreased reability for PC commands.
    - => Can be improved by allocating more power to control channels
  - Building corners in the urban areas
- Average TPC headroom (like 4dB) must be assumed to compensate limited power control dynamics

WCDMA Handover

Handover types in WCDMA



SHO = Soft HandOver
HHO = Hard HandOver

AAiT

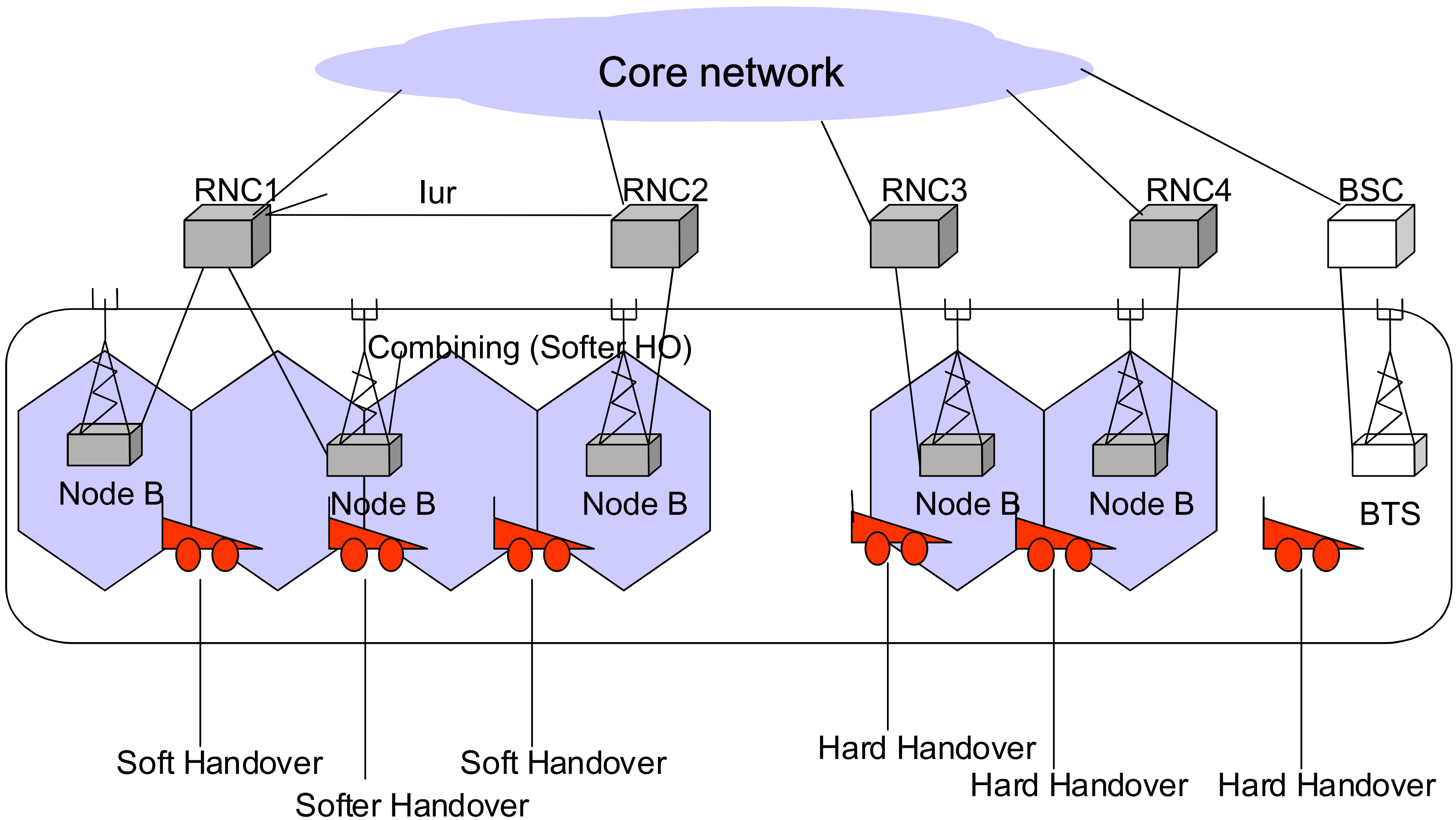
WCDMA Handover control: HHO

- 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: hard handover (cell reselection)

WCDMA Handover control: SHO

- UE always keeps at least one radio link to UTRAN.
  - *Soft* HO: UE is simultaneously controlled by two or more cells belonging to different Node B of the same RNC or to different RNC.
  - *Softer* HO. UE is controlled by at least two cells under one base station site.
  - Dedicated channels: SHO applied
- Handover can be either network or UE initiated
  - Serving RNC makes the decisions in both cases

WCDMA Handover control



AAiT

Hard handover (HHO)

- Both intra and inter-frequency HHO's
- 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 TX power must be re-evaluated
  - This decreases the capacity in heavy traffic situations and can make the near-far effect worse.
- Absence of Iur (connection between RNC's) will cause HHO
- 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

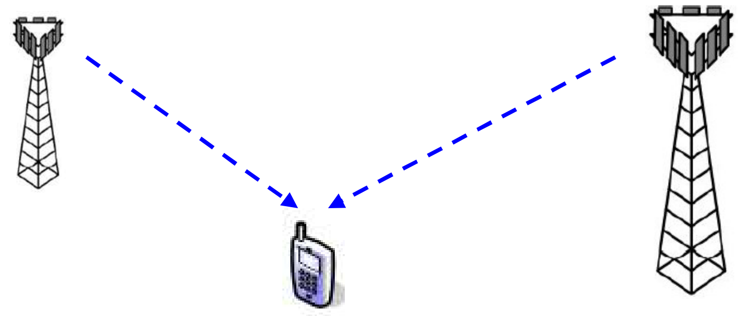
Inter frequency handover (IFHO) in WCDMA

- IFHO can be used to
  - Provide coverage (micro ↦ macro cell when micro and macro on different frequencies)
  - Reduce cell loading (load balancing between different frequency carriers)
- Not so straightforward to perform in UE due to need of compressed mode
- IFHO is generally seen as a means of optimisation as the traffic evolves, but can be used also e.g. to provide indoor coverage on separate carrier (safe solution but lowers the network capacity)

Soft Handover (SHO)

- SHO help to avoid near-far effect in case of 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

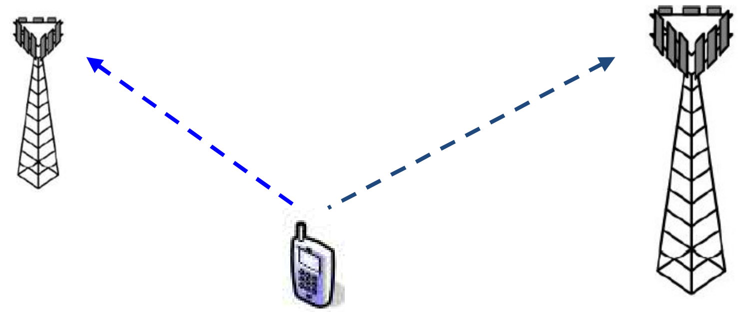


DOWNLINK:

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

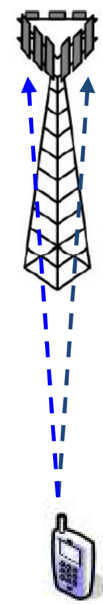
AAiT

Softer/Soft Handover



UPLINK:

- More complex situation than in DL
- During <u>softer HO</u>, same procedure in Node B's RAKE like in DL case
  - – Produced gain is 1-3 dB
  - – Better performance than in soft HO because signals are combined in the same Node B and MRC combining is possible
- During <u>Soft HO</u>, the combining of signals is done in the RNC
  - – Selection combining performed for baseband signal
  - – Based on Cyclic Redundancy Check (CRC)
  - – Better frame to be used in open loop PC (target SIR estimation)



AAiT

Soft Handover: Active and Monitored set

From UE point of view cells are divided into different mutually excluding sets defined by:

- Active Set
  - The cells in the active set participate to the SHO.
- Neighbour Set/Monitored Set
  - The cells that are continuously measured by the UE but are not part of the Active Set. The monitored set can consist of intra-frequency, inter-frequency and inter-RAT cells
- The number of cells in active+monitored sets is limited to 32

Soft Handover: Active and Monitored 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, removed or replaced in the Active Set
- Maximum Active Set Size parameter
  - 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 decreases the SHO performance (best candidate cells may be excluded in some situations)

Soft Handover: Measurements

- 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 determined for the signal ”in the air”
- *Eb/No depends* on the service (bit rate, 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 and stationary UE’s should be just long enough to avoid fast fading errors
    - Too long filter length will cause HO delays for a fast moving UE

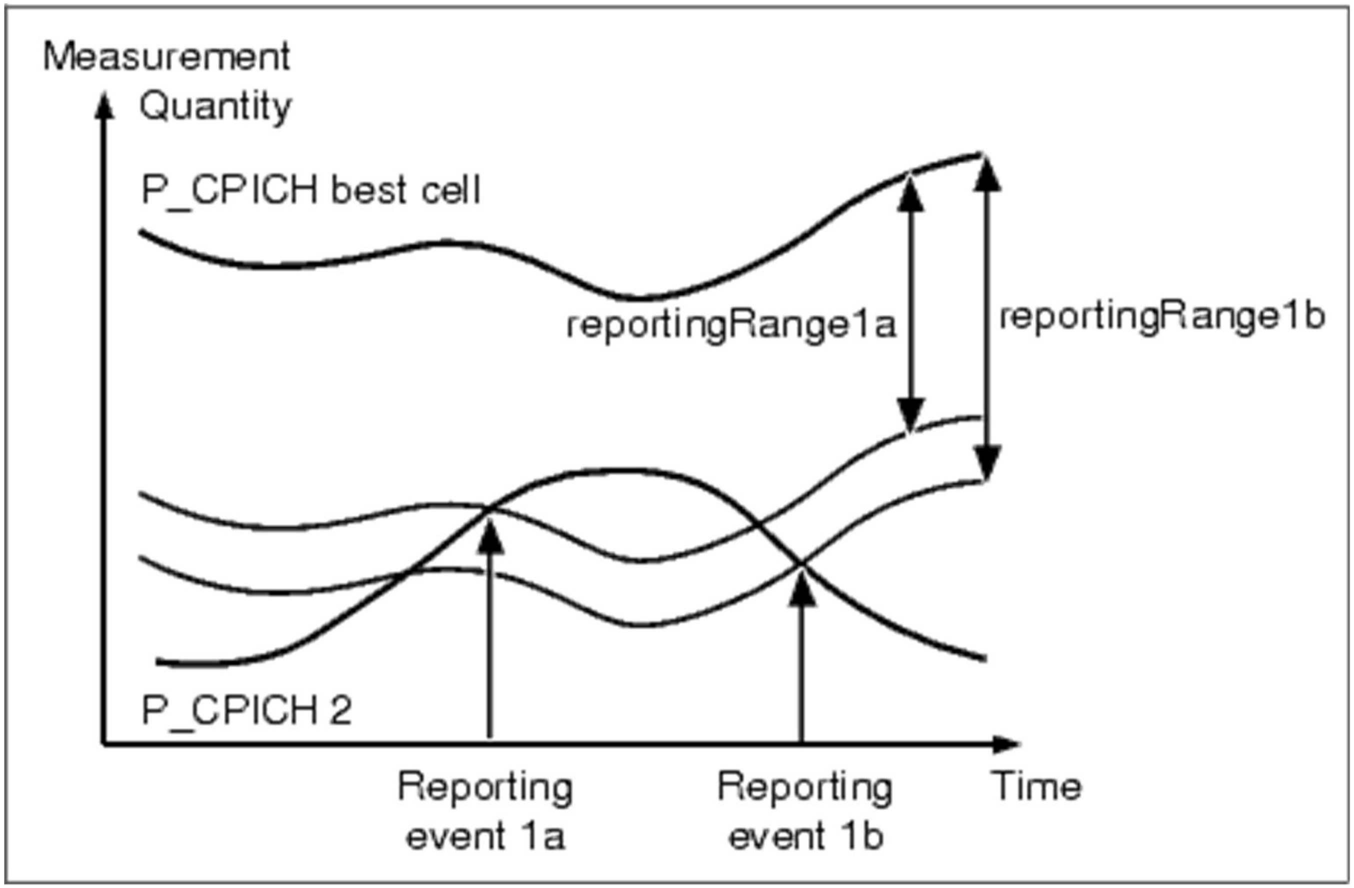
Soft Handover: Reporting Ranges and Events

Event based triggered measurements and reporting:

- *Reporting ranges* 1a and 1b depend on the best cell power.
- Basic *reporting events* 1a, 1b and 1c
  - 1a: P-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 is done by RNC based on measurements and available resources

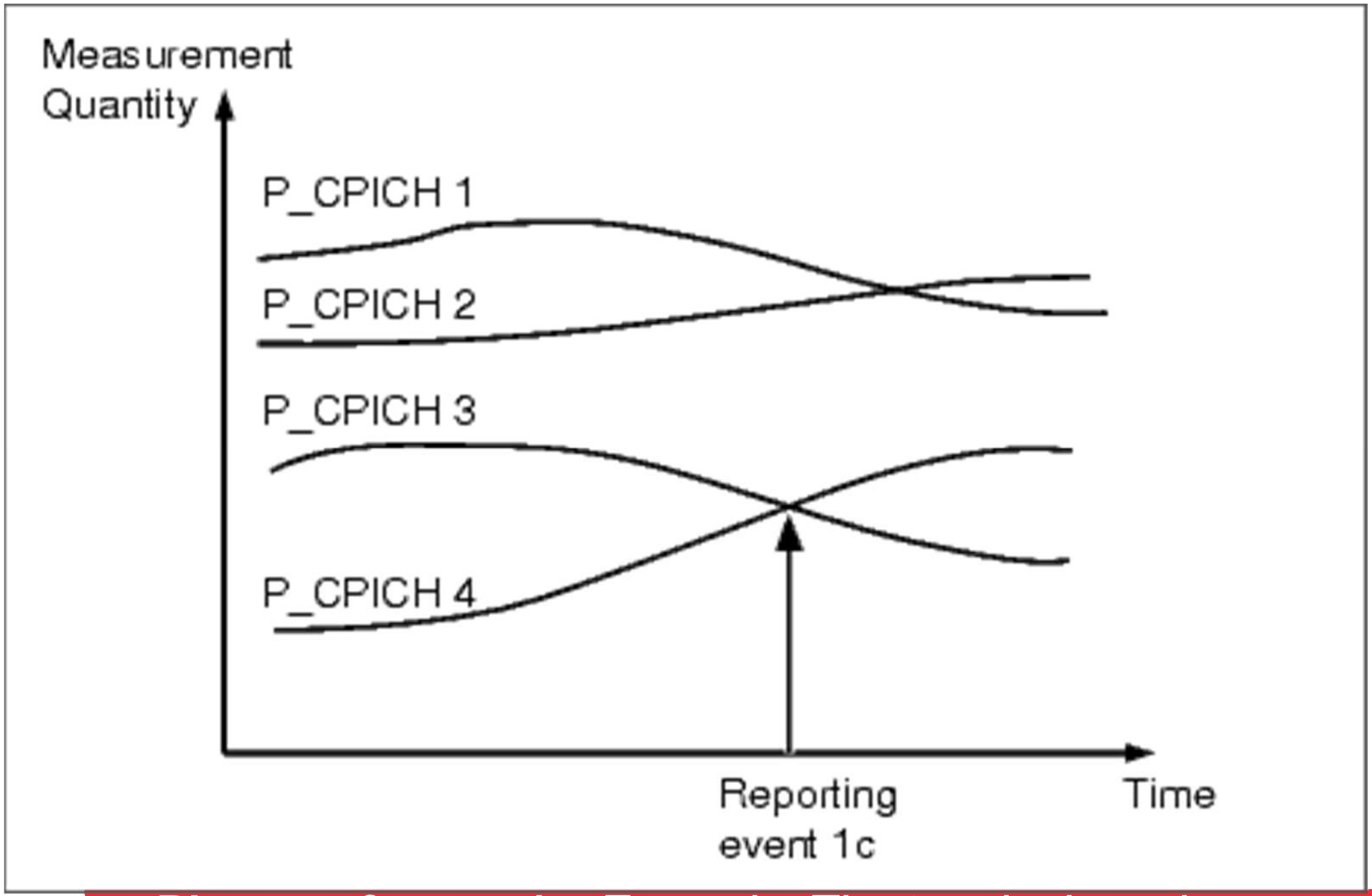
AAiT

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, next slide)

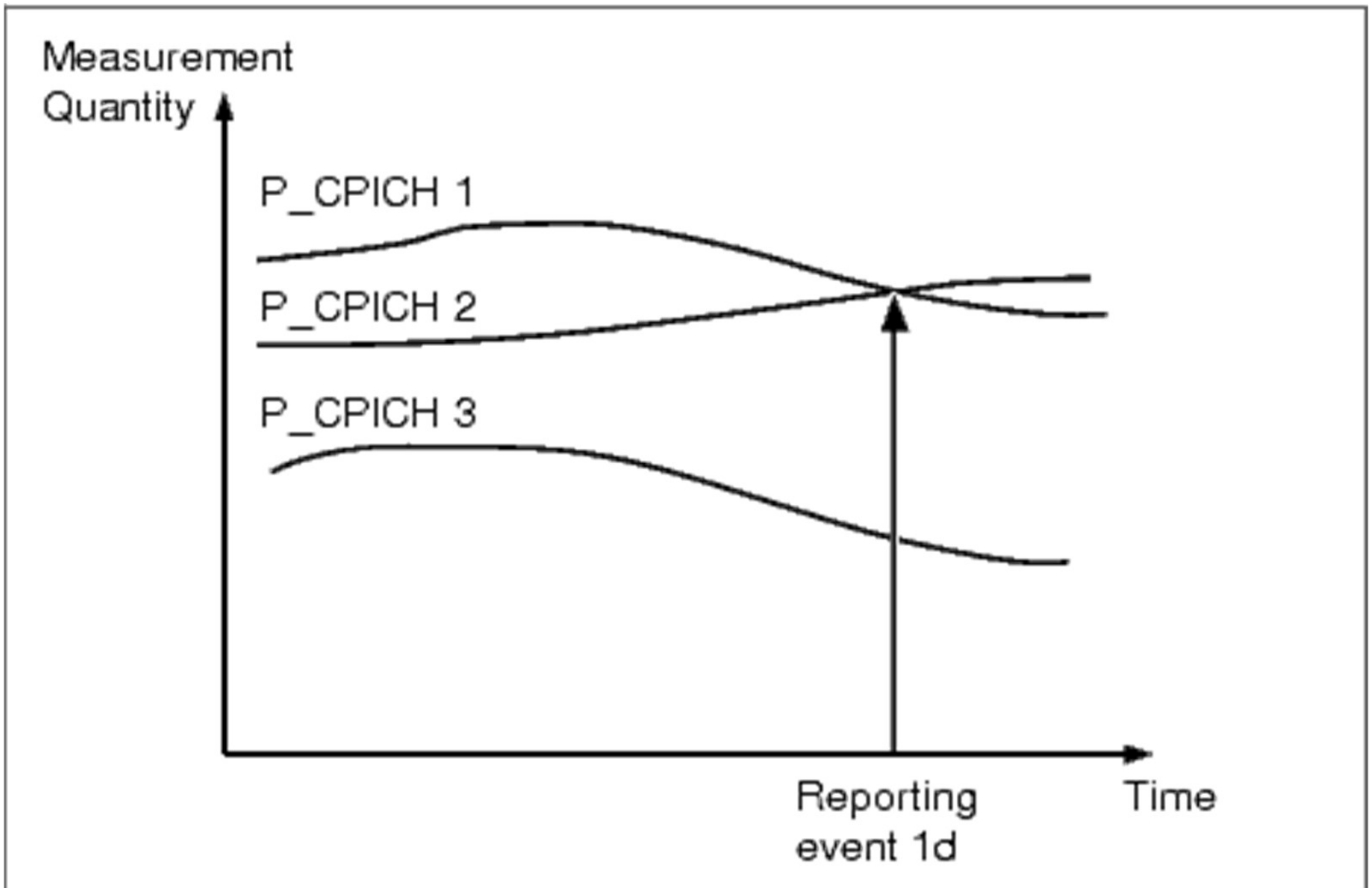
Soft Handover



- **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, then new cell is proposed as a replacement of the worst cell in the Active Set

AAiT

Soft Handover

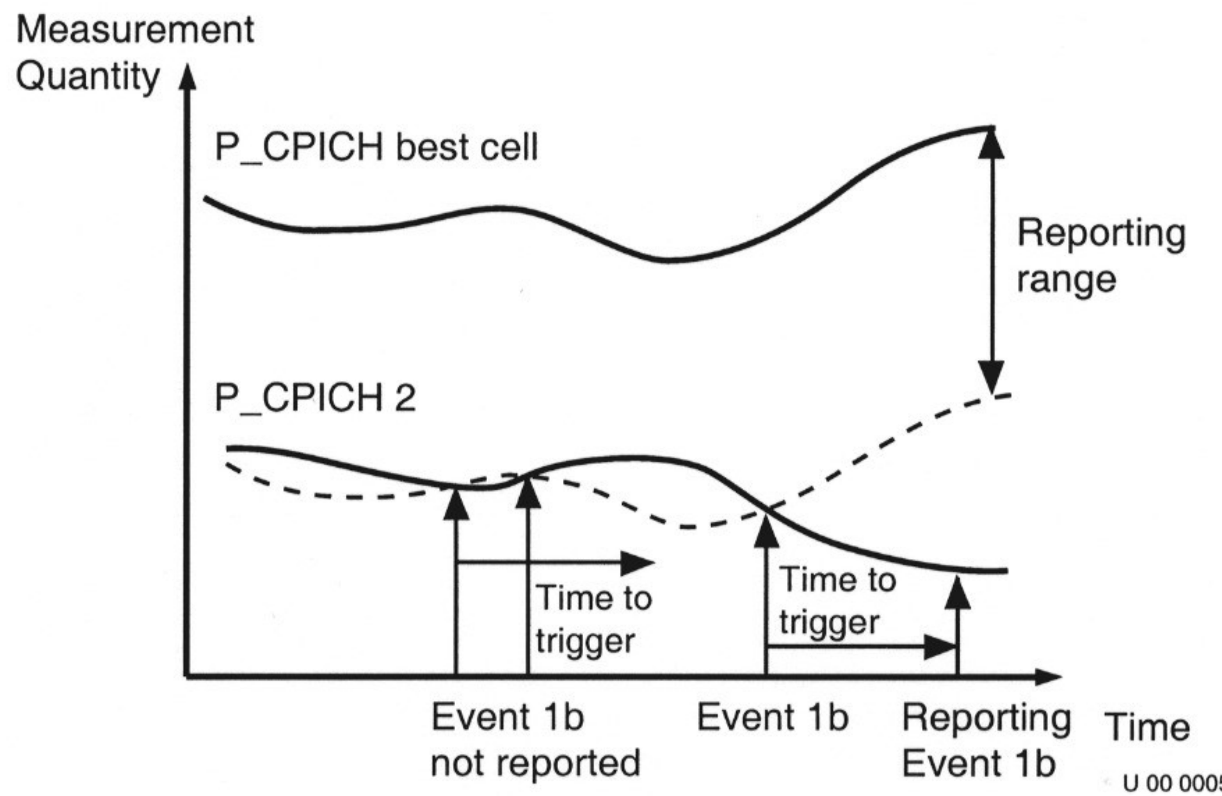


- **Picture of event 1d.** Example: The terminal sends an event 1d report to the RNC if the cell belongs to the monitored cells list and Active Set is not full. Then cell is proposed to be added to the Active Set. If the Active Set is full, the cell is proposed as a replacement of the strongest cell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

AAiT

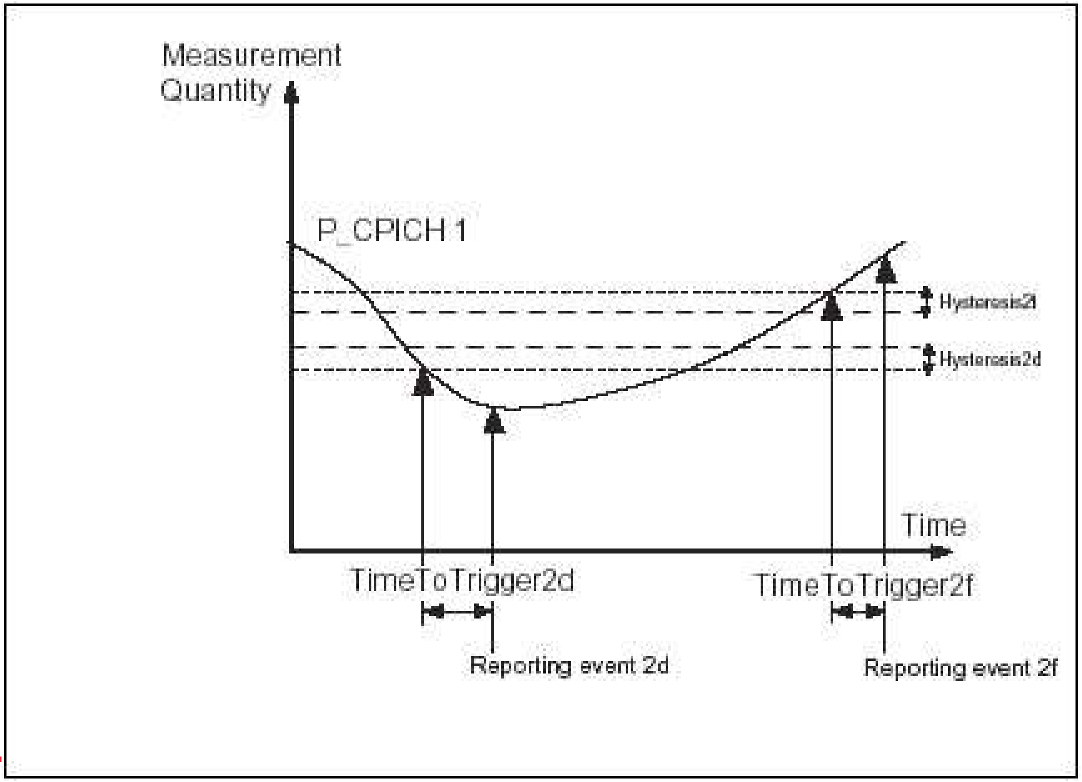
Soft Handover

- ❖ Time-to-trigger: Repor are send only if event lasts long enough in order to avoid unnecessary signalling overhead.



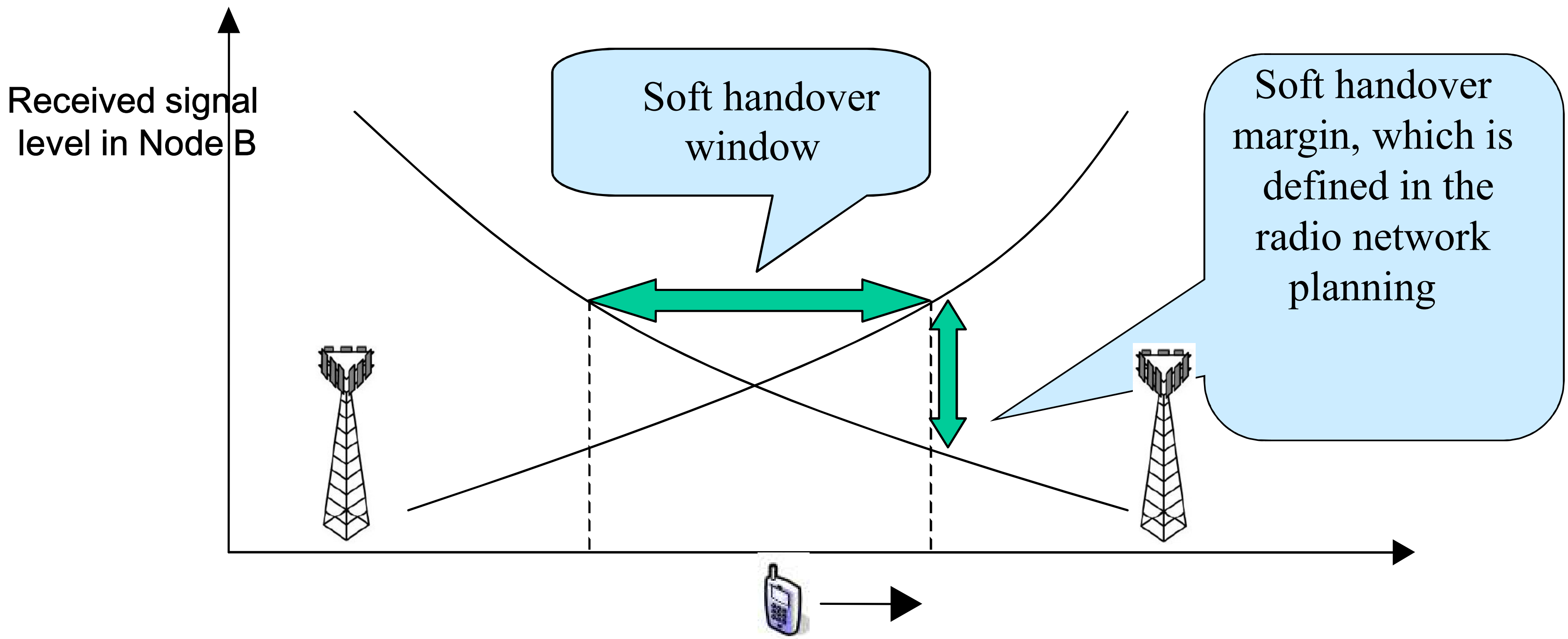
Inter-Frequency HO (IFHO)

- 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 interruption 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
  - Ec/Io of current carrier is the measure
  - Events 2d and 2f defined for IFHO
  - Time to trigger used



AAiT

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 can 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 synchronize to
- HO parameter adjustments is part of the network optimization

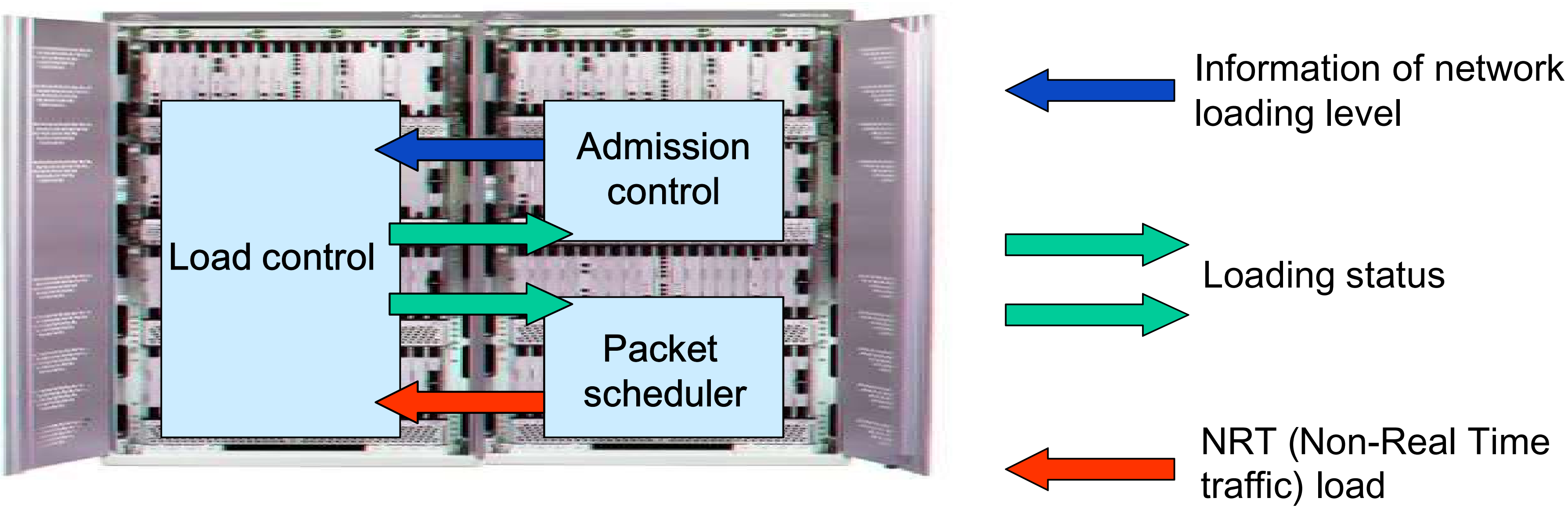
AAiT

Admission and Congestion Control, Packet Scheduler

Admission and Congestion Control

- Congestion/Load Control's general responsibility is to keep 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:



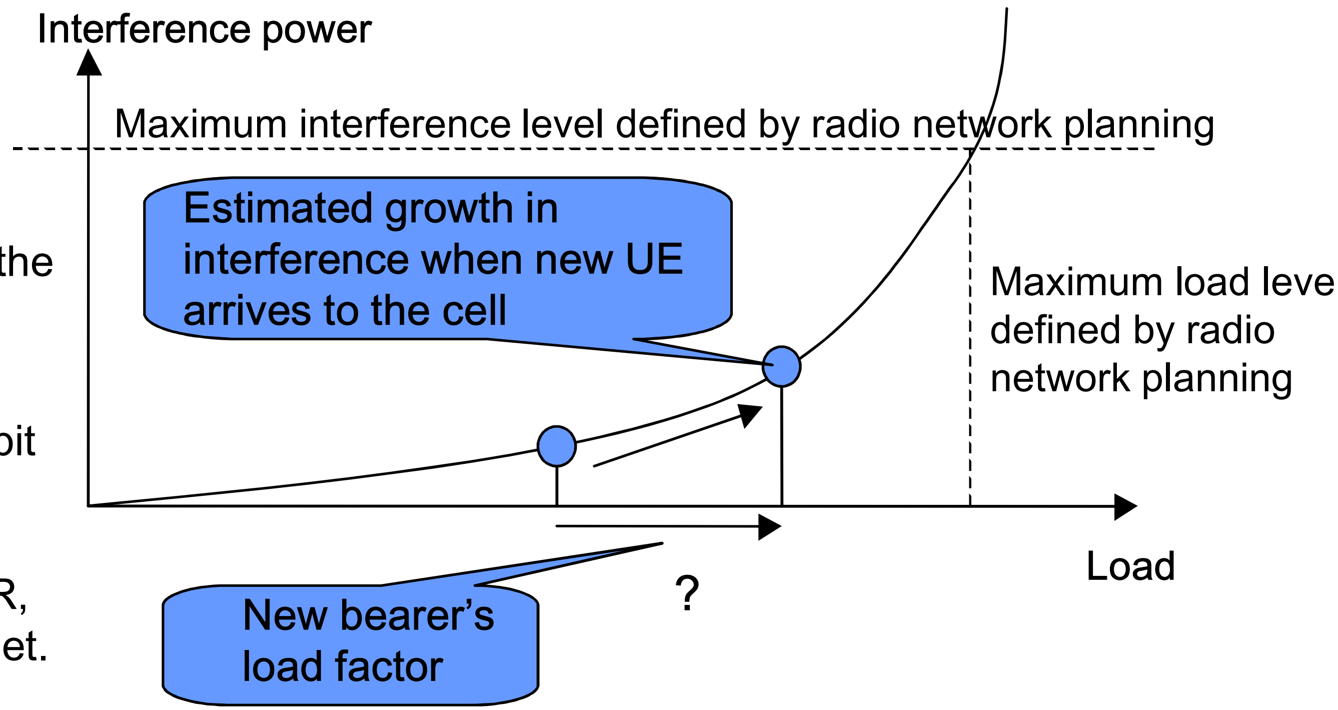
AAiT

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.



AAiT

Congestion control

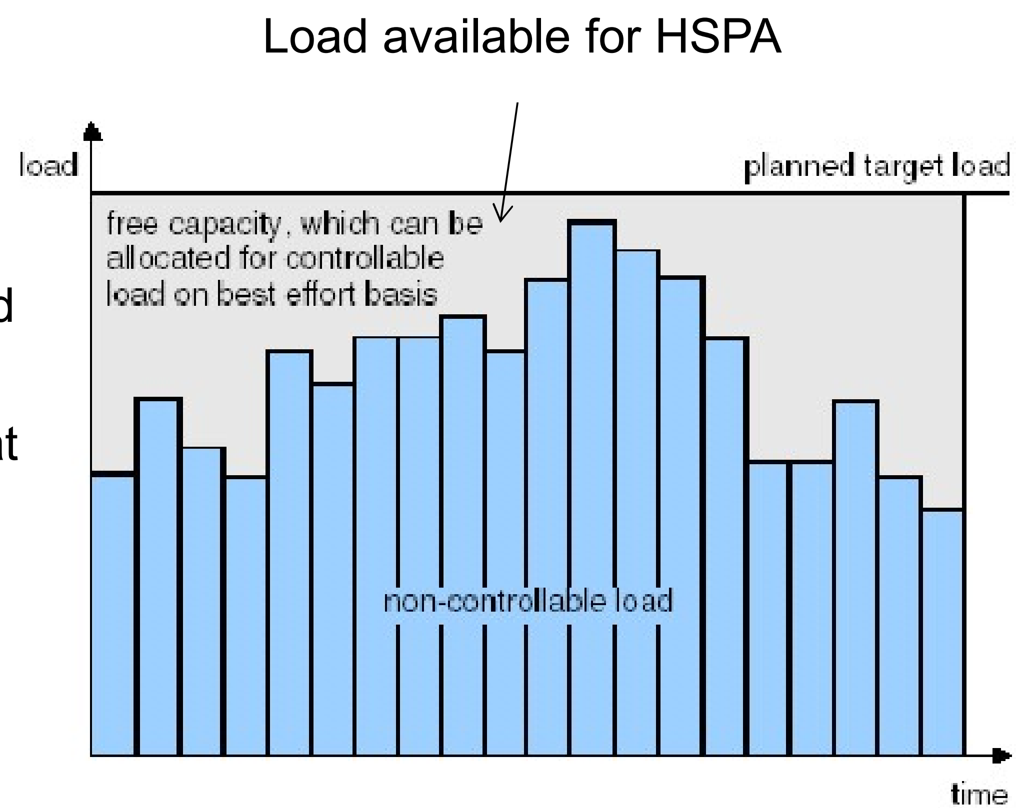
- In case of congestion the use of resources is scaled down to reach normal loading status
- The priorisation and order of congestion control actions are based on vendor specific algorithms.
- Actions that can be carried out in order to decrease the load
  - Deny power-up commands received from UE (downlink)
  - Reduce the UL Eb/No target used in UL fast power control
  - Reduce the throughput of packet data traffic
  - Handover UEs 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 non-real time (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 is usually allocated to HSPA.
❖ 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

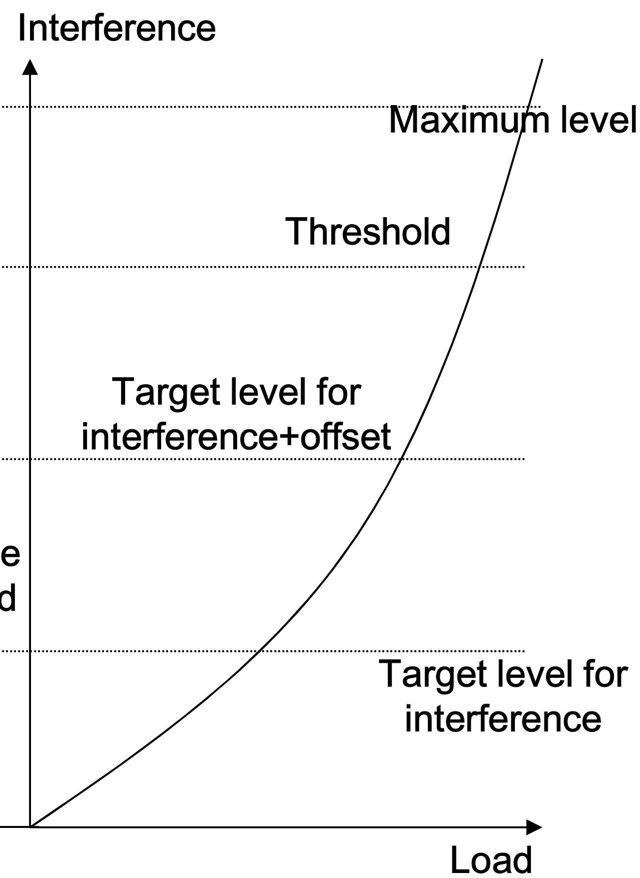


- The amount of scheduled capacity depends on:
  - UE and BTS capabilities,
  - the current load in the cell,
  - the availability of physical resources.

AAiT

Control summary

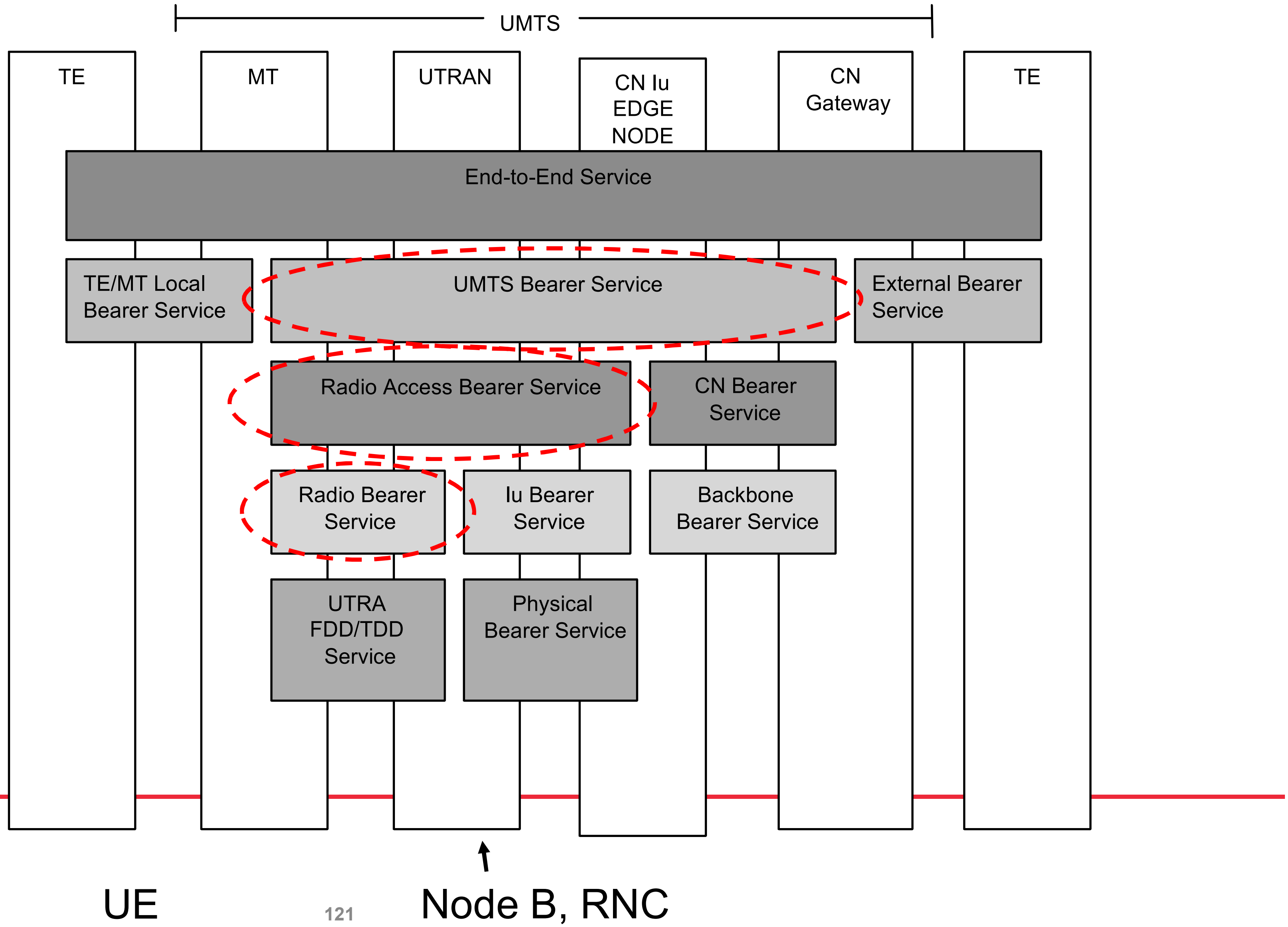
Admission control	Congestion control	Packet Scheduler
	Overload actions	Decrease bit rates and NRT Bearers are dropped
No new bearers are admitted	Preventive load control actions	Decrease bit rates
No new bearers are admitted	No actions	NRT load is not increased, but bit rate changes are allowed
New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



Contents

AAiT

Radio Access Bearer



AAiT

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
- The result is a compromise, in which the QoS requirements and network's capacity are 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

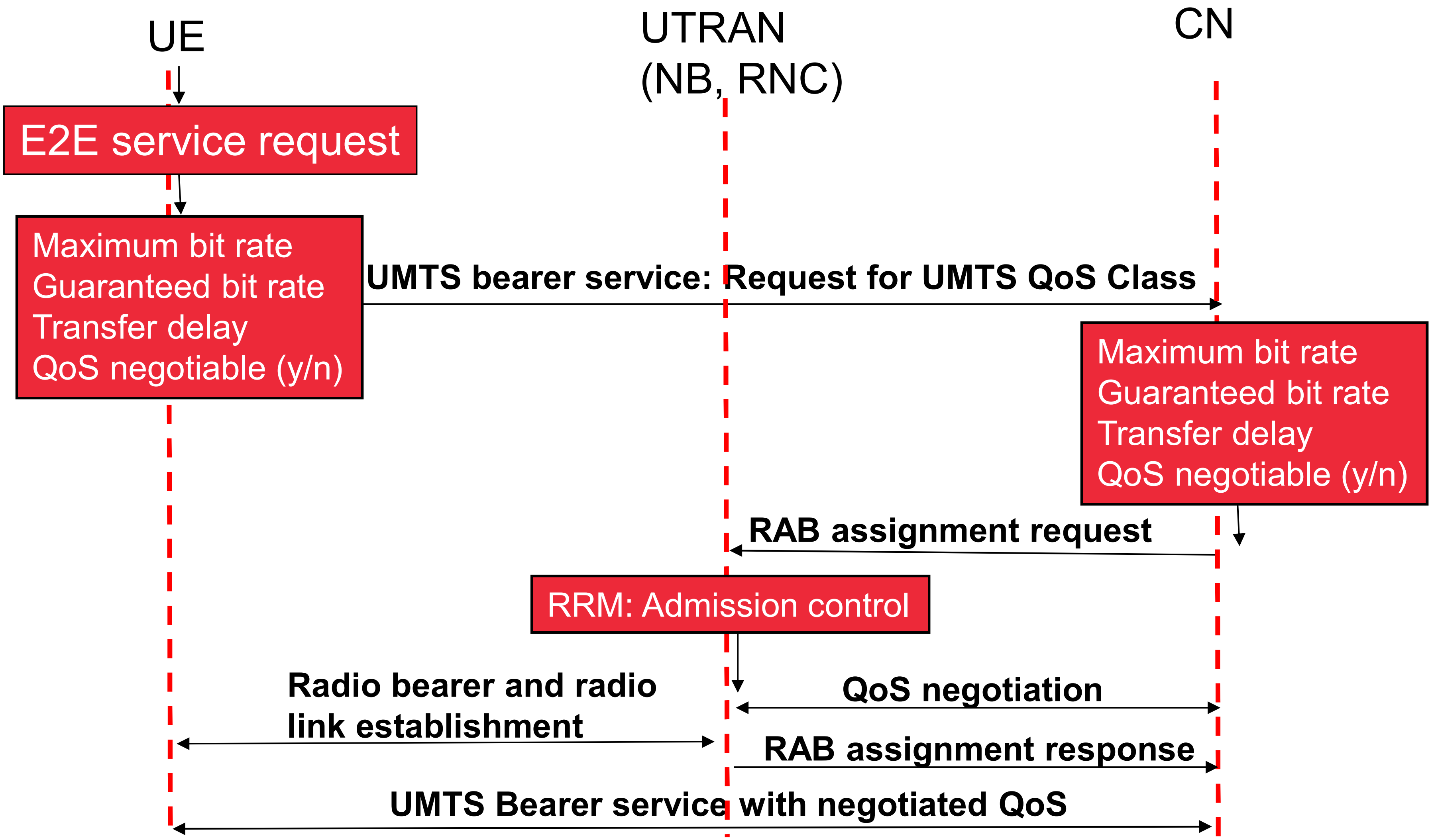
Traffic Class	Properties
Conversational class	Minimum fixed delay, no buffering, symmetric traffic, guaranteed bit rate
Streaming class	Minimum variable delay, buffering allowed, asymmetric traffic, guaranteed bit rate
Interactive class	Moderate variable delay, buffering allowed, asymmetric traffic, 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.
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.
QoS negotiable	QoS of some services are not negotiable (speech), packet data services admit various QoS classes

AAiT

QoS Negotiation

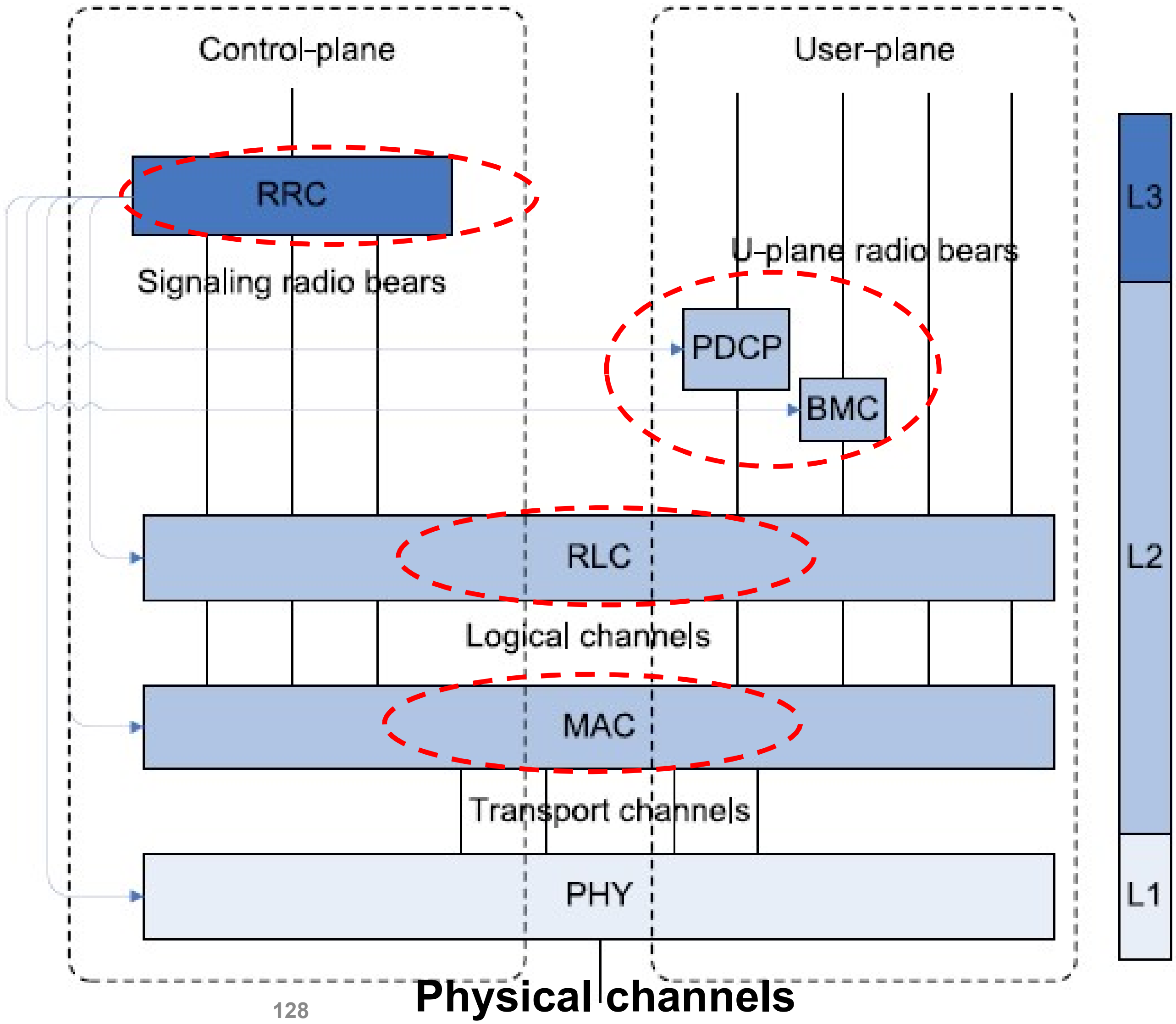


AAiT

QoS in UMTS

- The QoS over the air interface is implemented by matching each radio bearer with a transport channel whose format 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)
- 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

Elements of WCDMA radio interface protocol architecture



AAiT

Main WCDMA radio interface protocols

- The radio interface protocols are needed to set up, reconfigure and release the Radio Bearer services.
- The protocol layers above the physical layer (Layer 1) are called the data link layer (Layer 2) and the network layer (Layer 3).
- In the UTRA FDD the Layer 2 is split into sublayers. In the control plane, Layer 2 contains two sub-layers – Medium Access Control (MAC) protocol and Radio Link Control (RLC) protocol.
- In the user plane, in addition to MAC and RLC, two additional service-dependent protocols exist: Packet Data Convergence Protocol (PDCP) and Broadcast/Multicast Control Protocol (BMC).
- Layer 3 consists of one protocol, called Radio Resource Control (RRC), which belongs to the control plane.

The idea behind layered protocol structure is to multiplex traffic flows of different kinds and origins. In UTRAN context layered structure simplifies the design of service provision that varies in e.g. QoS and rate requirements.

Radio interface protocol architecture

- The physical layer offers services to the MAC layer via transport channels and MAC layer offers services to the RLC layer by means of logical channels.
- The RLC layer offers services to higher layers via service access points (SAPs), which describe how the RLC layer handles the data packets
- On the control plane, the RLC services are used by the RRC layer for signalling transport. On the user plane, the RLC services are used either by the service-specific protocol layers PDCP or BMC.

Radio interface protocol architecture

- The RLC services are called Signalling Radio Bearers in the control plane and Radio Bearers in the user plane for services not utilising the PDCP or BMC protocols.
- The Packet Data Convergence Protocol (PDCP) exists only for the PS domain services. Its main function is header compression. Services offered by PDCP are also called Radio Bearers.
- The Broadcast Multicast Control protocol (BMC) is used to convey messages originating from the Cell Broadcast Centre.
- The RRC layer offers services to higher layers via service access points

MAC Functions

- Mapping between logical channels and transport channels.
- Selection of appropriate Transport Format for each Transport Channel, depending on the instantaneous data rate.
- Priority handling between data flows of one UE. This is achieved by selecting 'high bit rate' and 'low bit rate' transport formats for different data flows.
- MAC handles
  – Dedicated channel (DCH)
  – Broadcast channel (BCH)
  – Paging channel (PCH)
  – Forward link access channel (FACH)
  – Random access channel (RACH)

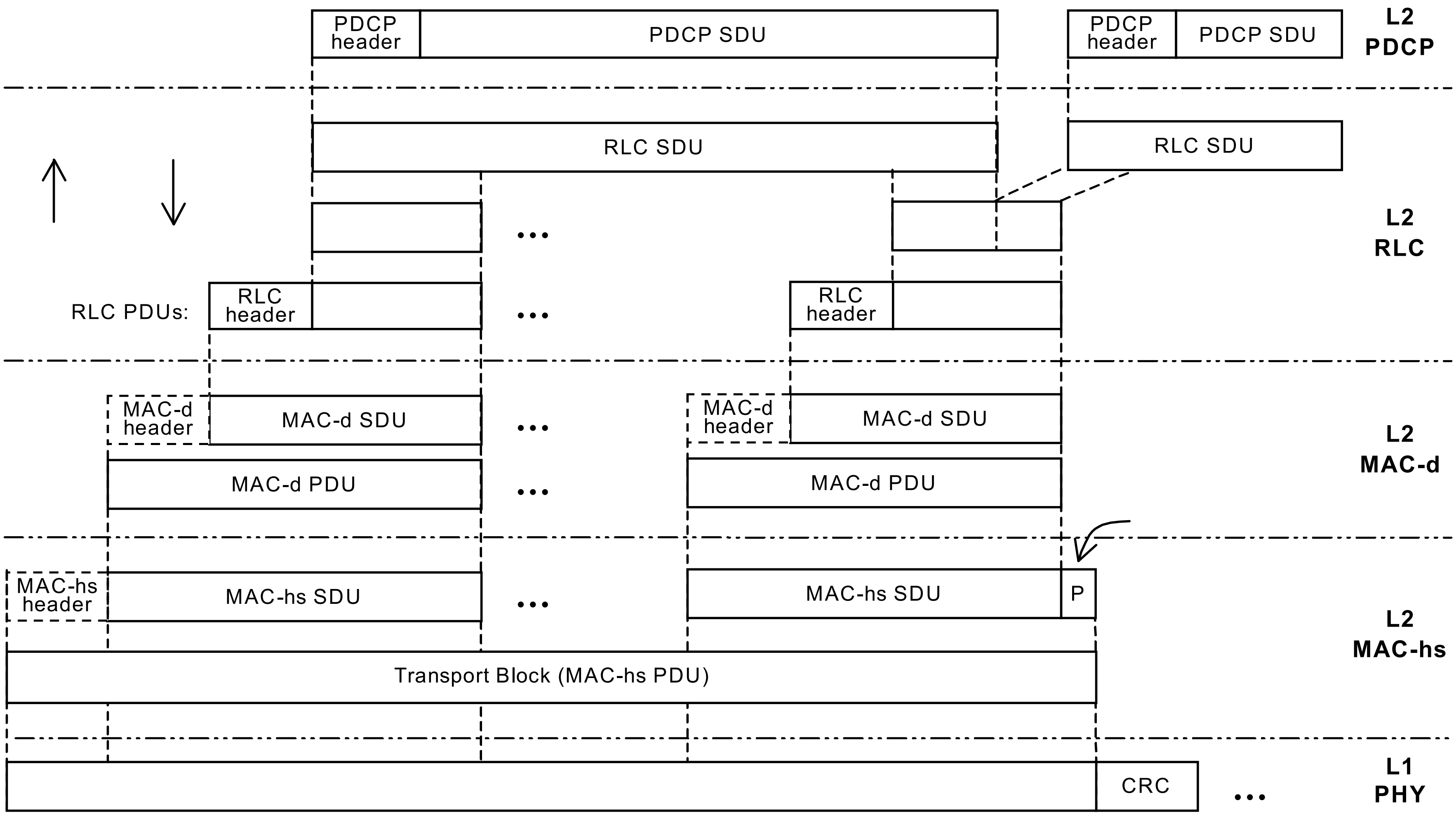
MAC Functions

- Priority handling between UEs by means of dynamic scheduling
- MAC handles part of the service multiplexing for common transport channels (RACH/FACH) and for dedicated transport channels.
- Traffic volume monitoring.
  - If the amount of data is too high or too low, MAC sends a measurement report on traffic volume status to RRC. The RRC can also request MAC to send these measurements periodically. The RRC uses these reports for triggering reconfiguration of Radio Bearers and/or Transport Channels.

Radio Link Control (RLC)

- RLC is mainly responsible for segmentation, retransmission and buffering user and control data.
- In RLC the data unit from upper layer (Protocol Data Unit (PDU)) is segmented and put into RLC payload units in buffer.
- There are 3 operation modes of each RLC instance:
  - Transparent mode (TM), unacknowledged mode (UM), and acknowledged mode (AM)
- For all RLC modes, the Cyclic Redundancy Check (CRC) is added in the header of RLC PDU and checked in physical layer.
- In addition, AM uses an Automatic Repeat Request (ARQ) mechanism for error correction and in case of erroneous reception the retransmission is made in SRNC.
- In network RLC is located in RNC.

Data flow through PHY/MAC/RLC/PDCP



AAiT

Radio Resource Control (RRC)

- The major part of the control signalling between UE and UTRAN is Radio Resource Control (RRC) messages.
  - RRC messages carry all parameters required to set up, modify and release Layer 2 and Layer 1 protocol entities.
- The RRC performs admission control and handover decisions.
- RRC also manages the two basic operational modes of a UE:
  - Idle mode and connected mode.
  - The connected mode can be further divided into service states, which define what kind of physical channels a UE is using.

Radio Resource Control (RRC)

- In the idle mode, after the UE is switched on, it selects a PLMN to contact. Then UE looks for a suitable cell and after finding it follows its control channel.
- After finding a cell in idle mode, the UE is able to receive system information and cell broadcast messages. The UE stays in idle mode until RRC connection is established.
- UTRAN has no information of individual idle mode UEs and can only address, for example, all UEs in a cell or all UEs monitoring a paging occasion.

Other protocols

- **PDCP:** Compression of e.g. TCP/IP and RTP/UDP/IP headers in the transmitting entity, and decompression at the receiving entity. Transfer of user data. This means that the PDCP receives a PDCP SDU and forwards it to the appropriate RLC entity and vice versa.
- **BMC:** This protocol is designed to control broadcast and multicast services, originating from the Broadcast domain, on the radio interface.
- **MBMS:** Enables transmission of content to multiple users in a point-to-multipoint manner

  - **TCP = Transport Control Protocol**
  - **RTP = Real Time Protocol**
  - **UDP = User Datagram Protocol**
  - **BMC = Broadcast/Multicast Control protocol**
  - **MBMS = Multimedia Broadcast Multicast Service**