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Cellular Network Planning and Optimization
Part VI: WCDMA Basics

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TKK, 24.1.2008

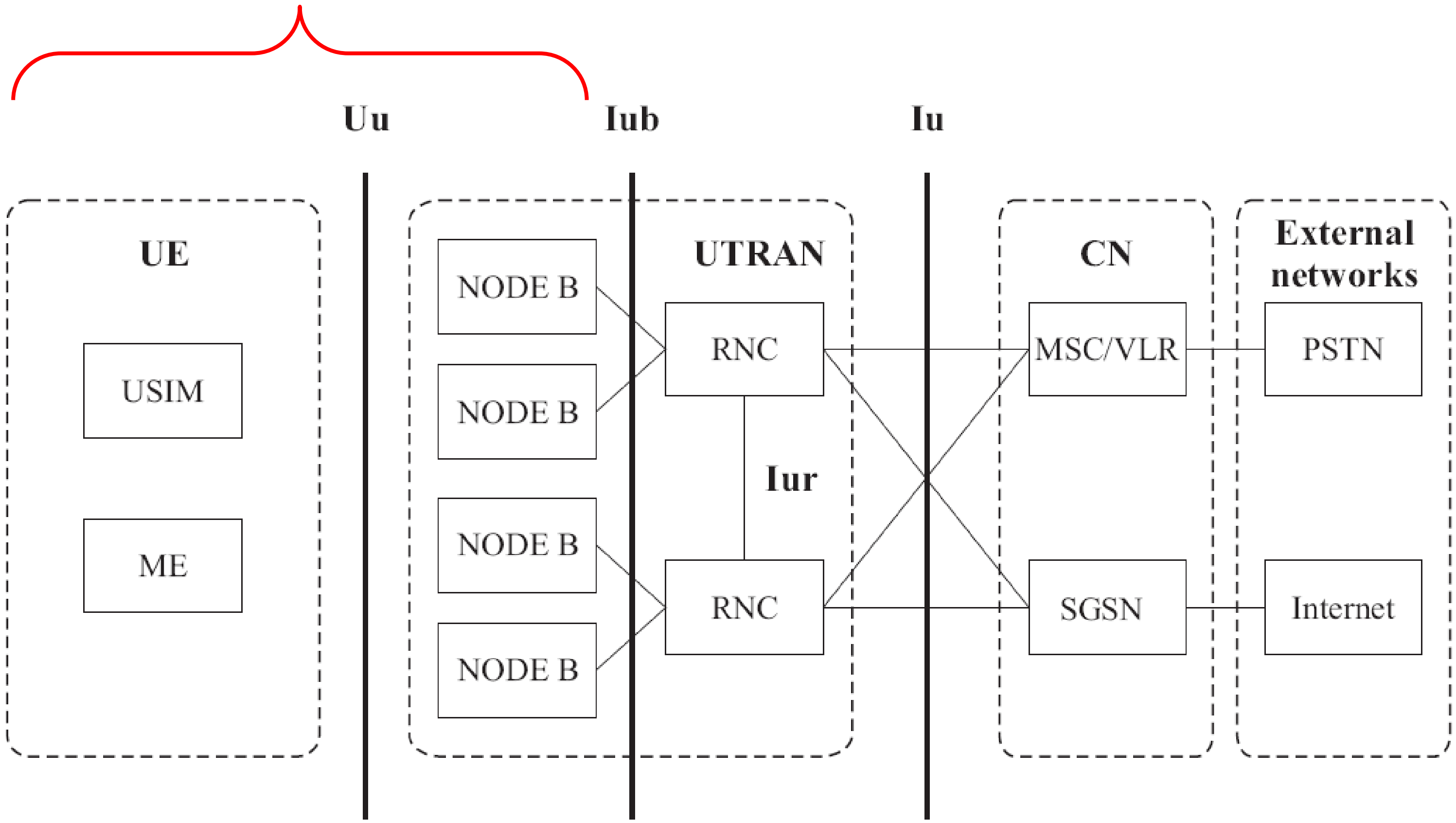
Outline

- Network elements
- Physical layer
- Radio resource management

Network elements

Network elements

Our main focus area



Network elements in a 3G WCDMA based PLMN

Network elements

- Typically PLMN is operated by a single operator
  - Connected to other PLMNs and networks like Internet
- User Equipment (UE) contains
  - Mobile equipment (ME): Radio communication over Uu interface
  - UMTS Subscriber Identity Module (USIM): Subscriber identity information, authentication algorithms, encryption keys etc

Network elements

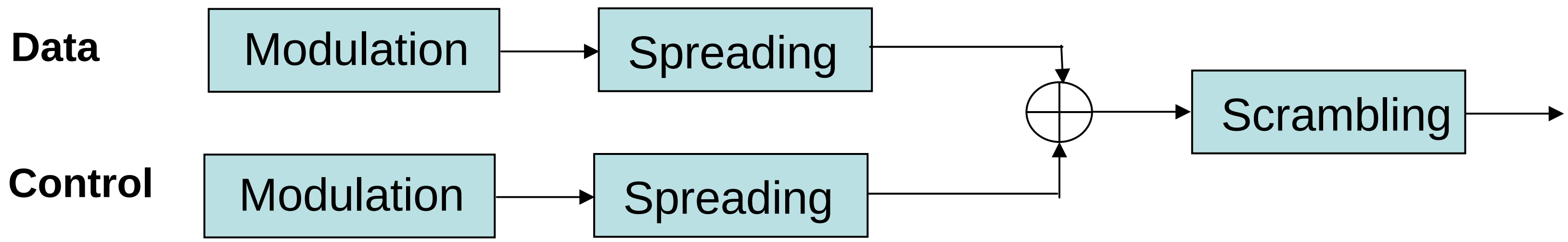
- UMTS Terrestrial Radio Access Network (UTRAN)
  - Node B (Base Station): Handles/manages the traffic between Uu and Iub interfaces. Basic tasks like coding, interleaving, rate adaptation, modulation, spreading etc.
  - Radio Network Controller (RNC): Control radio resources in its operation area. Provide services for Core Network (CN). Load and congestion control, admissions control, code allocation, radio resource management tasks.

Network elements

- Mobile Services Switching Centre (MSC)/Visitor Location Centre (VLR)
  - Handles switching in Circuit Switched (CS) connections and hold visiting users service profiles.
- Serving GPRS Support Node (SGSN)
  - Similar functionality as in MSC/VLR but used for Packet Switched (PS) services
- Other CN elements
  - Gateway MSC (GMSC): Handles incoming and outgoing CS connections
  - Gateway GPRS Support Node (GGSN): Like GMSC but in PS domain
  - Home Location Register (HLR): Master copy of users service profiles

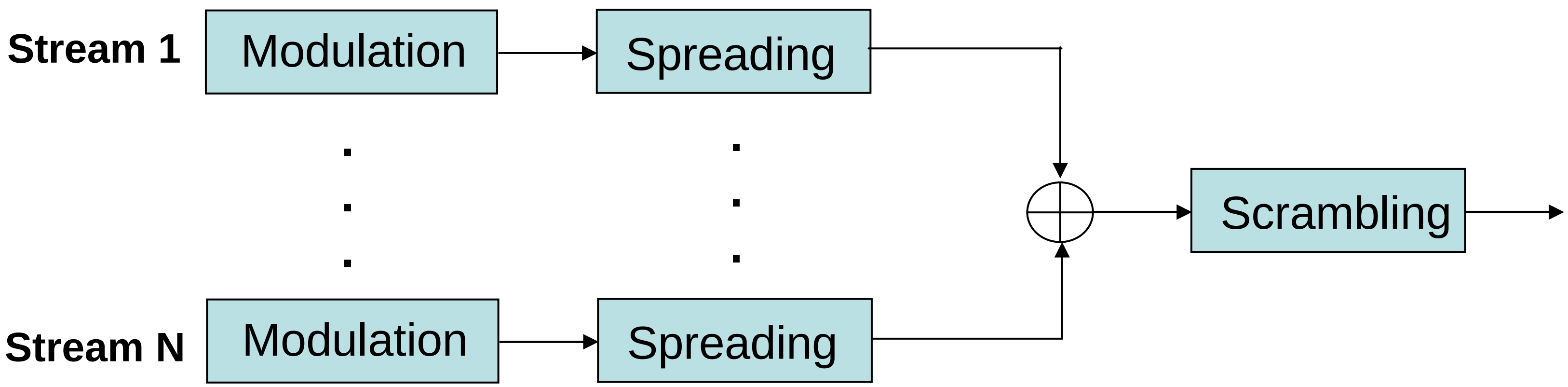
Physical layer

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)

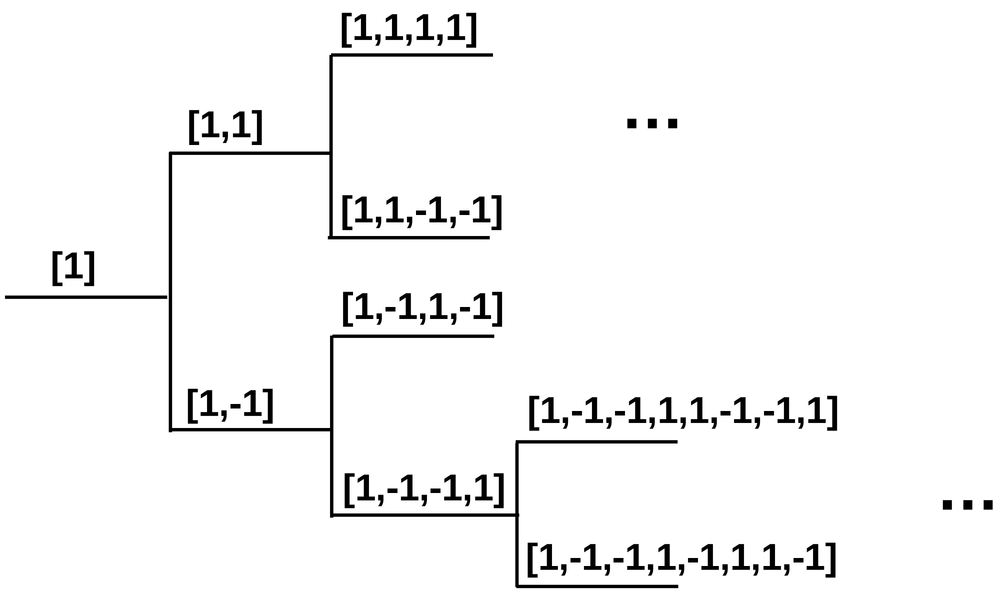
Downlink transmission path



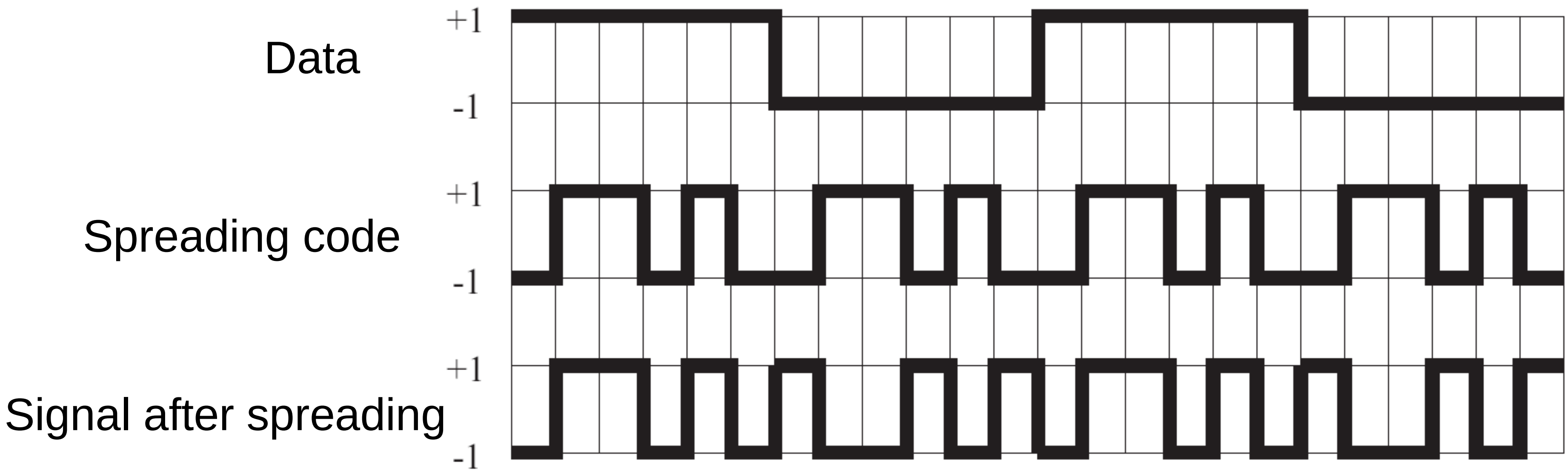
- Users within a cell (sector) are separated by orthogonal spreading codes (sometimes also called as channelization codes)
- Cells (sectors) are separated by scrambling codes
- QPSK modulation

Spreading

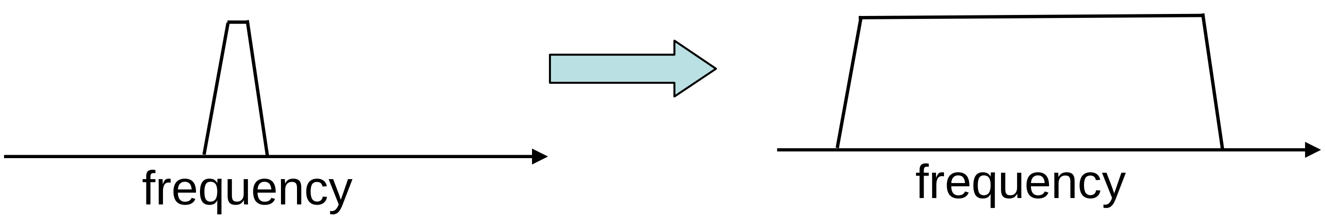
- Spreading is done using orthogonal codes
  - Codes remain orthogonal only if synchronization is perfect
  - Multi-path fading will reduce the orthogonality



Spreading



Spreading expands the signal to wide band



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

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

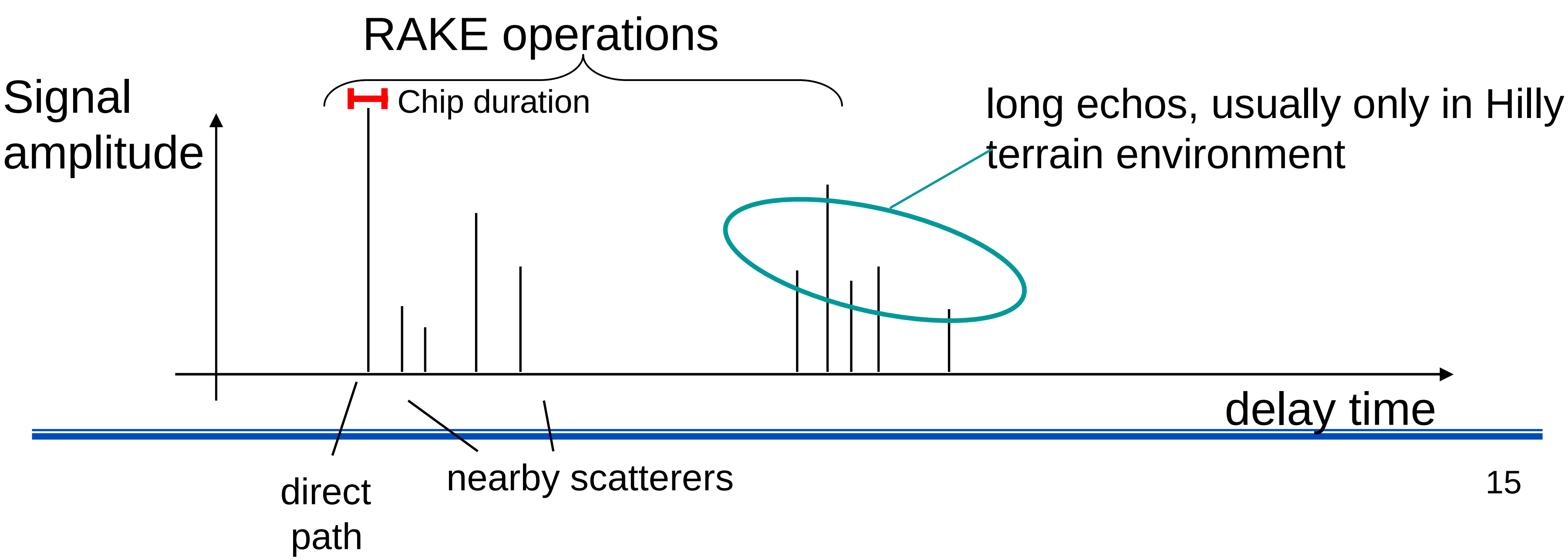
$$\text{Spreading gain} = 10\log_{10}(SF)$$

Spreading

- Some measures that are used in WCDMA receiver investigations
  - CINR = Carrier to interference and noise ratio, also SINR is used
  - 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 interference from other users.
  - Notation E_b / N_0 is commonly used for *E*

Spreading

- 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.



RAKE

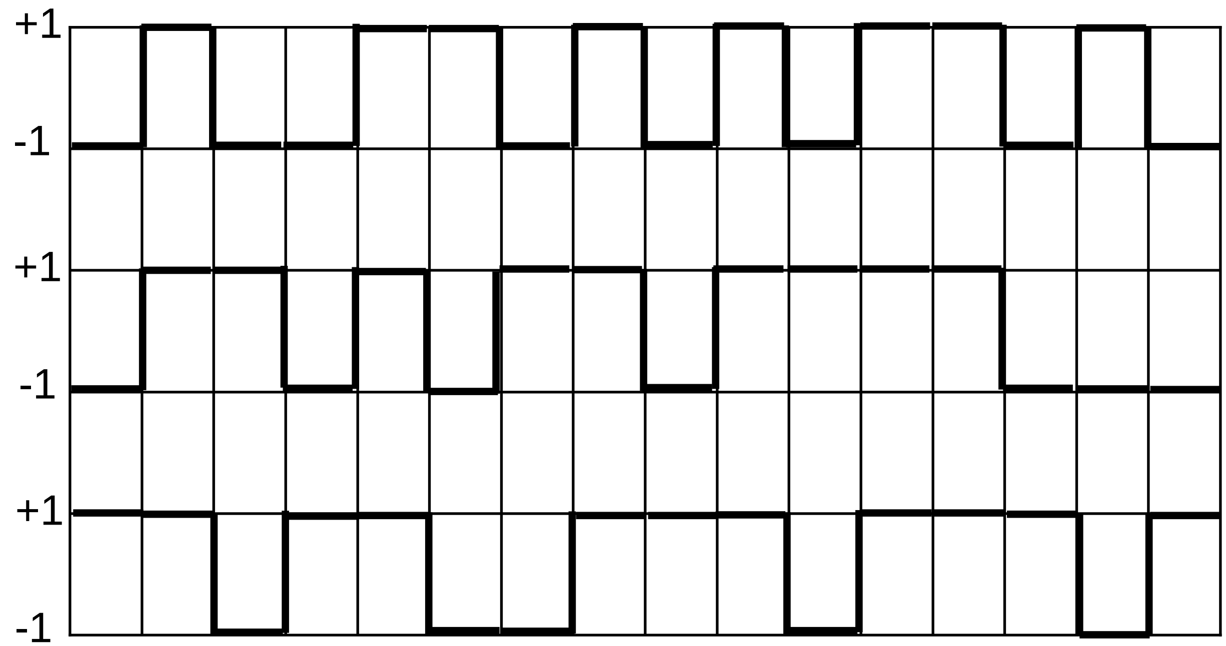
- A basic receiver that is used in WCDMA is called as RAKE
  - The multipath channel through which a radio wave propagates can be viewed as a sum of many delayed copies of the original transmitted wave, each with a different magnitude and time-of-arrival at the receiver. Each multipath component contains 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.

Scrambling

Signal after spreading

Scrambling code

Signal after scrambling



Scrambling

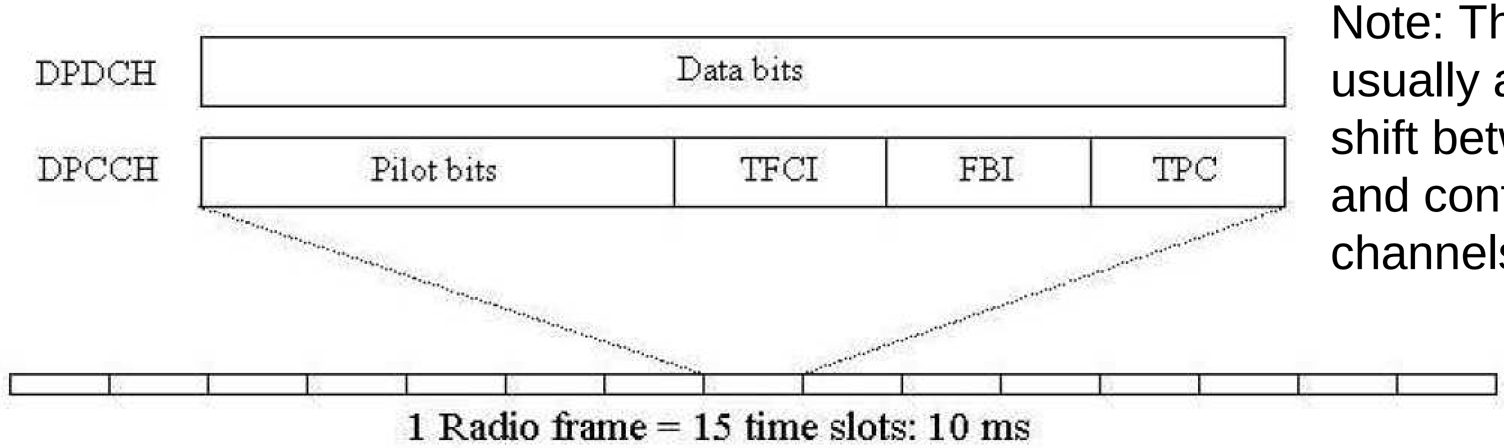
- Scrambling codes are used to separate users in uplink and cells in downlink
- Scrambling is used on top of spreading
- Scrambling is not changing the signal bandwidth
- In downlink scrambling codes are allocated to the cells (sectors) in network planning phase
  - Number of scrambling codes is high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

Important channels/uplink

- 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

Control information in DPCCH

- Pilot 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 is applied

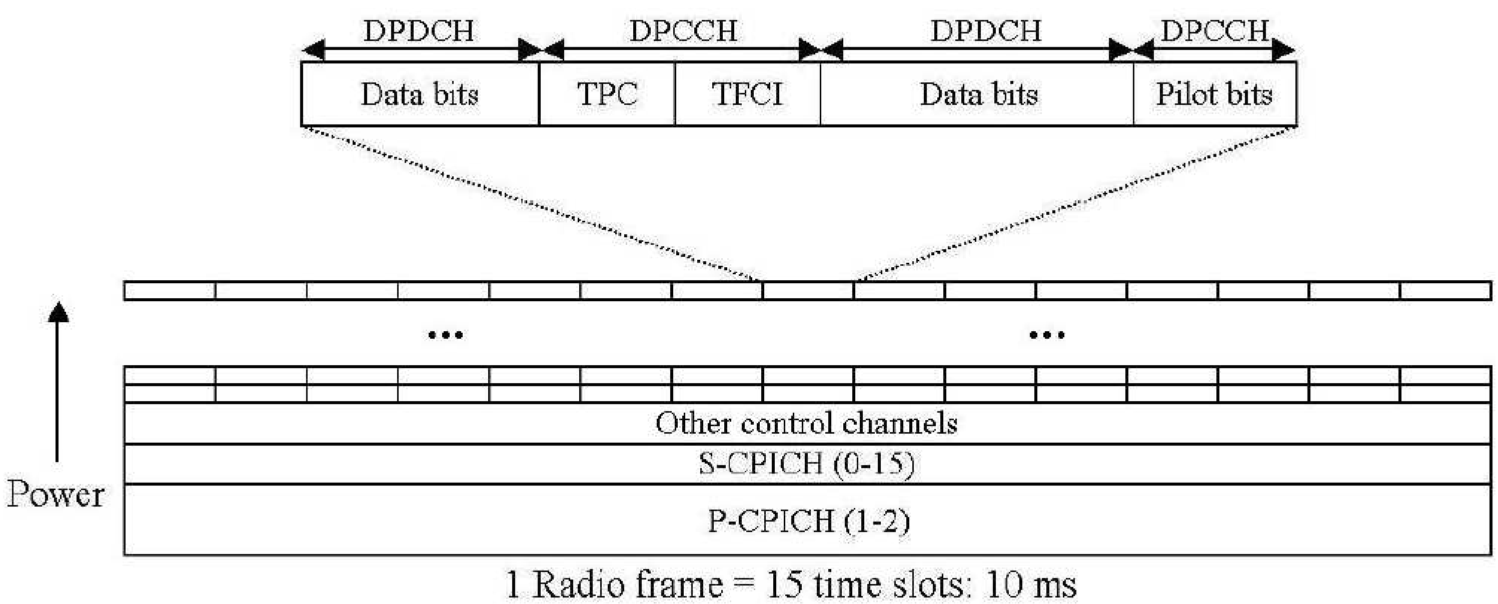
Uplink DPDCH data rates

- 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

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

Important channels/downlink

- 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



Important channels/downlink

- Common Pilot Channel (CPICH)
  - CPICH aid channel estimation at the terminal
  - Spreading factor = 256
  - (*) Terminal makes handover and cell selection measurements from CPICH => CPICH should be heard everywhere in the cell
  - (*) Cell coverage and load can be adjusted through CPICH
    - If CPICH power is reduced part of the terminals will hand over to adjacent cells
- Synchronization channel (SCH)
  - (*) Synchronization channel is needed for cell search
  - Spreading factor = 256

(*) Important property from network planning perspective

Important channels/downlink

- Primary Common Control Physical Channel (Primary CCPCH)
  - Carry broadcast channel and all terminals in the system should be able to receive it.
  - (*) If CCPCH decoding fails then terminal cannot access to the system => CCPCH transmission power high.
  - No pilot bits, channel estimation done from CPICH which is transmitted with same antenna radiation pattern
  - Spreading factor = 256, ½ rate coding

(*) Important property from network planning perspective

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

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 control

- From network planning perspective it is important to keep in mind that control channels take part of the DL power

	Activity [%]	Percentage of the maximum base station power [%]	Power allocation with 20 W. maximum power [W]
Common pilot channel (CPICH)	100	10	2.0
Primary synchronization channel (SCH)	10	6	1.2
Secondary synchronization channel (SCH)	10	4	0.8
Primary common control physical channel (CCPCH)	90	5	1.0
Total common channels	**-**	**~ 15**	**~ 3**

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

RRM algorithms

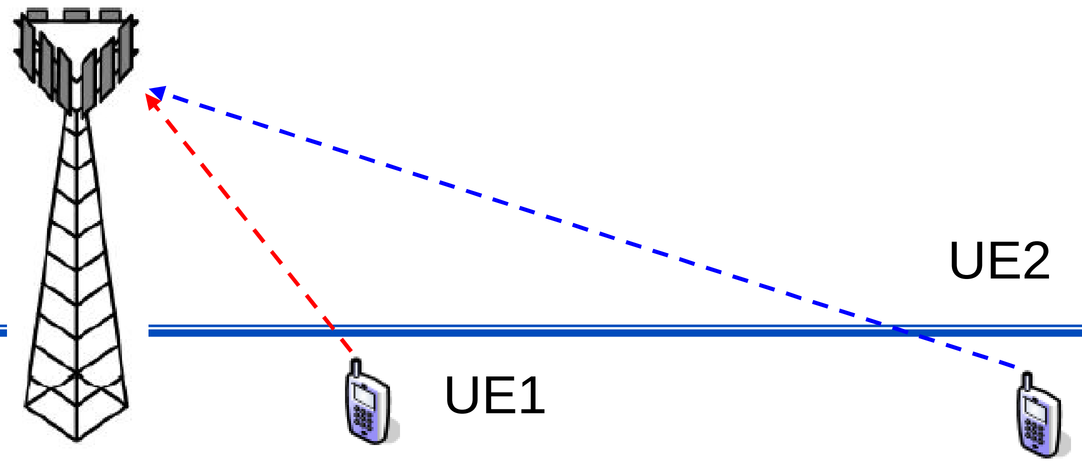
- Family of RRM algorithms:
  - Power control
    - Fast power control (Node B, UE)
    - Outer loop power control (RNC)
  - Handover control (RNC)
  - Admission control (RNC)
  - Load control (RNC)
    - Fast load control (Node B)
  - Packet scheduling (RNC)

Power control

- 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



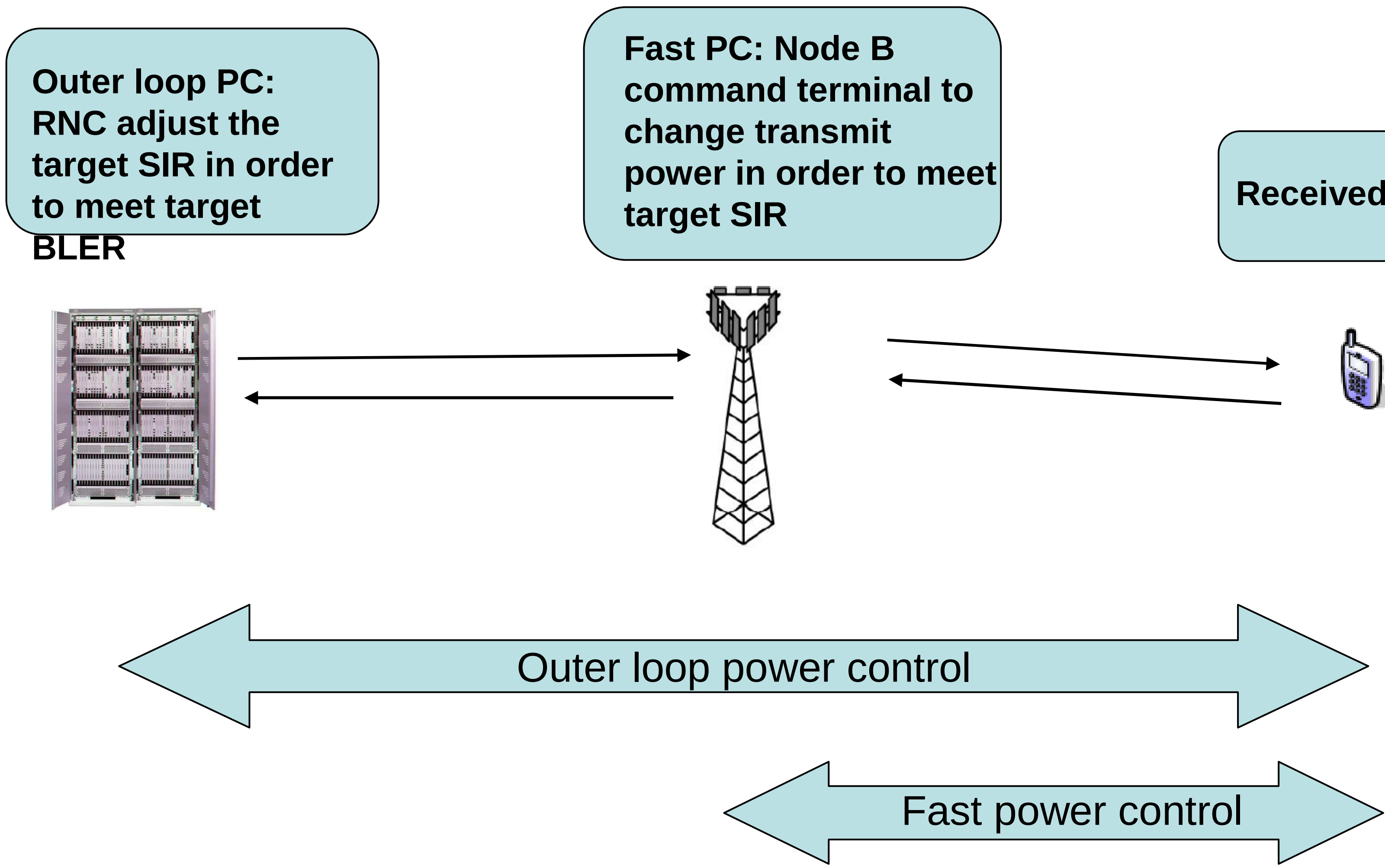
Power control

- 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



Uplink outer loop PC

- The goal is to control the target SIR in order to remain the wanted QoS with minimum transmit power
- The target BLER is defined with the admission control algorithm
- The uplink algorithm is controlled in RNC and downlink algorithm in UE
- 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

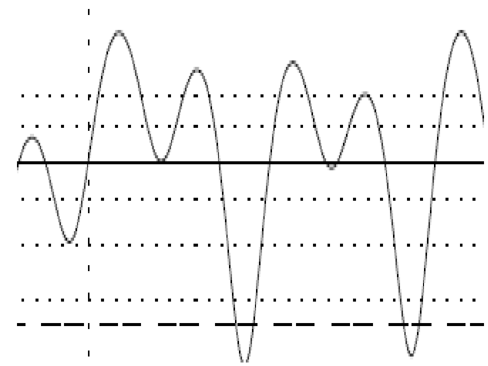
Downlink outer loop PC

- 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.

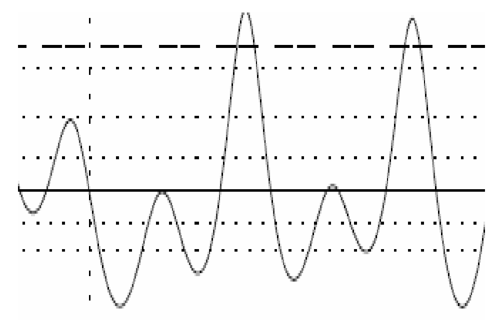
Fast power control

- 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



Uplink fast PC

- 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 Bs ask for it and decreased if at least one node B demands it

Downlink fast PC

- Similar as DL fast PC:
  - UE measures SIR on DL DPCCH during the pilot period
  - 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