WCDMA for UMTS

Luc Vandendorpe

UCL Communications and Remote Sensing Lab.

UCL
Université catholique de Louvain

Introduction

- Second generation (like GSM) enabled voice traffic to go wireless
- In several countries there are now more mobile phones than landline (wired) phones
- Data handling capability of 2nd generation is limited
- Third generation: should provide high bit rate services that enable transmission and reception of high quality images and video and provide acces to the WEB
- Third generation: referred to as UMTS (Universal Mobile Telecommunications System)

Introduction

- WCDMA (Wideband CDMA) is the main third generation air interface in the world

- Specification created in 3GPP (Third Generation Partnership Project) which is joint standardisation project of Europe, Japan, Korea, USA and China.

- In 3GPP WCDMA is called UTRA (Universal Terrestrial Radio Access) FDD and TDD

Introduction

- Work for 3rd generation started in 1992 when the WARC (World Administrative Radio Conference) of the ITU (International Telecommunication Union) identified frequencies around 2 GHz for 3G
- Withing the ITU, 3G was named IMT2000 (International Mobile Telephony-2000)
- The target of IMT was to have a single worldwide standard
- WCDMA will be used by Europe, Japan, Korea in the WARC-92 spectrum allocated for 3G
- In North America, spectrum auctioned for 2G. No specific spectrum for IMT-2000

Introduction

- Other standards can be used for 3G: EDGE (Enhanced Data Rates for GSM Evolution) and Multicarrier CDMA (CDMA 2000)

- EDGE: up to 500kbps with the GSM carrier spacing of 200kHz

- Multicarrier CDMA: enhancement of IS-95

Introduction: situation in the world

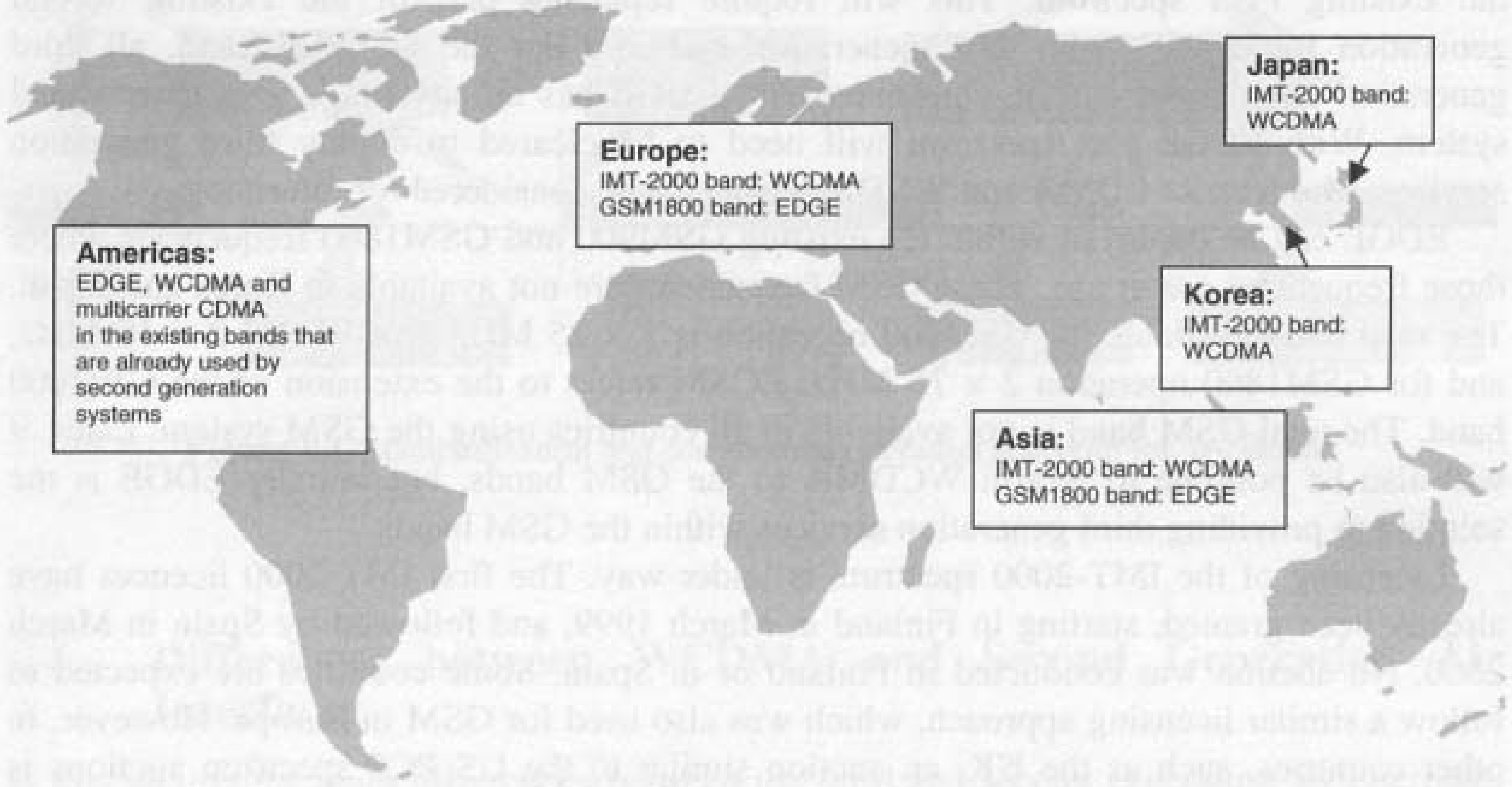


Figure 1.1. Expected air interfaces and spectrums for providing third generation services

Spectrum/band allocation

- In Europe and most of Asia, the IMT-2000 bands (2×60GHz) (1920-1980 and 2110-2170 MHz) will be available for WCDMA FDD
- About TDD: in Europe it is expected to be in 1900-1920 and 2020-2025 MHz (25 MHz in total)
- Japan and Asia: FDD bands like in Europe
- In Japan part of the TDD spectrum is used for PHS (cordless telephone)
- In the USA no spectrum left for 3G. The existing PCS spectrum will have to be refarmed to allow 3G; EDGE has an advantage there because it can be deployed in GSM 900 and 1800 bands

Spectrum/band allocation

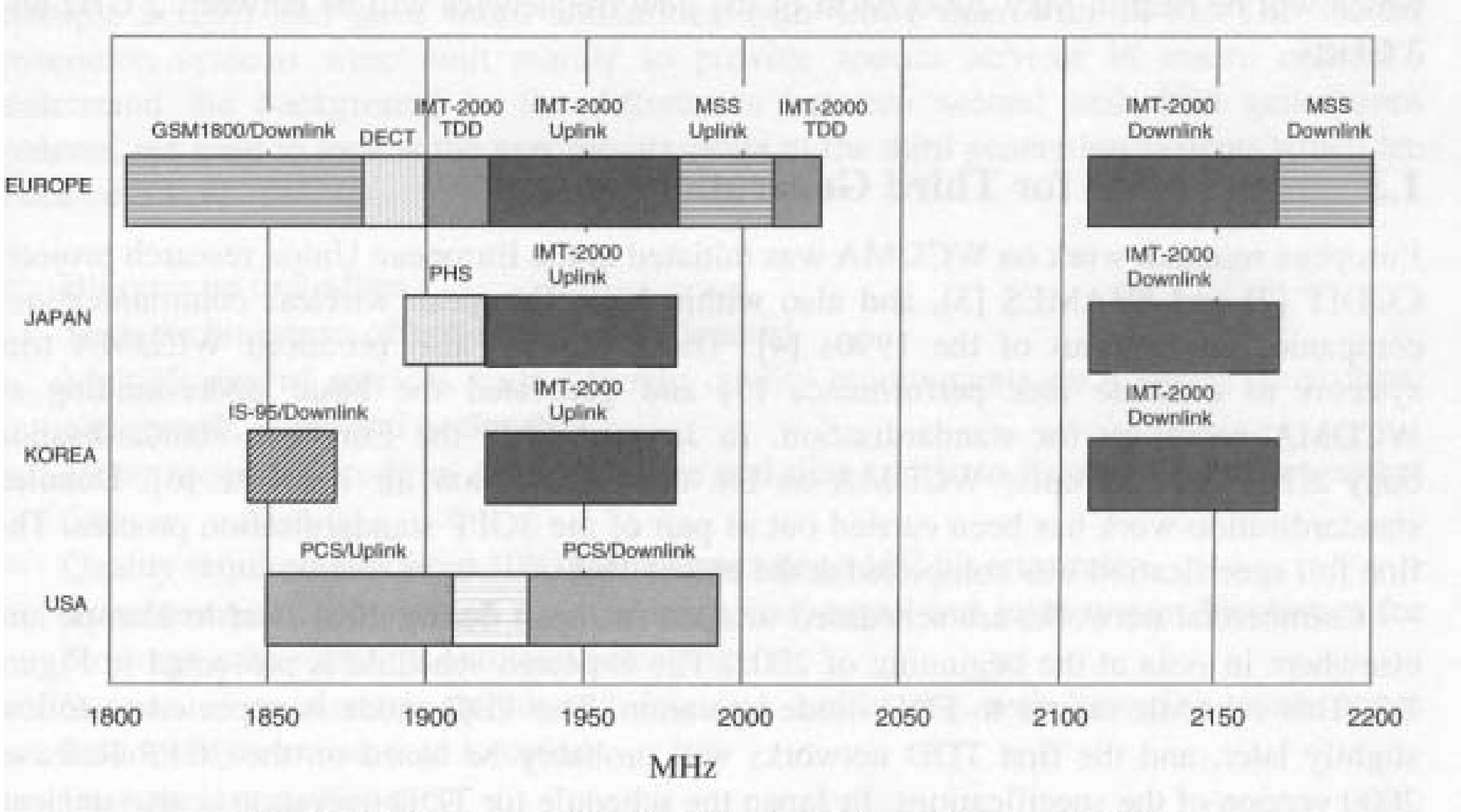


Figure 1.2. Spectrum allocation in Europe, Japan, Korea and USA

Differences between WCDMA and 2G

- Bit rates up to 2Mbps
- Variable bit rate to offer BW on demand
- Multiplexing of services with different quality requirements on a single connection (speech, video, data)
- Quality requirements from 0.1 FER (frame error rate) to 10^{-6} BER
- Coexistence of 2G and 3G and inter-systems handovers
- Support of asymmetric uplink and downlink traffic (like ADSL: WEB implies more downlink traffic)

Differences between WCDMA and GSM

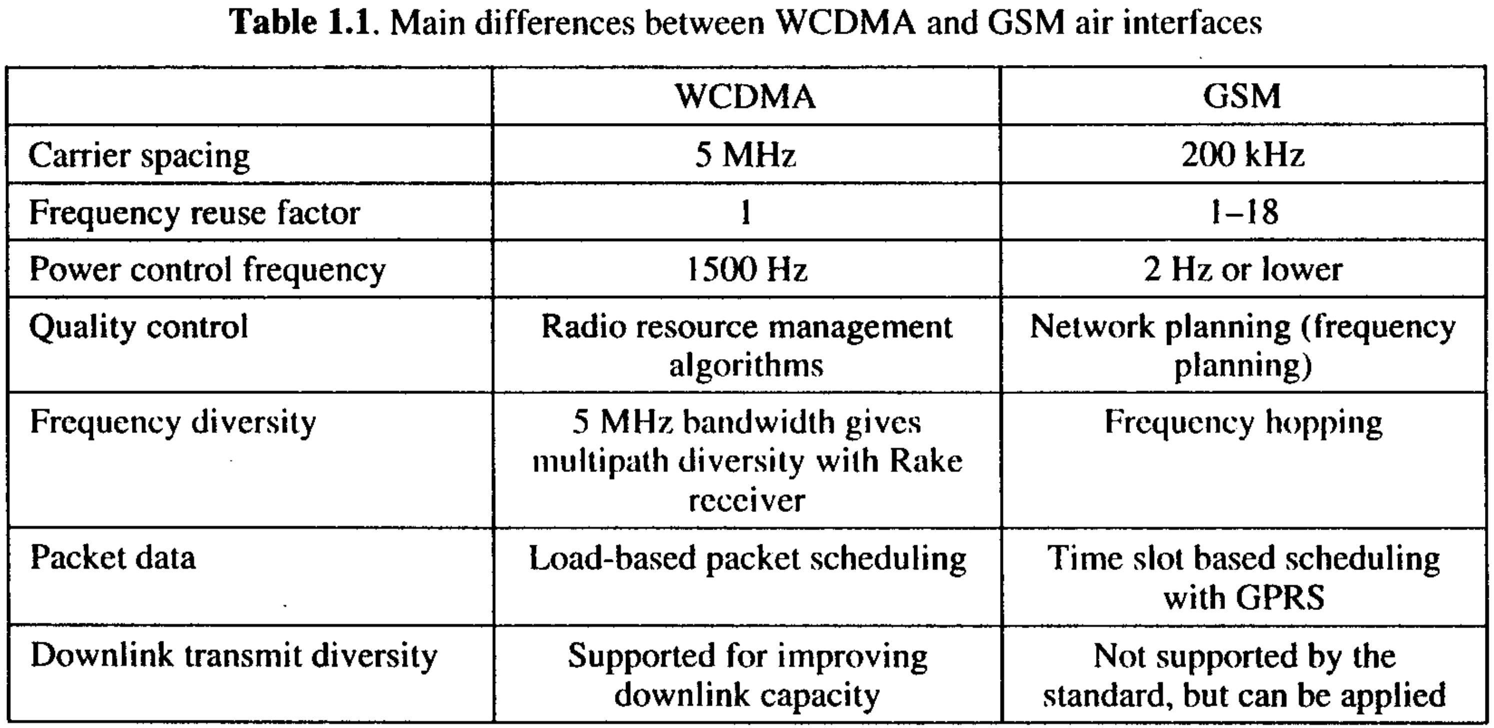


Table 1.1. Main differences between WCDMA and GSM air interfaces

	WCDMA	GSM
Carrier spacing	5 MHz	200 kHz
Frequency reuse factor	1	1–18
Power control frequency	1500 Hz	2 Hz or lower
Quality control	Radio resource management algorithms	Network planning (frequency planning)
Frequency diversity	5 MHz bandwidth gives multipath diversity with Rake receiver	Frequency hopping
Packet data	Load-based packet scheduling	Time slot based scheduling with GPRS
Downlink transmit diversity	Supported for improving downlink capacity	Not supported by the standard, but can be applied

Differences between WCDMA and GSM

- Larger BW required to support high bit rate
- GSM covers also services and core network aspects. The GSM platform will be used with the WCDMA air interface
- Transmit diversity is included in WCDMA to improve downlink capacity to support asymmetry

Differences between WCDMA and IS-95

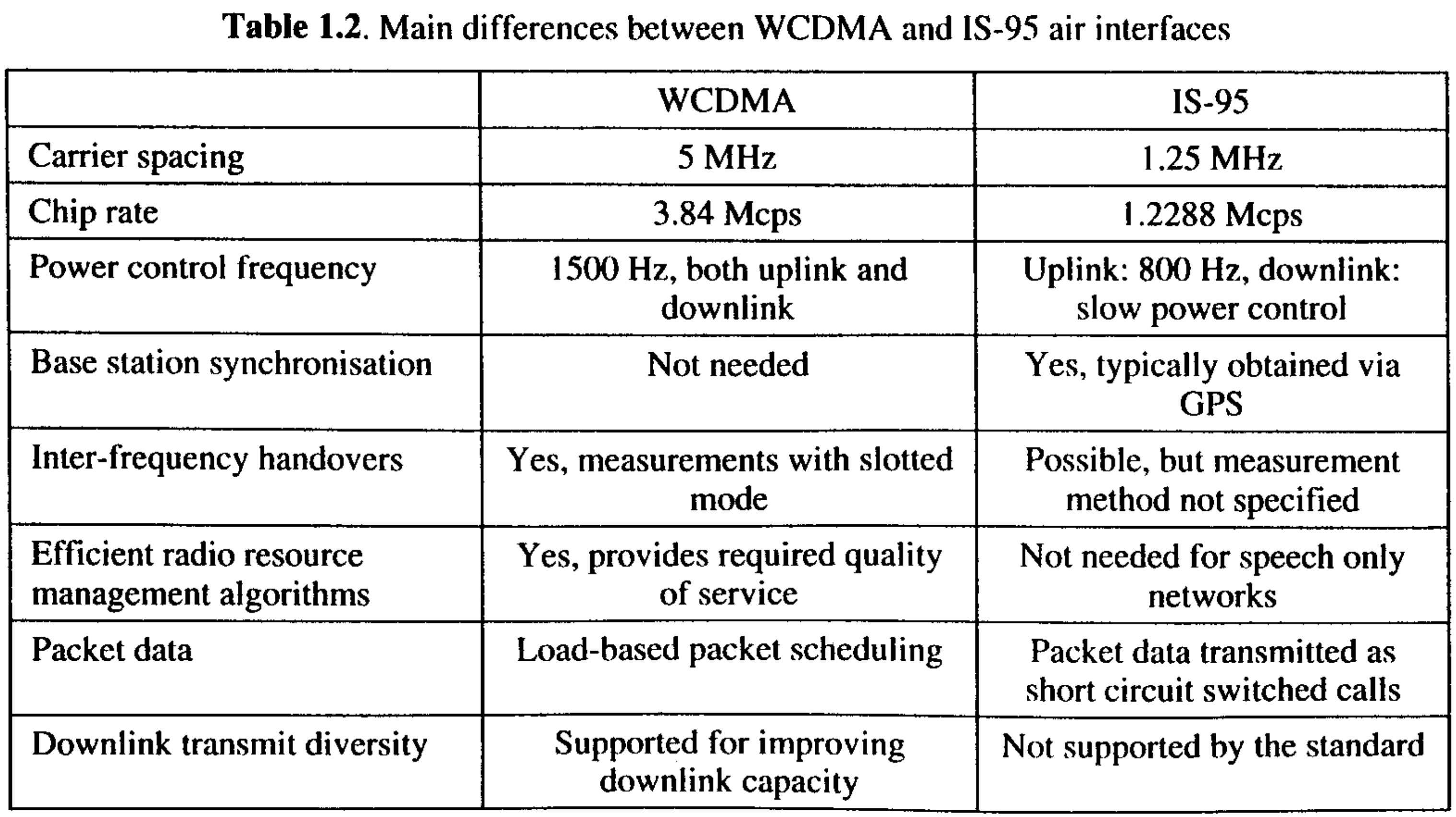


Table 1.2. Main differences between WCDMA and IS-95 air interfaces

	WCDMA	IS-95
Carrier spacing	5 MHz	1.25 MHz
Chip rate	3.84 Mcps	1.2288 Mcps
Power control frequency	1500 Hz, both uplink and downlink	Uplink: 800 Hz, downlink: slow power control
Base station synchronisation	Not needed	Yes, typically obtained via GPS
Inter-frequency handovers	Yes, measurements with slotted mode	Possible, but measurement method not specified
Efficient radio resource management algorithms	Yes, provides required quality of service	Not needed for speech only networks
Packet data	Load-based packet scheduling	Packet data transmitted as short circuit switched calls
Downlink transmit diversity	Supported for improving downlink capacity	Not supported by the standard

Differences between WCDMA and IS-95

- Larger BW of WCDMA gives more multipath diversity, especially in small urban cells

- WCDMA has fast closed-loop power control in both UL and DL; IS-95 has only in UL. in DL it increases DL capacity

- IS-95 targeted mainly for macro-cells and use GPS sync of the base-stations; more dfficult in non LOS environments

- WCDMA uses asynchronous base-stations; it impacts handover

- Also possibility of having inter-frequency handover in WCDMA (several carriers per base-station); not specified in IS-95

WCDMA description: spreading and modulation

- Spreading is used in combination with scrambling

- Scrambling: used on top of spreading; needed to separate terminals or base stations from each other

- Scrambling does not change the chip rate nor the bandwidth

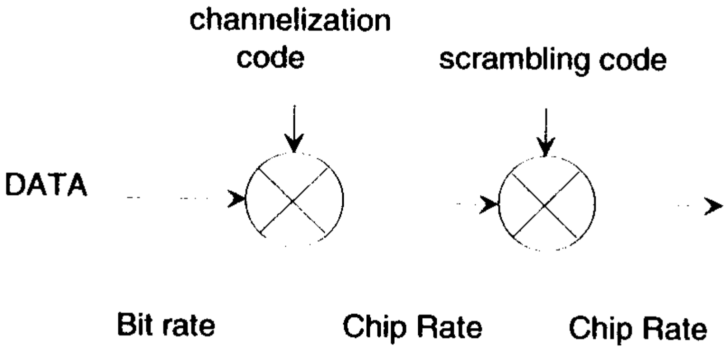


Figure 6.3. Relation between spreading and scrambling

Channelization codes

- Transmissions from a single source are separated by Channelization codes: downlink connections in one sector or the dedicated physical channels in the uplink from one terminal
- Based on OVSF technique (Orthogonal Variable Spreading Factor)
- Allows spreading to be changed while maintaining orthogonality between codes

Channelization codes

- See code tree

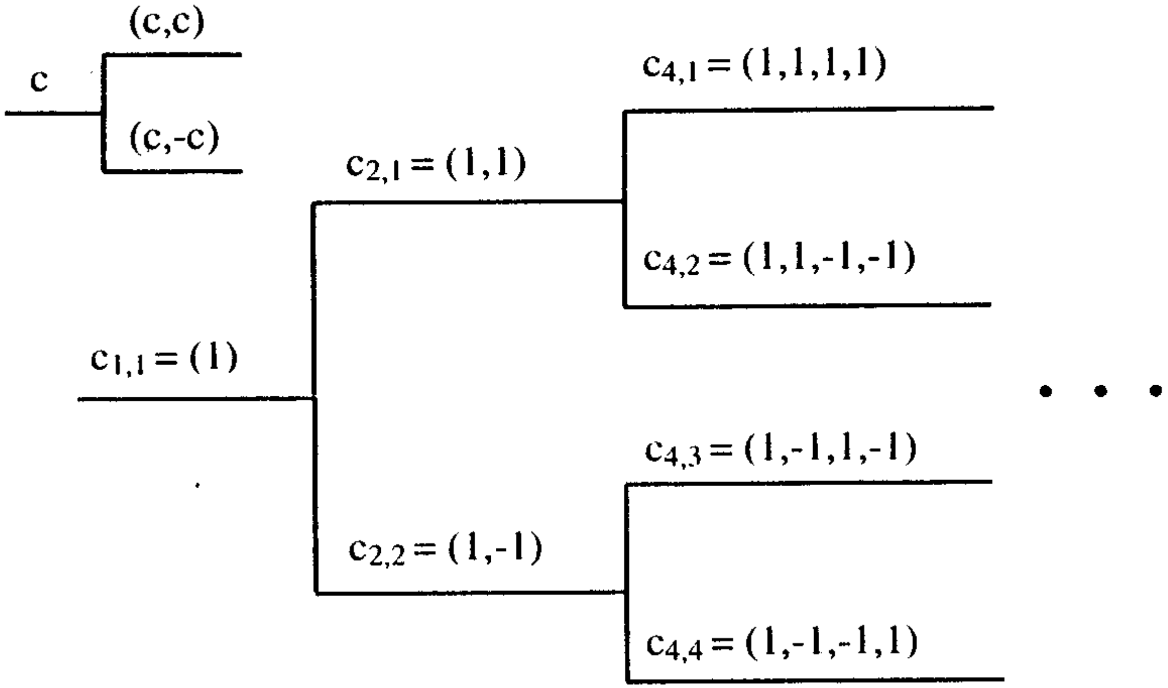


Figure 6.4. Beginning of the channelisation code tree

OVSF

- Generation process inspired from Hadamard codes
- Restriction: when a code is intended to be used, no other code generated from the intended code can be used (as for higher SF); no code between the intended coded and the root can be used (as for smaller SF)
- Restrictions apply to individual sources; do not apply to different base stations (separation by scrambling) or to different mobiles in the uplink (separation by scrambling)
- Chip rate: 3.84 Mchips/sec (subject to changes)

Channelization and scrambling codes

- Channelization (OVSF)(Increases BW)
  - UL: separate DPDCH (Dedicated Physical Data CHannel) from same terminal; DL: separate connections to different users in one cell
  - UL: 4-256 chips; DL also 512
- Scrambling (Does not hange BW)
  - UL: separate terminals; DL: separate sectors
  - UL: if long code, 38400 chips (Gold codes); if short code (JD), 256 chips (extended S); DL: 38400 chips

Uplink

- For the terminal, maximise terminal amplifier efficiency and minimize audible interference due to terminal transmission

- When no speech information, time multiplexing of power control info (1.5kHz) would lead to audible interference

- Therefore the two dedicated channels (data and control) are I-Q code multiplexed instead of time multiplexed

- Pilot and control are maintained on a separate continuous channel; no pulsed transmission

Figure 6.5. Parallel transmission of DPDCH and DPCCH when data is present/absent (DTX

Uplink

- For the best power amplifier efficiency, PAR (peak to average) ratio should be as low as possible (minimal back-off)

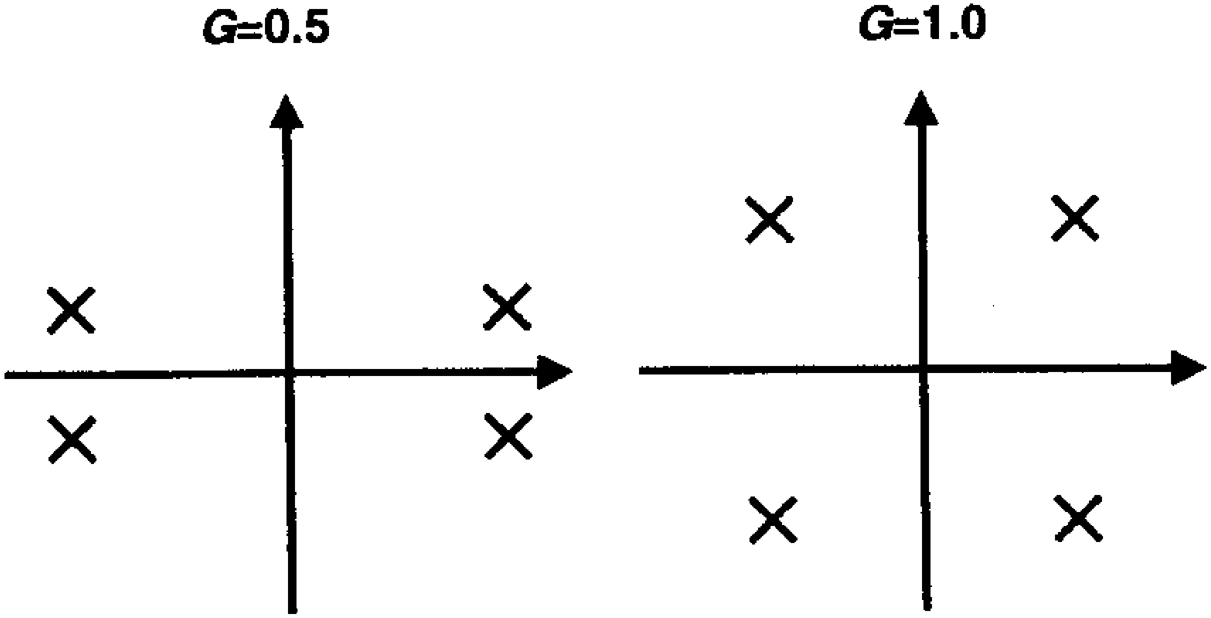
- With I-Q code multiplexing called dual-channel QPSK, levels of DPDCH and DPCCH (Dedicated Physical Control CHannel) are different

- When data rate increases (to maintain identical E_b) could lead to BPSK-like transmission (unbalanced)

- Therefore complex spreading is used to "share" I-Q info with the two branches

Uplink

- Two possible constellations before scrambling (depending on the level of the pilot)



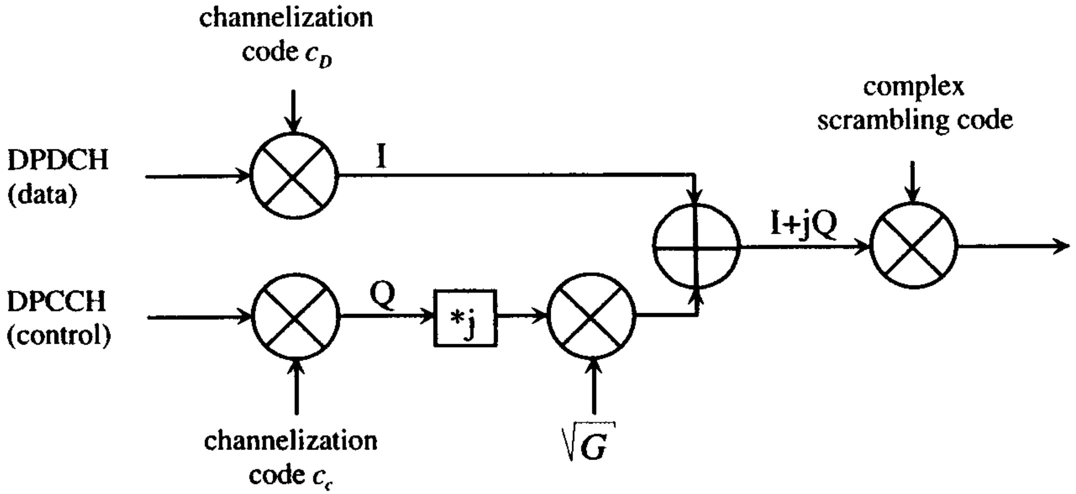
Uplink

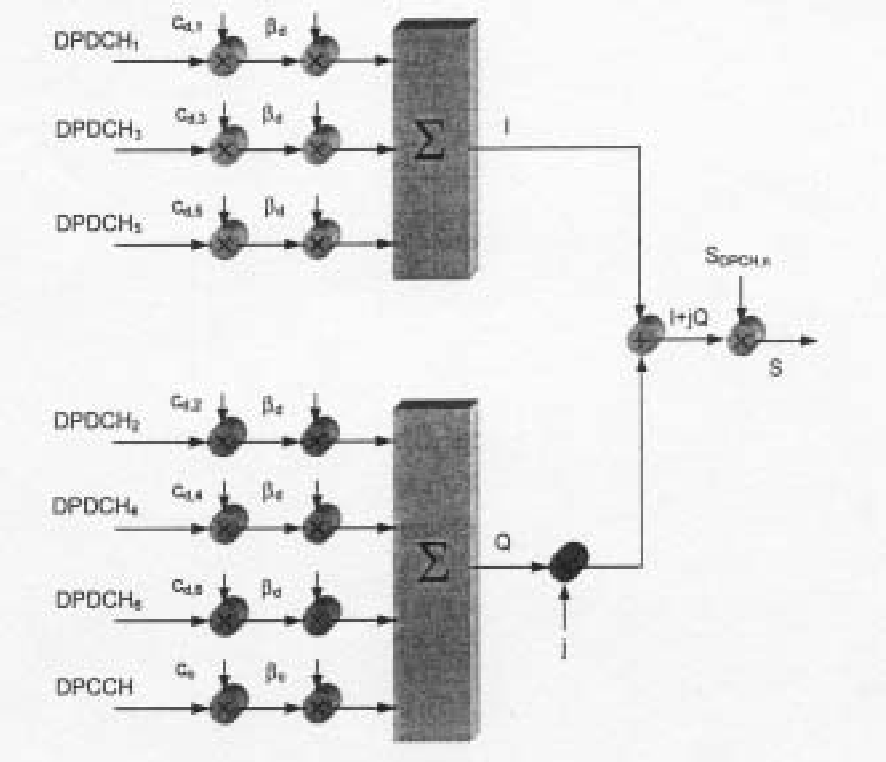
- Efficiency remains the same as with balanced QPSK
- Efficiency of the power amplifier does not depend on G
- Power difference between DPDCH and DPCCH quantized to 4 bits

Uplink spreading

- When code used by the DPCCH, the same code cannot be used even of a different I or Q branch
- Would otherwise interfere with the phase estimation achieved with DPCCH
- Spreading factor of the DPDCH can change on a frame basis
- There is a single DPCCH per radio link; but there may be several DPDCH
- For DPDCH the same OVSF code can be used on different I-Q branches

Uplink spreading





Uplink frame structure for DPDCH/DPCCH

- 1 frame=10msec=15 slots=15 $\times$ 2560 chips=15 $\times$ 2560/(256/2^k) $=$ 15 $\times$ 10 $\times$ 2^k bits (SF=2^k, $k = 0, \cdots, 6$)

- For DPCCH, SF=256 always hence always 10 bits per DPCCH slot

- TFCI: rate information; TPC: transmission power control; Pilot: for channel estimation

Uplink frame structure for DPDCH/DPCCH

- Advisable to transmit with single DPDCH as long as possible (for PAR reasons)

- With single DPDCH:
  - 960kbps can be obtained with SF=4, no coding
  - 400-500 kbps with coding

- With 6 codes, up to 5740 kbps uncoded or 2Mbps (or even more) with coding

Uplink frame structure and bit rates

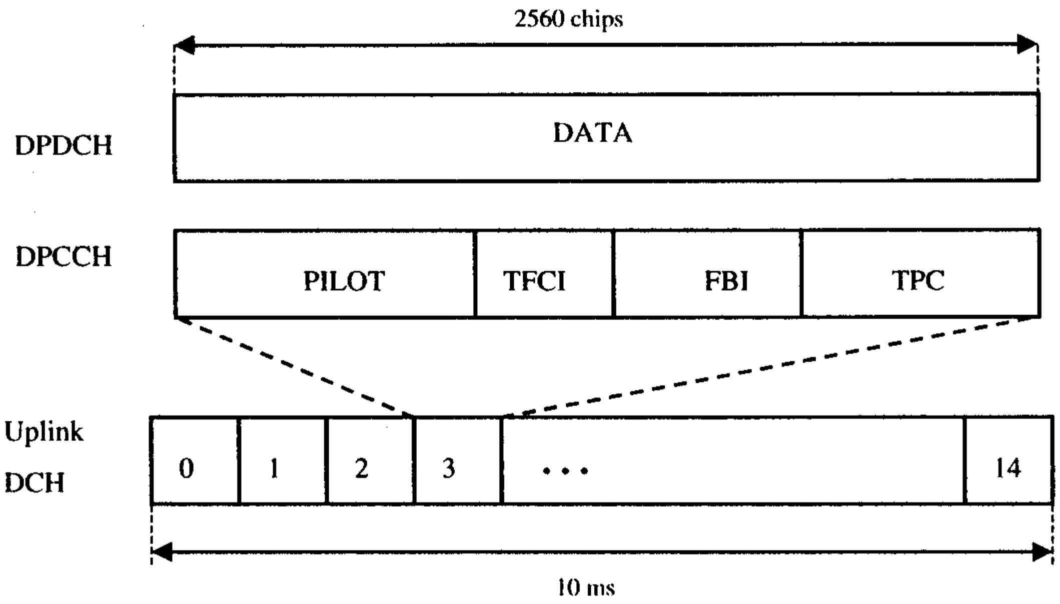


Table 6.2. Uplink DPDCH data rates

DPDCH spreading factor	DPDCH channel bit rate (kbps)	Maximum user data rate with ½-rate coding (approx.)
256	15	7.5 kbps
128	30	15 kbps
64	60	30 kbps
32	120	60 kbps
16	240	120 kbps
8	480	240 kbps
4	960	480 kbps
4, with 6 parallel codes	5740	2.3 Mbps

Uplink scrambling codes

- Specific to each source
- Long codes: truncated to the 10 msec frame length; hence 38400 chips (if 3.84Mcps) (code used for real part, and the same for imaginary but with delay)
- Used if base station is rake based
- Short codes: 256 chips (two codes used for real and imaginary parts)
- Used if joint detection or interference cancellation is implemented

Downlink modulation

- Normal QPSK with time multiplexed control and data streams
- Audible interference not an issue because common channels have continuous transmission

Downlink spreading

- OVSF based like in the UL
- Same real code for I and Q bits
- Code tree under a single scrambling code shared by several users
- One scrambling code and hence code tree per sector
- Common channels and dedicated channels share the same code tree (one exception for the SCH-synchronization channel)
- Channel spreading factor does not change on a frame-by-frame basis

Downlink spreading

- Variable bit rate taken care of by rate matching or discontinuous transmission

- If multicode transmission for a single user, parallel code channels have different channelization codes

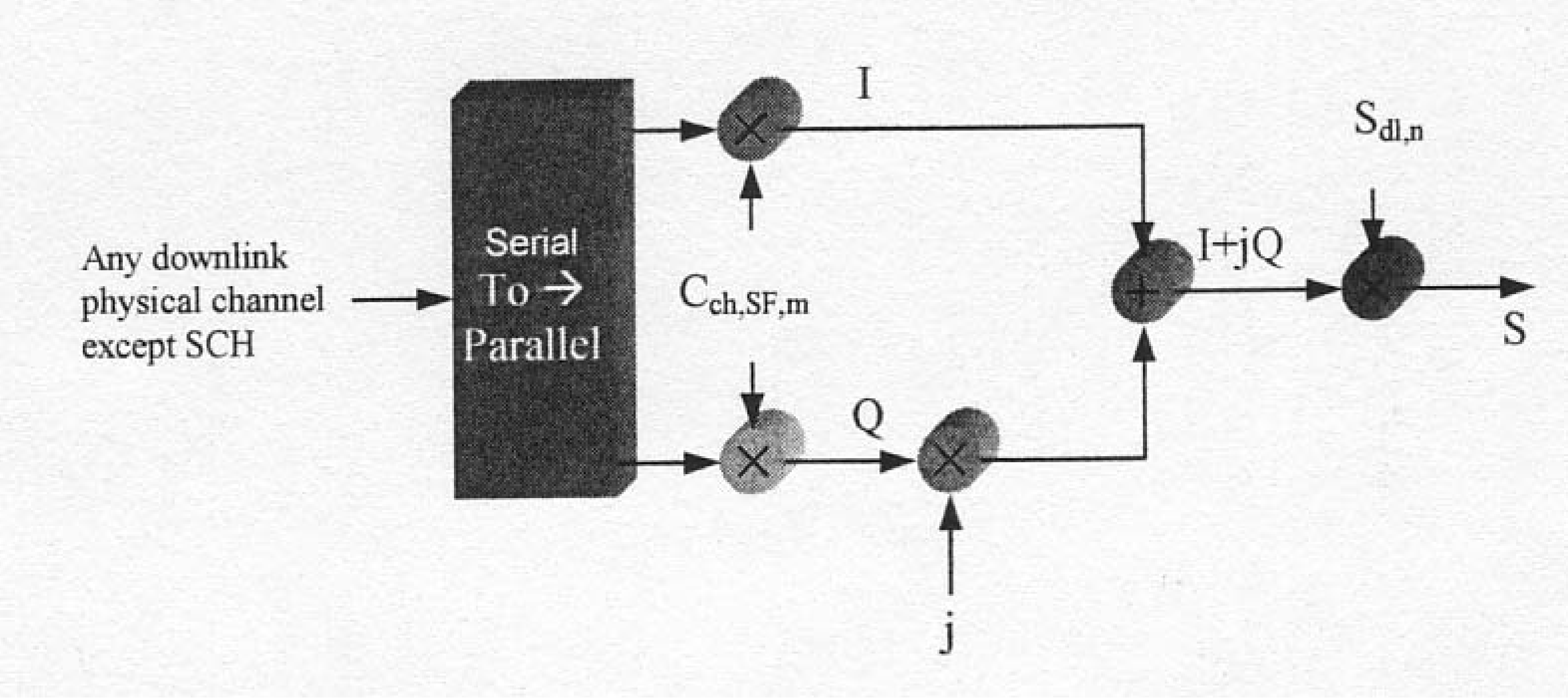
- SF all the same with multicode transmission

Downlink scrambling

- Long codes like in the UL (complex spreading)
- Code period truncated to 10 msec (to ease the task for the terminal to find the right code phase, with a 31 degree code generator)
- Primary set of 512 codes; if needed, secondary set of 15 codes per primary code, meaning 8192 codes in total (512×16)
- Before the terminal synchronizes with the cell spreading code it must synchronize with a code word identical for all cells (actually a first code common to all cells and a second specific to groups of cells; only needed at power-on)
- No prior timing is available so matched filtering must be implemented

Downlink

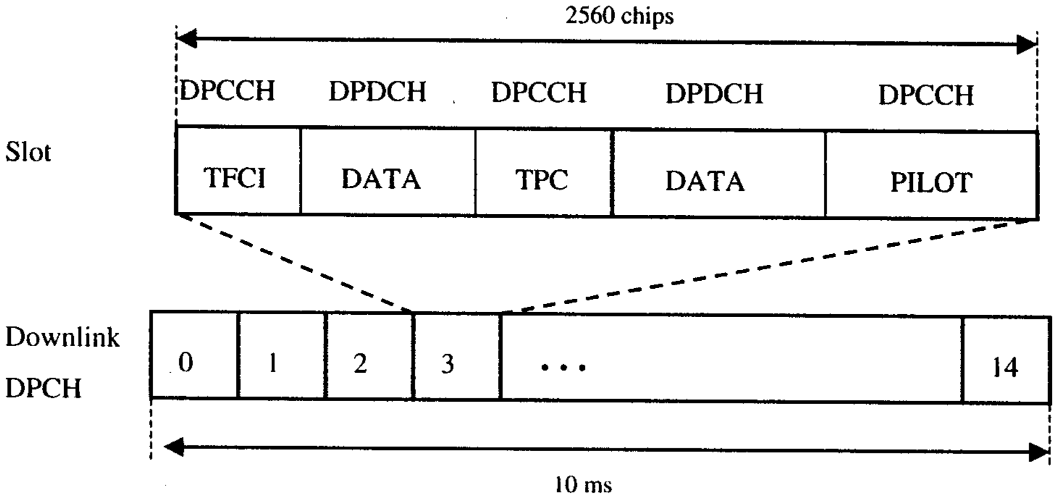
- Summary



Downlink frame structure and bit rates

Table 6.3. Downlink Dedicated Channel symbol and bit rates

preading factor	Channel symbol rate (kbps)	Channel bit rate (kbps)	DPDCH channel bit rate range (kbps)	Maximum user data rate with ½-rate coding (approx.)
512	7.5	15	3–6	1–3 kbps
256	15	30	12–24	6–12 kbps
128	30	60	42–51	20–24 kbps
64	60	120	90	45 kbps
32	120	240	210	105 kbps
16	240	480	432	215 kbps
8	480	960	912	456 kbps
4	960	1920	1872	936 kbps
4, with 3 arallel codes	2880	5760	5616	2.3 Mbps



Rate matching

- Used to match the number of bits to be transmitted to the number available in a single frame
- Achieved by either puncturing or repetition
- In UL repetition is preferred; puncturing only used when terminal limitations are reached, or to avoid multicode transmission
- May change on a frame-by-frame basis

Channel coding

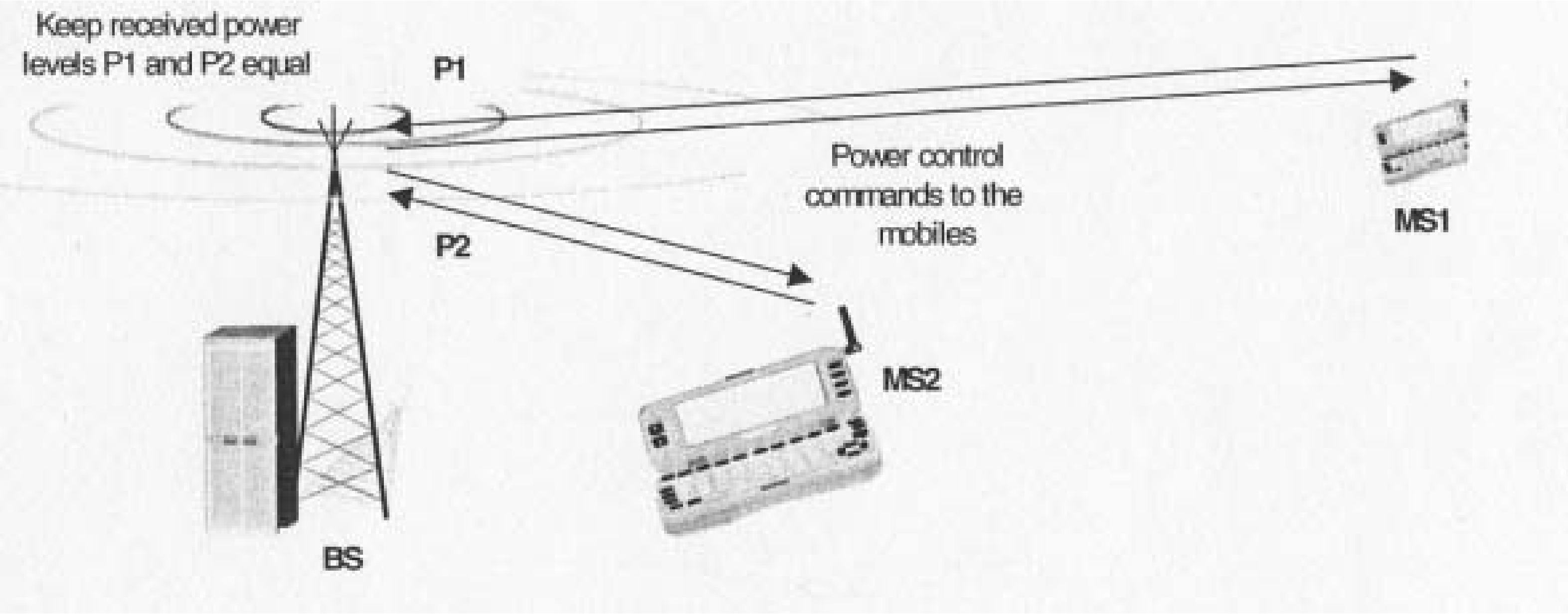
- Two methods:
  - 1/2 rate and 1/3 rate convolutional coding for low data rate services (like in 2G)
  - 1/3 rate turbo coding for higher data rate services
    - 8 state PCCC (parallel concatenated convolutional code)
    - minimum blocks of 320 bits should be processed to outperform conv. coding (however block of 40 bits are also possible)

Power control

- Important aspect, especially in the uplink

- Near-far problem:
  - Codes are not orthogonal or the orthogonality is destroyed by multipath propagation
  - With equal transmit power a MS close to the BS may hide a MS at the cell border (e. g. with additional 70 dB attenuation)
  - Power control has as an objective to control the transmit powers of the different MS so that their signals reach the BS with the same level

Power control



Power control

- Open loop power control: estimate the path loss from the signal received in DL

- Not accurate: in FDD, UL and DL frequencies are different and fast fading is uncorrelated between UL and DL

- However used in WCDMA to provide a course initial power setting

- Solution: Fast closed-loop power control: BS performs frequent estimations of the received SIR (Signal-to-Interference Ratio) and compares to a target SIR

Power control

- It commands the mobile station to lower or increase its power (in which cas the mobile causes increased interference to other cells !)

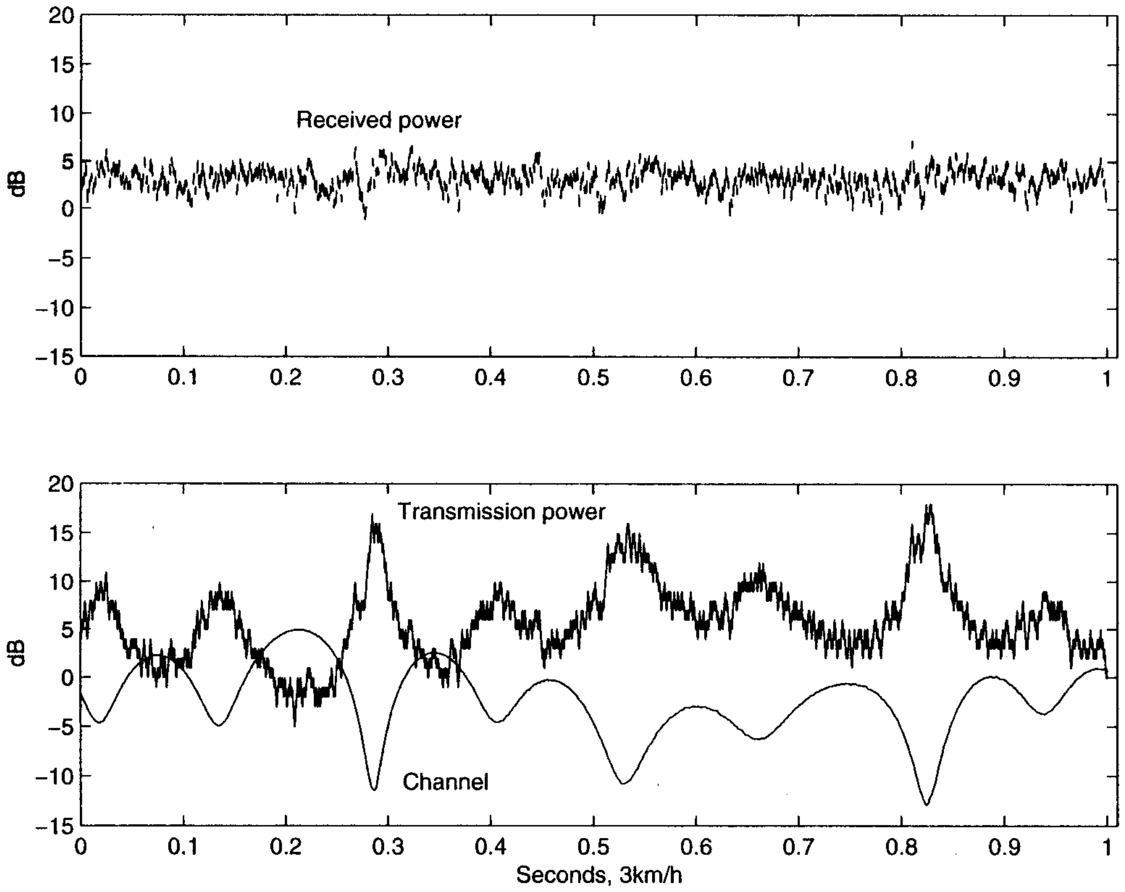
- The command-react cycle is 1500 times per second for each mobile station (faster than any fading mechanism)

- Also used in DL (no near-far problem however); all signals originate from the same BS

- Desirable to provide additional power to mobiles closed to the cell edge

Power control illustration

- Uplink, fading channel at low speed



Power control in WCDMA

- Fast power control: 1 command per slot or rate 1500Hz
- Basic step size 1dB (also multiples or smaller step sizes)

Soft handover

- A mobile is in the overlapping coverage area of two sectors belonging to different base-stations
- Signals are received from the two BS and recombined by a rake receiver
- Avoids near-far similar situation when a mobile enters a new cell and has not yet been power controlled
- Softer handover: same situation but between two sectors belonging to the same BS

Handover

- Previous slide: Intra-mode handover

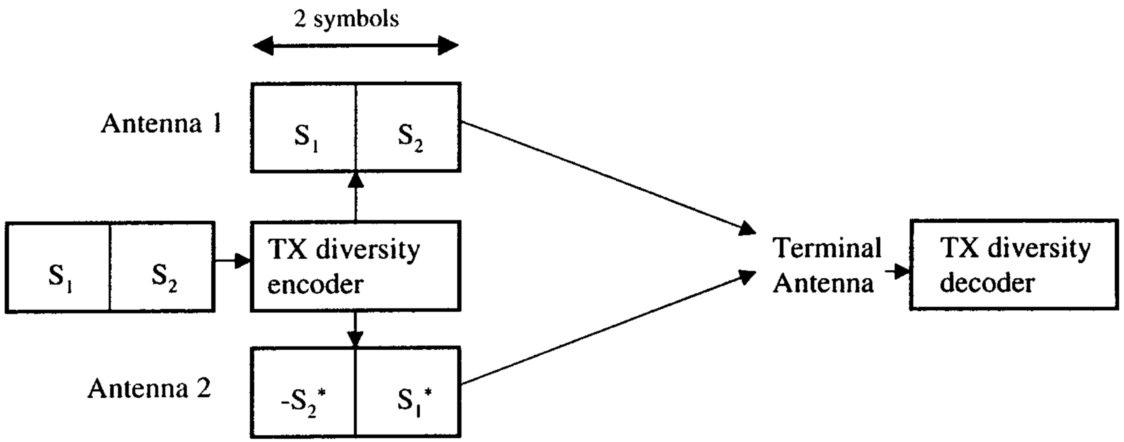
- Inter-mode handover also supported: the dual mode FDD-TDD terminals may "handover" from FDD to TDD (measurements mechanisms are implemented)

- Inter-system handover also supported: handover to GSM is currently only foreseen

Transmit diversity

- Closed loop transmit diversity:
  - the BS uses two transmit antennas
  - mode 1: the terminal feedback controls the phase adjustments (of the second antenna wrt to the first one) to maximize the power received at the terminal (FBI field in the slot)
  - mode 2: the amplitude is adjusted on top of the phase
- Open loop transmit diversity: space time block coding based transmit diversity-STTD

Block diagram of STTD



Transmit diversity

- Assume each transmit antenna is affected by frequency flat fading h_i and fading is constant over 2 signalling intervals

- At time 0 transmit s_0 from antenna 0 and s_1 from antenna 1

- The received signal for that signalling period is $r_0 = h_0 s_0 + h_1 s_1 + n_0$

- At time 1 transmit $-s_1^*$ from antenna 0 and s_0^* from antenna 1

- The received signal for that signalling period is $r_1 = -h_0 s_1^* + h_1 s_0^* + n_1$

Transmit diversity

- Compute the following combinations (it is not MRC):

$$\begin{aligned} t_0 &= h_0^* r_0 + h_1 r_1^* && (1) \\ t_1 &= h_1^* r_0 - h_0 r_1^* && (2) \end{aligned}$$

- It comes

$$\begin{aligned} t_0 &= (|h_0|^2 + |h_1|^2) s_0 + h_0^* n_0 + h_1 n_1^* && (3) \\ t_1 &= (|h_0|^2 + |h_1|^2) s_1 + h_1^* n_0 - h_0 n_1^* && (4) \end{aligned}$$

- Equivalent to what would be received with one transmit antenna, two receive antennas and MRC; therefore diversity order 2

- 2 transmit and M receive antennas would lead to diversity order $2M$, equivalent to $2M$ MRC (the actual gain depend on many parameters)

UTRA

- Complex and efficient technology;
- Still to come ....